



Import risk analysis: citrus (*Citrus* spp.) fresh fruit for human consumption

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Version 1.1

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Approved for general release

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Version information

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1.0		Enrico Perotti	28 May 2021
1.1	Updated with risk status of Armoured Scale insects	Enrico Perotti	19 October 2021

New Zealand is a member of the World Trade Organisation and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures ("The Agreement"). Under the Agreement, countries must base their measures on an International Standard or an assessment of the biological risks to plant, animal or human health.

This document provides a scientific analysis of the risks associated with the importation of *Citrus* fresh produce from selected countries. It assesses the introduction of pests and pathogens associated with *Citrus* fruit imported from selected countries, and assesses the potential impacts of those organisms should they enter and establish in New Zealand. The document has been internally and externally peer reviewed and is now released publicly for feedback. Any significant new science information received that may alter the level of assessed risk will be included in a review, and an updated version released.

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Import Risk Analysis

Background

This import risk analysis (IRA) has been developed in response to a request to review the current import health standards (IHSs) for fresh *Citrus* fruit for human consumption, and to develop new IHSs for new countries and/or for new *Citrus* fresh fruit commodities.

Exporting countries covered by current IHSs and included in the scope of this IRA:

- Australia
- Egypt
- Japan
- Mexico
- New Caledonia (France)
- Samoa
- Spain
- United States
- Vanuatu

New countries (not covered by an existing IHS) that will also be included in the scope of this IRA:

- Brazil
- China
- Cook Islands
- Fiji
- Korea
- Peru
- Solomon Islands
- Viet Nam

Citrus fresh fruit commodities as submitted by exporting countries or listed in existing IHSs and as classified in this IRA are provided in Summary Table 1.

Summary Table 1 List of *Citrus* commodities as submitted or in current IHSs against those assessed in this IRA. NB: For the purposes of this IRA, the naming system of Swingle has been used (see section 2.2).

<i>Citrus</i> commodities as submitted or in current IHSs	<i>Citrus</i> commodities as classified in this IRA
Lemon (<i>C. limon</i>)	<i>Citrus limon</i> (L.) Burm.f.
Limonia (<i>Citrus limonia</i>)	<i>Citrus limon</i> (L.) Burm.f.
Meyer lemon (<i>C. meyeri</i>)	<i>Citrus limon</i> (L.) Burm.f.
Grapefruit (<i>C. paradisi</i>)	<i>Citrus paradisi</i> McFad.
Hassaku (<i>C. hassaku</i>)	<i>Citrus paradisi</i> McFad.
Orange (<i>C. sinensis</i>)	<i>Citrus sinensis</i> (L.) Osbeck
Iyokan (<i>C. iyo</i>)	<i>Citrus sinensis</i> (L.) Osbeck
Mandarin/Tangerine (<i>C. reticulata</i>)	<i>Citrus reticulata</i> L.
Mandarin (<i>C. unshiu</i> × <i>C. reticulata</i> var. <i>Shiranuhi</i>)	<i>Citrus reticulata</i> L.
Satsuma mandarin (<i>C. unshiu</i> ; <i>C. unshiu</i> × <i>C. sinensis</i> var. <i>Kiyomo</i>)	<i>Citrus reticulata</i> L.
Tahitian/Persian lime (<i>C. latifolia</i>)	<i>Citrus latifolia</i> (Yu. Tanaka) Tanaka
Mexican/Key lime (<i>C. aurantiifolia</i>)	<i>Citrus aurantiifolia</i> (Christ.) Swingle
Sweet lime (<i>C. limettioides</i>)	<i>Citrus aurantiifolia</i> (Christ.) Swingle
Pomelo/Pummello (<i>C. maxima</i>)	<i>Citrus maxima</i> (Burman) Merr.
Tangelo (<i>C. reticulata</i> × <i>C. paradisi</i>)	<i>Citrus reticulata</i> × <i>Citrus paradisi</i>

Citrus commodities as submitted or in current IHSs	Citrus commodities as classified in this IRA
Tangor (<i>C. reticulata</i> × <i>C. sinensis</i>)	<i>Citrus reticulata</i> × <i>Citrus sinensis</i>
Unshu (<i>C. reticulata</i>)	<i>Citrus reticulata</i> L.

Note that the taxonomy of commercially grown *Citrus* is complex; almost all cultivated *Citrus* “species” are hybrids derived from the same three or four parent species.

Objectives

Biosecurity New Zealand’s objectives in developing this IRA for *Citrus* fresh fruit for human consumption are to determine which pests and diseases are:

1. associated with *Citrus* fresh fruit, and
2. meet the risk evaluation criteria for additional measures beyond the commodity description proposed for the IHSs,

in order to ensure that the known biosecurity risk from regulated organisms associated with imported *Citrus* fresh fruit is managed appropriately.

IRA methodology

The IRA process involves two principal stages:

- Hazard identification
- Pest risk assessment

IRA Scope

The scope of the IRA considers the following key questions:

- What are the risk management questions?
- What is the commodity description?
- What basic measures to manage known risks will be required for all commodities from the listed countries?

Risk management questions	
General description	Specific questions that the risk manager needs answered in order to make a decision. They are based on the commodity description and basic measures (see description below) for that commodity type.
Description specific to this <i>Citrus</i> fresh fruit IRA	Does each assessed pest and disease (note that “pest” refers to both arthropods, such as insects and mites, and pathogens, such as fungi and bacteria): <ol style="list-style-type: none"> 1. meet the criteria to be a quarantine pest¹, and 2. meet (or potentially meet) the criteria to be considered for additional measures (i.e. over and above basic measures)? For the pests and diseases that meet or potentially meet the criteria to be considered for additional measures, the following question is considered: <ol style="list-style-type: none"> 1. Which specific <i>Citrus</i> fruit pathways are they associated with (i.e. which countries and types of <i>Citrus</i> fruit)?

Commodity description	
General description	The commodity description defines the form of the commodity that is covered by the IHS, e.g. the commodity species and the countries under consideration. The commodity description may also include commercial production and/or grading requirements or other commodity quality specifications.

¹ A quarantine pest is an organism that is not present in New Zealand (or is present but still represents a biosecurity risk, e.g. is capable of vectoring pathogens not present in New Zealand) and is capable of establishing and causing harm in New Zealand.

Description specific to this <i>Citrus</i> fresh fruit IRA	Commercially produced fresh <i>Citrus</i> fruit belonging to any of the fruit types/species requested by exporting countries (see summary, Table 1). The fruit may have the calyx attached but not the stem, leaves or other plant parts. The commodity definition excludes material or produce that is visibly damaged (e.g. fruit must have an intact skin, free from defects such as splits and cuts). “Commercially produced” is defined as a process/system where activities, such as in-field monitoring, in-field pest control activities, harvesting, cleaning, sorting and grading have been undertaken to produce a commodity that is free of defects such as broken skin, rot and damage. Depending on the systems in place, these activities can be undertaken at any stage from the point of planting to the point of export. <i>NB: this definition is for the purposes of risk assessment. The definition of “commercial production” in the context of risk management is slightly different (see the Glossary and Abbreviations section).</i>
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Basic measures	
General description	The minimum level of risk management for a particular commodity that all exporting countries must meet. They are not pest-specific but are likely to manage, or partially manage, a wide range of pests. Basic measures are based on information already known about the risks, e.g. from previous risk assessments, previous IHSs for the same or similar commodities.
Description specific to this <i>Citrus</i> fresh fruit IRA	Consignments of fresh <i>Citrus</i> spp. fruit imported into New Zealand must: <ol style="list-style-type: none"> 1. be free from contamination (including visible disease and pests, soil and other organisms, objects or material capable of harbouring or spreading pests of biosecurity concern) and other extraneous material not included in the commodity description; 2. be free from conditions that may indicate pest or disease contamination (including rots and damage); 3. comply with the commodity description (e.g. have an intact skin (on export), be free from defects such as splits and cuts, have no leaves or stems attached, and be commercially produced); 4. be packaged in clean and either new or refurbished material; and 5. be secured in a manner to prevent contamination.

Hazard identification

A hazard is a pest (including arthropods and pathogens) or disease that:

- is not present in New Zealand (or is present but still represents a biosecurity risk, e.g. is capable of vectoring pathogens not present in New Zealand),
- has the ability to establish and cause harm in New Zealand, and
- is associated with imported risk goods and import pathways.

Hazard identification (hazard ID) is the process where, depending on the scope of the IRA, a list of pests and diseases potentially associated with the commodity is compiled and then assessed against specified criteria, in order to determine which potential hazards require further assessment. The objective for hazard identification in this IRA is to identify all pests and diseases that meet, or may meet, the risk evaluation criteria for requiring additional measures over and above basic measures.

The risk evaluation criteria for pests and diseases of citrus fresh fruit to be considered for additional measures are:

- The pest or disease and associated damage are not easy to see on the *Citrus* fruit, including when undertaking visual inspection, because
 - the pest can burrow into the fruit without obvious symptoms, or
 - the pest can hide in the navel and/or under the calyx of the *Citrus* fruit, or
 - a pest or disease may take time or require particular environmental conditions to cause the fresh fruit to show signs of contamination; and
- the pest or disease has an ability to get off the fruit and onto a host in the New Zealand environment; and

- the pest has the potential to establish and cause harm in New Zealand.

Because this IRA will be used to develop IHSs for a number of different *Citrus* fruit types and for a number of countries, the hazard ID needs to take into account pests and diseases that are associated with any of the commercial *Citrus* types and any of the countries within the scope of this IRA.

The results of the hazard ID provide the following:

- Pests and diseases identified as associated with the commodity, present in at least one exporting country and potentially not being managed by compliance with the commodity description and basic measures and therefore requiring further assessment. These are addressed in the pest risk assessment section below and listed in Summary Table 2.
- Groups (e.g. genera or families) and high-profile pests and diseases that did not meet the criteria to require pest risk assessment. These are listed in Appendix 1, along with the rationale for excluding them.

Pest risk assessment

The purpose of risk assessment is to determine the level of risk that hazard pests and diseases (identified at the hazard ID stage as requiring further assessment) pose to New Zealand. Specifically, the pest risk assessment (PRA) concludes whether the pest or disease, based on assessment against the risk evaluation criteria, may need to be considered for additional measures over and above basic measures.

Pests and diseases that may need to be considered for additional measures are those that:

- are associated with fresh *Citrus* fruit of any species/types requested by exporting countries and meeting the commodity description;
- are present in any of the exporting countries within the scope of this IRA;
- have traits (see the 'Hazard identification' section above) that indicate they may not be adequately managed by the basic measures; and
- have the potential to establish and cause harm in New Zealand.

The PRA addresses the following:

- Likelihood of entry:
 - The strength or frequency of the association with the host fruit
 - The likelihood of entry given the application of basic measures
- Likelihood of exposure and establishment:
 - The ability of the pest or disease to move from imported fruit and into a suitable environment to allow establishment (exposure)
 - The suitability of the New Zealand environment for the pest or disease (including climate, host plants and vectors)
- The potential impacts in New Zealand:
 - Economic impacts: on *Citrus* and other economically important plants (symptoms on individual plants, crop yield, costs of management practices, trade restrictions, etc.)
 - Environmental impacts: on native plants and ecologies
 - Other impacts (e.g. human health, sociocultural)

Summary Table 2 shows pest species for which PRAs were carried out, and the PRA conclusion with respect to consideration for additional measures.

Summary Table 2: Pest species for which PRAs were carried out, and the management considerations

Pest group	Species requiring PRAs	PRA recommendation
Fungi	<i>Elsinoe australis</i> , <i>Phyllosticta</i> spp.	Require consideration for additional measures
Bacteria	<i>Xanthomonas citri</i>	Requires consideration for additional measures
Oomycetes	<i>Phytophthora palmivora</i>	Requires consideration for additional measures
Insects: Order Diptera, fruit flies (receiving individual PRAs)	<i>Anastrepha fraterculus</i> , <i>Anastrepha ludens</i> , <i>Bactrocera dorsalis</i> , <i>Bactrocera minax</i> , <i>Bactrocera trilineola</i> , <i>Bactrocera tryoni</i> , <i>Bactrocera tsuneonis</i> , <i>Bactrocera xanthodes</i> , <i>Ceratitis capitata</i> , <i>Zeugodacus cucurbitae</i> , <i>Bactrocera zonata</i>	Require consideration for additional measures
Insects: Order Diptera, fruit flies (not covered by other PRAs and assessed in a single group PRA)	<i>Anastrepha obliqua</i> , <i>Anastrepha serpentina</i> , <i>Anastrepha sororcula</i> , <i>Anastrepha striata</i> , <i>Anastrepha suspensa</i> , <i>Bactrocera aquilonis</i> , <i>Bactrocera carambolae</i> , <i>Bactrocera correcta</i> , <i>Bactrocera curvipennis</i> , <i>Bactrocera distincta</i> , <i>Bactrocera frauenfeldi</i> , <i>Bactrocera jarvisi</i> , <i>Bactrocera kirki</i> , <i>Bactrocera kraussi</i> , <i>Bactrocera latifrons</i> , <i>Bactrocera melas</i> , <i>Bactrocera neohumeralis</i> , <i>Bactrocera psidii</i> , <i>Bactrocera trivialis</i> , <i>Bactrocera melanotus</i> , <i>Bactrocera passiflorae</i> , <i>Bactrocera</i> sp. nr <i>passiflorae</i> , <i>Zeugodacus tau</i>	Require consideration for additional measures
Insects: Order Lepidoptera (moths, butterflies)	<i>Gymnandrosoma aurantium</i> , <i>Marmara gulosa</i> , <i>Spodoptera littoralis</i>	<i>S. littoralis</i> : does <u>NOT</u> require consideration for additional measures Others: require consideration for additional measures
Insects: Order Hemiptera, family Pseudococcidae (mealybugs)	<i>Nipaecoccus viridis</i> , <i>Planacoccus kraunhiae</i> , <i>Planococcus minor</i>	Require consideration for additional measures
Insects: Order Hemiptera, family Diaspididae (armoured scale insects)	See Appendix 3	
Insects: Order Hemiptera, family Psyllidae (psyllids)	<i>Diaphorina citri</i> , <i>Trioza erytrae</i>	Require consideration for additional measures
Insects: Order Thysanoptera (thrips)	<i>Caliothrips fasciatus</i> , <i>Chaetanaphothrips orchidii</i> , <i>Scirtothrips dorsalis</i> , <i>Thrips palmi</i>	<i>T. palmi</i> : does <u>NOT</u> require consideration for additions measures Others: require consideration for additional measures

Pest group	Species requiring PRAs	PRA recommendation
Subclass Acari (mites) (families Eriophyidae, Tenuipalpidae, Tetranychidae)	<i>Aculops pelekassi</i> , <i>Eotetranychus lewisi</i> , <i>Tetranychus kanzawai</i>	Require consideration for additional measures
Insect vectors of pathogens	Aphids: <i>Aphis craccivora</i> , <i>Aphis gossypii</i> , <i>Aphis spiraecola</i> , <i>Brachycaudus persicae</i> , <i>Macrosiphum euphorbiae</i> , <i>Macrosiphum</i> <i>rosae</i> , <i>Myzaphis rosarum</i> , <i>Myzus persicae</i> , <i>Toxoptera aurantia</i> , <i>Toxoptera citricida</i> Mealybugs: <i>Planococcus citri</i> , <i>Pseudococcus calceolariae</i> , <i>Pseudococcus longispinus</i> , <i>Pseudococcus</i> <i>viburni</i> Thrips: <i>Frankliniella occidentalis</i> , <i>Frankliniella intonsa</i> , <i>Thrips tabaci</i>	Do <u>NOT</u> require consideration for additional measures
Mite vectors of pathogens	<i>Brevipalpus californicus</i> , <i>Brevipalpus</i> <i>obovatus</i> , <i>Brevipalpus phoenicis</i>	Require consideration for additional measures

Annex 1: Supporting Evidence

Contents	Page
1. Risk analysis background and process	11
1.1 Background	11
1.2 Scope and approach for this risk analysis	11
1.3 The risk analysis process	14
1.4 References for Chapter 1	19
2. Commodity and pathway description	20
2.1 Commodity description	20
2.2 Taxonomy of plant commodities under consideration	21
2.3 General information related to likelihood of entry	23
2.4 General information related to likelihood of establishment	23
2.5 General information related to impacts of pests and diseases	30
2.6 References for Chapter 2	31
3. Hazard identification	35
3.1 References for Chapter 3	36
4. Risk assessment	38
4.1 Risk management questions	38
4.2 Criteria and traits for additional measures	38
4.3 Assessment method	38
4.4 References for Chapter 4	42
5. Pest risk assessments: Fungi	43
5.1 <i>Elsinoe australis</i> (sweet orange scab) and <i>E. fawcettii</i> (citrus scab)	43
5.2 <i>Phyllosticta citricarpa</i> (citrus black spot)	59
6. Pest risk assessments: Bacteria	77
6.1 <i>Xanthomonas citri</i> pv. <i>citri</i> and <i>Xanthomonas citri</i> pv. <i>aurantifolii</i> (citrus canker)	77
7. Pest risk assessments: Oomycetes	93
7.1 <i>Phytophthora palmivora</i> (brown rot, gummosis of citrus)	93
8. Insects: Diptera, Tephritidae (fruit flies)	105
8.1 <i>Anastrepha fraterculus</i> (South American fruit fly)	105
8.2 <i>Anastrepha ludens</i> (Mexican fruit fly)	117
8.3 <i>Bactrocera dorsalis</i> (Oriental fruit fly)	126
8.4 <i>Bactrocera minax</i> (Chinese citrus fly)	139
8.5 <i>Bactrocera trilineola</i> (Vanuatu fruit fly)	149
8.6 <i>Bactrocera tryoni</i> (Queensland fruit fly, Qfly)	160
8.7 <i>Bactrocera tsuneonis</i> (Japanese orange fly)	173
8.8 <i>Bactrocera xanthodes</i> (Pacific fruit fly)	183
8.9 <i>Bactrocera zonata</i> (peach fruit fly)	198
8.10 <i>Ceratitis capitata</i> (Mediterranean fruit fly, medfly)	209
8.11 <i>Zeugodacus cucurbitae</i> (melon fly)	221
8.12 Other fruit flies	236
9. Insects: Hemiptera, Pseudococcidae (mealybugs)	300
9.1 <i>Nipaecoccus viridis</i> (spherical mealybug)	300
9.2 <i>Planococcus kraunhiae</i> (Japanese mealybug)	315
9.3 <i>Planococcus minor</i> (Pacific mealybug)	328
10. Insects: Hemiptera, Psylloidea (psyllids)	340
10.1 <i>Diaphorina citri</i> (Asian citrus psyllid)	340
10.2 <i>Trioza erytreae</i> (African citrus psyllid)	352

11. Insects: Lepidoptera (moths, butterflies)	362
11.1 <i>Gymnandrosoma aurantianum</i> (citrus fruit borer)	362
11.2 <i>Marmara gulosa</i> (citrus peelminer)	372
11.3 <i>Spodoptera littoralis</i> (African cotton leafworm)	380
12. Insects: Thripidae (thrips)	390
12.1 <i>Caliothrips fasciatus</i> (bean thrips)	390
12.2 <i>Chaetanaphothrips orchidii</i> (orchid thrips)	398
12.3 <i>Scirtothrips dorsalis</i> (yellow tea thrips)	407
12.4 <i>Thrips palmi</i> (melon thrips)	418
13. Mites	428
13.1 <i>Aculops pelekassi</i> (pink citrus rust mite)	428
13.2 <i>Eotetranychus lewisi</i> (Lewis spider mite)	437
13.3 <i>Tetranychus kanzawai</i> (kanzawa spider mite)	444
14. Vector analysis	453
14.1 Insect vector analysis: aphids, mealybugs, thrips	453
14.2 Mite vector analysis: <i>Brevipalpus</i> spp. (flat mites or false spider mites), vectors of citrus leprosis viruses	486
Appendix 1: Summary of taxa excluded at hazard identification	497
Appendix 2: Glossary and Abbreviations	517
Appendix 3: Risk Status of Armoured Scale Insects	520

1. Risk analysis background and process

1.1 Background

This import risk analysis (IRA) has been developed in response to a request to review the import health standard (IHS) for fresh *Citrus* fruit for human consumption. Some of the existing country/commodity *Citrus* IHSs and schedules in IHS 152.02: *Clearance and Importation of Fresh Fruit and Vegetables into New Zealand* have not been reviewed for a significant number of years. Additionally, there are a number of countries wishing to gain market access for *Citrus* to New Zealand; this IRA also addresses the extension of the IHS to cover these new exporting countries.

The purpose of the IRA is to identify and assess biosecurity risks associated with the commodities. The decisions that this IRA will inform are:

- a. whether any pests and diseases² on fresh *Citrus* fruit require consideration for additional measures; and
- b. whether to remove any pests in the current fresh *Citrus* fruit IHSs that do not require additional measures due to new scientific evidence.

The objective of the IRA is to:

- a. identify pests and diseases which are associated with the commodity and may require additional measures; and
- b. assess these pests and diseases using a method which provides sufficient evidence about the biosecurity risks for a robust and transparent decision on whether additional measures may be required to manage these pests.

For any particular risk good³, there is a commodity definition that describes the minimum condition of the commodity that is covered by this IRA. The commodity definition is important as many pests and diseases may not be associated with a commodity that is defined in a certain way (e.g. more pests may potentially be associated with a commodity definition of fresh beans for consumption than a commodity definition of frozen beans for consumption).

For particular types of risk goods, there are existing basic measures in IHSs that apply to all commodities that come under that particular type of risk good. The basic measures manage the risks of a wide range of organisms, regardless of whether those organisms are named in a pest list.

Commodity definitions and basic measures for commodities are proposed during the planning phase of the IHS development process, prior to the development of the IRA. The commodity definitions and basic measures are based on the nature and risks of a particular commodity class (e.g. germplasm, fresh produce) and other information related to that particular commodity. The basic measures also mean that risk assessments and IHSs are robust in the face of many emerging and unknown risks.

1.2 Scope and approach for this risk analysis

This risk analysis considers the effects on the New Zealand economy, environment, society and human health from organisms potentially associated with the importation of fresh citrus fruit for consumption.⁴

This *Citrus* IRA will be assessing the current IHSs and new market access requests for commercial imports of fresh *Citrus* fruit for human consumption.

² Quarantine pests under IPPC

³ Regulated article under IPPC

⁴ Specifically, this IRA covers sections 23(4)(b)(i), (ii) and (iii) of the Biosecurity Act:

(i) the likelihood that the goods will import organisms:

(ii) the nature of the organisms that the goods may import:

(iii) the possible effect on human health, the New Zealand environment, and the New Zealand economy of the organisms that the goods may import

The scope of the *Citrus* IRA project includes reviewing and assessing pests and diseases associated with fresh *Citrus* fruit from the countries listed in Table 1.1.

Table 1.1 Countries and *Citrus* species⁵ included in the *Citrus* IRA Project, as either submitted by exporting countries or listed in existing IHSs. See Table 2.2 for the taxonomy used in this IRA.

Country	Review of or new IHS	Commodities (as submitted)
Africa		
Egypt	New	Lime (<i>Citrus aurantiifolia</i>), Lemon (<i>C. limon</i>), Grapefruit (<i>C. paradisi</i>), Mandarin (<i>C. reticulata</i>), Tangelo (<i>C. reticulata</i> × <i>paradisi</i>), Pomelo (<i>C. maxima</i>)
Egypt	Review	Orange (<i>C. sinensis</i>)
Asia		
China	New	Mandarin (<i>C. reticulata</i>), Orange (<i>C. sinensis</i>), Pomelo (<i>C. maxima</i>), Grapefruit (<i>C. paradisi</i>), Lemon (<i>C. limon</i>)
Japan	Review	Mandarin (<i>C. reticulata</i>)
Japan	New	Mandarin (<i>C. unshiu</i> × <i>C. reticulata</i> var. <i>Shiranuhi</i>), Satsuma/Mandarin (<i>C. unshiu</i> × <i>C. sinensis</i> var. <i>Kiyomo</i>), Iyokan (<i>C. iyo</i>), Hassaku (<i>C. hassaku</i>) Ponkan (<i>C. reticulata</i>)
Korea	New	Unshu (<i>C. reticulata</i>)
Viet Nam	New	Pomelo (<i>C. maxima</i>), Mexican Lime (<i>C. aurantiifolia</i>), Tahitian Lime (<i>C. latifolia</i>) Limonia (<i>C. limonia</i>)
Europe		
Spain	Review	Orange (<i>C. sinensis</i>)
North America		
Mexico	Review	Orange (<i>C. sinensis</i>)
Mexico	New	Persian lime (<i>C. latifolia</i>)
United States	Review	Lime (<i>C. aurantiifolia</i>), Lemon (<i>C. limon</i>), Grapefruit (<i>C. paradisi</i>), Mandarin/Tangerine (<i>C. reticulata</i>), Orange (<i>C. sinensis</i>) Tangelo (<i>C. reticulata</i> × <i>paradisi</i>), Pomelo (<i>C. maxima</i>)
South America		
Brazil	New	Tahitian lime (<i>C. latifolia</i>), Lemon (<i>Citrus limon</i>), Orange (<i>C. sinensis</i>), Mandarin orange (<i>C. reticulata</i> / <i>C. deliciosa</i>)
Peru	New	Key/Mexican lime (<i>C. aurantiifolia</i>), Tahitian lime (<i>C. latifolia</i>), Mandarin (<i>C. reticulata</i>), Satsuma mandarin (<i>C. unshiu</i>), Grapefruit (<i>C. paradisi</i>), Orange (<i>C. sinensis</i>)

⁵ The taxonomy of commercial citrus fruit is complex. Almost all of the cultivated citrus “species” are hybrids derived from the same three or four parent species. Details on the taxonomic system used in this IRA are provided in Section 2.

Country	Review of or new IHS	Commodities (as submitted)
Oceania		
Australia	Review	Lime (<i>C. aurantiifolia</i>), Lemon (<i>C. limon</i>), Grapefruit (<i>C. paradisi</i>), Mandarin/Tangerine (<i>C. reticulata</i>), Orange (<i>C. sinensis</i>) Tangelo (<i>C. reticulata</i> × <i>paradisi</i>), Tangor (<i>C. reticulata</i> × <i>sinensis</i>)
Cook Islands	New	Tahitian lime (<i>C. latifolia</i>)
Fiji	New	Tahitian lime (<i>C. latifolia</i>), Meyer lemon (<i>C. meyeri</i>)
New Caledonia	Review	Tahitian lime (<i>C. latifolia</i>)
New Caledonia	New	Mexican lime (<i>C. aurantiifolia</i>)
Samoa	Review	Tahitian lime (<i>C. latifolia</i>)
Samoa	New	Pomelo (<i>C. grandis</i>), Meyer lemon (<i>C. meyeri</i>), Grapefruit (<i>C. paradisi</i>), Mandarin/Tangerine (<i>C. reticulata</i>), Tangelo (<i>C. reticulata</i> × <i>paradisi</i>), Orange (<i>C. sinensis</i>)
Solomon Islands	New	Lime (<i>C. aurantiifolia</i>)
Vanuatu	Review	Lime (<i>C. aurantiifolia</i>), Tahitian lime (<i>C. latifolia</i>), Lemon (<i>C. limon</i>), Grapefruit (<i>C. paradisi</i>), Mandarin/Tangerine (<i>C. reticulata</i>), Orange (<i>C. sinensis</i>) Tangelo (<i>C. reticulata</i> × <i>paradisi</i>), Pomelo/Pummello (<i>C. maxima</i>)

For the purpose of scoping the IRA, the risk evaluation criteria are based on the minimum intervention to manage pest risk on *Citrus* fresh produce. For most commodities this includes a combination of the commodity description and basic measures. The commodity description defines the minimum form of the commodity that is covered by the IHS. The commodity description may include commercial grading requirements or other commodity quality specifications. Basic measures are the minimum level of risk management that all *Citrus* fresh produce exporting countries must meet. The import risk analysis process aims to determine which pests and diseases may be associated with the commodity as defined by the commodity description, may not be managed by the basic measures, have the ability to move from the commodity to a host in the environment and the potential to establish and/or cause harm in New Zealand. Such pests and diseases may need to be considered for additional measures. Refer to Chapter 2 for details of the commodity description and basic measures.

The import risk analysis will answer the following questions:

1. Which pests and diseases may need to be considered for additional measures?
2. For the pests and diseases which may need to be considered for additional measures, which specific *Citrus* fruit pathways are they associated with (i.e. which countries and types of *Citrus* fruit).

Pests and diseases which may need to be considered for additional measures are those that:

1. are associated with fresh *Citrus* fruit of any species listed in Table 1.1 which meet the commodity description (see “IRA scope”, page v); and
2. are present in any of the countries listed in Table 1.1; and
3. have traits which indicate they may not be adequately managed by the basic measures listed in section 2.3
4. have a viable establishment pathway from fruit; and
5. have the potential to establish and/or cause harm in New Zealand.

The traits of a pest or disease which indicate it may not be adequately managed by basic measures would mean that the pest or pathogen and/or associated damage is not easy to see on the *Citrus* fruit, including when undertaking fruit grading or visual inspection. This may occur because:

1. the pest can burrow into the fruit without obvious symptoms, or
2. the pest can hide in the navel and/or under the calyx of the *Citrus* fruit, or
3. the pest or disease may take time or require particular environmental conditions to express symptoms.

The pests and diseases which meet the criteria above will undergo a risk assessment that considers the following factors:

- a) the strength or frequency of the association with the host fruit; and
- b) the extent to which the basic measures will reduce the risk; and
- c) the suitability of the environment in New Zealand for the pest or disease (including climate, host plant(s) availability and presence of vectors); and
- d) the ability of the pest or disease to move from imported fruit to a suitable environment to allow establishment (see section 2.4); and
- e) the impact on host plants in New Zealand (*Citrus* and other plants including native species), and the consequent potential economic, sociocultural and environmental impacts; and
- f) potential impact on human health.

The World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures (SPS agreement) states that phytosanitary measures must be supported by a risk assessment and not be maintained without sufficient evidence. That is, Biosecurity New Zealand must have evidence that a pest or disease would not be sufficiently managed by the commodity description (including basic measures) in order to require additional measures.

1.3 The risk analysis process

1.3.1 Overview

The Biosecurity New Zealand process for undertaking an IRA builds on the existing international frameworks for risk analysis under the World Organisation for Animal Health (OIE) and the International Plant Protection Convention (IPPC), and extends the scope under the SPS Agreement to include all of the values required by the Biosecurity Act (1993)⁶.

The individual steps in the process for developing an IRA are the same for both the OIE and IPPC. However the standards, guidelines and recommendations for animal health (sanitary) and plant health (phytosanitary) measures are developed by different international bodies. This means that there are differences in the detail of how IRA is done for animal health (OIE) and plant health (IPPC). The MPI process and methodology for undertaking an IRA is summarised in Table 1.2.

The main output is an IRA which is used in the development or review of an IHS under the Biosecurity Act (1993). An IHS specifies the requirements to be met for the effective management of risks associated with importing risk goods⁷.

Table 1.2 The basic process of import risk analysis

Commissioning		Drafting			Signoff and closeout
		Hazard identification	Risk assessment	Reviewing	
Approval to start	Plan the project	Manage the project			Closeout

⁶ Biosecurity Act section 23(4)(b)(iii) "...human health, the New Zealand environment, and the New Zealand economy...". As defined in section 2(1), environment includes "(a) ecosystems and their constituent parts, including people and their communities; and (b) all natural and physical resources; and (c) amenity values; and (d) the aesthetic, cultural, economic, and social conditions that affect or are affected by any matter referred to in paragraphs (a) to (c)".

⁷ Section 22, Biosecurity Act 1993.

The Biosecurity Act (1993) requires a Chief Technical Officer to begin the process of developing an Import Health Standard by “analysing or assessing the risks associated with importing a class or description of goods”⁸.

While the Biosecurity Act does not state how the risks are to be assessed or analysed, it does state that the Chief Technical Officer must have regard to certain matters when developing an IHS for recommendation to the Director-General. A number of these are part of an IRA as described by the OIE and IPPC:

- The likelihood that the goods will import organisms⁹
- The nature of the organism that the goods may import
- The possible effect on human health, the New Zealand environment¹⁰, and the New Zealand economy of the organism that the goods may import
- In relation to risk management measures proposed for inclusion in an IHS, the extent to which the measures reduce or manage the likelihood or impacts of adverse effects from organisms that may be imported on or in association with goods¹¹. **NB:** in this IHS project, information relevant to risk management considerations has been provided, by the risk analysis team to the risk management team and the MPI treatments group, in documents outside the IRA.

An IRA is also a relevant factor in how a country meets its obligations under the SPS agreement and other agreements such as the Convention on Biological Diversity (CBD). Under the SPS agreement, risk management measures either must be based on existing international standards, guidelines or recommendations, or must be supported by a scientific justification¹². Measures must not be maintained without sufficient scientific evidence¹³. Measures must also not be unnecessarily trade-restrictive¹⁴. In order to meet these obligations, the SPS agreement requires that measures are based on a risk assessment. Under the CBD, countries must consider environmental impacts in decision-making and prevent the introduction of, control or eradicate alien species that threaten ecosystems, habitats and species.

The MPI process is equivalent to the process for plant health risk analysis under the International Standards for Phytosanitary Measures (ISPM) under the IPPC¹⁵. The main difference is in terminology. The most important aspects of this process are:

- The formulation of the risk management questions. These are an essential part of initiating or commissioning a risk analysis¹⁶.
- The risk management questions are formulated based on the commodity description and basic measures for that commodity type.
- Risk evaluation criteria are based on the risk management question, so that the risk assessment directly addresses the specific questions of the risk manager and the conclusions are clear to readers.

In MPI, the IRA is used by the commissioning team to develop a Risk Management Proposal and to develop or amend an IHS or Craft Risk Management System (CRMS). The Risk Management Proposal provides the rationale for the risk management decisions, while the IHS and CRMS are the

⁸ Section 23(1) Biosecurity Act 1993

⁹ From Section 2(1) Biosecurity Act 1993: “**organism**—(a) does not include a human being or a genetic structure derived from a human being; (b) includes a micro-organism; (c) subject to paragraph (a), includes a genetic structure that is capable of replicating itself (whether that structure comprises all or only part of an entity, and whether it comprises all or only part of the total genetic structure of an entity); (d) includes an entity (other than a human being) declared by the Governor-General by Order in Council to be an organism for the purposes of this Act; (e) includes a reproductive cell or developmental stage of an organism; (f) includes any particle that is a prion”

¹⁰ From section 2(1) Biosecurity Act 1993, “**environment** includes—(a) ecosystems and their constituent parts, including people and their communities; and (b) all natural and physical resources; and (c) amenity values; and (d) the aesthetic, cultural, economic, and social conditions that affect or are affected by any matter referred to in paragraphs (a) to (c)”

¹¹ Section 23(4)(b) and (d) Biosecurity Act 1993

¹² SPS Agreement 1995 Article 3(1) and (3)

¹³ SPS Agreement 1995 Article 5(7)

¹⁴ SPS Agreement 1995 Article 5(6)

¹⁵ ISPM 2: *Framework for Pest Risk Analysis*

https://www.ippc.int/static/media/files/publication/en/2019/05/ISPM_02_2007_En_Framework_PRA_2019-04-30_PostCPM14_InkAm.pdf and ISPM 11: *Pest Risk Analysis for Quarantine Pests*

https://www.ippc.int/static/media/files/publication/en/2019/05/ISPM_11_2013_En_PRA_QPs_2019-04-30_PostCPM14_InkAm.pdf

¹⁶ Refer to FAO Biosecurity Toolkit <http://www.fao.org/3/a1140e/a1140e.pdf>, e.g. P73

legal documents issued under the Biosecurity Act 1993 that include the requirements that commodities must meet before biosecurity clearance can be given for import into New Zealand¹⁷.

1.3.2 Commissioning and planning

The process for scoping and planning a risk analysis is described here as commissioning. During this process, information is gathered, shared and discussed, and decisions are made about what needs to be assessed and how the analysis will be done.

The information covered in the commissioning process can include:

- the current context for the work (e.g. new measures or a review of existing measures);
- input from stakeholders and interested parties (the process may include meetings with and gathering information from key stakeholders);
- the commodity description (e.g. the commodity species and the countries under consideration);
- the pathway description (e.g. the production system and intended end use of the commodity);
- the risk management question or questions (a risk management question is a specific question that the risk manager needs answered in order to make a decision);
- criteria and methods for identifying hazards;
- the analytical approach, including the hazard groups to be considered¹⁸ and the likely level of detail;
- definitions and/or criteria for risk descriptors;
- basic measures for the commodity class or proposed for the specific IHS or CRMS;
- peer review, signoff and closeout processes;
- information about consultation or publication;
- expected timelines.

The commodity and pathway information provides context for the hazard identification and risk assessment.

1.3.3 Hazard identification¹⁹

Hazard identification is the process for identifying pests and pathogens associated with imported risk goods and which have the ability to cause harm to New Zealand. The process consists of compiling a list of potential hazards and then assessing them against criteria to see whether they warrant further consideration. The hazard identification answers two different questions:

- Does the species meet the criteria to be considered a biosecurity risk or quarantine pest for New Zealand?
- Is the species associated with the commodity that is being assessed?

The criteria for a quarantine pest for New Zealand are derived from the Biosecurity Act and ISPMs 2, 5 and 11. These criteria are:

- Is the species absent from New Zealand?
- OR is the species present in New Zealand, but it meets one of the following criteria?
 - The species is under official control.
 - The species is a vector of quarantine pests.
 - There are subspecific taxa (subspecies, varieties, strains, etc.) within the species that are an increased risk to New Zealand compared with those already present.

¹⁷ <https://www.mpi.govt.nz/importing/overview/import-health-standards/>

¹⁸ For a review of an IHS or CRMS, it is not necessary to consider all groups of hazards – it may be necessary to only consider some of the associated hazard groups. However, for a new IHS or CRMS, all groups of hazards should be considered, even if they are not assessed in any detail.

¹⁹ Under the IPPC, the hazard identification process is known as pest categorisation in ISPM 2 and ISPM 11.

- There are other factors that would mean that the species may still be of concern in associated with imported goods (e.g. increased exposure to people through imported goods²⁰).
- AND does the species have the potential to establish in New Zealand and/or harm “human health, the New Zealand environment, and/or the New Zealand economy²¹”?

Association with the commodity is based on:

- association with the host species or genus;
- association with the specific parts of the plant; and
- whether a particular pest will stay associated with a commodity when it is being handled – for example, a large flying insect is unlikely to stay on a piece of fruit when it is picked.

For the hazard identification:

- a) A list of potential hazards must be compiled.**
- b) Potential hazards must be assessed against criteria which meet relevant international standards and the requirements of the Biosecurity Act 1993.**
- c) The hazard identification conclusions must be documented and supported by suitable evidence.**

Different approaches may be taken to compiling and presenting the list of potential hazards depending on the information needed for organisms in each pest/pathogen group. The approach for each group is determined during the commissioning process, once the risk management question and risk evaluation criteria have been established. The approaches to be used are documented in the plan. The specific approaches to hazard identification used in this import risk analysis are discussed further in section 3.

At the end of the hazard identification process, the list of hazards that warrant further assessment may be peer reviewed or discussed with risk managers and key stakeholders.

1.3.4 Risk assessment

A risk assessment evaluates the likelihood of introduction and consequence for a particular hazard, as well as the uncertainty in the conclusions. The SPS agreement describes the factors to take into account when assessing risk. These factors include:

- available scientific evidence;
- relevant processes and production methods;
- relevant inspection, sampling and testing methods;
- prevalence of specific diseases or pests;
- relevant ecological and environmental conditions; and
- potential harm in the event of the entry, establishment or spread of a pest.

A qualitative approach is suitable for the majority of import risk analyses and is currently the most common type of assessment undertaken to support the development and review of import requirements. Qualitative descriptors of likelihood, consequence and uncertainty are provided.

The risk assessment stage of the IRA process:

- a) must be documented and supported by suitable evidence, and**
- b) must answer the risk management question by following definitions or criteria agreed on during commissioning.**

As part of a pilot project to streamline IRAs, the assessments for the *Citrus* IRA have been structured using the CASE schema²², which is a tool for developing and presenting logical reasoning to make the arguments clearer to the reader. The use of this approach will be reviewed at the conclusion of the project.

²⁰ One example is venomous spiders on fresh fruit. Even if present in a country, there may be a higher likelihood of people getting bitten if the spiders are associated with fruit sold at a supermarket.

²¹ Biosecurity Act 1993

²² The CASE schema is based on presenting a **Contention** (the conclusion of the risk assessment) supported by **Arguments, Evidence** and **Sources**. Further information can be found at: <https://timvangelder.com/2019/04/07/what-is-the-case-schema/>

The approach to pest risk assessment used in this IRA is discussed further in section 4.

1.3.5 Assessment of uncertainties

The SPS agreement states that measures must be applied *only to the extent necessary* and must be supported by *sufficient scientific evidence*²³. Therefore, if there is insufficient evidence indicating that an organism may require consideration for additional measures (based on assessment against the risk evaluation criteria), then the lack of evidence suggests that it does not meet the criteria to be a hazard (see section 1.3.3). However, in some cases there may be good reason to consider a pest or pathogen even when evidence is insufficient (e.g. similarity to known pests or pathogens)²⁴.

Documenting significant uncertainty is an essential part of a risk assessment. Uncertainties such as contradictions in the evidence or a lack of evidence are documented in the IRA. Where the risk assessment identifies significant uncertainty affecting the conclusion, this is indicated in the wording of the conclusion. The risk management proposal (see section 1.3.1) gives further consideration to these risk assessments. See Chapter 4 for further information on how uncertainty is documented.

1.3.6 How the risk analysis informs risk management decisions

The conclusions of the risk assessments are used to develop a risk management proposal and the IHS. Specifically, the risk management proposal considers additional measures for those hazards that the risk assessment concludes will not, or may not, be managed by basic measures. The risk management proposal gives a rationale for the risk management decisions based on the assessments with significant uncertainty.

1.3.7 Review and consultation

The IRA must be reviewed to check that it is based on the best available and most credible information, that the document is clear and logical, that assumptions are valid and that conclusions are consistent with the evidence, with other conclusions in the IRA and with relevant conclusions in other assessments. The review process involves relevant experts within MPI and may involve experts from outside MPI, either from New Zealand or overseas where considered necessary. A representative from the team commissioning the IRA may be included in the review process.

The IRA may be reviewed as a whole or in parts. For example, it is common that individual assessments for pests or diseases are reviewed by an expert in that group.

For an IRA review:

- a) **The IRA must be reviewed by relevant staff from within MPI.**
- b) **Individual pest or pathogen assessments may be reviewed by relevant experts within MPI and also subject matter experts and/or relevant stakeholders from outside MPI, either from New Zealand or overseas.**
- c) **All review comments must be considered, and if internal or external reviewers' feedback²⁵ is not incorporated into the IRA, the rationale for the decision not to include that feedback must be clearly documented, and, where necessary, discussed with the reviewer.**

1.3.8 Conclusions of the risk analysis

The conclusions of the risk analysis are summarised in a risk management proposal that accompanies the draft IHS being consulted on. The risk analysis provides additional technical detail should submitters wish to see a more detailed scientific analysis of the biological risks.

²³ SPS Agreement 1995 Article 2.2

²⁴ SPS Agreement 1995 Article 5.7

²⁵ Note that this point does not apply to editing comments such as corrections to spelling, punctuation or grammar.

All submissions received from stakeholders will be analysed and compiled into a review of submissions. The IRA, risk management proposal and draft IHS will be modified where appropriate depending on the outcome of consultation.

1.4 References for Chapter 1

FAO (1995) *Guidelines for pest risk analysis*. International Standard for Phytosanitary Measures No. 2. Published by FAO on behalf of the Secretariat of the International Plant Protection Convention (IPPC); Rome, Italy.

FAO (2013) *Pest risk analysis for quarantine pests*. International Standard for Phytosanitary Measures No. 11. Published by FAO on behalf of the Secretariat of the International Plant Protection Convention (IPPC); Rome, Italy.

WTO (1995) World Trade Organization (WTO) Sanitary and Phytosanitary Measures Agreement (SPS). www.wto.org/english/tratop_e/sps_e/sps_e.htm.

2. Commodity and pathway description

2.1 Commodity description

The commodity for the IRA is commercially produced²⁶ fresh *Citrus* fruit belonging to any of the fruit types/species listed in Table 2.2. The fruit may have the calyx attached but not stem, leaves or other plant parts. The commodity definition excludes material or produce that is visibly damaged (e.g. fruit must have an intact skin, free from defects such as splits and cuts).

Table 2.1 puts the risks associated with *Citrus* fruit in the wider context of relative risks of different commodities, pathways and plant species. The information in the general commodity risk assessment and the section on the transfer of pests and pathogens will be used in the IRA when assessing the risk of pests which may be considered for additional measures. Further detail is given in subsequent sections.

Table 2.1 General commodity risk explanation

Question	Factors to consider
What is the relative risk associated with the commodity class?	Fresh produce – intermediate, it is not intended for propagation, but is not processed (refer to FAO 2017). Both types of plant material (produce for consumption and germplasm) have invertebrate pests and pathogens but many pathogens are only a risk on material that is propagated.
What is the relative risk associated with the type of material making up the commodity?	Fruit – while “consumption” pathways are intermediate in terms of risk, a number of pests of major importance (mainly economic rather than environmental) are known to be associated with fruit, e.g. fruit flies.
How likely is the commodity to carry pests that can establish in New Zealand?	<i>Citrus</i> is native to, and grown commercially in, areas overseas that have a similar climate to New Zealand, for example, parts of China, Japan and Australia. It is also grown in areas that are less similar to New Zealand. <i>Citrus</i> is therefore intermediate in terms of likelihood – it is higher than species grown in very specific climates, for example, mango, but lower than temperate species, for example, cherries. <i>Citrus</i> is grown commercially and in home gardens in New Zealand, although wild records are rare ²⁷ . Therefore, associated pests and pathogens, including those that are host-specific, are likely to come into contact with host plants in New Zealand.

²⁶ Process (system) where activities, such as in-field monitoring, in-field pest control activities, harvesting, cleaning, sorting and grading have been undertaken to produce a commodity that is free of defects such as broken skin, rot and damage. Depending on the systems in place, these activities can be undertaken at any stage from the point of planting to the point of export.

²⁷ Allan Herbarium

<https://nzflora.landcareresearch.co.nz/default.aspx?selected=NameDetails&TabNum=0&NameId=0BDA3A5C-4DA1-4289-9B8B-C0B3B3A7A6D6>

Question	Factors to consider
<p>How likely is the commodity to carry pests that cause major impacts in New Zealand? What are the values associated with the commodity species and the related species in New Zealand?</p>	<p>The pests and pathogens associated with <i>Citrus</i> fruit may affect many different host plants in New Zealand. However, the likelihood that particular hosts will be affected may be dependent on how closely related those hosts are to <i>Citrus</i>. There is a strong relationship between how closely related plant species are and how likely they are to share pests and pathogens (Gilbert and Webb 2007). Therefore, the host plants most likely to be affected by pests and pathogens carried on <i>Citrus</i> fruit are <i>Citrus</i> species. The next most likely are members of the same family (Rutaceae). There are both native (<i>Melicope</i> and <i>Leionema</i>) and introduced ornamental (e.g. <i>Choisya</i>, <i>Coleonema</i>) genera of the Rutaceae family in New Zealand. Some pests and pathogens associated with <i>Citrus</i> affect a wide range of other species, for example, fruit flies and mites.</p> <p>Pests and pathogens that are associated with <i>Citrus</i> but affect other members of the family have the potential for environmental impacts as well as impacts on amenity values. The native genera <i>Melicope</i> and <i>Leionema</i> do occur overseas in regions where <i>Citrus</i> is native or cultivated, e.g. Hawaiian Islands, across the Pacific to tropical Asia and Australia. Ornamentals in the family Rutaceae, such as <i>Choisya</i>, <i>Coleonema</i>, are widely grown around the world. Therefore, many common <i>Citrus</i> pests and pathogens have had the opportunity to switch hosts to these genera. This means that if pests of <i>Citrus</i> have not been recorded on these genera overseas, they are less likely to affect members of these genera in New Zealand.</p> <p><i>Citrus</i> is an important crop in New Zealand and is the third largest fresh fruit crop after kiwifruit and apples. The New Zealand <i>Citrus</i> industry comprises around 1,600 hectares located in the Bay of Plenty, Gisborne and Northland regions. In 2018, the domestic and export sales of fresh <i>Citrus</i> fruit were NZ\$58.5 million and \$12.0 million, respectively (Plant & Food Research FreshFacts 2019).</p>
<p>What is the level of knowledge of the pests associated with the commodity and related species in New Zealand and overseas?</p>	<p><i>Citrus</i> is a well-known fruit crop that is widely cultivated. Thus, there are reliable literature sources for some pests and pathogens associated with <i>Citrus</i> across a wide range of countries/continents. There is likely to be less information on native Rutaceae in New Zealand and abroad.</p>

In conclusion there is an intermediate risk associated with the importation of citrus fruit for human consumption. The risk is lower than for commodities imported for propagation and lower than for other fresh fruit commodities that may be more temperate in their distribution or that have many related native and economically important plants species in New Zealand (e.g. *Prunus* and *Malus*). The risk is higher than for fresh produce such as mango, which is more tropical in its distribution and has few related plants of importance in New Zealand. All citrus fruit are fruit fly hosts, which increases the risk associated with these commodities, compared with fresh produce that is not a fruit fly host, such as ginger.

2.2 Taxonomy of plant commodities under consideration

The taxonomy of citrus fruit species is unclear because of a long history of cultivation and hybridisation. The current wide diversity of commercial citrus fruit is believed to be derived from three or four ancestral species (see, for example, Barrett and Rhodes 1976, Nicolosi et al. 2000, Wu et al. 2018). Some of the lesser-known types (such as yuzu) also have parentage of other species. The ancestral species are believed to include:

- *Citrus maxima* (pomelo)
- *Citrus reticulata* (ancestral mandarin)
- *Citrus medica* (citron)
- *Citrus micrantha* (small-flowered papeda)

All main commercial citrus are hybrids involving parentage of those four species. The hybrids include both natural and deliberate crosses. As well as hybridising freely, many types of citrus have adventitious embryony (i.e. apomixis (Zhang et al. 2018), a form of asexual reproduction without fertilisation).

As a result of this complex history, there are various names applied to different types of fruit, and many fruit are only known by their common or trade name. Whether a plant is considered a hybrid or a species is a taxonomic question not necessarily relevant to the question of biosecurity risk.

The complexity of citrus taxonomy presents difficulties when it comes to categorising and grouping commodities for IHSs. Groupings need to be consistent with known phytosanitary risks (similar susceptibility to particular pests and pathogens), and this may be associated with the degree of relatedness (shared parentage) of commodities or shared physical characteristics. Fortunately, in 2002, INRA-CIRAD²⁸ published a review of all of the known cultivars, varieties, hybrids and species of *Citrus* in cultivation from around the world (INRA-CIRAD 2002). The review lists all the *Citrus* that were then known by the two major *Citrus* naming systems published by Tanaka and Swingle. While INRA-CIRAD (2002) will not contain more recent *Citrus* cultivars or varieties, the list is the most recent attempt to produce a coherent description of the cultivated *Citrus* complex. For the purposes of this IRA, the more simple naming system of Swingle is considered the most consistently aligned with the risk characteristics of the fruit. A list of the *Citrus* commodities from Table 1.1, but renamed according to the Swingle taxonomic system, is provided in Table 2.2.

Table 2.2 List of *Citrus* commodities assessed in this IRA based on the Swingle naming system and Table 1.1, using SRA INRA-CIRAD (2002)

<i>Citrus</i> species (or hybrids)	Synonyms	Common names
<i>Citrus aurantiifolia</i> (Christ.) Swingle	<i>Citrus limettioides</i>	Lime, Sweet lime, Key lime, Mexican lime
<i>Citrus latifolia</i> (Yu. Tanaka) Tanaka		Tahitian lime, Persian lime
<i>Citrus limon</i> (L.) Burm.f.	<i>Citrus limonia</i> , <i>Citrus meyeri</i>	Lemon, Meyer lemon; Limonia
<i>Citrus maxima</i> (Burman) Merr.	<i>Citrus grandis</i>	Pomelo, Pummelo
<i>Citrus paradisi</i> McFad.	<i>Citrus hassaku</i>	Grapefruit, Hassaku, Ruby grapefruit
<i>Citrus reticulata</i> L.	<i>Citrus unshiu</i> , <i>Citrus deliciosa</i>	Mandarin, Tangerine, Unshu, Satsuma
<i>Citrus sinensis</i> (L.) Osbeck	<i>Citrus iyo</i>	Orange, Iyokan, Valencia orange, Navel orange
<i>Citrus reticulata</i> × <i>Citrus paradisi</i>		Tangelo
<i>Citrus reticulata</i> × <i>Citrus sinensis</i>		Tangor

²⁸ Station de Recherche Agronomique, Institut National de la Recherche Agronomique - Centre International de Recherche et d'aide au Développement (INRA-CIRAD)

2.3 General information related to likelihood of entry

2.3.1 Pathway description

Basic measures are the minimum level of risk management that all citrus exporting countries must meet. The basic measures for importing fresh *Citrus* spp. fruit for consumption into New Zealand are:

1. Consignments of fresh *Citrus* spp. fruit imported into New Zealand must:
 - a. be free from infestation and contamination (including visible pests and diseases, soil, biotic material, or abiotic material capable of harbouring or spreading pests or diseases of biosecurity concern) and other extraneous material not included in the commodity description;
 - b. be free from conditions that may indicate pest or disease contamination (including rots and damage);
 - c. comply with the commodity description (e.g. be sourced from a production site that uses standard commercial production methods²⁹, have an intact skin (on export), free from defects such as splits and cuts, no leaves or stems attached);
 - d. be packaged in clean and either new or refurbished material; and
 - e. be secured in a manner to prevent contamination.
2. Fresh *Citrus* fruit will undergo official inspection in the export country and be sampled prior to being exported to New Zealand at a 95% confidence level that pest or disease infestation is less than 0.5% and the level of contamination by abiotic material is less than 0.1% w/w. Fruit lots with biosecurity risks (pests, rot or damage, trash and soil) or not complying with the commodity description (broken skin, stems, leaves) should not be exported to New Zealand as fresh produce. If the pest or disease is 100% detectable, a sample of 600 will provide a 95% confidence level that the level of pest or disease infestation is less than 0.5%. If the pest or disease is less than 100% detectable on inspection, the sample size will need to be increased to provide a 95% confidence level that the level of infestation is less than 0.5% (see ISPM 31 for an explanation).

2.4 General information related to likelihood of establishment

2.4.1 Exposure

When a pest or pathogen arrives in a new area, it usually needs to find or come into contact with a growing host plant in order to establish. This is termed “exposure” in MPI risk assessments and “transfer” under the IPPC.

In the case of germplasm, imported plant material is maintained in a habitat favorable for plant growth and is likely to be multiplied up to substantial numbers, resulting in a high likelihood of exposure, with low uncertainty for pests and pathogens associated with germplasm/propagation pathways.

In the case of fresh fruit and vegetables, the intended use is consumption, not propagation. There are two ways a pest or pathogen arriving with fresh fruit and vegetables may come into contact with a growing host plant:

1. A pest may fly or be blown off the fruit and find a host plant. Examples include mobile pests such as thrips and psyllids, as well as some fungi.
2. The fruit is discarded into an environment that allows the pest or pathogen to continue its life cycle and eventually come into contact with a host plant. Examples include flies, scales and citrus canker.

²⁹ Definition: a process (system) where activities, such as in-field monitoring, in-field pest control activities, harvesting, cleaning, sorting, and grading have been undertaken to produce a commodity that is free from defects such as broken skin, rot and damage. Depending on the systems in place, these activities can be undertaken at any stage from the point of planting to the point of export.

The likelihood of the first case (mobile pest) occurring depends largely on the mobility of the pest. However, the more mobile the pest is, the less likely it is to be associated with harvested and packed fruit in the first place, due to the level of handling the fruit receives during these processes.

The likelihood of the second case (discarded fruit material) occurring depends on waste material generated from the commodity (either parts of the commodity not generally consumed, e.g. rinds or seeds, or parts generally consumed that have degenerated to the point of being considered inedible). Waste material discarded into bagged rubbish that goes to landfill, or into kitchen disposal units that flush into the sewerage system, is unlikely to be a risk. However, waste discarded into compost bins, under plants as mulch or distributed as animal feed presents a potential exposure pathway.

2.4.2 Waste analysis

Citrus fruit has inedible skin and produces a moderate amount of waste, more than a commodity such as fresh ginger but less than a pineapple, and whole fruit being disposed of is not uncommon during wholesale and retail marketing and even in the consumer stage. Culled and unsold fruit, uneaten fruit and fruit remains may be disposed of by wholesalers, retailers, food services (e.g. restaurants, hospitals) and consumers (MPI, 2014). In addition, *Citrus* fruit can be a high-volume fresh produce commodity. Therefore, pests and pathogens associated with citrus fruit waste have a moderate to high level of exposure in comparison to other kinds of fresh produce. However, this likelihood is much less than with germplasm, as only a limited amount of the commodity ends up in an environment suitable for associated pests and pathogens to establish.

In New Zealand, landfilling has been the most common method of disposing of municipal solid waste and organic waste (Askarany & Franklin-Smith 2014). Fresh produce food waste may be disposed of by wholesalers, retailers, food services and consumers. The accurate proportion of commercial and household fresh produce waste that is disposed of by different disposal methods is difficult to survey (Waste Not Consulting 2009). It is important to note that the proportions in some of the following studies are for total food waste or organic waste, and as such, the proportion that comprises imported produce or citrus fruits is likely to be much smaller and affected by seasonal differences in fruit supply. In North America, Australia and New Zealand, the total loss of fruit and vegetables during distribution/retail marketing and at the consumer stage is 12% and 28% respectively (NRDC 2012 in Porat et al. 2018).

For commercial food waste:

- A waste analysis in New Zealand shows that approximately 20.3% of retail and 6.9% of non-domestic outlets (hospitals, restaurants, etc.) used high-risk methods (e.g. garden compost) to dispose of waste (Wigbout 1991, in MPI 2014).
- MPI (2014) also noted that wholesale fruit disposal pathways and practices were not covered. Although normal commercial practice is to reduce waste, fruit waste in New Zealand may be collected from unpacking areas (e.g. supermarket preparation rooms) and taken to rural areas where it is placed on the ground for eventual consumption by pigs or other farmed animals.
- A more recent survey on waste from supermarkets in New Zealand (Goodman-Smith 2018) found that 46% of supermarket food waste was used as animal feed, of which 30% was fresh fruit waste.
- 23% of supermarket food waste was landfilled, of which approximately 6% was fresh fruit waste (Goodman-Smith 2018).
- 1% of supermarket food waste was composted, of which approximately 65% was fresh fruit waste (Goodman-Smith 2018). It is not known whether this waste was composted in garden compost or commercial compost. Garden compost is a high-risk method, as compost sites are not always covered and often close to weeds, grasses and garden plants. In contrast, commercial compost is a low-risk method, as the waste will be put in tunnels for a few days, and the high temperature (a period of three to four days at greater than 55°C) is likely to kill most insects and mites and many pathogens (WasteMINZ, 2009).
- 15% of food that was not sold in supermarket went to food donation, of which fresh fruit comprised 13% (Goodman-Smith 2018).

For domestic food waste:

- A 2010 survey in New Zealand found that 71% of household organic waste was landfilled (Hogg et al. 2010).
- Approximately 13% of household organic waste was disposed of in disposal units (Hogg et al. 2010).
- Approximately 13% of household organic waste was composted (Hogg et al. 2010).
- In rural areas, one study in Taranaki found that 75% of farmers fed food waste to farm animals (Waste Not Consulting 2009), but the proportion of food waste that was fed to animals is unknown.

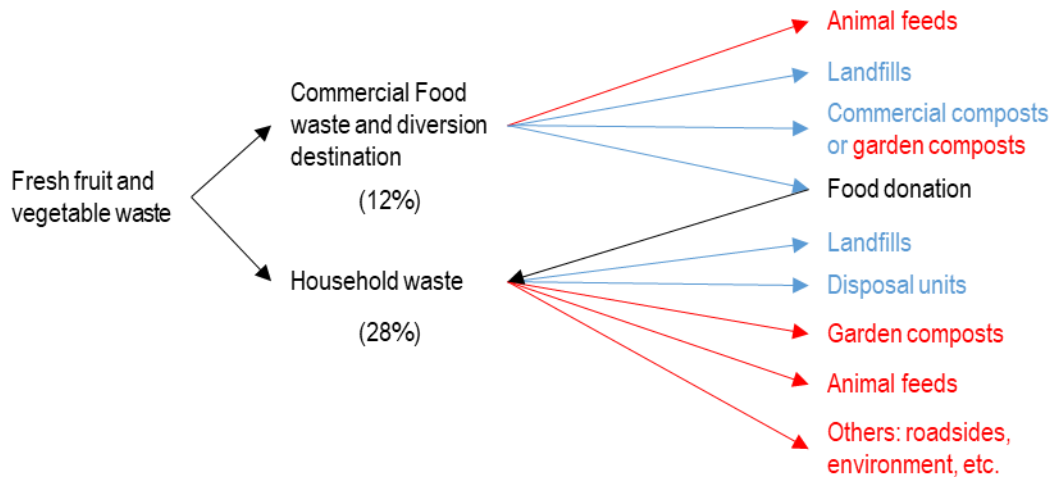


Figure 2.1 Disposal of fresh fruit and vegetable waste in New Zealand. Disposal methods in blue text are a low biosecurity risk; those in red text present a higher risk.

Note that when considering the likelihood of exposure of the pest or disease associated with the risk of waste from the commodity, there is a moderate level of uncertainty on the waste data, due to data limitations. First, waste data may not be very accurate or up to date. Data on household waste (Hogg et al. 2010) for fresh fruits and vegetables were estimated from organic waste, of which fresh fruits (including citrus) may only account for a small proportion. Apart from the supermarket survey (Goodman-Smith, 2018), the waste data were obtained about 10 years ago, although landfilling is still considered the primary means of disposing of waste in New Zealand. Second, it is uncertain how frequently suitable hosts would be present near composting sites in gardens or animal feeding locations, as no report has been found to investigate this.

Potential for the exposure of Citrus seed-transmitted and vector-transmitted pathogens

There is no evidence that seed from discarded *Citrus* fruit results in seedlings except under rare circumstances. That is, despite being commonly cultivated, few types of *Citrus* are reported to be naturalised in New Zealand, and those that are naturalised are not common or widespread in the wild³⁰. Seed from imported *Citrus* fruit could be deliberately planted; however, given that this is not the intended end-use and is unlikely to happen frequently, deliberate propagation is not considered further in this IRA. Pathogens that could only be transferred into the environment via seed growth have therefore been excluded from this IRA.

There are also vector-transmitted pathogens that may be detected in fruit, for example via PCR tests, but have no way of getting from fruit and onto a growing host in the absence of a vector. These have also been excluded from this IRA if the vector is not in New Zealand and not likely to be associated with the commodity under the commodity description.

³⁰ Allan Herbarium
<https://nzflora.landcareresearch.co.nz/default.aspx?selected=NameDetails&TabNum=0&NameId=0BDA3A5C-4DA1-4289-9B8B-C0B3B3A7A6D6>

2.4.3 New Zealand climate description

New Zealand in general exhibits a mid-latitude oceanic temperate climate (Cfb temperate with maritime climate in the Köppen classification (Köppen 1936; Rubel and Kottek 2010)). Annual precipitation varies substantially due to topography, from dry eastern and inland areas to very high precipitation (on a global scale) in west coast areas³¹. The driest New Zealand climates barely reach a conventional water deficit on average (although they can do so in extreme years and months). The New Zealand climate 'space' can be visualised as a three-dimensional simplified climate niche (Fig. 2.2). This represents the average monthly temperature and precipitation for each month of the year for 42 New Zealand climate stations.

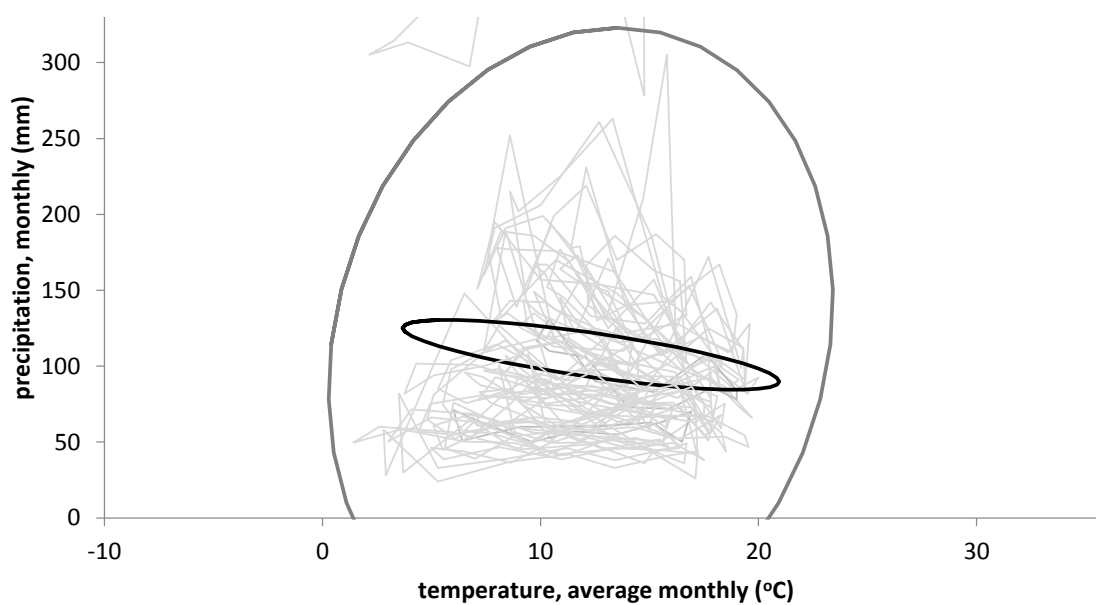


Figure 2.2 Climate niches of New Zealand. Thin grey lines: average monthly temperature (1981–2010) for 42 New Zealand climate stations (data from NIWA (2020)). Each polygon is composed of the 12 months of the year. Small black ellipse: average conditions for those 42 sites. Large ellipse: 95% inclusive ellipse.

As a consequence of being a small landmass in a large ocean, New Zealand has relatively low diurnal and seasonal temperature fluctuations (equable climate). Rainfall is close to evenly distributed between summer and winter. These features are similar in equatorial climates. However, there can be relatively rapid variations between days as large weather systems alternate over the oceans. Although such variations may also occur in continental climates, a key difference for organisms is the proximity of these variations to biological thresholds (such as frost).

Unlike many Northern Hemisphere continental climates with reliable lengthy warm and cold periods, a small temperature variation in a mild oceanic climate means a more significant change in the number of days crossing threshold degrees, which may in some cases restrict the ability of some organisms to establish. This feature is also common to smaller land masses and mountains of the Southern Hemisphere, which is why, globally, some of the most similar climate conditions to New Zealand are in the montane regions of the Andean Yungas cloud forests and grasslands (Halloy et al. 2008). This is reflected in high morphological similarities of adaptations (Halloy & Mark 1996).

Together with tussock grasslands, temperate rainforests are the global biome climate types most represented in New Zealand. The northernmost areas of New Zealand approximate subtropical temperature conditions, with an ability to grow a range of subtropical plants.

The northern part of New Zealand is the most climatically suitable for the establishment of new pests and pathogens coming from a subtropical/tropical climate. The area includes Kaitaia, Kerikeri,

³¹ This summary is written with crop pests and diseases in mind, focusing on the climate in inhabited and cultivated areas of New Zealand. Rainy outliers (e.g. Milford and Mt Cook) and high mountain climates are not considered, as they represent extremes with relatively low human and agricultural activity

Whangarei, Auckland (New Zealand's largest city) and Tauranga. The latter two cities both contain large active sea ports.

Citrus species are from the warmer temperate climates of the world, and most parts of New Zealand's coastal environments are ideal for them, as long as they are sheltered. Mature trees are either flowering or fruiting and commonly doing both together. The genus *Citrus* is widespread throughout the country with households commonly having Meyer lemon trees in their gardens. If conditions allow, other species of *Citrus* can be found growing in home gardens. *C. × aurantium* L., sour orange, *C. × limon*, especially cv. 'Meyer', Meyer lemon, *C. reticulata* Blanco, mandarin, tangerine or satsuma orange, and *C. × sinensis* are very commonly grown in warmer North Island areas. The Bearss cultivar of Tahitian lime, *C. × latifolia* cv. Bearrs (Yu. Tanaka) Tanaka is also common and will also grow in cooler areas of the North Island. Nevertheless, within New Zealand proper, no *Citrus* spp. has been reliably reported wild.

The main citrus-growing areas of New Zealand are the Northland, Auckland, Bay of Plenty and Gisborne regions. Most commercial production takes place in the Gisborne and Northland regions, followed by Auckland, Bay of Plenty and Hawke's Bay, with much less in other regions throughout the North Island and in parts of the South Island (Plant & Food Research 2019).

Climate in the regions where citrus is grown commercially:

- **Northland:** Kerikeri is a well-known orcharding town, with many varieties of *Citrus* fruit grown there. Avocado, kumara, macadamia and tamarillos are the other main crops grown there (HortResearch, 2005; Plant and Food Research, 2010). This is a subtropical zone, with warm humid summers and mild winters. Typical summer daytime maximum air temperatures range from 22°C to 26°C, but seldom exceed 30°C. Winter daytime maximum air temperatures range from 12°C to 17°C (NIWA 2008).
- **Auckland:** This region has the largest population in the country, with the greatest quantity of incoming goods and people, and contains the largest sea and air ports. Therefore it is likely to be one of the first places pests and diseases could establish. The Auckland region produces a variety of crops, including *Citrus* species such as mandarins, as well as strawberries, herbs, Asian vegetables, brassicas, chestnuts, greenhouse crops, lettuce, olives, onions, persimmons, pumpkins and silverbeet (HortResearch 2005; Plant and Food Research 2011). Auckland has the highest rate of naturalised plants of any city in New Zealand. The prime reasons for the high numbers of plant species are considered to be the moderate climate, favouring species from many climatic zones, and the availability of habitats (Esler 1988).
- **Bay of Plenty:** During summer, the region experiences average daily air temperatures over 20°C. The low-lying, coastal areas experience mild winters (NIWA 2013). Tauranga produces feijoas, citrus, avocados, asparagus, tamarillos and kiwifruit (HortResearch 2005; Plant and Food Research 2010).
- **Gisborne:** The climate is generally congenial, with a large number of sunshine hours and low wind. Rainfall is unevenly distributed, with a prominent winter maximum. There are small areas of the region with high productivity for fruits and vegetables (NIWA 2016). Prominent crop species include citrus, wine grapes, apples and squash (FreshFacts 2019).

The large number of pests associated with *Citrus* species means that a detailed assessment of establishment and potential distribution is not possible. With respect to establishment and range, climate is generally a more important consideration for invertebrate pests than for pathogens. However, although climate is not the primary indicator of a pathogen's ability to establish, it is a useful piece of information to consider, particularly if pathogen spread is dependent on a vector, and also in relation to the extent of disease expression. The climate overlap between New Zealand and where a pest has been reported is assessed using the tool described in Phillips et al. (2018). This tool is based on the climate (or composite) match index (CMI) CLIMEX-MCR of CLIMEX version 3.3. The tool allows the comparison of New Zealand's climate in general, or citrus-growing areas specifically, with areas where a pest occurs overseas. The higher the CMI, the more similar the climate of the region to which the CMI pertains and the New Zealand climate. A CMI of 0.7 or more between the New Zealand climate and the existing range of the pest indicates a high likelihood of climatic suitability for that pest to establish in New Zealand (Phillips et al. 2018).

For many of the pests assessed, this tool is likely to be a sufficient indication of climatic suitability in New Zealand for the pest to establish. Figure 2.3 shows the whole-world map with CMI data from Phillips et al. (2018). When using the tool, the map can be enlarged to show more detail at a regional level. For some pests assessed, more detailed climate niche envelopes (see Fig. 2.2 above) have been developed to compare the climate of the pest's known range with the New Zealand climate.

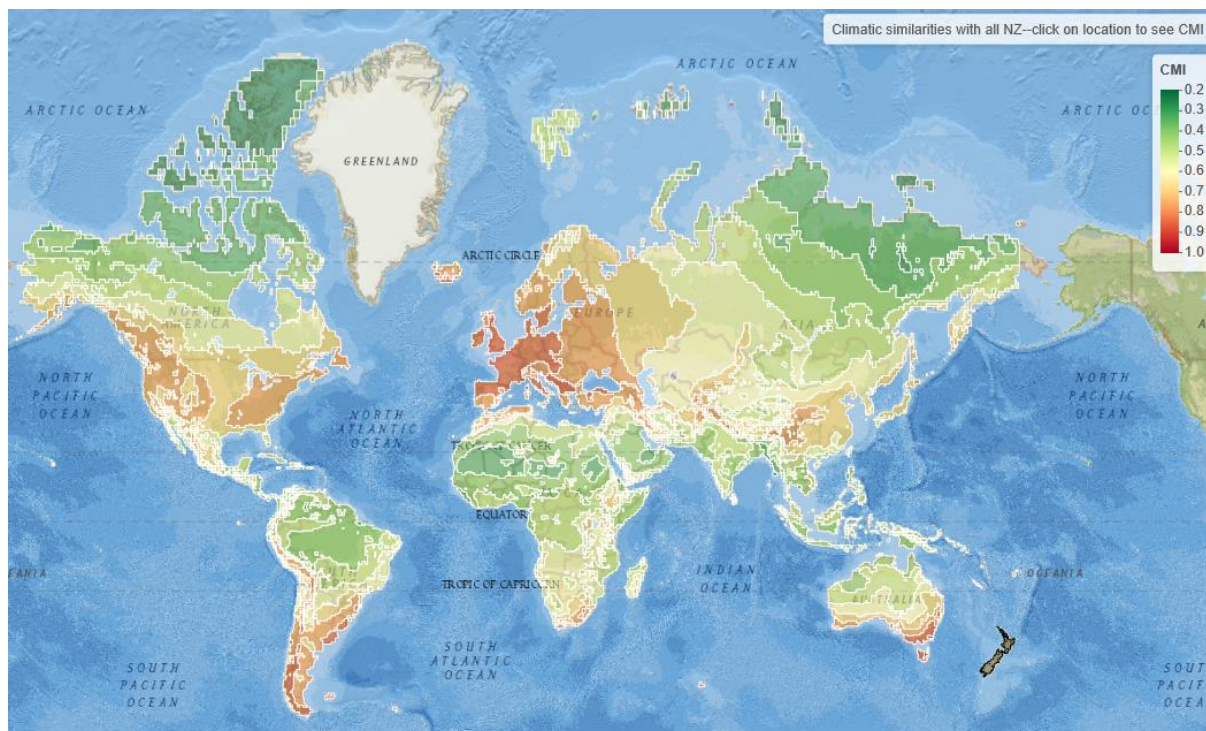


Figure 2.3 Climate match index (CMI). World climate similarities with All New Zealand (Phillips et al. 2018).

2.4.4 Shifting New Zealand climates with climate change

The global climate is warming rapidly and will continue to warm even faster as a result of greenhouse gas emissions (IPCC_WGI 2013; Allen et al. 2018; WMO 2019). Several studies have examined the effects of these changes on the New Zealand climate (NIWA 2017; MfE 2018). Warming temperatures and changing precipitation patterns will affect existing biodiversity, pests and diseases, and will change the likelihood of establishment of new arrivals (Gerard et al. 2013; Kean et al. 2015). However, climate change is not just a scenario for the future. Average New Zealand temperatures have risen substantially over the last century, with concomitant but more variable changes in threshold and extreme conditions (including frosts, heatwaves, droughts, tropical storms, etc). Sea surface temperatures (SSTs) around New Zealand are closely correlated with atmospheric warming, and in recent decades (since 1981), have been rising in the order of 0.1–0.3°C per decade (Sutton & Bowen 2019). This would equate to 1–3°C per century, close to the modelled predictions for 2100. Such trends are, to some degree, hidden by inter-annual variability, but are already significant for the biota, agriculture and human occupation.

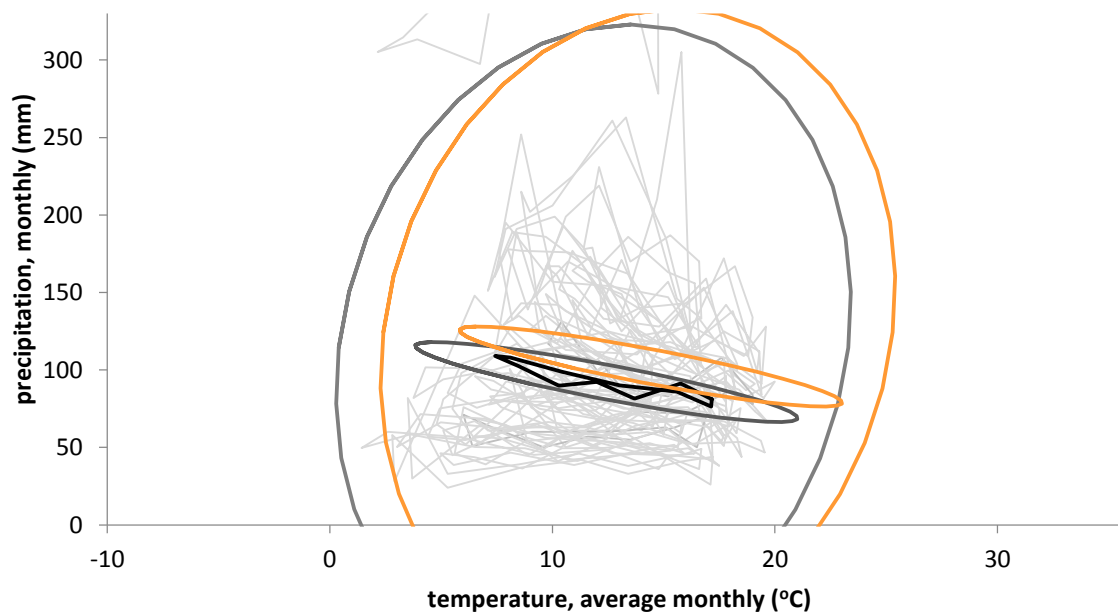


Figure 2.4 Shift of New Zealand climate niches with climate change. Grey polygons and black ellipses as in Fig. 2.2 (1981–2010 climate baseline). The orange ellipses represent the expected shift with a moderate climate change scenario (simplified as a +2°C increment and +10-mm monthly addition to precipitation).

These ‘shifting goal posts’ may lead to some confusion when reading climate change scenarios. Climate scenarios are expressed as degrees of change up to 2100, for example, a 2°C increase. However the baseline for that increase may not be explicit to the reader. The baseline is sometimes referred to as ‘conditions pre-industrial age’, or ‘beginning of 20th century’. Other times, it may be the ‘1961–1990 average’, or more recently, the ‘1981–2010’ average. Because of the continuous change since the pre-industrial period, the first baseline would lead to a 2°C increase by 2100. However, adding the same 2°C to a 1981–2010 baseline would mean ~3°C increase by 2100 in respect to pre-industrial conditions.

In New Zealand, some of the last years have already approximated a 2°C increase on pre-industrial levels. Although cool years will still occur, for an organism, some conditions in some years already approximate some models for 2100. Model scenarios for temperature increases for 2100 depend on many factors, but most scientists now expect there is little chance of keeping the increases below 2°C (Wallace-Wells 2019). For illustration’s sake, exploring a conservative 2°C average increase (as in NIWA scenarios³²) and a 10-mm monthly increase in precipitation allows us to investigate the consequences without making any judgement as to which is more likely.

We can then consider the likelihood of such scenarios. To give an idea of how conservative a +2°C is, consider that the average temperature in the last century has already climbed >1°C over pre-industrial values. As averages shift, so do the extremes of the distribution and the thresholds for frosts, degree days, etc. Note, for example, that the midpoint of July 2009–2018 is where extreme warm years were in 1928–1937; the extreme has already become the norm (Fig. 2.5)³³. Moreover, the pace of increase is accelerating, greenhouse gas emissions are still rising, and a series of potential tipping points may soon be breached. Due to prolonged lag times, the abrupt decline in emissions triggered from March 2020 due to the Covid-19 pandemic are not likely to affect trends in the next decades. If such declines were to continue, they could reduce the centennial temperature increase.

³² 2°C is an ‘in between’ of the 0.7°C to 3°C range of scenarios in NIWA: <https://niwa.co.nz/our-science/climate/information-and-resources/clivar/scenarios>, 20171221. However, in more detail, <https://ofcnz.niwa.co.nz/#/localCharts> shows an increase to 2100 of 2°C (RCP 6) to 3°C (RCP 8.5) annual mean (for six-model average) for Christchurch. Annual precipitation remains almost the same. Spring °C and mm follow the same pattern. Summer (DJF) increases less (1.5°C to 2.3°C). For rainfall, possible increases are around 10 mm; however, there will be considerable geographic variation and this is only illustrative.

³³ Note that climatologists typically prefer to use 30 years to represent a climatic period. Decadal periods are, however, useful for biological systems, as a decade is a long enough time to determine whether an organism can perish, establish or invade.

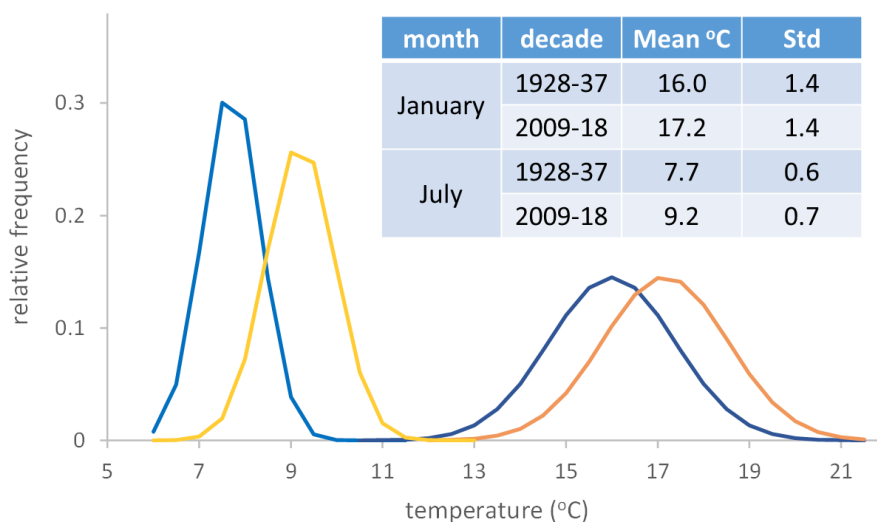


Figure 2.5: Schematic normalised frequency distribution of mean monthly temperatures for July (left) and January (right) for Wellington, New Zealand. The blue line is 1928–1937, the orange line 2009–2018. Calculated from NIWA National Climate Database (<https://cliflo.niwa.co.nz/>). Note that actual frequency distributions tend to skew further right.

As a result of such shifts, in future scenarios, frosts decrease substantially, by 30% (RCP 2.6) to 50% (RCP 8.5³⁴) for the year 2040 (MfE 2018).

2.5 General information related to impacts of pests and diseases

2.5.1 Plant family to which the commodity belongs

Citrus belongs to the family Rutaceae, a cosmopolitan family with around 150 genera (The Plant List 2013). *Citrus* is the main economically important genus, although there are other species which provide fruit, such as *Casimiroa*, and flavouring, for example, *Galipea officinalis*, which is the source of angostura bitters, and *Murraya koenigii*, used in Indian and Sri Lankan cooking (Mabberley 2008). There are also a number of ornamental species grown in New Zealand, such as *Boronia*, *Choisya* and *Coleonema* (Landcare Research 2020).

New Zealand has three endemic species in the Rutaceae: *Leionema nudum*, *Melicope simplex* and *M. ternata* (Landcare Research 2020). The two *Melicope* species are found in lowland areas in both the North and South Islands, while *L. nudum* is found only in the northern half of the North Island (AVH 2020). Neither the *Leionema* nor *Melicope* species are considered threatened (de Lange et al. 2018).

The Rutaceae is a common family in cultivation in New Zealand, but few species have naturalised, and none have done so extensively (Landcare Research, 2020).

2.5.2 New Zealand industry related to the plant commodity

The New Zealand citrus industry comprises around 1,660 hectares divided between approximately 316 growers, with most commercial production taking place in the Gisborne and Northland regions, followed by Auckland, Bay of Plenty and Hawke's Bay, with much less in other regions throughout the North Island and in parts of the South Island (Plant & Food Research 2019).

³⁴ In the latest IPCC report, RCPs (representative concentration pathways) are used to indicate emission scenarios, where 2.6 and 8.5 are the lowest and highest (e.g. (IPCC_WGI 2013; MfE 2018)).

Growers were estimated to have produced 34,096 tonnes of citrus in 2018/19 (Plant & Food Research 2019).

Commercial crops include oranges, mandarins, lemons, tangelos, limes and grapefruit (Plant & Food Research 2019). Most produce is grown for the domestic market (NZIER 2016). In 2018/19, the New Zealand domestic sales of fresh citrus fruit were NZ\$58.5 million (mandarins \$25.2 M, oranges \$18.0 M, lemons \$12.0 M, limes \$2.0 M, tangelos \$1.0 M, grapefruit \$0.3 M) (Plant & Food Research 2019). In 2019, export sales (free-on-board value) of fresh fruit were NZ\$12 million (lemons \$9.8 M, oranges \$1.7 M, mandarins \$0.4 M, tangelos \$0.1 M) (Plant & Food Research 2019). Processing mainly involves juicing citrus and other human consumption items (NZIER 2015). Domestic and export sales in relation to the processing of citrus has been estimated to be \$55.4 million, with the citrus processing value estimated as \$11.7 million (NZIER 2016). In 2012/2013 (April year), the impact of citrus on the GDP was estimated to be \$27.1 million (NZIER 2016). This was calculated from tree sales, farm gate sales, domestic sales, processing (mainly juice) and export sales. A summary of the New Zealand citrus industry is provided in Table 2.3.

Table 2.3 How big is New Zealand’s citrus industry? (NZCGI, accessed 23 October 2020)

	Growers*	Hectares Planted	Tonnes (Fruit)	Number of Trees	Domestic Sales	Export Sales
Citrus, total	320	1,663	29,740	1+ million	\$58.3 M	\$12 M
Mandarins	198	556	10,920	513,870	\$25 M	\$0.4 M
Oranges	183	783	10,100	320,840	\$18 M	\$1.7 M
Tangelos	28	22	640	11,105	\$1 M	\$0.1 M
Lemons	180	260	7,000	153,730	\$12 M	\$9.8 M
Limes	50	27	710	8,960	\$2 M	–
Grapefruit	18	15	370	4,247	\$0.3 M	–

* Many growers produce more than one citrus variety.

The average yield is 18 t/ha over all varieties. Information on the New Zealand citrus growing and import seasons are provided in Figures 2.6 and 2.7 respectively.

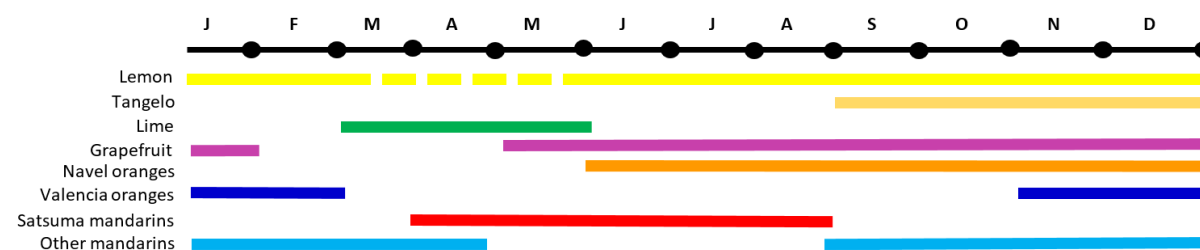


Figure 2.6 When is citrus in season in New Zealand? (NZCGI, accessed 23 October 2020)

Product	Origin	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Grapefruit	US												
Lemons	US												
Lime	AUS/USA												
Mandarin Afourer	AUS												
Mandarin Imported	US												
Minneloa Tangelo	US												
Oranges Navel	US												
Oranges Navel	AUS												
Pummelo	US												

Figure 2.7 When is citrus fruit imported into New Zealand? (MPI 2020)

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3. Hazard identification

A hazard is a pest or disease that is associated with imported risk goods and import pathways and that has the ability to cause harm to New Zealand. Hazard identification (hazard ID) is the process where, depending on the scope of the IRA, a list of pests and diseases potentially associated with the commodity is compiled and then assessed against specified criteria, in order to determine which species require further assessment. The objective for hazard identification in this IRA is to identify all pests and diseases that may require additional measures, based on assessment against the risk evaluation criteria (see “Hazard identification” section of the IRA overview, page v).

In order to identify pests and diseases that may require additional measures, hazard ID focused on the following traits (risk evaluation criteria):

- The pest or disease and/or associated damage is not easy to see on the citrus fruit, including when undertaking visual inspection, because
 - the pest can burrow into the fruit without obvious symptoms, or
 - the pest can hide in the navel and/or under the calyx of the citrus fruit, or
 - a pest or disease may take time or require particular environmental conditions to develop or to express symptoms; and
- the pest or disease has an ability to get off the fruit and onto a host in the New Zealand environment.

While the ability of a pest to establish and cause impacts is part of the definition of a hazard, this is generally only considered indicatively at the hazard identification stage. It is assessed in depth at the risk assessment stage.

Because this IRA will be used to develop IHSs for a number of different citrus fruit types and for a number of countries, the hazard ID needs to take into account pests and diseases that are associated with any of the commercial citrus types and any of the countries under consideration.

Hazard identification for this project used a range of sources including:

- CABI Crop Protection Compendium (2018/19)
- CABI horizon scan, list of all potential risks for *Citrus* imports to NZ, CABI horizon scan extract_20180319)
- CAB Abstracts
- Google Scholar
- Google
- EPPO Global Database
- Existing pest lists from *Citrus* IHSs
- New Zealand border interception data (LIMS, QuanCargo)
- Farr & Rossman (2017/2018) (for fungi and oomycetes)
- García Morales et al. (2016) (for scale insects)
- Migeon & Dorkeld (2018) (for mites)
- Ferris (2020) (for nematodes)
- MPI Emerging Risks System database
- general literature searches

A list of species identified at the hazard identification stage as associated with the commodity, present in at least one exporting country and potentially not being managed by basic measures, and therefore requiring further assessment (a Pest Risk Assessment), is provided in Table 3.1.

Table 3.1 Pest groups and conclusions for risk assessment following initial hazard identification

Pest group	Species requiring Pest Risk Assessments (PRAs)
Fungi	<i>Elsinoe australis</i> , <i>Phyllosticta</i> spp.
Bacteria	<i>Xanthomonas citri</i>

Pest group	Species requiring Pest Risk Assessments (PRAs)
Oomycetes	<i>Phytophthora palmivora</i>
Insects: order Diptera, fruit flies (receiving individual PRAs)	<i>Anastrepha fraterculus</i> , <i>Anastrepha ludens</i> , <i>Bactrocera dorsalis</i> , <i>Bactrocera minax</i> , <i>Bactrocera trilineola</i> , <i>Bactrocera tryoni</i> , <i>Bactrocera tsuneonis</i> , <i>Bactrocera xanthodes</i> , <i>Ceratitis capitata</i> , <i>Zeugodacus cucurbitae</i> , and <i>Bactrocera zonata</i>
Insects: order Diptera, fruit flies (not covered by other PRAs and assessed in a single group PRA)	<i>Anastrepha obliqua</i> , <i>Anastrepha serpentina</i> , <i>Anastrepha sororcula</i> , <i>Anastrepha striata</i> , <i>Anastrepha suspensa</i> , <i>Bactrocera aquilonis</i> , <i>Bactrocera carambolae</i> , <i>Bactrocera correcta</i> , <i>Bactrocera curvipennis</i> , <i>Bactrocera distincta</i> , <i>Bactrocera frauenfeldi</i> , <i>Bactrocera jarvisi</i> , <i>Bactrocera kirki</i> , <i>Bactrocera kraussi</i> , <i>Bactrocera latifrons</i> , <i>Bactrocera melas</i> , <i>Bactrocera neohumeralis</i> , <i>Bactrocera psidii</i> , <i>Bactrocera trivialis</i> , <i>Bactrocera melanotus</i> , <i>Bactrocera passiflorae</i> , <i>Bactrocera</i> sp. nr <i>passiflorae</i> , <i>Zeugodacus tau</i>
Insects: order Lepidoptera (moths, butterflies)	<i>Gymnandrosoma aurantium</i> , <i>Marmara gulosa</i> , <i>Spodoptera littoralis</i>
Insects: order Hemiptera, family Pseudococcidae (mealybugs)	<i>Nipaecoccus viridis</i> , <i>Planacoccus kraunhiae</i> , <i>Planococcus minor</i>
Insects: order Hemiptera, family Psyllidae (psyllids)	<i>Diaphorina citri</i> , <i>Trioza erytrae</i>
Insects: order Thysanoptera (thrips)	<i>Caliothrips fasciatus</i> , <i>Chaetanaphothrips orchidii</i> , <i>Scirtothrips dorsalis</i> , <i>Thrips palmi</i>
Subclass Acari (mites) (families Eriophyidae, Tenuipalpidae, Tetranychidae)	<i>Aculops pelekassi</i> , <i>Eotetranychus lewisi</i> , <i>Tetranychus kanzawai</i>
Insect vectors of pathogens	Aphids: <i>Aphis craccivora</i> , <i>Aphis gossypii</i> , <i>Aphis spiraecola</i> , <i>Brachycaudus persicae</i> , <i>Macrosiphum euphorbiae</i> , <i>Macrosiphum rosae</i> , <i>Myzaphis rosarum</i> , <i>Myzus persicae</i> , <i>Toxoptera aurantia</i> , <i>Toxoptera citricida</i> Mealybugs: <i>Planococcus citri</i> , <i>Pseudococcus calceolariae</i> , <i>Pseudococcus longispinus</i> , <i>Pseudococcus viburni</i> Thrips: <i>Frankliniella occidentalis</i> , <i>Frankliniella intonsa</i> , <i>Thrips tabaci</i>
Mite vectors of pathogens	<i>Brevipalpus californicus</i> , <i>Brevipalpus obovatus</i> , <i>Brevipalpus phoenicis</i>

Groups (e.g. genera or family) or high-profile species that did not meet the criteria for requiring pest risk assessment are listed in Appendix 1, along with the rationale for excluding them at the hazard identification stage.

3.1 References for Chapter 3

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4. Risk assessment

The purpose of the risk assessments in this import risk analysis (IRA) is to assess the level of risk that hazards (i.e. pests and diseases) present to New Zealand.

4.1 Risk management questions

Each individual pest risk assessment answers the following questions:

1. Does the pest or disease meet the criteria to be a quarantine pest under IPPC?³⁵
2. Does the pest or disease require (or potentially require) consideration for additional measures?

For the pests and diseases that require, or potentially require, consideration for additional measures, the following question is considered:

- Which specific *Citrus* fruit pathways are they associated with (i.e. which countries and types of *Citrus* fruit)?

4.2 Criteria and traits for additional measures

Pests and diseases that that require, or potentially require, consideration for additional measures are those that:

1. are associated with fresh *Citrus* fruit:
 - a. that is of any species listed in Table 1.1, and
 - b. that meets the commodity description (see additional information below);
2. are present in any of the countries listed in Table 1.1; and
3. have traits that indicate they may not be adequately managed by the basic measures listed in section 2.3.1; and
4. have a viable establishment pathway from fruit; and
5. have the potential to establish and cause harm in New Zealand.

Some traits that indicate a pest or disease may not be adequately managed by basic measures are listed below:

- the pest or disease and/or associated damage is not easy to see on the *Citrus* fruit, including when undertaking visual inspection;
- the pest can burrow into the fruit without creating obvious damage;
- the pest can hide in the navel and/or under the calyx of the *Citrus* fruit; or
- the disease may take time or require particular environmental conditions to become apparent.

The SPS Agreement states that phytosanitary measures must be supported by a risk assessment and not be maintained without sufficient evidence. That is, MPI must have evidence that a pest or disease would not be sufficiently managed by the commodity description and basic measures in order to require additional measures.

4.3 Assessment method

A range of different approaches can be used for risk assessment. The most important factor in determining the approach is the risk management question and the level of assessment needed to support a robust and transparent risk management decision.

In the case of the *Citrus* fresh produce IRA, the risk management question is specific, aiming to identify pests and diseases that may need measures in addition to basic measures.

³⁵ This question is a part of hazard identification (or pest categorisation in IPPC) but is documented in more detail as a part of the risk assessment.

The PRA used is called a **targeted PRA**, as it is targeted at answering a limited range of questions. The PRA method used covers the following questions:

- Does the pest or disease meet the criteria to be a quarantine pest under IPPC?
- Is the pest or disease associated with the commodity?³⁶
- Based on assessment against the risk evaluation criteria, does the pest or disease require, or potentially require, consideration for measures in addition to the basic measures?

In some cases, uncertainty in the assessment means that it is unclear whether the pest or disease meets the criteria or not. The pest or disease may pose a risk with respect to some risk evaluation criteria but not others, or the evidence may be limited. In other cases, the status of the pest or disease as a quarantine pest may be uncertain, or the association with the commodity may be weak. In these cases, the pest or disease requires further consideration in the risk management proposal, taking articles 2.2 and 5.7 of the SPS Agreement into account.

In the PRAs in this IRA the answer to the risk management question is given as either:

- *The pest or disease may be considered for additional measures: or*
- *It is recommended the pest or disease does not require consideration for additional measures.*

To answer these questions, the PRAs use the CASE schema. Under the CASE schema, the **contention** or **conclusion** (that is, the answer to the risk management question) is presented first, followed by the **arguments** supporting this contention and the **evidence** and **sources** supporting each argument.

For fresh produce IRAs, past experience has shown that the critical aspects of the risk that needs to be assessed are:

1. Likelihood of entry:
 - a. The strength or frequency of the association with the host fruit
 - b. Likelihood of entry given the application of basic measures
2. Likelihood of establishment:
 - a. The ability of the pest or disease to move from imported fruit and into a suitable environment to allow establishment (exposure)
 - b. The suitability of the New Zealand environment for the pest or disease (including climate, host plants and vectors)
3. The potential impacts in New Zealand:
 - a. Economic impacts: on *Citrus* and other economically important plants (symptoms on individual plants, crop yield, costs of management practices, trade restrictions, etc.)
 - b. Environment impacts: on native plants and ecologies
 - c. Other impacts (e.g. human health, sociocultural).

For each of the critical aspects listed above, the following criteria and rankings are used in this IRA to assess the overall risk of each pest or disease considered to be a hazard on the pathway.

1a. Strength or frequency of association with the commodity.

Strong	There is a clear biological reason that the pest or disease is on or inside citrus fruit and remains associated with the commodity.
Moderate	There is a link between the pest or pathogen and citrus fruit but not under all circumstances, for example, only when the pest is in high numbers, or the pest or disease is mobile and unlikely to remain on fruit during harvesting/processing, or there is another less strong or frequent relationship.
Weak	The pest or disease is only rarely associated with the commodity as described for this IRA.

³⁶ These first two questions are part of hazard ID but are included if there is further risk assessment done.

Negligible	The association of the pest or disease with the commodity as described for this IRA is so improbable it is not worth considering.
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For each of the following likelihood and impact scores, the following ranking scales will be used against the listed criteria:

High	Extending above the normal or average level
Moderate/Medium	Around the normal or average level
Low	Less than average, coming below the normal level
Very low	Close to insignificant
Negligible	Not worth considering; insignificant

1b. Likelihood of entry into New Zealand after the application of minimum measures

Criteria	The effect the biology and epidemiology of the pest or disease, the commodity description, the trade pathway and the application of the basic measures will have on the likelihood that the pest or disease will be associated with the commodity on arrival in New Zealand
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2a. The ability of the pest or pathogen to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure)

Criteria	The effect the biology and epidemiology of the pest or disease, the commodity description, and the commodity pathway and end use in New Zealand, will have on the likelihood that the pest or disease will be transmitted from a fruit into the environment and infest or infect a host immediately or survive in the environment until suitable hosts become available
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2b. Suitability of the NZ environment

Criteria	The effect the biology and epidemiology of the pest or disease will have on the likelihood that it will establish and build a population and spread into the environment, based on factors such as climate suitability and the availability of hosts or potential hosts
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3a,b,c. Impacts on New Zealand

Criteria	The effect the biology and epidemiology of the pest or disease will have on the extent to which the pest or disease will cause impacts on New Zealand plants and subsequently cause wider impacts on the economy, environment, sociocultural, and/or human health
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Confidence in the evidence – weight of evidence, uncertainty

Weighing the evidence is an inherent part of every scientific assessment. The analyst reviews all available data and comes to conclusions based on an assessment of their overall confidence in the results of all reviewed studies. The approaches and methods used in conducting such a 'non-formalised' inherent weighing of the evidence are mostly not spelled out, however (ESFA 2017).

Weight of evidence assessment is defined as a process that determines the relative support for possible answers to a scientific question. Reliability, relevance and consistency can be seen as three basic considerations in the weight of evidence assessment: how applicable the evidence is to the question of interest, the quality of the evidence and how consistent it is with other evidence for the same question (EFSA 2017).

Weight of evidence assessment and uncertainty are closely related. For example, SCENIHR (2012, in EFSA 2017) state that 'strength of evidence is inversely related to the degree of uncertainty', while Suter and Cormier (2011, in EFSA 2017) state that 'the weight of the body of evidence, based on the combined weights of individual pieces of evidence, may be used to express confidence or uncertainty in the results'. EFSA (2017) defines uncertainty as 'a general term referring to all types of limitations in available knowledge that affect the range and probability of possible answers to an assessment question.'

Overall scientific assessment

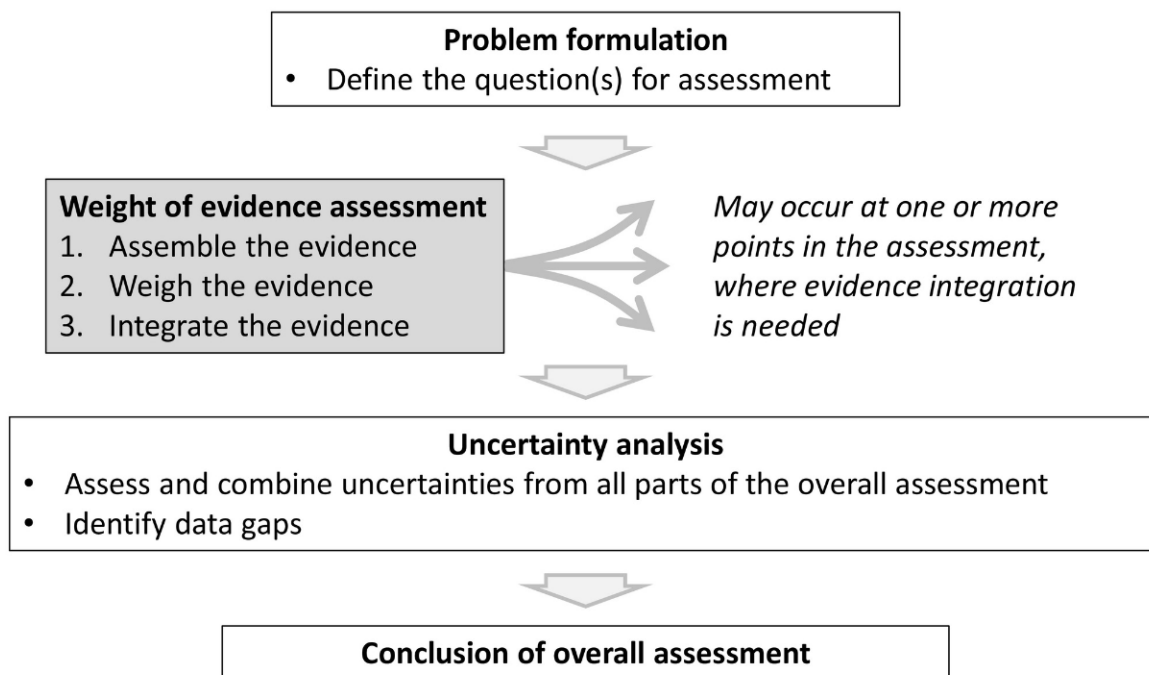


Figure 4.1: Diagrammatic illustration of weight of evidence assessment as a three-step process, which may occur at one or more points in the course of a scientific assessment (EFSA 2017).

In the PRAs in this project, the uncertainty associated with a conclusion/contention is stated in each contention. Unless the uncertainty is rated as low, the rationale for the uncertainty rating will be stated in the text.

Uncertainty will be rated as follows (taken from Defra 2011):

High	<ul style="list-style-type: none"> Scarce or no data available; evidence provided in unpublished reports; or Few observations and personal communications; and/or Authors' or experts' conclusions vary considerably
Moderate	<ul style="list-style-type: none"> Some or only incomplete data available; evidence provided in small number of references; authors' or experts' conclusion vary; or Limited evidence from field observations; or Solid and complete data available from other species that can be extrapolated to the species being considered
Low	<ul style="list-style-type: none"> Solid and complete data available; strong evidence in multiple references with most authors coming to the same conclusions; or Considerable and consistent experience from field observations

4.4 References for Chapter 4

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5. Pest risk assessments: Fungi

5.1 *Elsinoe australis* (sweet orange scab) and *E. fawcettii* (citrus scab)

Elsinoe australis (sweet orange scab) is a fungus that causes premature fruit drop and unsightly corky blemishes (scabs) on citrus fruit and occasionally leaves and twigs, particularly in sweet oranges and mandarins. This disease causes yield losses and reduces the market value of fresh citrus fruit.

Elsinoe fawcettii (citrus scab) also causes fruit drop, and causes scab symptoms on leaves, young twigs and fruit of many citrus species but does not usually affect sweet orange. *Elsinoe fawcettii* is present in New Zealand, but there are some pathotypes that affect different hosts and have not been reported in New Zealand.

Scientific name: *Elsinoe australis* Bitancourt and Jenkins (1936)

Order/Family: Myriangiales (previously Dothideales)/Elsinoaceae

Other names include: *Sphaceloma australis* Bitancourt & Jenkins (1936), sweet orange scab, SOS (CABI 2020a)

Scientific name: *Elsinoe fawcettii* Bitancourt and Jenkins (1936)

Order/Family: Myriangiales (previously Dothideales)/Elsinoaceae

Other names include: *Sphaceloma fawcettii* Jenkins (1925); *Sphaceloma fawcettii* var. *scabiosa* (McAlpine & Tyron) Jenkins (1936); citrus scab (CABI 2020b)

Taxonomic notes on *Elsinoe* spp. associated with citrus:

There are several pathotypes of *E. australis*, and they differ in their ability to cause disease in citrus.

The sweet orange scab (SOS) pathotype of *E. australis* was first reported in Paraguay in 1882 and mainly occurs in South America (Argentina, Bolivia, Paraguay, Uruguay and Brazil) (Bitancourt and Jenkins 1937; Sivanesan and Critchett 1974). It affects a range of citrus hosts, but sweet oranges (*Citrus sinensis*) are the major host (EFSA 2017).

Hyun et al. (2007, 2009) reported a new pathotype of *E. australis* from fruit of natsudaidai (*C. paradisi* as per SRA INRA-CIRAD 2002) in Korea. This pathotype has also been detected in Honshu, Japan³⁷ and is recently invasive in the USA, where it causes lesions on a much wider range of citrus hosts, including oranges, lemons and grapefruit (Kunta et al. 2013).

Two pathotypes of *E. australis* are reported from Australia, from finger lime (*Citrus australasica* (F. Muell.)) (Miles et al. 2015) and from jojoba (*Simmondsia chinensis*) (Ash et al. 2012).

Elsinoe australis (natsudaidai pathotype) was recently reported from poplar (*Populus tomentosa* and *P. deltoides*) in China (Zhou et al. 2020).

The closely related species *E. fawcettii* (citrus scab) is present in New Zealand and causes scab symptoms on several citrus hosts, but most pathotypes of this species do not affect sweet orange (*C. sinensis*), and there is no evidence of scab disease in sweet orange in New Zealand. NZFungi2 (2020) and PPIN (2020) have no collections of *E. fawcettii* from *C. sinensis* in New Zealand. There are several different pathotypes of *E. fawcettii*, and the Florida broad host range, Jingeul and satsuma mandarin pathotypes have not been reported in New Zealand (CABI 2020a).

The European Union regulates *E. australis* at the species level (EPPO, 2020). Given that there appear to be different pathotypes, it may be possible to justify measures for some countries by regulating at the pathotype level. However, this option should be approached with caution, because the recently invasive and very damaging pathotypes in USA appear more closely related to the natsudaidai pathotypes from Japan and Korea than the South American pathotypes.

³⁷ IPPC pest report 2014. Accessed September 2020 from https://www.ippc.int/static/media/files/pestreport/2014/05/28/detection_of_elsinoe_australis_in_japan.pdf.

Summary of conclusions

Given the arguments and evidence presented:

- *Elsinoe australis* and the Florida broad host range (FBHR) and satsuma mandarin (SM) pathotypes of *E. fawcettii* meet the criteria to be a quarantine pest for New Zealand. There was insufficient information about the pathotypes of *E. fawcettii* to assess them against the criteria for additional measures.
- *Elsinoe australis* has a strong association with citrus fruit, with low uncertainty.
- Basic measures reduce the likelihood of entry by a moderate degree, with low uncertainty. Consequently, the likelihood of entry is considered to be moderate, with low uncertainty.
- *Elsinoe australis* has a low ability to move from imported fruit and into a suitable environment, that is, onto a host plant, to allow establishment, with moderate uncertainty.
- The suitability of the New Zealand environment for *E. australis* to establish is considered high, with low uncertainty.
- Impacts of *E. australis* are likely to be restricted to citrus and areas where citrus is produced, so the level of impact caused by *E. australis* is likely to be low overall for New Zealand, with low uncertainty, but moderate for the citrus industry and domestic citrus growers.
- *Elsinoe australis* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Moderate	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Low	Low

5.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Elsinoe australis* meets the criteria to be a quarantine pest for New Zealand.

The criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Elsinoe australis is recorded as absent from New Zealand.

- It is recorded as absent in NZFungi2 (2020) and NZOR (2020).
- It is not recorded in PPIN (2020).
- It is listed as 'regulated' in BRAD and ONZPR (2020).

Elsinoe australis has the potential to establish and spread in New Zealand.

- *Elsinoe australis* is commonly reported from areas with a very similar climate to New Zealand, indicated by a climate match index (CMI) of ≥ 0.7 (Phillips et al. 2018). The sweet orange pathotype is reported in South America, including Argentina, Uruguay (and Rio Grande do Sul in Brazil (EPPO 2020). The natsudaidai pathotype has been reported from Jeju Island, Korea and Honshu, Japan (Hyun et al. 2007; EPPO 2020). A closely related pathotype is recently

invasive in some US states (Louisiana, Florida, Mississippi, Texas, Arizona and parts of California) (Kunta et al. 2013).

- *Elsinoe australis* is most often reported from *Citrus* and *Fortunella* species (CABI, 2020a; EPPO, 2020). Citrus is commercially grown in New Zealand and commonly grown in gardens.

Elsinoe australis has the potential to cause impacts to New Zealand.

- *Elsinoe australis* has the potential to harm citrus that is of economic importance to New Zealand.
- *Elsinoe australis* has the potential to have sociocultural impacts: citrus is commonly planted in home gardens.

Given the arguments and evidence below, Florida broad host range (FBHR) and satsuma mandarin (SM) pathotypes of *E. fawcettii* meet the criteria to be a quarantine pest for New Zealand.

There are several different pathotypes of *E. fawcettii* of which only the Florida broad host range (FBHR) pathotype has been reported to infect sweet orange (Timmer et al. 1996; Hyun et al. 2009). China has at least one additional pathotype of *E. fawcettii* (SM), which was found pathogenic to Satsuma mandarins (*C. unshiu* × *C. sinensis* var. Kiyoma) but not to other hosts tested (Hou et al. 2014).

Korea also has an additional pathotype (Jingeul), isolated from Jingeul clementine mandarin (*C. sunki*), which was not found in New Zealand (Hyun et al. 2009). However, it is not clear whether this citrus cultivar is present in New Zealand, so the Jingeul pathotype has not been assessed in this PRA.

The Florida broad host range (FBHR) and satsuma mandarin (SM) pathotypes of *E. fawcettii* have not been reported in New Zealand:

- There is no mention of different pathotypes or strains of *E. fawcettii* in NZFungi2 (2020), NZOR (2020) or PPIN (2020).
- A study by Hyun et al. (2009) did not find the FBHR pathotype in any of the isolates from New Zealand citrus that they tested.

The FBHR and SM pathotypes of *E. fawcettii* have the potential to establish and spread in New Zealand.

- These pathotypes of *E. fawcettii* have been reported from areas with a very similar climate to New Zealand, indicated by a climate match index (CMI) of ≥ 0.7 (Phillips et al. 2018).
 - The Florida broad host range pathotype is reported from Florida, USA; Jeju Island, Korea (Hyun et al. 2009). Jeju Island and parts of Florida have a CMI of 0.7 (Phillips et al. 2018).
 - The SM pathotype was isolated in China from satsuma mandarins in Chenggu, Shanxi; Yidu, Hubei; Meizhou, Guangdong; Jinping; Guizhou; Lingchuan; Guangxi; Huaning, Yunnan; Laozhu, Zhejiang and lemons in Mengdian Yunnan (Hou et al. 2014). Many of these areas have a CMI of 0.7–0.8 (Phillips et al. 2018).
- Hosts of the FBHR and SM pathotypes are commonly grown in New Zealand in commercial production and home gardens:
 - The FBHR pathotype causes scabs on fruit and leaves of lemon (*C. limon*), rough lemon (*C. limon* syn. *C. jambhiri*), grapefruit (*C. paradisi*), sour orange (*C. aurantium*), Temple and Murcott tangors (*C. sinensis* × *C. reticulata*) and the fruit of sweet orange (*C. sinensis*) (Timmer et al. 1996).
 - The SM pathotype is reported from leaves and fruit of satsuma mandarin and leaves of lemon (Hou et al. 2014).
- Other pathotypes of *E. fawcettii* are already in New Zealand (Hyun et al. 2009; PPIN 2020; NZFungi2 2020; see below), and it is assumed that environmental conditions in New Zealand would also be suitable for the FBHR and SM pathotypes to establish.

The FBHR and SM pathotypes of *E. fawcettii* have the potential to cause impacts to New Zealand.

- *Elsinoe fawcettii* (citrus scab) causes scab symptoms on leaves, young twigs and fruit of many citrus species and can cause premature fruit drop (Timmer et al. 1996; EFSA 2017). It does not usually affect sweet orange (*C. sinensis*) (Timmer et al. 1996; EFSA 2017). In severe infections, *E. fawcettii* can cause malformation and stunting of leaves and defoliation (EFSA 2017). Warty lesions and scabs on young twigs, shoots and stems can lead to stunting of young plants in nurseries (EFSA 2017).
- Citrus scab does not currently affect sweet oranges in New Zealand, and satsuma mandarins are only mildly susceptible to the pathotypes present in New Zealand.
 - The lemon, Tryon's, Florida narrow host range and SRGC (satsuma, rough lemon, grapefruit, clementine) pathotypes have been reported in New Zealand from Meyer, Villafranca, Yen Ben and rough lemons, clementine mandarins and grapefruit (Hyun et al. 2009).
 - Citrus cultivars commonly grown in New Zealand that are currently considered highly susceptible to *E. fawcettii* are Yen Ben, Villafranca and Meyer lemons; Clementine and Kara mandarins; and Lemonade (Fullerton et al. 2019).
 - Currently, satsuma mandarins are considered mildly susceptible to the pathotypes of citrus scab currently present in New Zealand (Fullerton et al. 2019).
 - NZ collections of *E. fawcettii* in the Landcare databases (NZFungi2) and PPIN are mainly from Auckland, Northland and Bay of Plenty but also Coromandel, mid-Canterbury, Wellington, Nelson, Taranaki and Wanganui from fruit, leaves and occasionally shoots of *C. aurantiifolia*, *C. limon*, *C. reticulata*, *C. paradisi*, *C. grandis*, and Tangelo. Neither database records *E. fawcettii* from *C. sinensis*.
- The FBHR and SM pathotypes of *E. fawcettii* cause citrus scab on hosts that are commercially important in New Zealand, including some hosts that are currently unaffected or only mildly affected by citrus scab:
 - The FBHR pathotype causes citrus scab disease in lemon, rough lemon, grapefruit, sour orange, Temple and Murcott tangors and sweet orange (Timmer et al. 1996).
 - The satsuma mandarin (SM) pathotype was isolated from leaves and fruit of satsuma mandarin and lemon and caused citrus scab symptoms in fruit and leaves of satsuma mandarin in pathogenicity testing (Hou et al. 2014).
- Therefore, the FBHR and SM pathotypes of *E. fawcettii* have the potential to cause impacts to citrus production in New Zealand through direct damage to citrus crops, damage to citrus plants, particularly young plants in nurseries, and through increased costs of managing the disease with fungicides.

The FBHR and SM pathotypes of *E. fawcettii* were not assessed further at this time, because there is very little information about their distribution in areas not included in the study by Hyun et al. (2009), and most studies do not assess their impacts separately from *E. fawcettii* sensu stricto.

However, it is recommended that a status of quarantine is assigned for FBHR and SM pathotypes of *E. fawcettii*.

5.1.2 Hazard identification: commodity association

Given the arguments and evidence below, *Elsinoe australis* is associated with citrus fruit.

Elsinoe australis is reported from citrus fruit.

- *Elsinoe australis* occurs on citrus fruit, especially oranges and mandarins (Bitancourt and Jenkins 1937; Kunta et al. 2013; EFSA 2017).

5.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Elsinoe australis* has a strong association with citrus fruit.

There are many reports of *E. australis* infecting citrus fruit.

- *Elsinoe australis* infects young citrus fruit, causing scab lesions from which the fungus can be isolated (Bitancourt and Jenkins 1937; Timmer et al. 1996; Timmer 2000; Chung 2011, Kunta et al. 2013).
- The major host of *E. australis* is sweet orange (*C. sinensis*), and it has also been reported from many other citrus species (Table 6.1.1):

Table 6.1.1 Citrus species susceptible to sweet orange scab caused by *E. australis* (Kunta et al. 2013; Farr and Rossman 2020; CDFA 2020)

Scientific name	Common name
<i>C. sinensis</i>	Sweet orange
<i>C. aurantiifolia</i>	Mexican lime
<i>C. aurantium</i>	Bitter orange
<i>C. australasica</i>	Finger lime
<i>C. limon</i>	Lemon
<i>C. reticulata</i> × <i>C. sinensis</i>	Tangor
<i>C. paradisi</i>	Grapefruit
<i>C. reticulata</i>	Mandarin, Satsuma mandarin
<i>C. maxima</i>	Pomelo (detected in a survey in Japan ³⁸)
<i>C. latifolia</i>	Tahiti lime

- *Elsinoe australis* has been isolated and cultured from lesions on infected citrus fruit (Bitancourt and Jenkins 1936,1937; Timmer et al. 1996; Hyun et al. 2001; Kunta et al. 2013)

Elsinoe australis can be associated with *Citrus* fruit commodities.

- *Elsinoe australis* can be spread to new areas through the movement of infected fruit (Chung and Timmer 2008; EFSA 2017; CDFA 2020).
- *Elsinoe australis* is frequently detected during border quarantine inspections of fruit. The EPPO Reporting Service (2020) report that *E. australis* was intercepted 10 times on *Citrus* fruit (oranges, lemons and mandarins) from South America (Argentina, Guatemala and Uruguay) since 2008. Searches of CAB Abstracts found frequent mentions of *E. australis* on citrus fruit (lemon, sweet, sour and mandarin oranges, and Mexican lime) entering USA from Brazil in annual USDA lists of intercepted plant pests. CDFA (2020) reports that dozens of interceptions of infected fruit have been made on shipments entering California from Florida, Louisiana, Puerto Rico and Texas. The closely related species *E. fawcetti*, was intercepted five times at the New Zealand border on lime fruit from the US and several Pacific Islands between 1997 and 2016 (LIMS, 2020).
- *Elsinoe australis* is recorded in several countries in the scope of this IRA, although not always in natural infections of *Citrus* (see Table 6.1.2). In Brazil and some U.S. states, *E. australis* is reported as causing economically important citrus disease. In Korea, *E. australis* has only been reported from natsudaidai and not from citrus commodities considered for importation into New Zealand in this IRA. In Japan, it has been reported from several citrus species, but with only minor symptoms.
- In the USA, *E. australis* was first reported in Texas and Louisiana in 2010 and is now found in six US states (Louisiana, Florida, Mississippi, Texas, Arizona and parts of California), causing scab symptoms on fruit and sometimes leaves of citrus hosts including sweet orange,

³⁸ IPPC pest report 2014.

https://www.ippc.int/static/media/files/pestreport/2014/05/28/detection_of_elsinoe_australis_in_japan.pdf Accessed September 2020.

grapefruit and mandarin (Kunta et al. 2013; USDA-APHIS 2020). Isolates from Texas cluster with the Korean natsudaikai pathotype in molecular analysis (Kunta et al. 2013).

- In Australia, two pathotypes of *E. australis* have been reported, one from finger lime and one from jojoba, but natural infections have not been reported from citrus commodities that New Zealand will be importing. In China, *E. australis* has recently been reported from poplar, but not from natural infections of *Citrus*.

Table 6.1.2 Distribution of *E. australis* in countries included in the scope of this IRA

Country	Pathotype	Distribution in country and reported hosts	Uncertainty
Australia	Finger lime; jojoba black scab (natsudaikai-like);	Finger lime (<i>Citrus australasica</i>) and jojoba (<i>Simmondsia chinensis</i>) in New South Wales and Queensland. Not reported from other citrus commodities in natural infection. <ul style="list-style-type: none"> • The finger lime pathotype caused scab symptoms on <i>C. aurantium</i> cv. Murcott tangor in pathogenicity tests but could not cause scab symptoms on the other orange, mandarin, lemon or grapefruit varieties tested or on natsudaikai (Miles et al. 2014) • The jojoba black scab (JBS) pathotype did not cause symptoms on any <i>Citrus</i> species tested, even <i>C. paradisi</i> (Ash et al. 2012). • No report of natural infection of other <i>Citrus</i> hosts found in searches. 	High uncertainty about whether the pathotypes of <i>E. australis</i> , other than the finger lime pathotype in Australia, infect commercial citrus varieties in natural infection.
Brazil	Sweet orange	Reported from <i>Citrus</i> , especially sweet orange and mandarin in Goias, Minas Gerais, Rio de Janeiro, Rio Grande do Sul and Sao Paulo (Bitancourt and Jenkins 1937; CABI 2020a; EFSA 2017; EPPO 2020).	Low uncertainty. There are many reports of <i>E. australis</i> from <i>Citrus</i> fruit in Brazil.
China	Natsudaikai-like	Poplar – <i>Populus tomentosa</i> and <i>P. deltoides</i> from Nanjing and Wuhu in southeastern China (Zhao et al. 2020). Not reported from citrus commodities in natural infection (affected one hybrid <i>Citrus</i> species but not on fruit of orange, lemon or grapefruit in pathogenicity testing). No report of natural infection of <i>Citrus</i> found in searches.	High uncertainty about whether the pathotype of <i>E. australis</i> in China infects <i>Citrus</i> in natural infection, given there is only a single report from poplar. The natsudaikai-like pathotype reported by Zhao et al. (2020) was not found in natural infections of <i>Citrus</i> .
Cook Islands	N/A	Absent, unreliable record (EPPO 2020) and <i>E. australis</i> is not on the pest list provided by the Cook Islands NPPO. However, CABI (2020a) records it as present.	Moderate uncertainty due to conflicting records. CABI (2020a) reports <i>E. australis</i> in the Cook Islands, and it was reported present in distribution maps from 1998 and 2012 (CAB Abstracts search, September 2020).
Egypt	N/A	Not recorded (CAB Abstracts; Farr and Rossman 2020; Google; Google Scholar). The MPI Importing Countries Phytosanitary Requirements for Egypt lists <i>E. australis</i> as a quarantine pest in the table of unrecorded pests to be declined entry into Egypt.	Low uncertainty.
Fiji	N/A	Absent, invalid record (e.g. EPPO considers a local record invalid) (EPPO, 2020). However, CABI (2020a) record as present.	Moderate uncertainty due to conflicting records. CABI (2020a) reports <i>E. australis</i> in Fiji, and it was reported present in distribution maps from 1998 and 2012 (CAB Abstracts search, September 2020).

Country	Pathotype	Distribution in country and reported hosts	Uncertainty
Japan	Natsudaikai	Restricted distribution, Honshu (EPPO 2020). Minor symptoms initially detected on pomelo fruit (<i>C. maxima</i>), and <i>E. australis</i> was detected in Aichi prefecture, Honshu in satsuma mandarin, navel orange and hybrid of natsudaikai and orange in a subsequent survey (IPPC pest report, 2014 ³⁹). Symptoms were reported as minor, with no substantial damage or economic losses (IPPC pest report, 2014).	Low uncertainty.
Korea	Natsudaikai	Natsudaikai fruit from Jeju Island (Hyun et al. 2001; 2007; 2009). Isolates from natsudaikai were non-pathogenic to satsuma mandarin, rough lemon, sour orange, grapefruit, cleopatra mandarin, and natsudaikai leaves and were only pathogenic to natsudaikai fruit. CABI (2020a) and EPPO (2020) record it as present.	Low uncertainty about presence in Korea, but moderate uncertainty about whether the Korean natsudaikai pathotype infects commercial varieties of citrus. Pathotypes identified as the natsudaikai pathotype in Japan and USA affect a wider range of hosts.
Mexico	N/A	No report of <i>E. australis</i> found in searches (CAB Abstracts; Farr and Rossman 2020; Google; Google Scholar).	Low uncertainty.
New Caledonia	N/A	Absent, Invalid presence record (CABI 2020a; EPPO 2020). Symptoms of scab on <i>Citrus</i> in New Caledonia initially attributed to <i>E. australis</i> are now thought to have been caused by <i>E. fawcettii</i> (Sivanesan and Critchett 1974).	Low uncertainty.
Peru	N/A	No report of <i>E. australis</i> found in searches (EPPO 2020; CAB Abstracts; Farr and Rossman 2020; Google; Google Scholar).	Low uncertainty.
Samoa	N/A	Present (pest list provided by Samoan NPPO).	High uncertainty due to conflicting records. <i>Elsinoe australis</i> is on the pest list provided by the Samoan NPPO and was reported present in CABI distribution maps from 1998 and 2012 (CAB Abstracts search, September 2020). However, EPPO (2020) and CABI (2020a) now record it as "Absent, Unconfirmed presence record."
Spain	N/A	Not reported in Spain (EFSA 2017) No report of <i>E. australis</i> found in searches (CAB Abstracts; Farr and Rossman 2020; Google; Google Scholar).	Low uncertainty.
Solomon Islands	N/A	No report of <i>E. australis</i> found in searches (EPPO 2020; CAB Abstracts, Farr and Rossman 2020; Google; Google Scholar).	Low uncertainty.
USA	Natsudaikai	Sweet orange, tangerine, grapefruit, lemon, mandarin and other citrus fruit and sometimes leaves (Kunta et al. 2013). USDA-APHIS (2020) records that sweet orange scab is found in Arizona, Florida, Louisiana, Mississippi, Texas and portions of California.	Low uncertainty.
Vanuatu	N/A	No report of <i>E. australis</i> found in searches (EPPO 2020; CAB Abstracts;	Low uncertainty.

³⁹ Accessed September 2020 from https://www.ippc.int/static/media/files/pestreport/2014/05/28/detection_of_elsinoe_australis_in_japan.pdf.

Country	Pathotype	Distribution in country and reported hosts	Uncertainty
		Farr and Rossman 2020; Google; Google Scholar).	
Viet Nam	N/A	No report of <i>E. australis</i> found in searches (EPPO 2020; CAB Abstracts; Farr and Rossman 2020; Google; Google Scholar).	Low uncertainty.

Given the arguments and evidence below, basic measures reduce likelihood of entry by a moderate degree. Consequently, the likelihood of entry is considered to be moderate, with low uncertainty.

Infected fruit is usually easily detected and likely to be removed.

- Symptoms of *E. australis* are likely to be visible on fruit (see Figure 6.1.1). Symptoms range from small, flattened off-white pustules to large coalesced round or irregular lesions of corky tissue (Bitancourt and Jenkins 1937; Kunta et al. 2013). The lesions may be deeply furrowed from rupture of the corky tissues. The shape, size and colour of lesions depends on the citrus species and variety (EFSA 2017).
- It can be difficult to detect *E. australis* in the early stages of infection, but the incubation period for symptoms to develop on fruit is approximately 10 days (Bitancourt and Jenkins 1937). Immature young fruit up to 6 to 8 weeks after petal fall are highly vulnerable to infection (CDFA 2020), but only young tissues are attacked (Sivanesan and Critchett 1974) when fruit are less than 20mm diameter (MAF 2008). Young fruits may become distorted and may drop prematurely (Sivanesan and Critchett 1974; CDFA 2020).
- Because the latent period for symptoms of *E. australis* is short, symptoms are likely to be visible by the time fruit are mature enough to harvest and export. Mature fruit are not susceptible to the fungus, so it will not continue to spread through the consignment.

Figure 6.1.1 Top left and top centre: Sweet orange scab lesions on green fruit⁴⁰; Top right: Sweet orange scab lesion on a satsuma (*C. unshiu*)⁴¹; Bottom: Oranges with sweet orange scab symptoms⁴²



⁴⁰ Cesar Calderon, Cesar Calderon Pathology Collection, USDA APHIS PPQ, Bugwood.org. <https://www.ipmimages.org/browse/detail.cfm?imgnum=5499766> <https://www.invasive.org/browse/detail.cfm?imgnum=5499770>

⁴¹ Don Ferrin, Louisiana State University Agricultural Center, Bugwood.org. <https://www.invasive.org/browse/detail.cfm?imgnum=5473708>

⁴² Florida Division of Plant Industry, Florida Department of Agriculture and Consumer Services, Bugwood.org. <https://www.ipmimages.org/browse/detail.cfm?imgnum=5372451>



However, the evidence suggests that some infected fruit will not be detected. Symptoms of *E. australis* can be minor and can be missed or not recognised as disease symptoms during production or phytosanitary inspection.

- Fruit infected with *E. australis* has been frequently intercepted in quarantine inspections in Europe and the USA (see entry section), suggesting that symptoms were missed or misidentified. Likewise, the closely related (but non-regulated) *E. fawcettii*, which produces similar scab symptoms, was intercepted in 2016 on a commercial consignment of limes from USA (*C. aurantiifolia* and *C. latifolia*). *Elsinoe fawcetti* has been recorded at the border on limes from Samoa (LIMS 2020).
- In Texas, *E. australis* was commonly isolated from wounds referred to as “late-season windscar” that were not always recognisable as symptoms of disease (Kunta et al. 2013).

Likelihood of establishment:

Given the arguments and evidence below, the ability of the *E. australis* to move from imported fruit onto a host plant to allow establishment is rated as low, with moderate uncertainty.

Elsinoe australis is likely to survive and develop on waste of citrus fruit (whole fruit or fruit pieces).

- *Elsinoe australis* can survive and produce spores in old lesions on fruit (Bitancourt and Jenkins 1937; Sivanesan and Critchett 1974).

Most waste from imported citrus in New Zealand will be disposed of using low-risk methods, so *E. australis* will be unable to spread from the citrus host.

- Most kitchen waste in New Zealand is disposed of in bags in landfills or in kitchen disposal units, and in these situations, *E. australis* is unlikely to reach a new host (see waste analysis in Chapter 2).

Elsinoe australis can spread to citrus trees if infected fruit or peels are discarded in the New Zealand environment near citrus trees, although the likelihood of this occurring is low.

- *Elsinoe australis* is usually spread by asexual spores (conidia), which are produced in large quantities on lesions on old fruit (Bitancourt and Jenkins 1937; CDFA 2020; Chung 2011). Spores are primarily distributed by rain splash between trees but can also spread short distances by air (Bitancourt and Jenkins 1937). The sexual stage (teleomorph) of *E. australis* has only been reported in Brazil, and there is very little information about its role (Bitancourt and Jenkins 1936; Chung 2011).

Orange, mandarin, lemon and other citrus hosts of *E. australis* are widely available in New Zealand, and fruit is likely to be at a susceptible stage at times when *citrus* fruit is imported.

- In New Zealand, 783 ha are planted in commercial oranges, 556 ha in lemons, 257 ha in lemons (Plant & Food Research 2019). Citrus trees are commonly grown in domestic gardens.
- Most citrus fruit in New Zealand sets in November (late spring/early summer) (Brown 2019), although some citrus trees in New Zealand produce fruit throughout the year.
- Immature young fruit up to 6 to 8 weeks after petal fall are the most vulnerable to infection with *E. australis* (CDFA 2020; Sivanesan and Critchett 1974).
- This means that young vulnerable fruit is likely to be present in early summer when domestic citrus supply is low and citrus fruit is likely to be imported to fill the gap in the domestic market.
- However, young fruit would need to be growing close enough to where citrus fruit or peel was discarded for spores to spread to them via water splash or windblown rain.

There is moderate uncertainty in this conclusion, because the maximum distance of spore dispersal by natural means is unknown (EFSA 2017). Lesions that have been missed during production and phytosanitary inspection are likely to be small, and it is not known how much inoculum will be produced in small lesions.

Sweet orange scab is spread by rain splash, and it is likely to spread easily in New Zealand once it infects a susceptible host:

- *Elsinoe australis* can spread even if the previous crop has already been harvested and fruit waste is removed (Kunta et al. 2013). Old lesions on fruits, leaves and twigs are the probable source of infection at the start of each season (Sivanesan and Critchett 1974). Although scabs on leaves are not severe, they may play an important role as a source of inoculum (Bitancourt and Jenkins 1937).

Given the arguments and evidence below, the New Zealand environment is likely to be suitable for the establishment of *E. australis*.

Environmental conditions in New Zealand are likely to be suitable for *E. australis* to establish and spread, especially in the north of New Zealand where most commercial citrus is grown.

- *Elsinoe australis* can grow at constant temperatures from 9.5°C to 35°C. The optimal temperature is near 26°C, with best growth between 24.5°C and 29°C (Bitancourt and Jenkins 1937; MAF 2008). Germination of conidia and infection is possible if there is moisture present from dew, fog or irrigation and does not require rainfall. A wet period of 1–2 hours will allow conidia to form and 2–3 hours are needed for conidia to infect the fruit (Bitancourt and Jenkins 1937; MAF 2008).
- As most commercial citrus fruit sets in November (Brown 2019), young susceptible fruit will be most abundant in December and early January, when temperatures are likely to be warm enough for the fungus to grow. For example, in Kerikeri, a citrus-growing region, summers are warm and humid, and daytime maximum air temperatures usually range from 22°C to 26°C (see the New Zealand climates section). These conditions are likely to favour infection of young fruit with *E. australis*.

Elsinoe australis is commonly reported from areas with very similar climate conditions to the whole of New Zealand, indicated by a climate match index (CMI) of ≥ 0.7 , modelled by Phillips et al. (2018).

- The current global distribution of *E. australis* is shown in Figure 6.1.2.

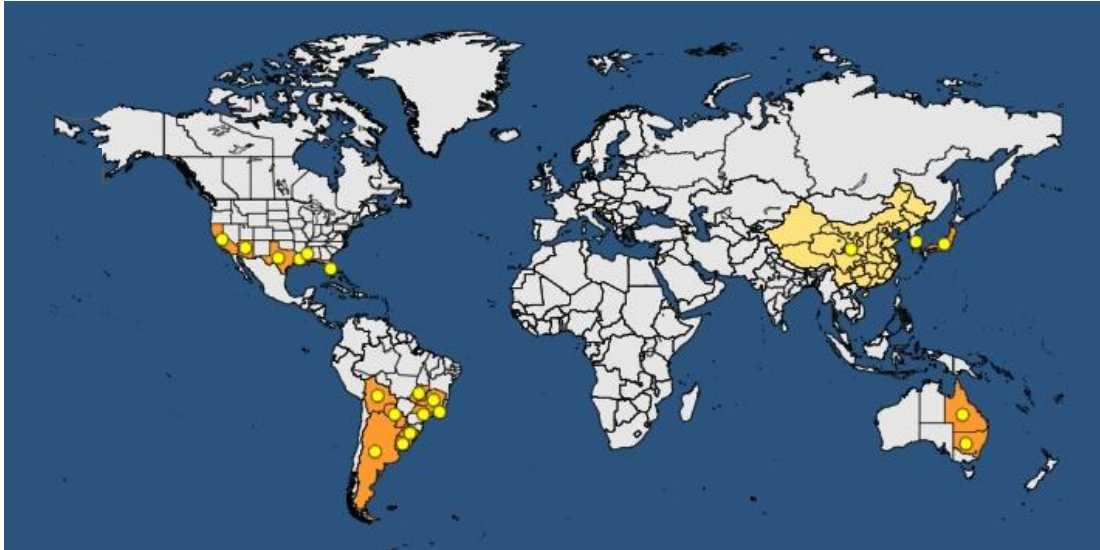


Figure 6.1.2 Distribution of *E. australis* (EPPO, 2020)

- The sweet orange pathotype is reported in South America, including Argentina (CMI: 0.7–0.9), Uruguay (CMI: 0.7–0.9) and Rio Grande do Sul in Brazil (CMI: 0.7–0.9) (EPPO, 2020).
- The natsudaikai pathotype has been reported from Jeju Island, Korea (CMI: 0.7) and Honshu, Japan (CMI: 0.6–0.8) (Hyun et al. 2007; EPPO 2020). A closely related pathotype is recently invasive in some US states (Louisiana, Florida, Mississippi, Texas, Arizona and parts of California (Kunta et al. 2013). In general, these states have CMIs of 0.6–0.8 with the whole of New Zealand.
- *Elsinoe australis* is also reported from New South Wales, Australia and China (Nanjing, Jiangsu and Wuhu, Anhui in southeastern China), which have a CMI of 0.7 with New Zealand.
- *Elsinoe australis* is reported in areas with hotter and more tropical climates than New Zealand, including Bolivia, other regions of Brazil (Goias, Minas Gerais, Rio de Janeiro and Sao Paolo), Paraguay and Queensland Australia.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *E. australis* is likely to be low for New Zealand overall, but moderate for the citrus industry, with high uncertainty around the magnitude of impacts on citrus production.

Elsinoe australis can cause moderate economic impacts on the citrus industry through premature fruit drop, damage to fruit and impacts on overseas exports:

- *Elsinoe australis* infects young fruit, leading to raised and corky lesions (scab pustules) (Bitancourt and Jenkins 1937; Kunta et al. 2013; Timmer et al. 2000). Fruit with scabs are misshapen and can drop early, resulting in significant quality and yield losses in epidemic regions (Timmer et al. 2000; CDFA 2020). The damage caused to the remaining fruit by scab (scarred and distorted fruit) does not affect the internal fruit quality but reduces its marketability as fresh fruit and for export (CDFA 2020; EFSA 2017).
- Bitancourt and Jenkins (1937) reported that it was common for approximately one third of fruit produced in Sao Paolo, Brazil to be unfit for export due to sweet orange scab blemishes. In severely affected groves 50–60% of fruit was damaged by the disease.
- *Elsinoe australis* is highly likely to increase the impact of scab diseases on the citrus industry, since citrus scab does not currently affect sweet oranges in New Zealand and satsuma mandarins are only mildly susceptible to the pathotypes of *E. fawcettii* that are currently present in New Zealand.
 - Oranges and mandarins (clementine and satsuma) are highly susceptible to *E. australis* (Bitancourt and Jenkins 1937; Sivanesan and Critchett 1974). Oranges are not usually susceptible to citrus scab caused by *E. fawcettii* (EFSA 2017; Hyun et al.

2009) and satsuma mandarins are only mildly susceptible to the citrus scab pathotypes currently present in New Zealand (Fullerton et al. 2019).

- New Zealand collections of *E. fawcettii* in the Landcare databases (NZFungi2) and PPIN are mainly from Auckland, Northland and Bay of Plenty but also Coromandel, mid-Canterbury, Wellington, Nelson, Taranaki and Wanganui from fruit, leaves and occasionally shoots of *C. aurantiifolia*, *C. limon*, *C. reticulata*, *C. paradisi*, *C. grandis*, and tangelo. Neither database records *E. fawcettii* from *C. sinensis*.
- Therefore, *E. australis* would be likely to affect yields and marketability of oranges and satsumas, and impacts would not be mitigated by existing management of *E. fawcettii*. In 2019, export sales of fresh oranges were worth NZ\$1.75 million, and the value of domestic orange sales was \$18 million (Plant & Food Research 2019).
- Establishment of *E. australis* is likely to increase production costs for oranges and other susceptible fruit, because fungicide applications are typically required to manage the disease (EFSA 2017; Schultz et al. 2013; Olsen et al. 2011; UF/IFAS Citrus extension 2020). In Florida, two sprays (at $\frac{2}{3}$ petal fall and 2–3 weeks later) with azoxystrobin, trifloxystrobin, pyraclostrobin, ferbam, and/or copper fungicides are recommended to create a barrier on the fruit during its most susceptible growing period (UF/IFAS Citrus extension 2020). Therefore, extra fungicide sprays to control *E. australis* are likely to be an additional management cost for orange and satsuma production, although the disease is likely to be mitigated by existing measures for *E. fawcettii* in susceptible crops such as lemons, grapefruit and clementine mandarins.
- However, it is unlikely that *E. australis* will cause long-term damage to trees in citrus orchards. CDFA (2020) listed stunting of young trees (both nursery and field planted) as a potential impact of the pathogen. However, although *E. fawcettii* is reported to commonly cause lesions on shoots and leaves, *E. australis* does not usually affect the general health of sweet orange plants. Lesions on leaves and shoots are rare and do not contribute much to the impact of the fungus (Bitancourt and Jenkins 1937; Chung 2010). Although leaf lesions were reported in infections of *Citrus* with *E. australis* in Texas (Kunta et al. 2013), recent information from agricultural extension services in Texas, Arizona, Florida and Louisiana confirm that *E. australis* mainly affects fruit in the USA (e.g. Schultz et al. 2013; Olsen et al. 2011; UF/IFAS Citrus extension 2020; LSU AgCentre (accessed 29 September 2020) and other articles on the LSU AgCentre website).

Establishment of *E. australis* may result in increased phytosanitary measures to maintain access to overseas markets in areas where the pest is absent.

- For example, EPPO (2020) added it to their list as an A1 quarantine pest in 2019, and it is a quarantine pest in Australia, the USA and many other countries (EPPO 2020; Plant Health Australia 2020; USDA-APHIS 2020).
- An incursion of *E. australis* in New Zealand could cause impacts from removal of productive plants, costs of surveillance and loss of income from sales of fresh citrus in domestic and export markets. For example, since sweet orange scab was first detected in Texas in 2010, it has spread to Louisiana, Florida, Mississippi, Texas, Arizona and parts of California, and there are quarantine zones and surveillance for *E. australis* in all these states (USDA-APHIS 2020). There are strict requirements (e.g. packhouse procedures, fungicide treatments) for fresh citrus fruit and citrus nursery stock before it can be transported outside of the affected areas.

There is high uncertainty about the magnitude of economic impacts of *E. australis* on citrus production.

- Effects on fruit quality and yield may differ depending on which pathotype of *E. australis* was to establish in New Zealand, and how that pathotype interacted with the New Zealand environment and citrus varieties. The difference in host range, symptoms and impacts of the natsudaidai pathotype in Korea, Japan, USA and now possibly China show that impacts of this fungus can be difficult to predict.
- Several citrus cultivars grown in New Zealand (Yen Ben, Villafranca and Meyer lemons, Lemonade, Clementine and Kara mandarins) are highly susceptible to citrus scab caused by *E. fawcettii*, and Satsuma mandarins are mildly susceptible (Fullerton et al. 2019). It is therefore uncertain whether there will be additional yield losses in lemons or mandarins due to *E. australis*, and impacts of the disease may be mitigated by existing management measures for citrus scab in some of these crops.

Environmental impacts from *E. australis* are likely to be low overall for New Zealand but may be moderate in citrus-producing areas due to increased use of fungicides to control the disease.

- In states of the USA where *E. australis* is present, fungicide applications are recommended to manage the impacts of the pathogen (Schultz et al. 2013; Olsen et al. 2011; UF/IFAS Citrus extension 2020; LSU AgCentre (accessed 29 September 2020) and other articles on the LSU AgCentre website).
- Since *E. australis* is mostly reported as a citrus pathogen, and there are no native species of *Citrus* (or *Poncirus* or *Fortunella*), it seems likely that environmental impacts would be low. However, there is moderate uncertainty in this conclusion, given that there are recent reports of *E. australis* from unrelated genera such as *Populus* and *Simmondsia*.

Elsinoe australis is unlikely to cause any direct health impacts on human health:

- *Elsinoe australis* is a plant pathogen and has not been reported to affect human or animal health.
- However, there is moderate uncertainty in this conclusion, as there may be indirect impacts on human health if there is increased use of fungicides for pathogen control.

Social impacts of *E. australis* are likely to be low, with low uncertainty:

- *E. australis* can cause premature fruit drop and is likely to affect the productivity of citrus trees in home gardens.
- The production of homemade marmalade from citrus fruits may be affected if people consider the peel of diseased fruit to be unsuitable. However, such impacts have not been reported in the literature.
- Damage to fruit from home gardens may make such fruit unattractive; although the damage is limited to the peel and is not known to affect the quality or taste of the fruit itself.

Risk assessment summary:

Given the arguments and evidence below, *E. australis* may be considered for additional measures.

- *Elsinoe australis* has a strong association with *Citrus* fruit (most commercial citrus cultivars);
- The evidence suggests that some fruit infected with *E. australis* will not be detected, because symptoms can be minor and can be missed or not recognised as disease symptoms during production or phytosanitary inspection. Therefore, basic measures reduce the likelihood of entry of *E. australis* to a moderate degree. Consequently, the likelihood of entry is considered to be moderate, with low uncertainty.
- *Elsinoe australis* has low ability (with moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The New Zealand climate is likely to be suitable for the establishment of *E. australis*.
- Hosts of the pest (citrus) are commercially grown in New Zealand and are commonly grown in home gardens.
- *Elsinoe australis* has been recorded to cause severe damage to citrus fruit, and there are high costs of control in areas with similar climate to New Zealand. The closely related fungal citrus scab species *E. fawcettii* is already present in New Zealand and affects some of the same hosts. Impacts of *E. australis* are likely to be high in oranges and satsuma mandarins but mitigated by existing management of citrus scab in other commercial citrus varieties. Therefore, it is likely to cause moderate impacts on the citrus industry in New Zealand and low impacts to the overall economy of New Zealand;
- *Elsinoe australis* is present (although sometimes with restricted distribution or host range) in several countries in the scope of this IRA, including Australia, Brazil, China, USA and Korea.

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5.2 *Phyllosticta citricarpa* (citrus black spot)

Phyllosticta citricarpa (citrus black spot) causes severe spots and lesions affecting the rinds of fruit and sometimes leaves. Although the juice quality is unaffected, the blemished fruit is unappealing and unsuitable for marketing as fresh fruit. Most commercial citrus species are affected, and severe losses have been reported in lemons, sweet oranges and grapefruit.

Scientific name: *Phyllosticta citricarpa* (McAlpine) Aa (1973)

Order/Family: Botryosphaerales/Botryosphaeriaceae

Other names include: *Guignardia citricarpa* Kiely (1949), *Phoma citricarpa* McAlpine (1899)

Taxonomic notes: *Citrus* is host to several other *Phyllosticta* and *Guignardia* species, and historically, these species were sometimes identified as *P. citricarpa* (Glienke et al. 2011; Wang et al. 2012), which can lead to uncertainty in distribution records (see Appendix 1). For example, *P. capitalensis* and *G. mangiferae* are widespread geographically, have broader host ranges than *P. citricarpa*, are present in New Zealand (NZFungi2 2020) and non-regulated (BRAD 2020; ONZPR 2020).

Summary of conclusions

Given the arguments and evidence presented:

- *Phyllosticta citricarpa* meets the criteria to be a quarantine pest for New Zealand.
- *Phyllosticta citricarpa* has a strong association with citrus fruit with low uncertainty.
- Basic measures for importing citrus fruit reduce the likelihood of entry of *P. citricarpa* by a low degree with low uncertainty. Consequently, the likelihood of entry is considered high, with low uncertainty.
- *Phyllosticta citricarpa* has low ability to move from most imported citrus fruit and into a suitable environment to allow establishment, that is, onto a host plant with moderate uncertainty. However, it is very uncertain whether *P. citricarpa* can move from imported *C. latifolia* or *C. aurantium* fruit onto a host plant to allow establishment.
- The suitability of the New Zealand environment for *P. citricarpa* to establish is considered high, with low uncertainty.
- The level of impact caused by *P. citricarpa* is likely to be moderate for New Zealand overall with low uncertainty but high for the citrus industry.
- *Phyllosticta citricarpa* may be considered for additional measures on most citrus fruit commodities.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	High	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Moderate	Low

5.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Phyllosticta citricarpa* meets the criteria to be a quarantine pest for New Zealand

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁴³).

Phyllosticta citricarpa is not known to be present in New Zealand:

- *Phyllosticta citricarpa* is recorded as 'recorded in error' in NZFungi2 (2020) and NZOR (2020), although it is recorded as present in PPIN (2020). It is listed as 'Regulated' in BRAD (2020) and ONZPR (2020).

Phyllosticta citricarpa has the potential to establish and spread in New Zealand:

- *Phyllosticta citricarpa* is reported from many areas with a very similar climate to the whole of New Zealand, indicated by a climate match index (CMI) of ≥ 0.7 (Phillips et al. 2018), including parts of Argentina, Australia (New South Wales and Queensland), Uruguay and South Africa (EFSA 2014; EPPO 2020a)
- The host range is *Citrus* and species in related genera in the Rutaceae such as *Poncirus* and *Fortunella* (Baayen et al. 2002; EFSA 2014; Farr and Rossman 2020).
- Citrus is commercially grown in New Zealand and commonly grown in home gardens (see section 2.5).

Phyllosticta citricarpa has the potential to cause economic, social and environmental impacts to New Zealand:

- *Phyllosticta citricarpa* has the potential to harm *Citrus* that is of economic importance to New Zealand.
- *Phyllosticta citricarpa* has the potential to have sociocultural impacts: *Citrus* is commonly planted in home gardens.
- Given that the reported hosts of *P. citricarpa* are the *Citrus*, *Poncirus* and *Fortunella* species and that there are no native species in these genera (see Chapter 2), impacts on native plants are likely to be low.
- However, it is highly likely that increased applications of fungicides would be required to manage the pathogen in commercial production areas, and this would have environmental impacts.

5.2.2 Hazard identification: commodity association

Phyllosticta citricarpa is associated with citrus fruit

Phyllosticta citricarpa is reported from citrus fruit:

- *Phyllosticta citricarpa* causes lesions on citrus fruit, and most commercial varieties of citrus are hosts of *P. citricarpa*, including lemons, sweet oranges, grapefruit and mandarins (EFSA 2014; Kotzé 1981; Miles and Smith 2019).

5.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Phyllosticta citricarpa* has a strong association with citrus fruit (with low uncertainty) and can be associated with

⁴³ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining "harm".

commercially traded (export) citrus fruit of most commercial varieties (with low uncertainty):

Phyllosticta citricarpa has been reported from citrus fruit.

- *Phyllosticta citricarpa* has been isolated from disease lesions on symptomatic citrus fruit of most commercial citrus varieties, including sweet orange, mandarin, grapefruit and lemon. Species susceptible to *P. citricarpa* are listed in Table 6.2.1.
- *P. citricarpa* can be present as latent mycelia in susceptible hosts and as an endophyte in citrus fruit without symptoms (Baldassari et al. 2006, 2008; EFSA 2014; Wang et al. 2016).
- Tahitian lime (*C. latifolia*) fruit does not show symptoms in natural infection, even in areas with high levels of inoculum (Baldassari et al. 2008; Wang et al. 2016). However, *P. citricarpa* was isolated from asymptomatic Tahitian lime fruit peel, suggesting the fungus can be present in fruit as an endophyte (Baldassari et al. 2008).
- Sour orange (*C. aurantium*) and its hybrids are often reported as not susceptible to the pathogen (Baldassari et al. 2008; EFSA 2014; Kotzé 1981), but the fungus has been isolated from lesions on fruit of this species (Baldassari et al. 2008; Baayen et al. 2002; Glienke et al. 2011; Wulandari et al. 2009).

Table 6.2.1 Citrus species susceptible to citrus black spot caused by *P. citricarpa* (EFSA 2020)

Scientific name	Common name
<i>C. limon</i> (L.) Burm.f.	Lemon
<i>C. sinensis</i> (L.) Osbeck	Sweet orange
<i>C. reticulata</i> Blanco	Mandarin, Satsuma mandarin
<i>C. paradisi</i> Macfad.	Grapefruit
<i>C. medica</i> L.	Citron
<i>C. aurantiifolia</i> (Christm.) Swingle	Key lime, Sweet lime
<i>C. hystrix</i> DC	Kaffir lime

There is low uncertainty in this conclusion for most commercial citrus fruit varieties, because *P. citricarpa* has been frequently reported from these species.

However, there is moderate uncertainty about the host status of pomelo (*C. maxima*). Wulandari et al. (2009) classified all *Phyllosticta* isolates in their study that came from pomelo (*C. maxima*) as *P. citriasiana*, although most had previously been classified as *P. citricarpa*. These isolates came from China, Thailand and Viet Nam. In a later study, several *Phyllosticta* isolates from pomelo in Guangdong, Guangxi and Fujian were identified as *P. citriasiana* (Wang et al. 2012). *Phyllosticta citriasiana* was not identified from other citrus species and *P. citricarpa* was not identified in pomelo in these studies. However, Glienke et al. (2011) identified an isolate from *C. maxima* in Brazil as *P. citricarpa*.

Phyllosticta citricarpa can be associated with citrus fruit commodities.

- *Phyllosticta citricarpa* has a long latent period in fruit, and symptoms do not start to develop until fruit is fully grown and beginning to ripen (Kotzé 1981; Agostini et al. 2006). Infected fruit may appear healthy and might therefore be harvested and packaged for export.
- Viable *P. citricarpa* has been detected on imported citrus fruit from Brazil and China during border inspections in Europe (EFSA 2014; EPPO reporting service 2020; see Table 6.2.2). During 1999–2012 there were 859 interceptions of *P. citricarpa* on citrus fruit consignments entering Europe from countries outside the European Union (EFSA 2014). Most interceptions of *P. citricarpa* on fresh citrus fruit were on fruit originating in Brazil or South Africa (EFSA 2014). Brazil is one of the countries included in the new IHS.
- However, *P. citricarpa* has not been intercepted on citrus fruit at the New Zealand border (LIMS 2020). This is probably because there are no IHSs for citrus from countries or areas of countries where the fungus is known to be present, except Australia where there are targeted measures for *P. citricarpa* (as *G. citricarpa*) on citrus imports. New Zealand has an existing IHS for citrus from the USA, but citrus has not been imported from Florida since 2005 (MPI Quancargo database, checked 6 October 2020), well before the current incursion of *P. citricarpa* in that state.

Phyllosticta citricarpa is present in at least four of the countries in the scope of this pest risk assessment, with low uncertainty (see Table 6.2.2.). There are reliable recent records of *P. citricarpa* causing citrus disease in some regions of Australia, China, Brazil and the USA. The Korean NPPO listed *P. citricarpa* on the pest list they provided to MPI. There are no recent reliable records of *P. citricarpa* in the Cook Islands, Egypt, Fiji, Japan, Mexico, Peru, Samoa, Spain, Vanuatu and Viet Nam. EPPO (2020a) reports *P. citricarpa* as absent from these countries, and it was not on the pest lists provided by the countries. *Phyllosticta citricarpa* is not reported in New Caledonia or Solomon Islands (see Table 6.2.2).

Table 6.2.2 Distribution of *P. citricarpa* in countries in the scope of the pest risk assessment.

Country	Information	Uncertainty
Australia	Present in New South Wales, Northern Territories, Queensland and Victoria (Miles et al. 2013; EPPO 2020a; Farr and Rossman 2020). Absent in Western Australia ⁴⁴ and South Australia, and the European Union recognises these areas as pest-free areas for the disease. ⁴⁵	Low uncertainty.
Brazil	Present, restricted distribution (Rio Grande do Sul, Rio de Janeiro, Sao Paolo) (EPPO 2020a; EFSA 2014; Farr and Rossman 2020). The EPPO reporting service (2020) records numerous interceptions on citrus from Brazil, mostly on oranges (<i>C. sinensis</i>) but also mandarins (<i>C. reticulata</i>) and lemon (<i>C. limon</i>).	Low uncertainty.
China	Present, restricted distribution (Fujian, Guangdong, Guangxi, Jiangsu, Sichuan, Hong Kong, Yunnan, Zhejiang) (EPPO 2020a; Wang et al. 2012). EPPO reporting service (2020): <i>C. maxima</i> , <i>C. paradisi</i> , <i>Citrus</i> sp.	Low uncertainty.
Cook Islands	Absent, confirmed by survey (EPPO 2020a). No reports found in searches. Farr and Rossman (2020) have records on several species from a single 1981 survey/technical report. A search of CAB Abstracts ⁴⁶ found an abstract of 1990 distribution map for <i>G. citricarpa</i> (same as Fiji, Samoa, Spain); CAB Abstracts, Farr and Rossman 2020)	Low uncertainty.
Egypt	Absent, confirmed by survey (EPPO 2020a). Farr and Rossman (2020) have no record. A search of CAB Abstracts found several distribution maps for <i>G. citricarpa</i> (1966, 1983, 1990).	Low uncertainty.
Fiji	Absent, confirmed by survey (EPPO 2020). Farr and Rossman (2020) have records on several species from a 1981 survey/technical report (same one as Cook Islands) and a 1972 list. A search of CAB Abstracts found an abstract of a 1990 distribution map for <i>G. citricarpa</i> .	Low uncertainty.
Japan	Absent, confirmed by survey (EPPO 2020a), based on information dated 1992. EPPO consider historical records to be doubtful and presumably relating to <i>G. mangiferae</i> . Farr and Rossman (2020) have records on natsudaikai, unshiu and <i>Citrus</i> sp. from a 2007 index of fungi inhabiting woody plants in Japan.	Low uncertainty.
Korea	Absent, confirmed by survey (EPPO 2020a) EPPO note there are doubtful records presumably concerning <i>G. mangiferae</i> . Farr and Rossman (2020) have a single record from a 2004 list of plant diseases in Korea.	Requires clarification. Korea included <i>P. citricarpa</i> on their list of diseases associated with unshiu mandarin, and the EPPO current pest situation is based on information dated 1992.
Mexico	Absent unreliable record (EPPO 2020a). Farr and Rossman (2020) have no record.	Moderate uncertainty. Stringari et al. (2009) report a single isolate in a molecular phylogeny as <i>G. citricarpa</i> from citrus black spot lesions in Mexico. A search of CAB Abstracts found no other relevant records. EPPO reporting service (2020) records a single interception from Mexico of <i>P. citricarpa</i>

⁴⁴ Western Australia Department of Primary Industries and Regional Development, Citrus black spot: pest data sheet. <https://www.agric.wa.gov.au/plant-biosecurity/citrus-black-spot-pest-data-sheet> Accessed 5 October 2020.

⁴⁵ MICoR (Australian Government Department of Agriculture, Water and the Environment Manual of Importing Country Requirements, Lemons – European Union): “The European Union formally recognises the states of South Australia, and Western Australia as free from Black spot” (*Phyllosticta citricarpa*).

⁴⁶ Search terms used for all CAB Abstracts searches in this table were ‘citricarpa’ and the country name.

Country	Information	Uncertainty
		from <i>C. paradisi</i> in 2016 with an asterisk, indicating it is not known in the country of origin. Since these interception reports include passenger pathway interceptions, the fruit may not have been grown in Mexico.
New Caledonia	No report found in CAB Abstracts searches. No record in EPPO (2020a) or Farr and Rossman (2020).	Low uncertainty.
Peru	Absent, confirmed by survey (EPPO 2020a). Farr and Rossman (2020) have no record. A CAB Abstracts search found abstracts for 1990, 1983 and 1966 distribution maps for <i>G. citricarpa</i> and a 1942 Peruvian flora that records <i>Phoma citricarpa</i> on citrus.	Low uncertainty.
Samoa	Absent, confirmed by survey (EPPO 2020a). Farr and Rossman (2020) have records on several species from a 1981 survey/technical report (same one as Cook Islands, Peru, Spain and Fiji). A CAB Abstracts search found an abstract for the 1990 distribution map for <i>G. citricarpa</i> .	Low uncertainty.
Spain	Absent, confirmed by survey (EPPO 2020a). Farr and Rossman (2020) have no record. A CAB Abstracts search found abstracts for 1990, 1983 and 1966 distribution maps for <i>G. citricarpa</i> .	Low uncertainty.
Solomon Islands	No record in EPPO (2020a) or (CABI 2020). Farr and Rossman (2020) have no record. A CAB Abstracts search found no records.	Low uncertainty.
USA	Present, restricted distribution (southern Florida) (EPPO 2020a; USDA-APHIS 2020)	Low uncertainty.
Vanuatu	Absent, unreliable record (CABI 2020; EPPO 2020a). Farr and Rossman (2020) have no record. A CAB Abstracts search found several distribution maps (under the name New Hebrides) for <i>G. citricarpa</i> from 1966, 1983 and 1990.	Moderate uncertainty. The IHS for citrus from Vanuatu currently has additional measures for <i>P. citricarpa</i> (as <i>Guignardia citricarpa</i>) (MAF Biosecurity New Zealand 2006)
Viet Nam	Absent, confirmed by survey (EPPO 2020a). No record in Farr and Rossman (2020). A CAB Abstracts search found several distribution maps for <i>G. citricarpa</i> (e.g. 1966, 1983, 1990).	Moderate uncertainty. EPPO reporting service (2020) records two past detections on <i>C. maxima</i> and one on <i>C. limon</i> .

Given the arguments and evidence below, basic measures only reduce the likelihood of entry of *P. citricarpa* by a low degree. Consequently, the likelihood of entry is considered high, with low uncertainty.

Infected fruits can show symptoms late in production and at the time of phytosanitary inspection, and symptomatic fruit are likely to be detected and removed.

- Symptoms of *P. citricarpa* on fruit can start to develop once the fruit is fully grown and starts to ripen (Kotzé 1981).
- Examples of lesions on fruit caused by *P. citricarpa* are shown in Figure 6.2.1. Obvious symptoms of infection such as these would be extremely unlikely to escape detection.



Figure 6.2.1 Lesions on citrus fruit caused by *P. citricarpa*. From left to right: Citrus black spot lesions⁴⁷; Hard spot on orange, with pycnidia visible in the middle of the lesions⁴⁸; Cracked spot lesions on Valencia orange⁴⁹.

However, the evidence suggests that some infected fruit is not detected and removed during production or phytosanitary inspection:

- Symptoms of *P. citricarpa* appear at fruit maturity or post-harvest (Agostini et al. 2006; Kotzé 1981). The latent period before symptoms develop can last for up to 24 weeks after the fruit is infected (Tran et al. 2020). Infected fruit can be symptomless at the time of harvest and packaging for export and can subsequently develop symptoms in transit or storage (Agostini et al. 2006; Er et al. 2013; Tran et al. 2020).
- During this period, latent mycelium can be present in asymptomatic fruit (EFSA 2014).
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.

General handling after harvesting is not likely to remove fruit with latent infections.

- General handling after harvesting (e.g. washing and brushing) only treats the surface of fruit, so it will not remove latent mycelium in the rind.
- Waxing and some post-harvest fungicide treatments slows postharvest development of *P. citricarpa* but does not prevent it altogether (Agostini et al. 2006).
- Packhouse treatments that reduce the recovery of viable *P. citricarpa* from existing lesions include a warm water bath (43–47°C for three minutes), chemical tank (1,000 µg/ml guazatine, 503 µg/ml imazalil sulphate, 500 µg/ml 2,4-D sodium salt) or polyethylene wax application (Korf et al. 2001). The warm water bath, chemical tank or a chlorine bath reduce the viability of conidia in existing lesions to zero. However, none of the treatments eliminated the pathogen completely, and the Korf et al. (2001) study examined fruit with visible lesions, so it is of limited relevance.

Phyllosticta citricarpa is likely to survive transit and storage in citrus commodities.

- EFSA (2014) considered that *P. citricarpa* is very likely to survive transport and storage either as conidia within pycnidia in fruit lesions or as latent mycelium present in asymptomatic fruit.
- Storing the fruit at 8°C slowed symptom development, compared with storage at ambient temperatures, but did not prevent it (Agostini et al. 2006). Live *P. citricarpa* was still detected in symptomatic peel and fruit after 40 days of storage at different combinations of temperature (8°C or ambient temperature: 18–25°C) and humidity (saturated, moist or dry) (Agostini et al. 2006).
- Viable *P. citricarpa* could be isolated from lesions on untreated fruit, and fruit exposed to various packhouse treatments, after 3 weeks of storage at 4.5°C (Korf et al. 2001).
- Lesions and pycnidia of *P. citricarpa* developed in asymptomatic, latently infected fruit maintained at 4°C, 12°C or 22°C over a period of 11 weeks, although development was slower at lower temperatures (Er et al. 2013). New lesions developed between weeks 9–11 at 4°C, indicating that the fungus was still viable after at least 9 weeks of cold storage.
- Post-harvest symptom development is influenced by the temperature in the packhouse and during transport to market, with more lesions developing at 27°C than 20°C (Kotzé 1981). More lesions develop on fruit kept at high light intensities than on fruit stored in darkness (Kotzé 1981).
- New *P. citricarpa* lesions were observed on citrus fruit after cold storage for 5 weeks, followed by incubation for 2 weeks under optimum conditions for symptom expression (25–27 °C under constant light and > 80% humidity) (Moyo et al. 2020). In orange fruit 4.4 % of lesions formed pycnidia, and in lemon fruit 6.6 % of lesions formed pycnidia (Moyo et al. 2020).
- From a risk management perspective, it is worth noting that most commercial citrus fruit transported to New Zealand in cold storage, would not be exposed to the prolonged periods

⁴⁷ Florida Division of Plant Industry Archive / CC BY-SA (<https://creativecommons.org/licenses/by-sa/3.0>). https://commons.wikimedia.org/wiki/File:Citrus_Black_Spot_Lesions.jpg

⁴⁸ Cesar Calderon – USDA APHIS PPQ, Bugwood.org / CC BY-SA (<https://creativecommons.org/licenses/by-sa/3.0>). https://commons.wikimedia.org/wiki/File:Citrus_Black_Spot.jpg

⁴⁹ P. Barkley – Biological and Chemical Research Institute, Bugwood.org / CC BY-SA (<https://creativecommons.org/licenses/by-sa/3.0>). https://commons.wikimedia.org/wiki/File:Citrus_Black_Spot_on_Valencia_orange.jpg

of light and warmer temperatures that promote symptom development until after they have entered New Zealand

However, it is very unlikely the pathogen will spread further through the consignment.

- Undamaged mature fruit are not susceptible to infection by *P. citricarpa* conidia (spores) at temperatures of either -0.5 or 20°C (Korf et al. 2001).
- EFSA (2014) concluded that it is very unlikely (with low uncertainty) that the pathogen will multiply or increase in prevalence during transport or storage of infected citrus fruit, since:
 - the optimal temperature for hyphal growth of *P. citricarpa* in synthetic medium is approximately 25°C;
 - the pathogen is largely inactive at temperatures below 15°C; and
 - citrus fruit is usually stored and transported at low temperatures (EFSA 2014).

There is low uncertainty in this conclusion. Without additional measures, it is highly likely that fruit containing latent *P. citricarpa* or small fungal lesions will escape detection during production and phytosanitary inspection. It is also highly likely that *P. citricarpa* in citrus fruit can survive packhouse procedures, storage and transit to New Zealand. In addition, since citrus fruit is often transported at cold temperatures and in the dark, lesions may be slow to develop and may not yet be visible at the time of verification inspection at the New Zealand border.

Likelihood of establishment:

Given the arguments and evidence below, the ability of the *P. citricarpa* to move from imported citrus fruit (apart from *C. latifolia* or *C. aurantium*) onto a host plant to allow establishment is rated as low, with moderate uncertainty.

Phyllosticta citricarpa is likely to survive and develop on the waste of citrus fruit (whole fruit, pieces and peel).

- Live *P. citricarpa* was still detected in symptomatic peel and fruit after 40 days of storage at different combinations of temperature (8°C or ambient temperature: 18–25°C) and humidity (saturated, moist or dry) (Agostini et al. 2006). Lesions and pycnidia of *P. citricarpa* developed in asymptomatic, latently infected fruit after 9–11 weeks at 4°C, 12°C or 22°C (Er et al. 2013).

Most waste from imported citrus in New Zealand will be disposed of using low-risk methods, so *P. citricarpa* will be unable to spread from the citrus host.

- The majority of kitchen waste in New Zealand is disposed of in bags in landfills or in kitchen disposal units, and in these situations, *P. citricarpa* is unlikely to reach a new host (see the waste analysis in Chapter 2).

Orange, mandarin, lemon, grapefruit and other citrus hosts of *P. citricarpa* are extensively grown in New Zealand, and fruit is likely to be at a susceptible stage at times when citrus fruit is imported and at times of the year when seasonal weather conditions are likely to favour development and spread of the pathogen.

- Most commercial citrus species are susceptible, especially lemons and Valencia oranges (Kotzé 1981).
- In New Zealand, 783 hectares (ha) are planted in commercial oranges, 556 ha in mandarins, 257 ha in lemons and 15 ha in grapefruit (FreshFacts 2019). Citrus trees are commonly grown in domestic gardens.

Phyllosticta citricarpa can spread to nearby citrus trees if infected fruit or peels are discarded in the New Zealand environment near citrus trees, although the likelihood is low.

- Ascospores (sexual spores) produced in leaf litter have historically been considered the most important means for dispersal of *P. citricarpa* (e.g. Fourie et al. 2013; Kotzé 1981). Ascospores require two mating types to be present and are not produced on fruit. However, in Brazil, Zimbabwe and Queensland, Australia, conidia (asexual spores) are now recognised as a significant source of inoculum for spreading the pathogen, even though ascospores are present (Spósito et al. 2011; Wang and Dewdney 2019).

- Although there are recent studies that indicate that fresh citrus fruit is not an epidemiologically significant pathway for the entry, establishment and spread of citrus black spot, these studies assess the likelihood based on treatments being applied.
 - For example, Gottwald et al. (2021) developed a probabilistic model using a Monte Carlo simulation to investigate the overall probability of *P. citricarpa* infecting commercially produced fresh citrus at several different production areas, remaining viable throughout production and transport, and establishing at various endpoint locations. The inputs integral to this model included estimates for the efficacy of pre-harvest control measures (e.g. in-field fungicide treatments) and packinghouse treatments (e.g. disinfectant washes, fungicide dips/drenches, drying and waxing) to mitigate *P. citricarpa*.
 - Likewise, Moyo et al. (2020) studied the viability of *P. citricarpa* in naturally infected orange and lemon fruit. Despite the fact that these authors concluded that fruit was not an epidemiologically significant pathway for the fungus, they observed that new fungal lesions developed on both treated and untreated orange and lemon fruit after a period in cold storage, and that pycnidia (asexual fruiting bodies) in lesions on untreated fruit produced viable spores.
- Conidia of *P. citricarpa* are produced in lesions on infected fruits (as well as on leaves and branches) and can be spread by water splash and windblown rain (Tran et al. 2017; EFSA 2014). EFSA (2014) considered that if citrus fruit, peel or other citrus by-products with pycnidia of *P. citricarpa* are discarded underneath or in close proximity to susceptible citrus trees, the pathogen can be dispersed by natural means and can infect susceptible plant tissues.
- *Phyllosticta citricarpa* is recently invasive in Florida, where the disease originated from a single clonal lineage. Only one mating type is present, and *P. citricarpa* reproduces asexually, so only conidia (asexual spores) are produced (Wang et al. 2016; Hendricks et al. 2020). Despite this, *P. citricarpa* has been able to spread in Florida. The fungus was first reported in Florida in 2010 (Schubert et al. 2012), and by July 2019 the quarantine zone had been extended to encompass 1160.32 km² in Lee, Charlotte, Collier, Hendry and Polk counties (Hendricks et al. 2020).
- Recent studies of *P. citricarpa* in Florida, USA, where the fungus does not produce wind-dispersed ascospores, suggest that conidia can be spread by windblown rain over much greater distances than previously reported, within rows of trees in an orchard (3.36 m spacing), across rows (6.70 m spacing) and upwards into the topmost parts of a canopy (reaching heights of > 3 metres) (Hendricks et al. 2017; 2020). The incursion in Florida indicates that *P. citricarpa* can spread widely, even when only conidia, such as those produced on fresh fruit, are present.
- The temperature range for conidia to germinate and form appressoria (infective structures) in vitro (in medium containing citrus juice) was between 12–32°C with an optimum of 24°C (Wang and Dewdney 2019). Mean daily maximum temperatures of between 12 and 24°C are common across most of New Zealand through most of the year (see the climate section in Chapter 2, section 4), meaning that conditions for appressoria formation are widely available in New Zealand.
- The majority of citrus fruit in New Zealand sets in November (late spring/early summer) (Brown 2019), although some citrus trees in New Zealand produce fruit throughout the year.
- Fruit are reported to be susceptible to infection by *P. citricarpa* for up to 30 weeks from fruit set, but the susceptible period may be shorter or longer depending on local weather conditions, *Citrus* variety and inoculum pressure (EFSA 2014; Lanza et al. 2018; Tran et al. 2020). Leaves do not usually develop symptoms (except in lemon) but are reported to be susceptible for 10 months post formation (EFSA 2014).
- Susceptible fruit is likely to be present throughout the summer when temperatures are more likely to favour germination of conidia, and susceptible leaves are likely to be present for most of the year. In summer, domestic citrus supply is low, and citrus fruit is likely to be imported to fill the gap in the domestic market. Susceptible leaves are likely to be present all year round.
- However, citrus trees would need to be growing close enough to where citrus fruit or peel were discarded for conidia to be spread to them via water splash or windblown rain.

There is moderate uncertainty in this conclusion, because there are no current data on the proportion of waste from imported citrus that is discarded in and around citrus orchards or composted in home gardens. Although Hogg et al. (2010) reported that New Zealanders discard around 400,000 tonnes of

kitchen waste each year and about 12.5% is composted, there are no data on the proportion of composted waste that is imported *Citrus* (see section 2.4). Also, the distance of compost heaps from *Citrus* hosts in home gardens is likely to be highly variable.

Given the arguments and evidence below, it is uncertain whether *P. citricarpa* can move from imported *C. latifolia* or *C. aurantium* fruit onto a host plant to allow establishment.

There is no evidence that *P. citricarpa* can produce conidia to allow it to spread from *C. latifolia* or *C. aurantium* fruit to nearby citrus fruit or leaves.

- Tahitian lime (*C. latifolia*) fruit does not show symptoms in natural infection, even in areas with high levels of inoculum (Baldassari et al. 2008; Wang et al. 2016). However, *P. citricarpa* has been isolated from asymptomatic fruit peel and can colonise and form viable ascospores in leaves of Tahitian lime (Baldassari et al. 2008).
- Sour orange (*C. aurantium*) and its hybrids are often reported as not susceptible to the pathogen (Baldassari et al. 2008; EFSA 2014; Kotzé 1981), but the fungus has been isolated from lesions on fruit of this species (Baldassari et al. 2008; Baayen et al. 2002; Glienke et al. 2011; Wulandari et al. 2009).
- EFSA (2014), EPPO (2020b) found no evidence of reproduction and no reference to production of conidia on either of these species.

Given the arguments and evidence below, the suitability of the New Zealand environment for *Phyllosticta citricarpa* to establish is considered high.

Phyllosticta citricarpa is commonly reported from subtropical citrus-growing areas with summer rainfall. Many of these areas have very similar climate conditions to the whole of New Zealand, indicated by a climate match index (CMI) of ≥ 0.7 , modelled by Phillips et al. (2018).

- The current global distribution of *P. citricarpa* is shown in Figure 6.2.2, and the CMI for each country/state is given in Table 6.2.3. Climate is highly unlikely to limit the establishment of *P. citricarpa*, because it is reported from many areas with very similar climates to New Zealand including Argentina, Uruguay, some regions of Brazil, Australia (New South Wales, Queensland and Victoria), some provinces of China and the eastern provinces of South Africa.

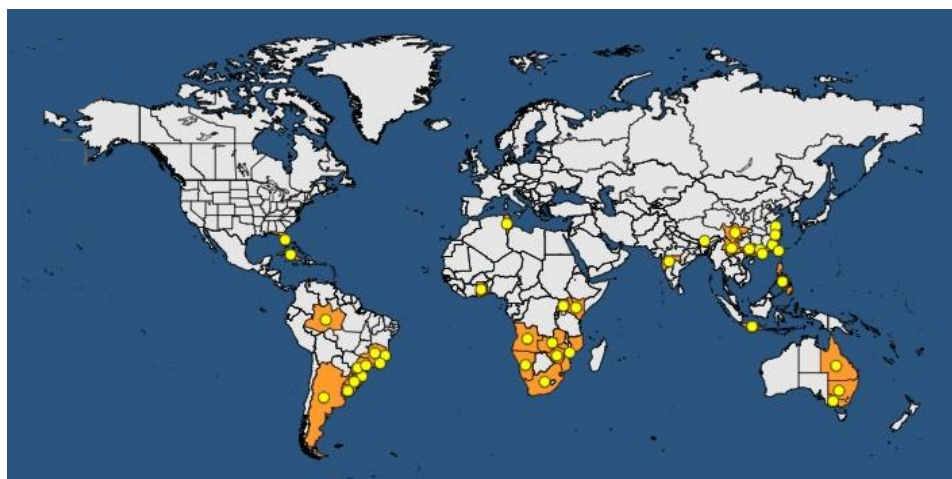


Figure 6.2.2 Distribution of *P. citricarpa* (EPPO 2020)

Table 6.2.3 Distribution of *P. citricarpa* (EPPO 2020)

CMI values of ≥ 0.7 have very similar climate conditions to the whole of New Zealand (Phillips et al. 2018)

Region	Country	State/Province (if recorded)	CMI range (Phillips et al. 2018)	
Africa	Angola (restricted distribution)		0.5–0.7	
	Ghana (restricted distribution)		≤0.6	
	Kenya		0.4–0.8	
	Mozambique		≤0.6	
	Namibia (few occurrences)		0.5–0.7	
	South Africa (restricted distribution; not present in Western Cape, Northern Cape, Free State)	Eastern Cape		0.7–0.9
		Gauteng		0.6–0.8
		KwaZulu-Natal		0.7–0.8
		Limpopo		0.6–0.7
		Mpumalanga		0.7–0.8
	North West Province		0.6–0.7	
	Tunisia (restricted distribution)		0.5–0.8	
	Uganda		0.5–0.8	
Zambia		≤0.6		
Zimbabwe		0.5–0.7		
Asia	Bhutan		0.4–0.7	
	China (restricted distribution)	Fujian		0.6–0.7
		Guangdong		0.4–0.7
		Guangxi		0.5–0.7
		Jiangsu		0.7
		Sichuan		0.6–0.8
		Yunnan		0.6–0.8
		Zhejiang		0.7
	India (restricted distribution)	Maharashtra		≤0.6
	Indonesia		≤0.6	
Philippines		≤0.6		
Taiwan		0.4–0.8		
North America	USA	Florida (Lee, Charlotte, Collier, Hendry and Polk counties)	0.5–0.6	
	Cuba		≤0.6	
South America	Argentina		0.6–0.9	
	Brazil	Amazonas		≤0.6
		Espírito Santo		≤0.6
		Minas Gerais		≤0.6
		Paraná		0.6–0.8
		Rio de Janeiro		0.5–0.7
		Rio Grande do Sul		0.7–0.9
		Santa Catarina		0.7–0.9
	São Paulo		0.5–0.7	
Uruguay		0.7–0.9		
Oceania	Australia	New South Wales	0.6–0.9	
		Queensland	0.4–0.8	
		Victoria	0.7–0.9	

Host availability is unlikely to be a limiting factor for *P. citricarpa* to establish in New Zealand.

- Most commercial citrus cultivars are susceptible to *P. citricarpa* to some degree (see Table 6.2.1) especially lemons and sweet oranges, which are commonly grown in New Zealand, both in commercial production and in home gardens. Citrus is commercially produced in both the North Island and the South Island, with most commercial production taking place in the North Island (see section 4.2 in Chapter 2).

Phyllosticta citricarpa can spread once it becomes established in a new area.

- In Nabeul, Tunisia (an area with a CMI of 0.7 with the whole of New Zealand), 339 orchards in the area were surveyed after symptoms were first observed, and some plants in 69 lemon and orange orchards already showed symptoms (Boughalleb-M'Hamdi et al. 2020).
- *Phyllosticta citricarpa* was first reported in Florida, USA in 2010 (Schubert et al. 2012), and by July 2019, the quarantine zone had been extended to encompass 1,160.32 km² in Lee, Charlotte, Collier, Hendry and Polk counties as of July 2019 (Hendricks et al. 2020).
- In South Africa, disease symptoms were observed for 30 years before the disease reached epidemic levels and fungicidal control became necessary (Kotzé 1981).

Phyllosticta citricarpa is spread by rain splash and wind, and it is likely to spread easily in New Zealand once it infects a susceptible host.

- Recent evidence suggests that *P. citricarpa* is commonly spread by conidia (asexual spores) produced in lesions on infected fruits, leaves and branches and dispersed by water splash or windblown rain (Tran et al. 2017, 2020; Hendricks et al. 2020) (see above). This means that the pathogen can establish in an area even if only one mating type is present, as has apparently happened in Florida.
- In Australia, South Africa and South America (Argentina, Brazil) ascospores (sexual spores) formed in pseudothecia in leaf litter from citrus trees are also a major source of inoculum to spread the disease (Reis et al. 2006; Tran et al. 2017).
 - Release of ascospores requires moisture from rainfall, irrigation or possibly heavy dew (EFSA 2014; Reis et al. 2006). Even a small amount of rain can trigger ascospore release (Reis et al. 2006).
 - Ascospore release in Argentina and South Africa peaks in December–January, and in Brazil, the peak is January–February (Reis et al. 2006). Ascospores are infectious at temperatures between 15 and 29.5°C and require 15 to 38 hours of wetness (Reis et al. 2006; EPPO 2020b).
 - Once released, ascospores are spread by wind currents to leaves, twigs and young fruit of citrus (Kotzé 1981).
 - The fruit of most citrus plants in New Zealand sets in November (late spring/early summer) (Brown 2019), although some citrus trees in New Zealand produce fruit throughout the year.
 - Fruit are susceptible to infection by *P. citricarpa* for at least 4–5 months after petal fall (Reis et al. 2006), and leaves are susceptible for 10 months post formation (EFSA 2014). Therefore, susceptible fruit and leaves will almost certainly be present at times when ascospores are released.
- As most commercial citrus fruit sets in November (Brown 2019), young susceptible fruit will be most abundant in December and early January when temperatures are likely to be warm enough for the fungus to release spores and infect fruit. For example, in Kerikeri, a citrus-growing region, summers are warm and humid, and daytime maximum air temperatures usually range from 22°C to 26°C (see the New Zealand climates section). These conditions are likely to favour the infection of young fruit with *P. citricarpa* ascospores.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *P. citricarpa* is likely to be moderate, with low uncertainty.

Damage and symptoms caused by *P. citricarpa* can reduce fruit quality.

- The most commonly observed fruit symptom is hard spots (see Figure 6.2.1 above), which are shallow lesions, 3–10 mm in diameter, with a grey to tan centre and a dark brown to black margin (FAO 2014). Pycnidia commonly form in the centre of hard spots (Miles et al. 2019). Other common lesion types include:
 - freckle spots (small (1–2 mm diameter) grey, tan or colourless spots with no halo, which seldom produce conidia) (FAO 2014);
 - virulent spots (sunken irregular red to brown or colourless lesions that form late in the season on heavily affected mature fruit; these grow rapidly, can cover two thirds of the fruit within 4–5 days and can cause premature fruit drop) (FAO 2014);

- false melanoses (small raised dark brown to black lesions with no conidia that develop on green fruit, are often surrounded by dark specks and may coalesce as the season progresses) (FAO 2014); and
- cracked spots (see Figure 6.2.1 above; cracked spots form when spider mites interact with the fruit lesions and have been observed in Brazil and Florida) (Miles et al. 2019).
- Infections near the pedicel (stem) of the developing fruit may lead to premature fruit drop (Baayen et al. 2002). Yield losses due to premature fruit drop have been reported in Brazil (Reis et al. 2006). Hendricks et al. (2020) discuss use of fungicides to reduce crop losses due to premature fruit drop, suggesting that such losses are also a concern in Florida.
- Except for *C. aurantium* and its hybrids and *C. latifolia*, all commercially grown citrus species are susceptible to black spot disease caused by *P. citricarpa* (Kotzé 1981). In particular, heavy losses of lemon, sweet orange and grapefruit crops are reported. Although the lesions do not usually affect the internal fruit or juice quality, infected fruit are unmarketable as fresh fruit (Kotzé 1981; Zavala et al. 2014).

Phyllosticta citricarpa has been reported to cause severe damage and production loss of citrus in areas with similar climate to New Zealand.

- In 1895 in New South Wales, *P. citricarpa* caused serious losses to late Valencia oranges from blemished fruit from infections in the field and from latent infections that developed on fruit in transit (Sutton and Waterston 1966).
- In 1945, more than 90% of fruit from unprotected trees in some areas of East and North Transvaal (now Limpopo and Mpumalanga) was unfit for export (Sutton and Waterston 1966).
- *Phyllosticta citricarpa* has also been reported to cause crop losses of lemons in Sichuan, Valencia oranges in Chongqing and some mandarin varieties in Zhejiang and Jiangxi (Wang et al. 2012).
- Damage from *P. citricarpa* is most severe when mean maximum temperatures are between 2–25°C while the fruit is maturing or when the temperature is 30°C when the fruit is mature (Sutton and Waterston 1966). Therefore, at the times when fruit is maturing in commercial citrus-growing areas, climate conditions are likely to favour severe damage from the disease. However, in New Zealand, average temperatures at harvest are likely to be lower than 30°C.
- Depending on the suitability of the climate and the susceptibility of hosts, it can take 5–30 years from the time citrus black spot symptoms are first noticed in an area for the disease to reach epidemic proportions (Kotzé 1981). However, if *P. citricarpa* established, New Zealand is likely to be at the shorter end of that timeframe, given that the New Zealand climate is likely to favour spread of the fungus and susceptible citrus varieties such as sweet oranges and lemons are commonly produced.

If *P. citricarpa* becomes established, there are likely to be increased costs to citrus producers from in-field fungicide applications during fruit development to prevent high levels of infection and damage to the crop.

- For example, in an experimental plot that was not treated with fungicide during the susceptible period of fruit development, the mature fruit showed 100% incidence of citrus black spot (Balदारassi et al. 2006).
- In Queensland, São Paulo and Florida, regular applications of fungicide are necessary throughout the period when fruit are susceptible to prevent fruit from being infected (Hendricks et al. 2020; Lanza et al. 2018; Tran et al. 2020).
- Furthermore, because of the long latent period, it is not possible to know if the fungicide applications have been successful until the end of the season when the visible citrus black spot symptoms develop on the fruit (Tran et al. 2020).
- It is likely that there would be additional costs and delay in implementing effective fungicide treatments because research would be required to adapt spray regimes for New Zealand conditions. In Brazil, field trials were required because spray regimes from South Africa were not as effective at controlling *P. citricarpa* in São Paulo (Lanza et al. 2018). Field trials to evaluate fungicide regimes were also carried out in Florida (Hendricks et al. 2020).
- Managing the disease with fungicides is costly, and it can be difficult to control the disease sufficiently to produce fresh fruit that is acceptable to consumers (Tran et al. 2017). Citrus black spot disease, caused by the fungus *P. citricarpa*, is estimated to cost Australian citrus

growers approximately AU\$80 million per year through export restrictions, fungicide applications and fruit damage (Hort Innovation 2018).

Citrus is economically important in New Zealand (for the value of *Citrus* in New Zealand, see Section 5.2 in Chapter 2).

- *Phyllosticta citricarpa* would be likely to affect yields and marketability of most commercial citrus crops in New Zealand, including oranges, lemons, mandarins, grapefruit and some limes.
- In 2019, export sales of fresh citrus fruit were worth NZ\$12 million, and the value of domestic orange sales was \$58.5 million (Plant & Food Research 2019).

There is low uncertainty in this conclusion. Economically significant disease has been recorded in areas with similar climate to New Zealand, so the impact of *P. citricarpa* on the New Zealand citrus industry is likely to be high. However, there is some uncertainty about how long it would take for impacts to become severe. Impacts are likely to increase over time as inoculum levels increase and the disease spreads to new areas of New Zealand.

Establishment of *P. citricarpa* is likely to increase phytosanitary measures required for export to countries where the pest is absent or regulated.

- *Phyllosticta citricarpa* is an A1 pest for the European Union (EPPO 2020a). It is still regulated by the USA and under eradication in parts of Florida (USDA-APHIS 2020). Parts of Australia are maintained as pest-free areas for *P. citricarpa*. Infected citrus fruit would not be acceptable for export to these areas.
- An incursion of *P. citricarpa* in New Zealand could cause impacts from removal of productive plants, costs of surveillance and loss of income from sales of fresh citrus in domestic and export markets. For example, Florida has maintained its quarantine zones for *P. citricarpa* since 2010, and fresh citrus fruit cannot be transported outside of these areas (USDA-APHIS 2020).

Environmental impacts from *P. citricarpa* are likely to be low overall for New Zealand but may be moderate in citrus-producing areas due to increased use of fungicides to control the disease.

- Developing fruit are susceptible to *P. citricarpa* for several months, and regular spraying with fungicide is current practice in areas with the disease:
 - For example, in Florida, the recommended fungicide regime for control of *P. citricarpa* is to apply fungicides on a 21- to 28-day cycle from early May (late spring) to mid-September (early autumn) (Hendricks et al. 2020). Recent research suggests that fungicide applications over an even longer period of 180 or 220 days would more effectively protect the fruit.
 - Recommended fungicides for control of *P. citricarpa* in Florida are copper, strobilurins, fenbuconazole, and premix combinations, such as azoxystrobin/difenoconazole and pyraclostrobin/boscalid (Hendricks et al. 2020).
 - In São Paulo, two copper sprays after petal fall are used to control *P. citricarpa* and other fungal pathogens (e.g. *Elsinoe* spp. and *Diaporthe citri*), and this is followed by different numbers of strobilurin (quinone outside inhibitor) sprays to prevent infection of fruit with *P. citricarpa* (Lanza et al. 2018).
- Since *P. citricarpa* is mostly reported as a citrus pathogen, and there are no native species of *Citrus* (or *Poncirus* or *Fortunella*), it seems likely that environmental impacts would be low. There are historic reports of a non-pathogenic form of *P. citricarpa* from other plant families (Anacardiaceae, Aquifoliaceae, Bignoniaceae, Burseraceae, Cunoniaceae, Dioscoreaceae, Gramineae, Lauraceae, Leguminosae, Liliaceae, Lythraceae, Magnoliaceae, Myrtaceae, Orchidaceae, Passifloraceae, Proteaceae, Rosaceae, Rutaceae, Solanaceae, Sterculiaceae, Theaceae) (Sutton and Waterston 1966). However, records on hosts outside the Rutaceae are doubtful and presumably refer to *Phyllosticta capitalensis* or *Guignardia mangiferae* (Farr and Rossman 2020; Glienke et al. 2011)

Phyllosticta citricarpa is unlikely to cause any direct health impacts on human health:

- *Phyllosticta citricarpa* is a plant pathogen and has not been reported to affect human or animal health.
- However, there may be indirect impacts on human health if there is increased use of fungicides for pathogen control.

Social impacts of *P. citricarpa* are likely to be low, with low uncertainty:

- *Phyllosticta citricarpa* can sometimes cause premature fruit drop, which would affect the productivity of citrus trees in home gardens.
- Damage to fruit from home gardens may make such fruit unattractive; although the damage is limited to the peel and is not known to affect the quality or taste of the fruit itself.

Risk assessment summary:

Given the arguments and evidence below, *Phyllosticta citricarpa* may be considered for additional measures.

- *Phyllosticta citricarpa* has a strong association with citrus fruit (most commercial citrus cultivars).
- Fruit can have latent infections that are not apparent at the time of production and phytosanitary inspection but develop later during transit and storage. Therefore, basic measures do very little to reduce the likelihood of entry of *P. citricarpa*. Consequently, the likelihood of entry is considered high, with low uncertainty.
- *Phyllosticta citricarpa* has low ability (with moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The New Zealand climate is likely to be suitable for the establishment of *P. citricarpa*.
- Hosts of the pest (e.g. *Citrus*) are commercially grown in New Zealand and are commonly grown in home gardens.
- *Phyllosticta citricarpa* has been recorded to cause severe damage to citrus fruit, and there are high costs of control in areas with similar climate to New Zealand. Therefore, it is likely to cause high impacts on the citrus industry in New Zealand and moderate impact to the overall economy of New Zealand.
- *Phyllosticta citricarpa* is present (although with restricted distribution) in several countries in the scope of this IRA, including Australia, Brazil, China, the USA and possibly Korea.

5.2.4 References

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6. Pest risk assessments: Bacteria

6.1 *Xanthomonas citri* pv. *citri* and *Xanthomonas citri* pv. *aurantifolii* (citrus canker)

Xanthomonas citri pv. *citri* causes citrus canker, a serious disease of citrus worldwide. The bacterium produces raised necrotic lesions on leaves, stems and fruit. Severe infections can result in defoliation, twig dieback, blemishes on fruit, premature fruit drop and tree decline (Gottwald and Graham 2000; Graham et al. 2004). *Xanthomonas citri* pv. *aurantifolii* strains cause less common forms of the disease.

Scientific name: *Xanthomonas citri* pv. *citri* (Hasse) Constantin, Cleenwerck, Maes, Baeyen, Van Malderghem, De Vos, Cottyn

Order/Family: Xanthomonadales/Xanthomonadaceae

Other relevant scientific names: *Pseudomonas citri*, *Xanthomonas campestris* pv. *citri*, *Xanthomonas citri*, *Xanthomonas axonopodis* pv. *citri*, *Xanthomonas smithii* subsp. *citri*, *Xanthomonas citri* subsp. *citri*

Common names: canker, Oriental canker, Asiatic canker, Asiatic citrus canker, canker A, cancrrosis A, pv. *citri* "Group A" strains, citrus canker type A, citrus bacterial canker type A, citrus bacterial canker

Acronyms: CBC, Xcc, XCC

Note: The most common and widespread form of the disease is Asiatic citrus canker (also referred to as canker A, cancrrosis A). The bacteria that cause this form of the disease were known as group A strains of *Xanthomonas axonopodis* pv. *citri*. This pathovar is now known as *Xanthomonas citri* pv. *citri* (syn. *X. citri* subsp. *citri*, *X. campestris* pv. *citri*). Isolates thought to be distinct variants of strain A (such as A* and Aw) have also been reported (Graham et al. 2004).

Scientific name: *Xanthomonas citri* pv. *aurantifolii* (Schaad et al.) Constantin et al.

Order/Family: Xanthomonadales/Xanthomonadaceae

Other relevant scientific names: *Xanthomonas axonopodis* pv. *aurantifolii*, *Xanthomonas campestris* pv. *aurantifolii*, *Xanthomonas citri* f. sp. *aurantifolia*, *Xanthomonas fuscans* subsp. *aurantifolii*

Common names: cancrrosis B (B strains), citrus canker, false canker (B strains), Mexican lime cancrrosis (C strains), South American canker

Note: Less common forms of the disease are caused by strains of another pathovar, *Xanthomonas citri* pv. *aurantifolii* (syn. *X. fuscans* subsp. *aurantifolii*, *X. axonopodis* pv. *aurantifolii*, *X. campestris* pv. *aurantifolii*). Cancrrosis B (false canker) caused by group B strains and cancrrosis C (Mexican lime cancrrosis) caused by group C strains appear to be restricted to South America (Carrera 1933; Namekata 1971). Their known hosts are limited compared with the Asiatic form.

The disease citrus canker has different forms with varying distributions and host ranges. These are caused by different strains and variants of the same, or closely related, bacterial species. Changes in taxonomy and nomenclature have resulted in multiple names used for some organisms in the literature and in MAF/MPI documents and databases.

Other pathogens have been considered in the past to cause forms of citrus canker:

- *Alternaria limicola*: A form of citrus canker from Mexico known as canker D, or citrus bacteriosis (Rodriguez et al. 1985), was thought to be caused by group D strains. However, this leaf and twig spot disease of Mexican lime was later found to be caused by *Alternaria limicola* (Das 2003; EFSA 2014).
- *Xanthomonas euvesicatoria* pv. *citrumelonis* (syn. *X. alfalfae* subsp. *citrumelonis*, *X. axonopodis* pv. *citrumelo*, *X. campestris* pv. *citrumelo*) which causes citrus bacterial leaf spot, was originally confused with citrus canker and named strain E (Schoulties et al. 1987; Graham et al. 2004). This pathogen, most often seen on citrumelo rootstock (*Citrus paradisi* × *Poncirus trifoliata*) and its parents, has been found in nursery conditions in Florida and is considered to be a minor pathogen with low impact in the citrus industry (EFSA 2014).

In addition, *Xanthomonas citri* pv. *bilvae* has been reported to cause a bacterial spot of rutaceous species, including *Citrus aurantifolia*. However, this has been reported only from India (EFSA 2014) and is out of scope for this import risk analysis.

This assessment focuses on *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii*, which are considered to be the two bacteria responsible for citrus bacterial canker disease. Most of the biological information in the literature refers to *X. citri* pv. *citri*, which causes the Asiatic form of citrus canker. However, the life cycle of *X. citri* pv. *aurantifolii* is expected to be similar.

Summary of conclusions:

Given the arguments and evidence presented:

- *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* meet the criteria to be quarantine pests for New Zealand.
- *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* have a strong association with citrus fruit (with low uncertainty).
- Basic measures are likely to reduce the entry on citrus fruit by a high degree (with low uncertainty); consequently, the likelihood of entry is considered to be low (with moderate uncertainty).
- The ability of *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* to transfer from imported fruit to suitable host plants is low (with high uncertainty).
- The suitability of the New Zealand environment for *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* to establish is considered high (with low uncertainty).
- *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* are likely to cause moderate impacts overall for New Zealand, but high impacts for the citrus industry.
- *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* may be considered for additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Moderate
The ability to move from the imported commodity onto a suitable host	Low	High
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Moderate	Low

6.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Xanthomonas citri* pv. *citri* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Xanthomonas citri pv. *citri* is not known to be present in New Zealand.

- *Xanthomonas citri* is recorded as absent from the New Zealand region in NZFungi2 (2020) and NZOR (2020).
- *Xanthomonas c. pv. citri* is recorded as eradicated from the New Zealand region in NZFungi2 (2020) [listed as *X. citri* subsp. *citri*], as eradicated/destroyed in New Zealand in NZOR (2020) [listed as *X. citri* subsp. *citri*], and as eradicated in New Zealand in PPIN (2020) [listed as *X. campestris* pv. *citri* and also as *X. axonopodis* pv. *citri*].

- The disease citrus canker was first observed in New Zealand in 1937 when a campaign for its eradication was begun. Neither the disease nor the bacteria (referred to by Pennycook as *X. campestris* pv. *citri*) have been detected in New Zealand since 1972 (Pennycook 1989). Surveys and other evidence (noted in PPIN 2020) have resulted in international acceptance that it has been eradicated (e.g. Smith et al. 1997).
- New Zealand has country freedom status for *X. citri* pv. *citri* (syn. *X. campestris citri*, *X. axonopodis* pv. *citri*) in the MPI country freedom status database⁵⁰.
- *X. citri* pv. *citri* is a regulated organism in New Zealand (ONZPR 2020).
- *X. citri* pv. *citri* was determined a notifiable organism in May 2002 and a regulated pest in June 2002. Its status is unwanted (ONZPR 2020).

Xanthomonas citri pv. *citri* has the potential to establish and spread in New Zealand.

Some of the countries/states where *X. citri* pv. *citri* has been recorded (Table 7.1.3) have areas with similar climates to New Zealand, as indicated by climate match index (CMI) values of ≥ 7 (Phillips et al. 2018), for example: China, Korea, Uruguay, Brazil, Japan.

- Known plant hosts of *X. citri* pv. *citri*, *Citrus* species, are widely grown in a number of regions of New Zealand, both commercially and in domestic gardens.
- The pathogen was once present in New Zealand (Pennycook 1989) but has been eradicated (PPIN 2020).

Xanthomonas citri pv. *citri* has the potential to cause economic impacts to New Zealand.

- *X. citri* pv. *citri* can cause economically significant disease in citrus, which is of economic importance to New Zealand.

Given the arguments and evidence below, *Xanthomonas citri* pv. *aurantifolii* meets the criteria to be a quarantine pest for New Zealand.

Xanthomonas citri pv. *aurantifolii* is not known to be present in New Zealand.

- *X. citri* pv. *aurantifolii* is recorded as absent from the New Zealand region in NZFungi2 (2020) and NZOR (2020).
- *X. citri* pv. *aurantifolii* is recorded as absent from the New Zealand region in NZFungi2 (2020) and NZOR (2020) [listed as *Xanthomonas fuscans* subsp. *aurantifolii* in both].
- New Zealand has country freedom status for *X. citri* pv. *aurantifolii* (syn. *X. campestris* pv. *aurantifolii*) in the MPI country freedom status database⁵⁰.
- *X. citri* pv. *aurantifolii* is a regulated organism in New Zealand and is an unwanted organism (ONZPR 2020) [listed as *X. fuscans* subsp. *aurantifolii* (syn. *X. axonopodis* pv. *aurantifolia*, *X. campestris* pv. *aurantifolii*) in these databases].

Xanthomonas citri pv. *aurantifolii* has the potential to establish and spread in New Zealand.

- Some of the countries where *X. citri* pv. *aurantifolii* has been recorded have areas with similar climates to New Zealand, as indicated by climate match index (CMI) values of ≥ 7 (Phillips et al. 2018), for example: Argentina, Uruguay, Brazil.
- Known plant hosts of *X. citri* pv. *aurantifolii*, *Citrus* species, are widely grown in a number of regions of New Zealand, both commercially and in domestic gardens.

Xanthomonas citri pv. *aurantifolii* has the potential to cause economic impacts to New Zealand.

- *X. citri* pv. *aurantifolii* can cause economically significant disease in citrus, which is of economic importance to New Zealand.

⁵⁰ MPI country freedom status database: <https://www.mpi.govt.nz/news-and-resources/resources/registers-and-lists/country-freedom-status/> Accessed September 2020.

6.1.2 Hazard identification: commodity association

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* are associated with citrus fruit.

Xanthomonas citri pv. *citri* is reported from citrus fruit.

- *X. citri* pv. *citri* is a bacterial pathogen that causes distinctive necrotic raised lesions on leaves, stems and fruit of citrus (Schubert et al. 2001).

Xanthomonas citri pv. *aurantifolii* is reported from citrus fruit.

- Cancrosis B (caused by *X. citri* pv. *aurantifolii*) produces canker-type lesions on fruit, leaves and twigs that are similar to but smaller than those caused by the A form (Gottwald and Graham 2000).
- Symptoms for Cancrosis C are the same as for those of canker A [*X. citri* pv. *citri*] (Graham and Gottwald 2000).

6.1.3 Risk assessment

Most biological information in the literature is in relation to *X. citri* pv. *citri*. For this assessment, it is assumed that *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* have similar life cycles. Information specific to *X. citri* pv. *aurantifolii* is given for citrus hosts, geographic distribution, climate similarities and impacts; otherwise, it is assumed that biological information for *X. citri* pv. *citri* is applicable to both.

Likelihood of entry:

Given the arguments and evidence below, *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* have a strong association with citrus fruit, with low uncertainty.

- Occurrence of *X. citri* pv. *citri* on fruit may be associated with lesions, injuries or blemishes, or may be epiphytic on the fruit surface (contamination).
- Lesions start as pinpoint spots that enlarge over time to become corky eruptions with raised margins and sunken centres. The area around the lesion may have an oily or water-soaked appearance, and lesions become surrounded by characteristic yellow halos. Lesions on fruit can vary in size due to both age and fruit susceptibility and are up to 1mm deep in the fruit rind (Gottwald and Graham 2000; Gottwald et al. 2002).
- The multiplication of *X. citri* pv. *citri* bacteria occurs at the lesion margin and occurs mostly as the lesion is still expanding (Gottwald and Graham 2000). The bacteria remain alive in the margins of lesions on the fruit until they fall and begin to decompose (Gottwald and Graham 2000; Gottwald et al. 2002).
- Cancrosis B (caused by *X. citri* pv. *aurantifolii*) produces canker-type lesions on fruit, leaves and twigs that are similar to but smaller than those caused by the A form (Gottwald and Graham 2000). Symptoms for canker C are the same as for those of canker A [*X. citri* pv. *citri*] (Graham and Gottwald 2000).

Plant hosts for *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* include *Citrus* spp. and close relatives.

- Hosts of *X. citri* pv. *citri* belong primarily to the plant family Rutaceae. They include most *Citrus* species and hybrids between citrus species and trifoliolate orange *Poncirus trifoliata* (Graham et al. 2004) (Table 7.1.1 and Table 7.1.2).
- The host range of the *X. citri* pv. *citri* pathotype A strain includes (but is not confined to) sweet orange (*Citrus sinensis*), grapefruit (*C. paradisi*), lemon (*C. limon*) and Mexican (key) lime (*C. aurantiifolia*) (EFSA 2014; Brunings and Gabriel 2003).
- Variants of the bacterium that are phylogenetically close but appear to be pathologically distinct in host range have also been reported, but from fewer hosts: the A* strain has been found primarily on Mexican lime (Verniere et al. 1998), and the A^w strain (also known as the Wellington strain) has been found on Mexican lime and alemow plants (*C. macrophylla*) (Sun et al. 2004; Rybak 2005; da Graça et al. 2017).
- *Citrus* species vary in their level of susceptibility (Gottwald and Graham 2000):
 - Grapefruit (*C. paradisi*), lime (*C. aurantiifolia*) and trifoliolate orange (*Poncirus trifoliata*) are highly susceptible.

- Sour orange (*C. aurantium*) and sweet orange (*C. sinensis*) are moderately susceptible.
- Most mandarin cultivars (*C. reticulata*) are moderately resistant.
- The relative susceptibility/resistance of commercial citrus cultivars and species to citrus canker is presented in Table 7.1.2.
- The known host range for *X. citri* pv. *aurantifolii* is much more restricted than for *X. citri* pv. *citri* (Table 7.1.1).

Table 7.1.1 Pathovar, pathotype classification and host range of xanthomonads causing citrus canker
(based on Table 2, EFSA 2014)

Species	<i>Xanthomonas citri</i>			
Pathovar ^(a)	<i>citri</i>		<i>aurantifolii</i>	
pathotype	A	A* (A ^w)	B	C
Disease	Asiatic canker		South American canker	
Host range	<i>Citrus</i> spp. ^(b) Several other rutaceous genera, e.g. <i>Poncirus</i> , <i>Fortunella</i>	<i>C. aurantiifolia</i> <i>C. macrophylla</i> (<i>C. latifolia</i>) (<i>C. sinensis</i> , <i>C.</i> <i>paradisi</i>) ^(c)	<i>C. aurantiifolia</i> <i>C. limon</i> <i>C. aurantium</i> (<i>C. sinensis</i>)	<i>C. aurantiifolia</i> (<i>P. trifoliata</i> × <i>C.</i> <i>paradisi</i>)
In bold : main host species in field conditions; in brackets: host species rarely infected in the field.				
(a): A pathovar is an infraspecies taxon. "The term pathovar is used to refer to a strain or set of strains with the same or similar characteristics, differentiated at infrasubspecific level from other strains of the same species or subspecies on the basis of distinctive pathogenicity to one or more plant hosts." (Young et al. 1991; Young et al. 2001)				
(b): With differential host susceptibility among species and/or cultivars. Many commercial cultivars range from susceptible to very susceptible (Gottwald et al. 2002) (Table 7.1.2).				
(c): Reported for strains originating from Iran (Escalon et al. 2013).				

Table 7.1.2 Relative susceptibility/resistance to citrus canker of commercial citrus cultivars and species
(from Gottwald et al. 2002)

Rating	<i>Citrus</i> cultivars
Highly resistant	Calamondin (<i>C. reticulata</i>); Kumquats (<i>Fortunella</i> spp.)
Resistant	Mandarins (<i>C. reticulata</i>) – Ponkan, Satsuma, Tankan, Satsuma, Cleopatra, Sunki, Sun Chu Sha
Less susceptible	Tangerines, Tangors, Tangelos (<i>C. reticulata</i> hybrids); Cravo, Dancy, Emperor, Fallglo Fairchild, Fremont, Clementina, Kara, King Lee, Murcott, Nova, Minneola, Osceola, Ortanique, Page, Robinson, Sunburst, Temple, Umatilla, Willowleaf (all selections); Sweet oranges (<i>C. sinensis</i>) – Berna, Cadenera, Coco, Folha Murcha, IAPAR 73, Jaffa, Moro, Lima, Midsweet, Sunstar, Gardner, Natal, Navelina, Pera, Ruby Blood, Sanguinello, Salustiana, Shamouti, Temprana and Valencia; Sour oranges (<i>C. aurantium</i>)
Susceptible	Sweet oranges – Hamlin, Marrs, Navels (all selections), Parson Brown, Pineapple, Piralima, Ruby, Seleta Vermelha (Earlygold), Tarocco, Westin; Tangerines, Tangelos – Clementine, Orlando, Natsudaidai, Pummelo (<i>C. maxima</i>); Limes (<i>C. latifolia</i>) – Tahiti lime, Palestine sweet lime; Trifoliolate orange (<i>Poncirus trifoliata</i>); Citranges/Citrumelos (<i>P. trifoliata</i> hybrids)
Highly susceptible	Grapefruit (<i>C. paradisi</i>); Mexican/Key lime (<i>C. aurantiifolia</i>); Lemons (<i>C. limon</i>); Pointed leaf Hystrix (<i>C. hystrix</i>)

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* are present in some citrus export countries that are considered in this import risk analysis.

- Citrus canker is endemic in India, Japan and other Southeast Asian countries from where it has spread to all other citrus-producing continents except Europe (Das 2003).

- The known geographic distribution of *X. citri* pv. *citri* is listed in Table 7.1.3 (EPPO 2020 and references)⁵¹.
- *X. citri* pv. *citri* is present in the following citrus export countries that are under consideration:
 - Brazil, China, Korea, Japan, Viet Nam, Australia, Fiji, Solomon Islands, USA
 - Mexico: transient, actionable and under eradication
- *X. citri* pv. *aurantifolii* has been reported only from South America (Gottwald and Graham 2000):
 - The B strain has been reported from Argentina, Paraguay and Uruguay. This strain appears to have disappeared in Argentina since the introduction of the more aggressive A strains (*X. citri* pv. *citri*) (Canteros et al. 2017; Fonseca et al. 2019).
 - The C strain has been reported from Brazil (Jaciani et al. 2009).
 - Brazil is one of the citrus export countries under consideration.

Table 7.1.3. Known geographic distribution of citrus canker. Information compiled in September 2020 from EPPO 2020. Countries in **bold** are included in the scope of this risk assessment. Countries underlined have records for both *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii*.

Continent/Region	Country (province/state)
Africa	Burkina Faso, Comoros, Congo (Democratic Republic), Ethiopia, Gabon, Ivory Coast, Madagascar, Mali, Mauritius, Mayotte, Réunion, Senegal, Seychelles, Somalia, Sudan, Tanzania
North America	USA, Mexico (transient, actionable and under eradication)
Central America and Caribbean	British Virgin Islands, Martinique (transient, under eradication)
South America	<u>Argentina</u> , Bolivia, Brazil , <u>Paraguay</u> , <u>Uruguay</u>
Asia	Afghanistan, Bangladesh, Cambodia, China , Christmas Island, Cocos Islands, East Timor, India, Indonesia, Iran, Iraq, Japan , Korea (Democratic People's Republic), Korea (Republic of) , Laos, Malaysia, Maldives, Myanmar, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Taiwan, Thailand, United Arab Emirates, Viet Nam , Yemen.
Oceania	Australia, Fiji , Guam, Marshall Islands, Micronesia, Northern Mariana Islands, Palau, Papua New Guinea, Solomon Islands

Given the arguments and evidence below, the basic measures are likely to reduce the entry of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* on citrus fruit by a high degree; consequently, the likelihood of entry is considered to be low (with moderate uncertainty).

Some degree of disease management is likely to take place in the field for commercial production of citrus.

- The disease citrus canker can reduce both the quality of the citrus fruit itself and the quantity that is produced. Therefore, some degree of disease management is likely to occur where citrus is grown commercially.
- The prevalence of *X. citri* pv. *citri* in citrus groves depends upon environmental conditions and management practices. Management practices to reduce the amount of disease, such as cultural practices and copper sprays (Gottwald and Graham 2000), result in fewer disease symptoms on fresh fruit for consumption. However, the specific activities that take place cannot be assumed and are unlikely to eliminate the pathogen.

Symptomatic fruit are likely to be detected and removed from consignments.

- Occurrence of *X. citri* pv. *citri* on fruit may be associated with lesions, injuries or blemished. Lesions on symptomatic fruit are obvious with a characteristic appearance and can be readily detected visually.

⁵¹ EPPO notes that the taxonomy of bacteria associated with citrus canker has been subject to many changes and that because their distribution list was established over a long period of time, it might cover taxa that are now considered to be separate (i.e. *X. citri* subsp. *citri* and *X. fuscans* subsp. *aurantifolii*).

- For commercial reasons, blemish-free fruit will be preferred over fruit that appears damaged when harvested as fresh fruit for consumption. It is likely that a certain amount of culling to remove symptomatic and other blemished, damaged or misshapen fruit will take place in the field at harvest. This can be highly effective in removing symptomatic fruit before reaching the packing house. Inspections at the packing house further reduce the likelihood of symptomatic fruit being packed. Ploper et al. (2004, in USDA 2007) reported that culling procedures in Argentina resulted in very low numbers (near zero) of symptomatic fruit reaching the packing bench and zero symptomatic fruit packed in boxes during their study.

However, some symptomatic fruit may go unnoticed during the export production process.

- During visual inspection, small lesions may escape detection or be attributed to other causes that produce similar symptoms (EFSA 2014).
- Importation of citrus to the EU requires that the fruit be free of symptoms of citrus canker disease. Despite this requirement, canker-like symptoms have been detected on commercial citrus fruit imported from countries outside the EU by Spanish inspection services at ports of entrance and packing houses. Subsequent diagnostic tests (isolation and PCR-based methods) detected viable *X. citri* pv. *citri* bacteria in the lesions (Golmohammadi et al. 2007).

General handling and processing after harvesting are likely to reduce the number of viable *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* bacterial cells by a high degree but are unlikely to remove all *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* from citrus fruit.

- Occurrence of *X. citri* pv. *citri* on fruit may be associated with lesions, injuries or blemishes, or it may be epiphytic on the surface (contamination) of fruit that otherwise appears healthy (Gottwald et al. 2009).
- The viability of *X. citri* pv. *citri* bacteria on fruit reduces after harvest whether in lesions or on the fruit surface (Gottwald et al. 2009). Epiphytic bacteria appear to be short-lived after fruit harvest, with experiments on satsuma mandarins under natural conditions showing survival on the fruit surface decreasing significantly after three days (Shiotani et al. 2009). Consequently, development of citrus canker disease on the fruit between harvest and packing house is unlikely.
- Packing house processes for cleaning fruit, such as brushing, washing with detergents and disinfectants, and drying, all act to reduce the epiphytic *X. citri* pv. *citri* populations (USDA 2009). Brushing increases the exposure of citrus canker to toxicants. Disinfectants such as chlorine and sodium ortho-phenylphenate (SOPP) further reduce inoculum levels. Washing before disinfecting removes organic matter and increases the effectiveness of disinfection treatments. Experimental work has shown that processing that includes pre-washing fruit with detergent over brushes followed by a disinfectant treatment further reduces amounts of *X. citri* pv. *citri* inoculum on infected or contaminated fruit (Gottwald et al. 2009; USDA 2009). Drying the fruit contributes to the reduction of epiphytic bacteria populations (Schubert et al. 2001). The cumulative effect of these treatments reduces the prevalence of viable *X. citri* pv. *citri* and, therefore, the inoculum associated with commercially packed and disinfected fruit (USDA 2009).
- However, disinfectant treatments such as chlorine and SOPP do not fully eliminate viable bacteria from fruit (Gottwald et al. 2009; Golmohammadi et al. 2007).
- In addition, a viable but not culturable (VBNC) state has been proposed for *X. citri* pv. *citri* in response to copper ions and other environmental stresses (Golmohammadi et al. 2013). Bacterial cells in this state would not be detected in by plating samples on agar media, which means that experimental work using such methods may underestimate the number of viable bacteria present.
- The specific post-harvest activities that take place in the packhouse cannot be assumed or guaranteed and are unlikely to eliminate the pathogen from the citrus commodity (Golmohammadi et al. 2007).

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* are likely to survive transit of citrus commodities.

- Storage and transport of citrus consignments from exporting countries to New Zealand are likely to occur at cool temperatures, with the length of time for shipment depending on the exporting country. For example, transport of fruit by sea from Korea may take up to three weeks and more than three weeks from Brazil. Storage temperatures may vary depending on the citrus variety (EFSA 2014).

- Low temperatures are not expected to have an impact on the survival of *X. citri* pv. *citri* (Goto 1962, in EFSA 2014). However, the amount of viable *X. citri* pv. *citri* bacteria decreases over time, both for fruit that ages on the tree and for fruit in cold storage (Gottwald et al. 2009).
- Commercial packing house procedures that include antimicrobial treatments can reduce populations of *X. citri* pv. *citri* on the surfaces of harvested fruit to a very low level (Gottwald et al. 2009). The bacteria have a limited ability to survive epiphytically, so surface populations are likely to decline further over the transit period.
- Gottwald et al. (2009) found that packhouse processes can reduce canker lesion activity by as much as 50% compared with unprocessed citrus fruit.
- Therefore, the conditions under which commercial citrus fruit consignments are processed, disinfected and packed, and the duration of time between harvest and market reduce the likelihood that viable pathogenic *X. citri* pv. *citri* bacteria will survive the journey.
- However, viable *X. citri* pv. *citri* bacteria in lesions have been demonstrated to survive transit on imported fresh citrus fruit even when fruit has been treated with officially approved chemicals (Golmohammadi et al. 2007; EFSA 2014).

The level of uncertainty in relation to entry is rated as moderate because the prevalence of citrus canker in areas of production may vary, along with details of in-field pest management activities, post-harvest activities and duration of transit.

Likelihood of establishment:

Given the arguments and evidence below, *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* have a low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* can survive on the skin of discarded citrus fruit and fruit pieces.

- The imported fresh citrus fruit is intended for human consumption, and waste material would be generated, including the fruit skin or peel, even for fruit that is consumed.
- *X. citri* pv. *citri* bacteria in lesions on the fruit surface have been demonstrated to survive transit on imported fresh citrus fruit even when fruit has been treated with officially approved chemicals (Golmohammadi et al. 2007; EFSA 2014).

Most citrus fruit waste in New Zealand is likely to be disposed of using low-risk methods, so *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* would be unable to spread from the infected fruit.

- Most kitchen waste in New Zealand is either bagged and sent to landfill or run through kitchen disposal units (see section 2.4.1, waste analysis). *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* in infected or contaminated fruit is unlikely to reach a new host in these circumstances.

However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, use as animal feed, cull piles or discarding directly into the environment.

- A small proportion of infected or contaminated fruit or peel is likely to be discarded in a home compost bin or open compost heap, or directly into the environment in gardens, roadsides, parks and public areas (see section 2.4.1, waste analysis). Cull piles may occur when large amounts of fruit are sorted and may be used for animal feed in outdoor environments.

The likelihood of *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* reaching citrus hosts if infected fruit or peels are discarded nearby is very low.

- Bacteria on plant surfaces die within hours from desiccation and exposure to direct sunlight (Graham et al. 2000, in Graham et al. 2004).
- When diseased fruit and leaves drop to the ground, bacterial populations decline to non-detectable levels in 1–2 months because of antagonism and competition with saprophytic microorganisms (Graham et al. 1989). Bacteria survive only a few days in soil, although they may last a few months in plant refuse in soil (Graham et al. 1989).
- Goto et al. (1978) observed canker leaf lesions on *C. natsudaidai* from splash dispersal (produced by a rainfall simulator) of rice straw contaminated with low concentrations of *X. citri*

pv. *citri*. They concluded that infected plant tissues on soil can provide inoculum for the infection of wounded susceptible seedlings by splash dispersal (EFSA 2014).

- There has been little research into the probability of transfer of *X. citri* pv. *citri* from infected fruit to citrus trees. Gottwald et al. (2009) performed a series of experiments to investigate the possibility of transmission of *X. citri* pv. *citri* from discarded cull piles of symptomatic fruit. Transmission did not occur under natural conditions in their study. However, in one instance in highly contrived conditions, a single lesion was formed on a trap plant at 0 metres from the cull pile (Gottwald et al. 2009). EFSA (2014) concluded that it is difficult to extrapolate their results to a situation where symptomatic fruit or peel has been discarded underneath or very close to susceptible mature citrus trees. The lower branches of citrus trees can be very close to the soil level, and these conditions can be very similar to the zero-metre situation for which an infection was observed by Gottwald et al. (2009) from fruit.
- *Citrus* that is discarded using high-risk methods has the potential to end up in close proximity to low-hanging citrus branches, as described above, especially in domestic gardens. However, there is a low likelihood of the combination of factors required for successful transfer of citrus canker inoculum to new host plants taking place.

There is potential for human touch to transfer the pathogens to citrus after handling infected fruit.

- Nursery workers can carry bacteria from one nursery to another on hands, clothes and equipment, and spread can also result from movement of contaminated pruning, hedging and spray equipment (Das 2003). Therefore, there is potential for bacteria to be transferred to a host plant by people handling infected fruit, although this is not likely to be a frequent situation.

The level of uncertainty associated with this conclusion is high. Waste data may not be very accurate or up to date (see section 2.4.1, waste analysis). It is uncertain what proportion of composting sites are exposed or uncovered (e.g. in a compost bin). The role of infected citrus fruit or peel as a source of primary inoculum allowing the transfer to susceptible host plants nearby is not well understood.

Given the arguments and evidence below, the suitability of the New Zealand environment for *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* to establish is considered high.

Climatic conditions in New Zealand are favourable for *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* to establish, especially in the north of New Zealand where most commercial *Citrus* is grown.

- Citrus canker occurs in areas of the world where high rainfall and high temperatures co-exist (CABI 2020). Establishment and spread is favoured by warm (20–32°C), wet conditions (Miles et al. 2009). During wet weather, bacteria ooze out of lesions and are spread by windblown rain to form new infections. Bacterial cells enter the plant tissue through natural openings such as stomata or wounds from insect feeding or physical damage. Entry through stomata is most effective before leaf tissues have fully expanded and cuticle and waxes have formed on the tissue surface (Miles et al. 2009). The disease occurs in severe form in seasons and/or areas characterised by warm and humid weather conditions (Das 2003).
- Some of the areas where *X. citri* pv. *citri* has been recorded (see Table 7.1.3) have a similar climate to New Zealand, as indicated by climate match index (CMI) values ≥ 7 (Phillips et al. 2018), for example:
 - All New Zealand climate match: Argentina (CMI 0.7–0.9); Uruguay (mostly 0.8–0.9 CMI); Brazil (parts of Paraná with 0.7–0.8 CMI, Rio Grande do Sul: 0.7–0.9 CMI, Santa Catarina: 0.7–0.9 CMI, parts of São Paulo with 0.7–0.8 CMI); Bolivia (parts with 0.7–0.8 CMI); USA (parts of Florida with 0.7 CMI ; parts of Texas with 0.7–0.8 CMI); Japan (parts of Shikoku with 0.7 CMI ; most of Honshu with 0.7–0.8 CMI); China (parts of Chongqing, Fujian, Guizhou, Hubei, and Hunan with CMI 0.7; parts of Gansu and Yunnan with 0.7–0.8 CMI; parts of Sichuan with 0.8 CMI), Republic of Korea (parts with 0.7 CMI)
- *X. citri* pv. *citri* has been previously established in New Zealand (recorded in Northland, Coromandel, Bay of Plenty and Taranaki (PPIN 2020; Pennycook 1989) but has been eradicated (PPIN 2020).

- Some of the areas where *X. citri* pv. *aurantifolii* have been recorded have a similar climate to New Zealand: northeastern Argentina (0.8–0.9 CMI), Uruguay (0.8–0.9 CMI) and the state of São Paulo Brazil (parts of São Paulo with 0.7–0.8 CMI).

Once established, *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* can spread to new host plants.

- *X. citri* pv. *citri* bacteria that multiply in lesions rely on free water for dispersal (Gottwald et al. 2002). Free moisture on the lesion surface allows bacteria to be released in a polysaccharide matrix that prevents bacteria from drying out. Bacteria exude from lesions during wet weather and are disseminated by splash dispersal at short range, windblown rain at medium to long range and human-assisted movement at all ranges (Graham et al. 2004).
- Windblown inoculum of *X. citri* pv. *citri* was detected 32 m from infected trees in Argentina (Stall et al. 1980, in EFSA 2014). Wind speeds of at least 8 m/s help bacteria to penetrate the stomata and other openings such as wounds (Graham et al. 1992). Water congestion of leaf tissues can be seen during rainstorms. Water congestion during inoculation with as few as 1–2 bacterial cells, forced through stomatal openings, can lead to infection and lesion formation (Gottwald and Graham 1992, Graham et al. 1992). Dispersal over longer distances has been observed after weather events such as thunderstorms, typhoons and hurricanes. For example, in Florida, dispersal over distances of 10–15 km has been attributed to storm events (Gottwald et al. 1997).
- Contaminated equipment and persons can also transmit inoculum. Long-distance spread normally occurs by human movement of diseased or exposed citrus plant material or by use of equipment contaminated by diseased citrus (Schubert et al. 2001).
- All aboveground plant parts are susceptible to infection (Leite and Mohan 1990). Bacteria enter plant tissues through openings such as stomata, lenticels or wounds (Gottwald and Graham 1992; Graham et al. 2004). The most susceptible plant tissues are young tissues that are expanding. Vigorously growing trees are most susceptible to infection by *X. citri* pv. *citri*. *Citrus* trees that have several growth flushes each growing season will have corresponding periods of increased susceptibility (Graham et al. 2004). Trees are most susceptible to disease when growth flushes coincide with warm temperatures (20–32°C), high rainfall and wind.

Known plant hosts of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* are available in New Zealand.

- Host species for *X. citri* pv. *citri* are found within the plant family Rutaceae. They include many *Citrus* species and hybrids between citrus species and trifoliate orange (*Poncirus trifoliata*) (Graham et al. 2004) (Table 7.1.1 and Table 7.1.2).
- Host records in New Zealand prior to the pathogen being eradicated include *Citrus limon*, *C. reticulata*, *C. sinensis*, *Citrus* sp. (citronelle) and *Citrus* sp. (grapefruit) (Pennycook 1989).
- There are fewer recorded hosts for *X. citri* pv. *aurantifolii*: both strains B and C occur on *C. aurantifolii*, and strain C has been recorded on several other citrus varieties, including lemon (*C. limon*) (Table 7.1.1).
- *Citrus* species are widely grown in a number of regions of New Zealand, both commercially and in domestic gardens. Commercial production takes place in both the North and South Islands, with the main areas being Northland, Auckland, Bay of Plenty, Hawke's Bay and Gisborne (Plant & Food Research 2019) (see section 2.4.2). Commercial crops include oranges, mandarins, lemons, tangelos, limes and grapefruit (Plant & Food Research 2019). (see section 2.5.2). Lemons are grown in domestic gardens through much of the country.
- Given that citrus is grown widely in New Zealand, especially in the North Island, and given that citrus canker has previously established in several citrus production areas in New Zealand, potential host plants are likely to occur in climatically suitable areas for establishment.

Given the arguments and evidence below, the level of impact caused by *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* is likely to be moderate for New Zealand overall (with low uncertainty).

Damage and symptoms of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* can reduce citrus fruit quantity and quality.

- The disease citrus canker is considered devastating to citrus, causing extensive damage to crops (Das 2003). Severe infection of the foliage can cause defoliation of trees. Severely blemished fruit can drop prematurely, leading to reduced yield and marketability as fresh fruit, although the internal quality of mature fruit with lesions is unaffected and is still edible and usable for juice.

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* cause disease on citrus, with impacts on commercial production, including in areas with similar climates to New Zealand.

- In Argentina, 83–97% of the fruit of grapefruit trees were diseased in unsprayed plots during 1979–1980, and, in the same plots, up to 88% of the leaves of summer growth flushes were infected. Up to 15% of fruit from unsprayed grapefruit plots fell prematurely to the ground (Stall and Seymour 1983). Premature fruit drop of up to 50% was reported for sweet orange cv. Hamlin and other cultivars.
 - Argentina has a similar climate to New Zealand, as indicated by CMI values of 0.7–0.9 (Phillips et al. 2018), especially in the northeastern part of the country where much citrus is grown and where *X. citri* pv. *citri* has had severe impacts on the industry (Canteros et al. 2017).
- The cost for living with citrus canker in Florida, USA was estimated to be US\$342 million per year in 2001 (Gottwald et al. 2002). The estimates were for commercial disease management costs and crop losses only.
- The total cost of a major national outbreak of citrus canker in Australia has been assessed at \$410 million (Alam and Rolfe 2006). If the citrus industry were closed down in Australia for five years, it has been estimated that over \$2 billion in direct revenue would be taken out of mainly rural communities (Alam and Rolfe 2006).
- An indirect consequence of the disease is the loss of fruit export markets (e.g. the European Union, Chile, Israel, New Zealand) for countries or areas where satisfactory control of the disease cannot be achieved (EPPO 2020; EFSA 2014). Countries and areas that have citrus canker as a quarantine pest are listed in the EPPO Global Database (EPPO 2020).
- Host species for *X. citri* pv. *citri* include many commercially grown *Citrus* species and hybrids between citrus species and trifoliolate orange *Poncirus trifoliata* (Graham et al. 2004). Some species and cultivars, such as grapefruit (*C. paradisi*), Mexican lime (*C. aurantiifolia*) and hybrids of trifoliolate orange used for rootstock, are more susceptible than others. Therefore, all citrus grown commercially in New Zealand could potentially be affected by the disease to some degree.
- *X. citri* pv. *aurantifolii* has a more restricted host range; nevertheless, commercially grown citrus crops would be directly affected by the disease, particularly lemons and Mexican limes, and indirect effects from its presence would still occur.
- If *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* established, then a considerable long-term effect on the citrus industry would be expected through lowered production, increased management activities and reduced access to or increased requirements for overseas markets where the disease is absent.
- Citrus canker occurs in areas of the world where high rainfall and high temperatures co-exist (CABI 2020). Should it establish again in New Zealand, the disease itself is likely to have the greatest impact on citrus production in warmer and wetter regions, such as Northland, which is one of the main commercial production areas for citrus in the country.

Establishment or an incursion of *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* is highly likely to cause trade impacts.

- The discovery of the presence of *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* in New Zealand is likely to have an immediate impact on exports of citrus because of the quarantine status of the pathogen in some countries that are markets (e.g. European Union). An MPI Organism Ranking System evaluation of *X. citri* pv. *citri* in 2014 estimated that the immediate impact on trade would be moderate.

If *X. citri* pv. *citri* or *X. citri* pv. *aurantifolii* were detected in New Zealand, the cost incurred by a response would be high.

- As *X. citri* pv. *citri* is one of the priority species for the Citrus industry's Government Industry Agreement (GIA), an eradication programme is likely to be undertaken, which would probably result in the large-scale removal of citrus plants.
- Eradication of past citrus outbreaks in Australia have cost growers and governments hundreds of millions of dollars and resulted in destruction of large areas of host trees (Miles et al. 2009). An eradication campaign for citrus canker in Emerald, Australia, completed in early 2009, was estimated to cost AU\$17.6 million and required in excess of 200,000 staff hours to complete (Gambley et al. 2009).
- Similarly, it is likely that a response programme would be undertaken for *X. citri* pv. *aurantifolii* if detected in New Zealand.
- Around 1,660 ha is planted in *Citrus* for commercial production in New Zealand, with 316 growers producing 34,096 tonnes. Domestic consumers spend approximately NZ\$18 million on oranges and \$40.5 million on other citrus fruits. Citrus has an export value of \$12 million (Plant & Food Research 2019).

It is likely that *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* will cause a low level of sociocultural impacts in New Zealand.

- The main hosts of *X. citri* pv. *citri* are *Citrus* spp., which are commonly grown in domestic gardens in New Zealand, particularly in warmer regions in the north. Lemons occur widely throughout the country domestically. *X. citri* pv. *aurantifolii* has a more restricted host range; however, strain C affects lemons.
- The disease would affect both appearance and productivity, although blemished fruit would still be suitable for consumption, and some varieties and cultivars are more resistant than others. Plants may require additional management such as copper sprays to ensure quality and quantity of fruit.

It is likely that *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* will have a very low level of impact on the environment.

- *Citrus* species, which are the primary hosts of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii*, are members of the Rutaceae family. There are two genera within Rutaceae endemic to New Zealand: *Melicope* and *Leionema*. Neither *Leionema* nor *Melicope* species are considered threatened (NZPCN 2020).

Xanthomonas citri pv. *citri* and *X. citri* pv. *aurantifolii* are not known to have any unwanted impacts on human health.

Risk assessment summary:

Given the arguments and evidence below, *Xanthomonas citri* pv. *citri* and *X. citri* pv. *aurantifolii* may be considered for additional measures.

- *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* have a strong association with citrus fruit.
- The basic measures are likely to reduce the entry of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* on citrus fruit by a high degree. However, some infested fruit will not be detected, especially when the volume of commodities is large, and general handling (e.g., washing and brushing) does not completely eliminate viable bacteria from fruit. Consequently, the likelihood of entry is considered to be low (with moderate uncertainty).
- *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* have a low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* to establish is considered high.
- Citrus hosts of *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* are grown commercially in New Zealand and are common garden plants.
- The level of impact caused by *X. citri* pv. *citri* and *X. citri* pv. *aurantifolii* is likely to be moderate for New Zealand overall, but high for the citrus industry.
- *X. citri* pv. *citri* is present in several citrus exporting countries considered in this import risk analysis: Brazil, China, Korea, Japan, Viet Nam, Australia, Fiji, Solomon Islands, USA and Mexico.

- *X. citri* pv. *aurantifolii* is present in one citrus-exporting country considered in this import risk analysis: Brazil.

6.1.4 References

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7. Pest risk assessments: Oomycetes

7.1 *Phytophthora palmivora* (brown rot, gummosis of citrus)

Phytophthora palmivora is an oomycete (or water mould) that causes brown rot of citrus fruit. It also causes other diseases such as root rot and dieback in citrus and many other host plants.

Scientific name: *Phytophthora palmivora* (E.J. Butler) E.J. Butler

Class/Order/Family: Oomycetes/Peronosporales/Peronosporaceae

Other names include: *Phytophthora arecae*, *Phytophthora cactorum* var. *arecae*, *Phytophthora faberi*, *Phytophthora hevae*, *Phytophthora omnivora* var. *arecae*, *Phytophthora palmivora* var. *heveae*, *Phytophthora palmivora* var. *theobromae*, *Phytophthora theobromae*, *Pythium palmivorum* (CPC 2020)

Summary of conclusions

Given the arguments and evidence presented:

- *Phytophthora palmivora* meets the criteria to be a quarantine pest for New Zealand.
- *Phytophthora palmivora* has a moderate association with most citrus fruit types, with moderate to high uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *P. palmivora* on the commodity by a moderate to high degree, with low uncertainty. Consequently, the likelihood of entry on the commodity is considered to be low, with low uncertainty.
- The ability of *P. palmivora* to move from imported citrus fruit and into a suitable environment to allow establishment, that is, onto another suitable host plant, is considered to be very low, with moderate uncertainty.
- The suitability of the New Zealand environment for *P. palmivora* to establish is considered to be low to moderate, with low uncertainty.
- The level of impact caused by *P. palmivora* is likely to be low to moderate, with low uncertainty. Its spread and disease expression are very likely to be limited by climate, though it may be more damaging in sheltered or protected environments.
- *Phytophthora palmivora* may be considered for additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Moderate	Moderate-high
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Very low	Moderate
Suitability of the New Zealand environment	Low-moderate	Low
Impacts on the New Zealand economy, environment, health and society	Low-moderate	Low

7.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Phytophthora palmivora* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: that the pest is not present in New Zealand, and it is of potential importance (it is able to establish and cause harm).

Phytophthora palmivora is not known to be present in New Zealand:

- NZFungi (2020) and PPIN (2020) report *P. palmivora* as absent.
- *Phytophthora palmivora* is an unwanted organism and a regulated pest (ONZPR 2020, as *P. palmivora* and *P. palmivora* var. *palmivora*).

Phytophthora palmivora has the potential to establish and spread within the warmer parts of New Zealand:

- *Phytophthora palmivora* has a very wide host range, and known plant hosts, including *Citrus* species, are widely grown in New Zealand, both commercially and in domestic gardens.
- *Phytophthora palmivora* is typically found in tropical and subtropical countries with high rainfall. Climate matching and climate modelling suggest that it is likely to have the ability to infect plants and spread in northern New Zealand, especially in the summer months of December to March. *Phytophthora palmivora* may be able to persist in the environment over other months as resistant spore stages.
- However, disease expression and spread are very likely to be limited by climate, particularly in the south of New Zealand.

The establishment of *P. palmivora* in New Zealand has the potential to cause unwanted impacts:

- *P. palmivora* infects more than 200 species of crop, ornamental, shade and hedge plants, including tomato, avocado, macadamia, potatoes and orchids.
- It causes brown rot epidemics on citrus in Florida, pre-harvest and post-harvest fruit rots in other crops and many other diseases on a wide range of hosts in other humid subtropical and tropical areas of the world. It has been reported killing kiwifruit plants in Turkey and is relatively common as the causal agent of black rot of economically important orchids in Taiwan.

7.1.2 Hazard identification: commodity association

Phytophthora palmivora is associated with citrus fruit

- *Phytophthora* species are able to infect many different tissues, including fruit (Graham et al. 1998; CPC 2020; Farr and Rossman 2020). *Phytophthora palmivora* causes fruit rots of numerous plant species, including species of citrus, e.g. *C. unshiu* in Japan (Tashiro et al. 2012); *C. sinensis* in the USA (Graham 2011; Dewdney and Johnson 2020).

7.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Phytophthora palmivora* has a moderate association with citrus fruit commodities, with moderate to high uncertainty:

Many citrus cultivars are reported to be affected by *P. palmivora*.

- *Phytophthora palmivora* has been reported from many *Citrus* species (Table 8.1.1).
- *Phytophthora palmivora* infections cause severe brown rot on citrus fruit under wet and warm conditions (Drenth and Sendall 2004). All citrus cultivars are affected by brown rots caused by *Phytophthora* species (Graham and Menge 2000, Brown and Eckert 2000), particularly by *Phytophthora nicotianae* or *P. palmivora* (Dewdney and Johnson 2020). In New Zealand,

brown rot of citrus is caused by *P. citrophthora* and *P. citricola* at moderate temperatures and *P. syringae* and *P. hibernalis* at cool temperatures (Mooney 2001). These pathogens also cause other diseases. Graham and Menge (2000) report that brown rot is particularly severe on winter crops of lemons in California and early-season oranges in Florida, while Dewdney and Johnson (2020) state it is usually most severe on Hamlin, Navel and other early-maturing sweet orange cultivars. The pathogens can survive and sporulate on the surface of pods or fruit under certain conditions (Brassier and Griffin 1979; Graham and Menge 2000; Graham and Timmer 2003).

- However, different species of brown rot-causing *Phytophthora* are prevalent in different areas, and in the same area at different times (Hao et al. 2018), and it is often unclear which *Phytophthora* species is responsible for brown rot in citrus (see the uncertainty section below).

Table 8.1.1 Records of *Phytophthora palmivora* from *Citrus* species in the scope of this pest risk assessment

Scientific name	Common name (from source)	Country (with host name given in source)	Source
<i>Citrus aurantiifolia</i>		Philippines (as <i>C. aurantiifolia</i>)	Farr and Rossman 2020
<i>Citrus aurantium</i>		India, Philippines, Trinidad and Tobago, United States (as <i>C. aurantium</i>)	Farr and Rossman 2020
<i>Citrus latifolia</i>	Persian lemon	Guatemala (as <i>C. latifolia</i>)	Abad-Campos et al. 2008
<i>Citrus limon</i>		India, Philippines (as <i>C. limon</i>), Egypt (as <i>Citrus volkameriana</i>)	Farr and Rossman 2020; CPC 2020; Farr and Rossman 2020
<i>Citrus maxima</i>		Philippines, Thailand (as <i>C. grandis</i>)	Farr and Rossman 2020
<i>Citrus medica</i>		India, Philippines, United States	Farr and Rossman 2020
<i>Citrus reticulata</i>	mandarin	India, Malaysia, Puerto Rico, United States (as <i>C. reticulata</i>)	CPC 2020; Farr and Rossman 2020
<i>Citrus sinensis</i>		China, India, Tanzania, United States (as <i>C. sinensis</i>)	Farr and Rossman 2020; Graham 2011; Dewdney and Johnson 2020
<i>Citrus paradisi</i>	grapefruit	Puerto Rico, Virgin Islands, Trinidad and Tobago	CPC 2020; Farr and Rossman 2020

NOTES

1. The records are from all plant parts, not specifically from fruit.
2. All citrus disease records are included, not specifically brown rot of citrus.
3. The country records are not exhaustive, only indicative (i.e enough to establish that the *Citrus* species has been reported as a host of *P. palmivora* in some part of the world).
4. Other *Citrus* species that have been reported as hosts of *P. palmivora* are: *C. nobilis* and *C. nobilis* var. *deliciosa* (India; Farr & Rossman 2020); *C. suhuiensis* (Malaysia; Farr & Rossman 2020) and *C. unshiu* (Japan; Tashiro et al. 2012) (all considered *Citrus reticulata*)

Phytophthora palmivora is widely distributed globally and is reported from all of the countries included in this IRA (Table 8.1.2), though it may not be reported from citrus or as causing brown rot in those countries:

- *Phytophthora palmivora* is present in Australia, Brazil, China, the Cook Islands, Egypt, Fiji, Japan, Korea, Mexico, New Caledonia, Samoa, Solomon Islands, Spain, Peru, the United States, Vanuatu, Viet Nam and other countries listed in Table 8.1.2.

Uncertainty

The association of citrus fruit commodities with *P. palmivora* is considered to be moderate, with moderate to high uncertainty:

- It is important to note that it is often unclear which *Phytophthora* species is responsible for brown rot. This is because many publications refer only to “Phytophthora brown rot” and do not further identify the causal agent, although *P. palmivora* is one of the species that is most commonly reported as a causal agent of brown rot on citrus fruit, along with *P. citrophthora*

and *P. nicotianae* (Graham and Menge 2000; Dewdney and Johnson 2020). Both these latter species are present in New Zealand (NZFungi 2020) and are reported to cause post-harvest brown rots on citrus here (Mooney 2001).

- Similarly, it is also often unclear which citrus species are affected by *Phytophthora*-induced brown rot, since many publications refer to the host only as “citrus”.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *P. palmivora* by a moderate to high degree.

Brown rot epidemics are only prevalent under certain conditions and can be managed in-field.

- *Phytophthora palmivora* infections cause severe brown rot on citrus fruit under wet and warm conditions (Drenth and Sendall 2004), and epidemics are prevalent during prolonged rains in late summer and autumn (Graham and Menge 2000).
- Post-harvest fungicides applied in the packhouse against brown rot caused by *P. palmivora* may not be effective, but in-field treatments applied to the canopy can provide effective control (Graham and Menge 2000).
- For general control of *Phytophthora* diseases, the most effective chemicals are based on phosphonate (Woodward and Boa 2019).

Phytophthora infections often cause fruit to fall to the orchard floor.

- Most fruit with brown rot caused by *Phytophthora* infections abscise (Graham and Menge 2000, Graham and Timmer 2003) and are unlikely to be harvested for export.

Brown rot-causing *Phytophthora* infections induce visible symptoms on the fruit surface that are usually easily detectable, leading to the removal of infected produce.

- *Phytophthora* infection of fruit produces a decay in which the affected area is light brown, leathery, and not sunken compared to the adjacent rind. White mycelium forms on the rind surface under humid conditions (Graham and Timmer 2003).
- Fruit with symptoms of brown rot would be rejected during routine harvesting and grading operations.
- If infected fruit is packed, brown rot may spread to adjacent fruit in the container. In storage, infected fruit have a characteristic pungent, rancid odour (Graham and Timmer 2003).

However, some infected fruit are likely to remain undetected.

- Fruit that are infected shortly before harvest may not show symptoms until after they have been held in storage a few days (Graham and Timmer 2003). These fruit may therefore be overlooked and may be exported.
- Transport of fruit is likely to be by sea and may take a number of weeks. The optimum carrying temperature is variable depending on the fruit type but is generally cool⁵² (between 8 and 14°C for grapefruit, lemons and limes, and between 2 and 7°C for oranges (BMT 2020)). Disease development is unlikely to occur at or below 22°C (the optimum temperature range for fruit infection and brown rot development is 27–30°C (Timmer et al. 2000)), and storage of fruit at 5°C significantly delays the development of brown rot (Brown and Eckert 2000). The carrying conditions during shipment and storage conditions may allow for pathogen survival but are not expected to be conducive for disease development. Under such conditions, it is likely that infection of citrus fruit by *P. palmivora* would not be detected on arrival into New Zealand.

Phytophthora palmivora has been identified at the New Zealand border, but not on fruit.

- *Phytophthora palmivora* has not been detected on fresh produce (of any type) at the New Zealand or European Union borders (EPPO 2020; LIMS 2020; Quancargo 2020). In New Zealand, it has been identified at the border around 14 times, all either on nursery stock (*Dracaena*, *Epipremnum*) or on unknown pathways (LIMS 2020). It has also been detected post border in 2018, in association with ornamental plants imported from Malaysia. The affected plants *Epipremnum*, *Philodendron* and *Ficus* were destroyed in post-entry quarantine (MPI internal report).

⁵² Note that cool storage is not equivalent to cool treatment, which is closely monitored and expected to remain within a very narrow range. The effect of cool storage on an organism should only be used as a broad generalization.

The overall likelihood of entry is considered to be low, with low uncertainty. Conditions for high levels of infection of citrus fruit with *P. palmivora* in fruit are apparently infrequent and can be managed. Fruit infection is usually conspicuous. However late infection combined with arrested development due to transit conditions may delay disease expression, and consequently infection may not be detectable.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Phytophthora palmivora* to move from imported citrus fruit onto a host plant to allow establishment is considered to be very low, with moderate uncertainty.

Phytophthora palmivora has the potential to spread to new hosts from infected fruit or peels if they are discarded in the New Zealand environment near citrus trees, or any of many other suitable hosts, but the likelihood of this occurring is considered to be very low:

- Fruit that is visibly infected with brown rot is likely to be discarded. The majority of organic waste in New Zealand is likely to be disposed of using low risk methods, meaning that infected fruit is unlikely to come into contact with suitable hosts for *P. palmivora*. The majority of waste in New Zealand is bagged and disposed of in landfills and into kitchen disposal units. In these situations, spores are unlikely to be released into the environment (see section 2.4.1).
- However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, discarding into the environment (e.g. roadsides, parks) and use as animal feed.
- Mycelium on infected citrus fruit surfaces can survive and can produce sporangia (Graham and Menge 2000, Graham and Timmer 2003). The optimum temperature for sporangium production by *P. palmivora* (*in vitro*) is 24°C, and wet conditions are necessary for 18 to 72 hours (Timmer et al. 2000). Under these conditions, which may not be commonly met in New Zealand, sporulation is profuse.
- Sporangia can germinate and infect host tissues directly, or they can release large numbers of zoospores. Sporangia are spread by windblown rain through the air and are carried with water movement in soil. *Phytophthora palmivora* sporangia are caducous⁵³ (Martin et al. 2012) and can be dispersed at least 0.5 m by rain splash. Zoospores are released in water and are dispersed by irrigation or surface water. Zoospores are able to swim for several hours and can directly infect plant tissues (Babadoost 2004; Lamour and Hausbeck 2003); however a large amount of surface moisture is required for their movement (Roberts and Kucharek 2018).
- *Phytophthora* grows and reproduces on both living and dead tissue in soil. Because it requires water for spore production and infection, root and trunk rots are most frequent in sites with poor drainage and frequent waterlogging. Fruit infection can be initiated during wet conditions when spores are splashed from the soil onto fruit that are touching, or near, the ground. According to Timmer et al. (2000), raindrops would be sufficient to propel small sporangium-filled droplets into the air where they could be carried some distance by wind, but sporangia of *P. palmivora* are not dispersed by wind currents alone (unlike sporangia of some *Phytophthora* species, e.g. *P. infestans*). If wet weather persists, secondary infections are caused by spores produced on those fruit being splashed or blown onto fruit higher on the tree and, less commonly, invertebrates such as snails and ants (Taylor and Griffin 1981; Graham and Menge 2000; Mooney 2001).
- Other *Phytophthora* species have been transmitted from experimentally infected detached fruit on the soil surface to growing plants. *Phytophthora ramorum* was transmitted from infected *Pyracantha* fruit to the roots of *Viburnum* plants (Tooley et al. 2016). Tooley et al. (2016) commented that “Regulators will have to consider fruit transmission [of *P. ramorum*] as a possibility allowing for spread of the disease”.
- The spread of *P. palmivora* is unlikely to be limited by host availability. The pathogen has been reported from over 130 species of crop, ornamental, shade and hedge plants⁵⁴,

⁵³ They become dislodged readily and separated from the sporangiophore and therefore are readily dispersed.

⁵⁴ not necessarily from fruit

including many that are common in the New Zealand environment, e.g. *Capsicum annum* (peppers), *Citrus* species, *Colocasia* species (taro), *Dianthus* species, *Ficus carica* (fig), *Fuchsia* species, *Grevillea* species, *Hedera helix* (English ivy), *Hibiscus* species, *Lycopersicon esculentum* (tomato), *Persea americana* (avocado), *Phaseolus* species (green and dried beans), *Philodendron* species, *Solanum tuberosum* (potato) and *Syzygium* species (Ho 1990; Graham and Menge 2000; Farr and Rossman 2017; CPC 2020).

There is a moderate level of uncertainty associated with the assessment that *Phytophthora palmivora* has a very low likelihood of moving from imported citrus fruit onto a new host. The amount of infected imported material that is disposed of in a high risk manner is likely to be extremely low and the optimal conditions for sporulation are not likely to be commonly met. However, it is not known what level of inoculum would be required to successfully infect a new host. Climate conditions in New Zealand are very likely to inhibit successful exposure of the pathogen, but it is not known how long the pathogen is able to survive unfavourable conditions.

Given the arguments and evidence below, the suitability of New Zealand's environment for the establishment of *Phytophthora palmivora* is considered to be low to moderate, with low uncertainty.

Phytophthora palmivora is a warm-climate species, historically restricted in distribution to tropical or subtropical regions (Table 8.1.2). Although the New Zealand climate is temperate and therefore not optimal for this species:

- Major impacts were reported on kiwifruit in Elazığ Province, Turkey (38°29'01" N; 38°34'44" E; Çiftçi et al. 2016). Most of this region has a 0.7 climate match index (CMI) with all of New Zealand (Phillips et al. 2018), indicating that at least some parts of New Zealand are climatically suitable for establishment and disease expression.
- Climate match assessments conducted by MPI (Fig. 8.1.1) indicate that this species is likely to be capable of infecting susceptible hosts and spreading in northern New Zealand, especially in the summer months of December to March. *Phytophthora palmivora* can also persist in the environment as dormant forms such as oospores⁵⁵ and chlamydospores, which are resistant to unfavourable conditions. Chlamydospores may form when soil moisture is limiting, conditions are cool or where the host roots are not actively growing and producing susceptible tissues for infection. Chlamydospores of some *Phytophthora* species can remain in the soil for several years (Kunta et al. 2020) and can serve as an inoculum source until the environmental conditions are optimal. However it is uncertain how long chlamydospores of *P. palmivora* can survive and how long they would survive under conditions in New Zealand.
- Therefore, it is likely that *P. palmivora* would be able to infect plants and be able to spread in northern New Zealand, especially in the summer months of December to March. Disease expression and spread are very likely to be limited by climate, even in northern New Zealand, and the pathogen is unlikely to establish in southern regions.

Table 8.1.2 Geographic distribution of *Phytophthora palmivora*

- Records are from all hosts, not only from *Citrus*
- Areas in bold are included in the Citrus IHS project

Continent/Region	Country/Area (source CPC (2020), unless otherwise noted)
Africa	Angola, Cameroon, Central African Republic, Democratic Republic of the Congo, Republic of the Congo, Côte d'Ivoire, Egypt [Note 1] , Equatorial Guinea, Gabon, Ghana, Liberia, Madagascar, Malawi, Mauritius, Morocco, Nigeria, Réunion, São Tomé and Príncipe, Senegal, Seychelles, Sierra Leone, Somalia, Tanzania, Togo, Uganda, Zimbabwe
Asia	Afghanistan, Brunei, Cambodia, China (Beijing, Fujian, Guangdong, Hainan, Jiangsu, Yunnan, Zhejiang) , India, Indonesia, Iran, Japan (Kyushu, Shikoku) , Jordan, Korea [Note 2] , Lebanon, Malaysia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, Turkey, Viet Nam

⁵⁵ Oospores are formed when two different mating types are present. The likelihood of this occurring in New Zealand as the result of an incursion is considered to be very low.

Continent/Region	Country/Area (source CPC (2020), unless otherwise noted)
Europe	France, Greece, Italy, Norway, Poland, Spain (incl. Canary Islands)
North America	Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guatemala, Haiti, Honduras, Jamaica, Mexico , Nicaragua, Panama, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, United States (Arizona, California, Florida, Hawaii, North Carolina, Tennessee, Virginia)
Oceania	American Samoa, Australia [Note 3] , Cook Islands [Note 4] , Fiji , French Polynesia, New Caledonia , Northern Mariana Islands, Papua New Guinea, Samoa, Solomon Islands [Note 5] , Tonga, Vanuatu
South America	Argentina, Bolivia, Brazil (Alagoas, Bahia, Espírito Santo, Maranhão, Pará, Paraná, São Paulo) , Colombia, Ecuador, Guyana, Peru , Suriname, Venezuela

Note 1. Regarded as a regulated non-quarantine pest by Egypt (EPPO)

Note 2. *Phytophthora palmivora* is present in Australia, including Western Australia (Barber et al. 2013); where it was previously considered to be absent and was treated as a quarantine pest (e.g. Biosecurity Australia 2005)

Note 3. Reported from the Cook Islands by Dingley et al. (1981)

Note 4. Reported from Soloman Islands by Newhook and Jackson (1977)

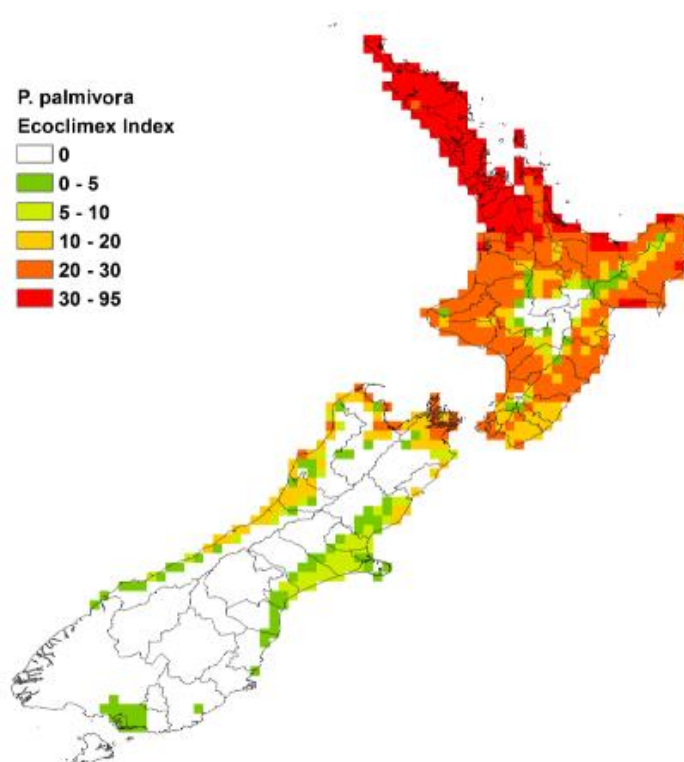


Figure 8.1.1 The potential distribution of *P. palmivora* in New Zealand, as predicted by CLIMEX modelling¹.

¹The Eco-climate index shows the potential long-term establishment of the species and ranges from low (white) through increasing suitability (green through to red). The index for *P. palmivora* is around 40 (out of 100) in suitable areas in New Zealand. This index for tropical areas is above 90. This indicates that although New Zealand is less suitable compared to tropical and subtropical areas, the environment may still facilitate establishment.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *P. palmivora* is likely to be low to moderate, with low uncertainty.

Phytophthora palmivora can cause severe damage, but the economic impacts of this pathogen are largely limited to tropical fruit crops in warm regions.

- *Phytophthora palmivora* has an extremely wide host range and can cause significant to severe losses to many tropical crops, for example, cocoa, durian, rubber, coconut, pineapple and oil palm. Symptoms include root rots, collar rots, stem cankers, leaf blights and pre-harvest and post-harvest fruit rots (CABI 2020; Drenth and Sendall 2004).
- *Phytophthora* species, and *P. palmivora* in particular, are able to cause multiple diseases on the same host. On cocoa, *P. palmivora* causes seedling dieback, root rot, stem canker, chupon wilt, leaf blight, cherelle wilt and black pod rot. Thus, both inoculum and susceptible host tissue are continuously available, and the disease potential is always present (Drenth and Guest 2004a).
- Hosts that are economically important to New Zealand include citrus, kiwifruit (*Actinidia* spp.) and cut flowers:
 - *Phytophthora palmivora* causes brown rot epidemics on citrus in Florida and California, and probably brown rot and foliage blights in other humid subtropical and tropical areas of the world (Graham and Menge 2000). Epidemics are prevalent during prolonged rains and high temperatures in late summer and early autumn (Graham and Menge 2000, Timmer et al. 2000). In southeast Asia, *P. palmivora* is one of the most common species causing *Phytophthora* disease in citrus (Drenth and Sendall 2004).
 - *Phytophthora palmivora* has been isolated from the roots and crowns of infected *Actinidia chinensis* var. *deliciosa* (cv. Hayward) plants in Turkey, causing crown and root rot symptoms on approximately 10% of plants in an experimental orchard (Çiftçi et al. 2016). Within two years, all the kiwifruit vines in the experimental orchard had died. Çiftçi et al. (2016) considered this to be a new host record, and considered that *P. palmivora* had the potential to be a major limiting factor in kiwifruit production, However, the host range and cultivar susceptibility within *Actinidia* is unknown. Further, it is not known whether kiwifruit in New Zealand would be impacted since this appears to be as yet the only report of infection of kiwifruit by *P. palmivora*.
 - In Taiwan, *P. palmivora* is known to cause severe black rot in economically important orchids, including *Cattleya*, *Cymbidium*, *Dendrobium*, *Oncidium* and *Phalaenopsis* (Tsai et al. 2006). Many of these species are grown in New Zealand.

However:

- Although damage can be severe, the economic impacts of this pathogen are largely limited to tropical fruit crops in warm regions (Biosecurity Australia 2005; Daniel and Guest 2008). In New Zealand, the severity of symptoms, spread and consequently the impact is very likely to be limited by the climate. Impacts in protected environments such as nurseries and glasshouses are likely to be more severe than in unprotected environments; for example, heavy losses in nurseries (hosts not specified) are reported due to seedling blight (Daniel and Guest 2008).
- An Australian risk assessment (Biosecurity Australia 2005) concluded that programmes to minimise the impact of *P. palmivora* on host plants are not likely to be more costly than existing management programs for other *Phytophthora* species; however this may depend on the crop and the country. For example, Zito and Timmer (1994) report that *P. palmivora* is a more aggressive and competitive pathogen of citrus roots, stems and fruit tissues than *P. nicotianae*. Therefore, even if *P. nicotianae* (for example) is being managed, the establishment of *P. palmivora* may result in extra costs and damage.

The establishment of *P. palmivora* is unlikely to cause serious trade impacts.

- *Phytophthora palmivora* is widely distributed globally. However, some trading partners may impose trade restrictions in the event of an incursion, e.g.:
 - EPPO⁵⁶ reports that several countries regard *P. palmivora* as a quarantine pest (Morocco, Bahrain and Chile), and Egypt regards it as a regulated non-quarantine pest.

⁵⁶ <https://gd.eppo.int/taxon/PHYTPL/categorization>

- In 2014 China closed the Californian fresh citrus fruit market (worth approximately US\$140 million), based on detections of two other *Phytophthora* species (*P. syringae* and *P. hibernalis*, claimed to be absent from China) on Californian fruit. The Chinese market is open again to Californian growers, but strict export protocols have been implemented to manage the pathogens (Hao et al. 2018).

The establishment of *P. palmivora* may cause environmental impacts, but these are likely to be limited by climatic unsuitability:

- *Phytophthora palmivora* is a highly polyphagous pathogen and has been recorded on several species represented by genera in the native flora including *Hibiscus*, *Solanum* and *Syzygium* species (Farr and Rossman 2020).
- It is most likely to establish in warmer, more humid regions of New Zealand. Amenity plants grown in sheltered conditions, such as tropical plant collections in botanic gardens, could be affected by this species. Although there are no native orchid species in the genera known to be affected by *P. palmivora*, Northland is the centre of diversity of native orchids in New Zealand, and this overlaps with the most likely area of establishment.
- *Phytophthora agathidicida* (previously known as PTA, the causal agent of kauri dieback) has been found in northern parts of New Zealand attacking kauri (*Agathis australis*), an iconic New Zealand tree species (Beever et al. 2009). Its biostatus (whether native or introduced) is not fully resolved, but it is reported to kill trees of all ages in natural forest remnants, amenity stands and silvicultural plantations (Bellgard et al. 2015). This indicates the potential for *Phytophthora* species to negatively impact on the natural environment and on socio-cultural values.

Phytophthora palmivora is unlikely to cause unwanted impacts on human health.

- No evidence of such impacts has been found.

Risk assessment summary:

Given the arguments and evidence below, *Phytophthora palmivora* may be considered for additional measures.

- Many citrus species are hosts.
- Infection of fruit that occurs close to harvest time may not be detected during general handling, especially when the volume of commodities is large.
- Cool storage in transit is likely to delay disease development, reducing the likelihood of detection during phytosanitary inspection.
- Hosts are widely available.

However:

- There is a very low likelihood of *P. palmivora* moving from imported fruit into a suitable environment to allow establishment.
- Only limited areas of New Zealand are likely to be suitable for the establishment of *P. palmivora*.

7.1.4 References

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8. Insects: Diptera, Tephritidae (fruit flies)

8.1 *Anastrepha fraterculus* (South American fruit fly)

Anastrepha fraterculus is native to the Americas and may represent a complex of cryptic species through its range. It attacks a wide range of fruits. The eggs and larvae are found inside the fruit, causing it to rot and become unmarketable.

Scientific name: *Anastrepha fraterculus* (Wiedemann, 1830)

Order/Family: Diptera/Tephritidae

Other names include: *Acrotoxa fraterculus*, *Anastrepha braziliensis*, *Anastrepha costarukmanii*, *Anastrepha fraterculus* var. *soluta*, *Anastrepha lambayecae*, *Anastrepha peruviana*, *Anastrepha pseudofraterculus*, *Anastrepha scholae*, *Anastrepha soluta*, *Anthomyia frutalis*, *Dacus fraterculus*, *Tephritis mellea*, *Trypeta fraterculus*, *Trypeta unicolor*

Taxonomic comments:

Anastrepha fraterculus is variable throughout its geographic range (South, Central and North America as far north as the south of Texas). The overwhelming evidence suggests that '*A. fraterculus*' is not a single species, but rather a species complex, with the taxa comprising it not yet formally described. So far, eight morphotypes have been characterised: Mexican, Venezuelan, Andean, Ecuadorean, Brazilian-1, Brazilian-2 and Brazilian-3 (Hernández-Ortiz et al. 2012; Hernández-Ortiz et al. 2015; Prezotto et al. 2019). This could have implications for biosecurity, as there could be changes in geographic distributions and recorded hosts attributed to each species.

Summary of conclusions

Given the arguments and evidence presented:

- *Anastrepha fraterculus* meets the criteria to be a quarantine pest for New Zealand.
- *Anastrepha fraterculus* has a strong association with citrus fruit.
- Basic measures are likely to reduce the entry of *A. fraterculus* on citrus fruit by a moderate degree (with moderate uncertainty); consequently, the likelihood of entry is considered to be low (with moderate uncertainty).
- *Anastrepha fraterculus* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *A. fraterculus* to establish is considered moderate (with low to moderate uncertainty).
- The level of impacts caused to New Zealand by *A. fraterculus* is likely to be high, mainly due to stricter phytosanitary requirements for citrus and other horticultural crops.
- *Anastrepha fraterculus* may be considered for requiring additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Moderate
The ability to move from the imported commodity onto a suitable host	Moderate	Low–moderate
Suitability of the New Zealand environment	Moderate	Low–moderate
Impacts on the New Zealand economy, environment, health and society	High	Low

8.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Anastrepha fraterculus* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Anastrepha fraterculus is not known to be present in New Zealand.

- *Anastrepha fraterculus* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- The quarantine status of *A. fraterculus* in New Zealand is 'regulated', and it is a notifiable organism and unwanted organism (ONZPR 2020).

Anastrepha fraterculus has the potential to establish and spread in New Zealand.

- The *Anastrepha fraterculus* complex occurs from Mexico to Northern Argentina. Some of the locations where it occurs have climatic similarities to parts of New Zealand. For example, *A. fraterculus* is widespread in Uruguay, which, over most of its area, has a climate match index (CMI) of 0.8–0.9 with New Zealand (Phillips et al. 2018), indicating the potential for *A. fraterculus* to establish in parts of New Zealand. Similarly, the Brazilian states of Santa Catarina (0.7–0.9 CMI), Rio Grande do Sul (0.7–0.9 CMI) and Paraná (mostly 0.7–0.8 CMI), and parts of northern Argentina (0.7–0.9 CMI) have areas with high climatic similarity to parts of New Zealand.
- *Anastrepha fraterculus* is a polyphagous species with a broad host range (CPC 2020; Liquido et al. 2018). Currently, 143 plant species/taxa, belonging to 63 genera in 32 families, are considered host plants for the *A. fraterculus* species complex under natural field conditions (Liquido et al. 2018) and another 124 plant taxa have “undetermined host status”. Hosts include cultivated crops such as *Citrus* spp., *Psidium guajava* (guava), *Malus domestica* (apple), *Passiflora edulis* (passionfruit), *Persea americana* (avocado), *Prunus persica* (peach), *Vitis vinifera* (grape) and *Pyrus communis* (European pear) (Weems 2015; CPC 2020; Liquido et al. 2018).
- Host species are present in climatically suitable areas of New Zealand, indicating the potential for establishment.

Anastrepha fraterculus has the potential to cause economic impacts on *Citrus* and other horticultural species in New Zealand.

- Host species, such as *Citrus* spp., *Malus domestica* (apple), *Passiflora edulis* (passionfruit), *Persea americana* (avocado), *Prunus persica* (peach), and *Pyrus communis* (European pear) are grown commercially in New Zealand and establishment could cause economic loss primarily due to a potential loss of pest free status and subsequent restrictions on trade.

8.1.2 Hazard identification: commodity association

Anastrepha fraterculus is associated with citrus fruit.

Anastrepha fraterculus is reported from citrus fruit.

- Larvae of *A. fraterculus* develop in the fruit of *Citrus*, including, but not limited to, *C. aurantium* (sour orange), *C. limon* (sweet lime), *C. maxima* (pomelo), *Citrus paradisi* (grapefruit), *C. reticulata* (tangerine) and *C. sinensis* (sweet orange) (White and Elson-Harris; 1994).

8.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Anastrepha fraterculus* has a strong association with citrus fruit.

Eggs and larvae of *A. fraterculus* can be associated with citrus fruit commodities.

- *Anastrepha fraterculus* is multivoltine. Eggs are deposited into ripening fruit, and, once hatched, larvae tunnel inside the fruit, feeding on pulp (Aluja 1994; Weems 2015; CPC 2020). The egg stage lasts 3 days in summer and 6 days in winter; the larval stage lasts 15–20 days in summer and 20–25 days in winter (Christenson and Foote 1960). There may be as many as 50 eggs in a single fruit (Christenson and Foote 1960). Larvae leave the fruit to pupate in the soil under the host plant (Weems 2015).
- Larvae have been recorded developing in the fruit of *Citrus*, for example: *C. aurantium* (sour orange), *C. limon* (sweet lime), *C. maxima* (pomelo), *Citrus x paradisi* (grapefruit), *C. reticulata* (tangerine) and *C. sinensis* (sweet orange) (White and Elson-Harris; 1994).

Anastrepha fraterculus infests many *Citrus* species and varieties, although this may vary depending on morphotype.

- *Anastrepha fraterculus* has been recorded as infesting many citrus species and varieties. Table 9.1.1 lists *Citrus* species/taxa that have validated host records for plants for the *A. fraterculus* species complex under natural field conditions (Liquido et al. 2018) and others that have “undetermined host status” (i.e. no validated record of infestation under natural field conditions (Liquido et al. 2018)).
- *Citrus* may not be a host for all morphotypes, for example:
 - In Mexico, *A. fraterculus* has not been reported attacking citrus under natural conditions (Aluja et al. 2003). Mexican *A. fraterculus* collected in the state of Veracruz were unable to develop successfully on *C. sinensis* cultivar Valencia (oranges) and *C. paradisi* cultivar Ruby Red (grapefruit) under laboratory and seminatural conditions (Aluja et al. 2003).
- Morphotypes that use some *Citrus* types as hosts may not use other *Citrus* types, for example:
 - According to Ruiz et al. (2015), lemons (*C. limon* var. Eureka) and sweet oranges (*C. sinensis* var. Valencia) are not hosts for the Brazilian-1 morphotype. In their study, eggs were laid, but there was poor egg hatch and zero survival of larvae to the pupal stage. No oviposition by *A. fraterculus* (likely Brazilian-1 morphotype based on the location of collection and with reference to Prezotto et al. 2019) occurred in lemons (var. Siciliano) (Dias et al. 2017). On the other hand, some *Citrus* types are hosts for the Brazilian-1 morphotype (e.g. grapefruit, sweet orange, tangerine in Dias et al. 2017, Ruiz et al. 2015).

Table 9.1.1: *Citrus* host plant records for *Anastrepha fraterculus* species complex (Liquido et al. 2018). The closely related genera, *Poncirus* and *Fortunella*, are included. Validated natural infestation = validated documentation of field infestation by *A. fraterculus*; “undetermined host status” = no validated record of infestation under natural field conditions, and its host association is based on reported interception at a port of entry, laboratory infestation, or a mere listing as a host without any accompanying verifiable data (Liquido et al. 2018).

Botanical name	Common name
Validated natural infestations:	
<i>Citrus aurantium</i> L.	Bigarade, bitter orange, Seville orange, sour orange, bigaradier, naranja agria, naranja amarga, naranja mateca, oranger amer, Myrtle-leaf orange, chinois, naranja mirtifolia
<i>Citrus limon</i> (L.) Burm.f.	Limetta of the Mediterranean, lumia of the Mediterranean, sweet lemon, sweet lime, lima, lima-de-bico, limero dulce, limeta dulce de Túnez, limette d'Italie, limette, douce de Tunisie, limettier doux, limón dulce, limonero dulce, limonette
<i>Citrus maxima</i> (Burm.) Merr.	Pomelo, pummelo, shaddock, pamplemousse, pamplemoussier, toronja
<i>Citrus paradisi</i> Macfad.	Grapefruit, pomelo, toronja

Botanical name	Common name
<i>Citrus reticulata</i> Blanco	Culate mandarin, mandarin, mandarin orange, mandarine orange, Swatow orange, tangerine, bergamota, mandarina, mandarinier, tangerine, King of Siam, king orange, tangor, mandarinier king, roi de Siam
<i>Citrus sinensis</i> (L.) Osbeck	Blood orange, navel orange, orange, sweet orange, Valencia orange, laranja-doce, laranjeira, laranjeira-doce, laranja-amarga, laranja-azedo, laranja-bigarade, laranja-da-terra, laranja-de-sevilha, naranja, naranjo dulce, navel, orange douce, oranger, oranger doux, sanguine
<i>Citrus reticulata</i> × <i>Citrus paradisi</i>	Tangelo, uglifruit
<i>Fortunella japonica</i> (Thunb.) Swingle	Marumi kumquat, round kumquat, round kumquat, kumquat marumi
<i>Poncirus trifoliata</i> (L.) Raf.	Hardy orange, Japanese bitter orange, trifoliolate orange, limoeiro-trifoliado, naranjo trébol, poncirus, oranger trifoliolé
“Undetermined host status”:	
<i>Citrus aurantiifolia</i> (Christm.) Swingle	Egyptian lime, Indian lime, Key lime, lime, Mexican lime, sour lime, West Indian lime, citron vert, citronnier gallet, lima, lima-ácida, lima mejicana, limão, limão-galego, limão-tahiti, lime acid, limeira, limerero, limettier, limettier des Antilles, limettier mexicain, limón agrio, limón ceutí, Indian sweet lime, Palestine sweet lemon, Palestine sweet lime, sweet lime, lima dulce de India, lima dulce de Palestina, limettier doux de Palestine
<i>Citrus limon</i> (L.) Osbeck	Lemon, citronnier, limão, limão-eureka, limão-gênova, limão-siciliano, limão-verdadeiro, limoeiro, limoeiro-azedo, limón, limonero, limonier, Indian sweet lime, Palestine sweet lemon, Palestine sweet lime, sweet lime, lima dulce de India, lima dulce de Palestina, limettier doux de Palestine
<i>Citrus medica</i> L.	Citron, cédrat, cédratier, cidra, cidreira, cidro, toronja
<i>Citrus reticulata</i> Blanco	Dancy tangerine, tangerine

Anastrepha fraterculus is present in some citrus export countries considered in this import risk analysis.

- The geographic range of *A. fraterculus* is South, Central and North America as far as the south of Texas (Table 9.1.2).
- *Anastrepha fraterculus* is present in the following citrus export countries that are under consideration:
 - Brazil, Peru, Mexico (EPPO 2020a)
- *Anastrepha fraterculus* is considered absent from the USA by their National Plant Protection Organisation (EPPO 2020a) and is a quarantine pest for that country. There are some old records from south Texas that are considered unreliable as to species. USDA-APHIS has an ongoing Mexican fruit fly (*Anastrepha ludens*) trapping network in southern Texas, which includes traps capable of attracting *A. fraterculus*, which are present in Mexico (CPC 2020).
- *Anastrepha fraterculus* was eradicated in 1964 in Chile (an export country under consideration) (EPPO 2020a).
- Although *A. fraterculus* has a wide distribution, at least eight morphotypes are known, and some of these are likely to be formally described as separate species at a later date. The morphotypes have different distributions through the overall geographic range for *A. fraterculus*, and it is likely that characteristics such as differences in climatic requirements and association with *Citrus* will vary between morphotypes. Each of the countries under consideration in this assessment has a unique set of cryptic species or morphotypes:
 - Brazil has three clearly defined morphotypes (Brazilian-1, Brazilian-2, Brazilian-3), that have been well characterised by genetic, morphological and behavioural studies (e.g. Cáceres et al. 2009; Hernández-Ortiz et al. 2012; Prezotto et al. 2019; Passos Roriz et al. 2017; Passos Roriz et al. 2018).
 - Mexico has only one morphotype (Mexican) (Hernández-Ortiz et al. 2012, Prezotto et al. 2019).
 - The Peruvian coastal plain where citrus is increasingly grown commercially has the Peruvian morphotype, whereas the Peruvian highlands support the Ecuadorian morphotype, and the Brazilian lineage has been collected on the east side of the Andes (Hernández-Ortiz et al. 2015; Prezotto et al. 2019).

Table 9.1.2: Known geographic distribution of *Anastrepha fraterculus* (EPPO 2020a, CPC 2020). Countries in **bold** are potential exporting countries under consideration in this import risk analysis.

Continent/Region	Country [State]
South America	Argentina, Bolivia, Brazil [Alagoas, Amapa, Bahia, Ceará, Espírito Santo, Goiás, Maranhão, Mato Grosso do Sul, Minas Gerais, Paraíba, Paraná, Pernambuco, Piauí, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, Santa Catarina, São Paulo, Tocantins], Colombia, Ecuador, Guyana, Paraguay, Peru , Suriname, Uruguay, Venezuela Eradicated from Chile in 1964
Central America and Caribbean	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama, Trinidad and Tobago
North America	Mexico USA: has been reported in south Texas but is considered absent by the US NPPO.

Given the arguments and evidence below, basic measures are likely to reduce the entry of *A. fraterculus* on citrus fruit by a moderate degree (with moderate uncertainty); consequently, the likelihood of entry is considered to be low (with moderate uncertainty)

Infested fruit may show signs of infestation and be removed from the consignment.

- Eggs or larvae of *A. fraterculus* are present inside the fruit. Infested fruit may show signs of oviposition punctures. Larvae tunnel through the interior of the fruit while feeding, and networks of tunnels may develop, accompanied by rotting. The internal damage may show as symptoms on the exterior of the fruit at later stages of infection. Sugary exudates may be produced in very sweet fruits (CPC 2020). Fruit showing obvious signs of infestation by *A. fraterculus*, such as oviposition punctures and other symptoms on the exterior, are likely to be detected and removed from a line or consignment during packhouse activities and inspections.

However, some infested fruit may go unnoticed during the export production process.

- If eggs or larvae are present in the fruit at low density or at an early stage of infestation, the external signs such as oviposition punctures may not be visually obvious. Much damage can occur inside the fruit before exterior symptoms appear (CPC 2020).
- Therefore, commercial processes and post-harvesting activities may reduce the presence of *A. fraterculus* to a low level, but not eliminate it. Low levels of fruit infestation are likely to go undetected, especially in high volumes of the fruit commodity.

General handling and processing after harvesting is unlikely to remove eggs and larvae of *A. fraterculus* from citrus fruit.

- Eggs and larvae are found inside the fruit and so would not be removed by routine activities in the packhouse such as washing and brushing, which only treat the fruit surface.

Anastrepha fraterculus may survive transit in some citrus commodities.

- Storage and transport of citrus consignments from exporting countries to New Zealand are likely to occur at cool temperatures, with the length of time for shipment depending on the exporting country. For example, transport of fruit from Brazil by sea may take more than three weeks.
- The larval stage of *A. fraterculus* lasts 15–20 days in summer and 20–25 days in winter, with the rate of larval development influenced by temperature (Christenson and Foote 1960).
- Machado et al. (1995, in Sequeira et al. 2001) reported lower-threshold temperatures for the life stages of *A. fraterculus*: egg (9.25°C), larva (10.27°C), pupa (10.78°C), and complete life cycle (10.72°C). Salles (2000, in Poncio et al. 2016) reported the base temperature (below which no development occurs) for *A. fraterculus* as 10.7°C.
- A recent study investigated the relative cold tolerance of five populations from three morphotypes of the *A. fraterculus* complex (Andean, Peruvian and Brazilian-1) in relation to

phytosanitary cold treatment of fruit (Diaz et al. 2020). Differences in mortality of third instars of the five *A. fraterculus* populations reared on nectarines were observed only with short treatment durations at temperatures ranging from $1.38 \pm 0.04^{\circ}\text{C}$ to $1.51 \pm 0.08^{\circ}\text{C}$ (mean \pm SEM). Using nectarines as a host, Diaz et al (2020) established that cold treatments of 15 d at $\leq 1.11^{\circ}\text{C}$ or 17 d at $\leq 1.67^{\circ}\text{C}$ will kill immature stages of Brazilian-1, Andean and Peruvian morphotypes. If applied to *Citrus*, the temperatures given could ensure disinfestation without chilling injury in many cultivars (Grout et al. 2011; De Lima et al. 2007).

- Therefore, some larvae may survive transit depending on transport temperatures and times, which are unspecified.

The level of uncertainty in relation to survival during transit is moderate. There is no specific information on the conditions of transit, including temperature and duration. There is a lack of New Zealand interception data for *Anastrepha* spp. in fresh produce, which would be informative if live specimens were detected. Species of *Anastrepha* have been intercepted by EPPO (2020b); however, the data does not indicate if the specimens are alive or dead. There is also potential for variation among morphotypes in development times and ability to survive low temperatures. There is potential for the host status of different types of *Citrus* to vary, depending on the morphotype of *A. fraterculus*, and this may need to be determined in specific instances.

Likelihood of establishment:

Given the arguments and evidence below, *Anastrepha fraterculus* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.

Anastrepha fraterculus can survive and develop on discarded citrus fruit and fruit pieces.

- Eggs are deposited into ripening fruit, and, once hatched, larvae tunnel inside the fruit, feeding on pulp (Aluja 1994; Weems 2015; CPC 2020). The egg stage lasts 3 to 6 days, and the larval stage lasts for 15 to 25 days of development time, depending on temperature (Christenson and Foote 1960). Larvae leave the fruit to pupate in the soil under the host plant (Weems 2015) or other substrates such as packaging for fruit (CPC 2020).
- If infested citrus fruit is discarded as whole fruit or fruit pieces, *A. fraterculus* may complete larval development in the waste and find a suitable location to pupate.

Most citrus fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any *A. fraterculus* present would either be killed or unable to escape from the citrus host.

- In New Zealand, the majority of kitchen waste is either bagged and sent to landfill or run through kitchen disposal units (see section 2.4.1, waste analysis). *A. fraterculus* in infested fruit is unlikely to survive in these circumstances.

However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, use as animal feed or discarding directly into the environment.

- A small proportion of infested fruit is likely to be discarded in a home compost bin or open compost heap, or directly into the environment (see section 2.4.1, waste analysis).
- *Anastrepha fraterculus* larvae move from citrus fruit to pupate in the soil in natural conditions but may also pupate in other sheltered situations such as in packaging (CPC 2020). Therefore, some larvae or pupae associated with discarded citrus may find suitable conditions to develop to adulthood. Adults emerge from pupae after 10–15 days (43.2 days at 15°C) (Salles 2000, in CPC 2020). The pupal stage lasts 15–18 days in summer and 20–25 days in winter, and in exceptional cases, adults have been known to emerge from pupae after 12, 14 and 18 months (Christenson and Foote 1960).
- Adults emerging from the soil are likely to be able to find food in the environment. Before becoming sexually active, adult *Anastrepha* go through a period during which they need to feed regularly on carbohydrates and water to survive and on protein sources to allow for gonad maturation (Aluja 1994). Nutrients can be found in liquids oozing from overripe or damaged fruit, bird faeces, leaf and fruit surfaces, and raindrops (Aluja 1994).
- *Anastrepha fraterculus* is polyphagous and can complete development on a wide range of unrelated species. At least 143 species/taxa belonging to 63 genera in 32 families are considered to be hosts under natural field conditions and another 24 plant taxa have

“undetermined host status” (Liquido et al. 2018). Recorded hosts, such as citrus, peach, persimmon, apple, avocado, passionfruit, grape, guava, fig, capsicum and mango, are available in many areas of New Zealand.

- If suitable hosts are located near the site for citrus fruit waste, *A. fraterculus* adults are likely to find them.

Anastrepha fraterculus can disperse to find a suitable host.

- Adult *A. fraterculus* that emerge from the soil disperse to find a suitable host plant. Dispersal is correlated with suitable environmental conditions. In a study on movement of adults from native breeding sites into apple orchards in Southern Brazil, most adults moved within 200 m from their release point in native forest; however, dispersal of up to 900 m to a nearby apple orchard was recorded (Kovaleski et al. 1999).
- A recent study by Ramos et al. (2019) on temporal patterns of *A. fraterculus* dispersion in apple orchards found that *A. fraterculus* entered two apple orchards in Brazil during fruit periods. This reinforces the findings of Kovaleski et al. (1999) that *A. fraterculus* can immigrate into areas where host fruit is present. However, the distance *A. fraterculus* is able to cover is not quantified due to the absence of a highly effective lure to improve sampling (Tan et al. 2014).

The level of uncertainty associated with this conclusion is low to moderate. Firstly, waste data may not be very accurate or up to date (see section 2.4.1, waste analysis). Secondly, it is uncertain what proportion of composting sites are exposed or uncovered (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *A. fraterculus* to establish is considered moderate (with low to moderate uncertainty).

New Zealand’s climate in some fruit-growing regions is likely to be suitable for establishment of *A. fraterculus*.

- Given the geographic distribution of *A. fraterculus* (Table 9.1.2), it is likely that parts of New Zealand will be climatically suitable for establishment. Some of the countries and regions where it occurs have areas with a high climate match with New Zealand, with climate match index (CMI) of 0.7 or greater (Phillips et al. 2018):
 - Argentina: the northeastern provinces of Corrientes and Entre Rios (Guillen and Sanchez 2007) are 0.7 and 0.7–0.8 CMI, respectively;
 - Brazil: southern states, for example, Paraná (mostly 0.7–0.8 CMI), Rio Grande do Sul (0.7–0.9 CMI), Santa Catarina (0.7–0.9 CMI) and São Paulo (areas in the south are 0.7–0.8 CMI);
 - Peru: large areas with 0.7–0.8 CMI;
 - Uruguay: 0.8–0.9 CMI.
- However, different taxa within the *A. fraterculus* species complex may vary in their ability to establish in New Zealand. A study by Godefroid et al. (2015) predicted the potential distribution of *A. fraterculus* in Europe, with it being climatically suited to parts of Europe particularly around the Mediterranean. The three conspecific lineages considered showed some strong differences in potential distributions. Climatic suitability for Europe was greater for the Brazilian lineage than for the Mexican lineage, and the Andean lineage showed little climatic suitability.
- The areas in Europe with highest climate suitability (Godefroid et al. 2015) are largely around the edge of the Mediterranean (Europe, Africa, Middle East), Portugal and the Atlantic coast (Spain, Portugal, France). These areas have a high climate match with New Zealand (0.8–0.9 CMI). However, very little of Europe overall showed climatic suitability for *A. fraterculus*. The findings from Godefroid et al. (2015) support the likelihood of establishment in at least some parts of New Zealand, particularly in the northern regions.

Anastrepha fraterculus is likely to find mates and has a high reproductive rate.

- Multiple larvae are contained within a single fruit, and after emergence, adults can disperse to find a suitable host. Surviving pupae from the larvae contained within a single fruit would be enough to establish a population if that fruit were discarded within range of a suitable host plant. Adults have been trapped on host plants as far as 900 m from their release point

(Kovaleski et al. 1999). Therefore, it would be likely that there would be enough emerging adults to establish a viable population.

- *Anastrepha fraterculus* has sexual reproduction. As multiple larvae are contained within a single fruit both males and females are likely to be present in the same location.
- Males establish territories on the underside of leaves and emit pheromones to attract receptive females (Aluja 1994) enhancing the opportunity for mate finding and therefore increasing the likelihood of establishment.
- Adults are long-lived (3–5 months in laboratory studies (Fletcher 1989) and 8 months in cages (Christenson and Foote 1960) have been reported). Salles (2000, in CPC 2020) reported that females can produce 278–437 eggs.

Host availability is unlikely to be a barrier to establishment and spread of *A. fraterculus*.

- *Anastrepha fraterculus* is polyphagous on a range of other unrelated plants, as well as *Citrus* spp. (Table 9.1.1). Many plants for which there are verified natural infestations (Liquidó et al. 2018), are grown in home gardens, amenity areas and as commercial crops, or occur as environmental weeds in New Zealand, for example:
 - *Acca sellowiana* (feijoa), *Capsicum annuum* (pepper), *Cydonia oblonga* (quince), *Crataegus monogyna* (hawthorn), *Diospyros kaki* (persimmon), *Eriobotrya japonica* (loquat), *Ficus carica* (fig), *Fragaria × ananassa* (strawberry), *Malus domestica* (apple), *Olea europaea* (olive), *Passiflora caerulea* (blue passion flower), *Passiflora edulis* (passionfruit), *Passiflora tripartita* var. *mollissima* (banana passionfruit), *Persea americana* (avocado), *Prunus armeniaca* (apricot), *Prunus avium* (sweet cherry), *Prunus domestica* (plum), *Prunus persica* (peach), *Psidium cattleianum* (purple guava), *Psidium guajava* (guava), *Punica granatum* (pomegranate), *Pyrus communis* (pear), *Rubus fruticosus* (blackberry), *Rubus idaeus* (raspberry), *Vaccinium corymbosum* (blueberry), *Vitis vinifera* (grape).
- The main citrus-growing areas in New Zealand are Northland, Auckland, Bay of Plenty, Hawke's Bay and Gisborne. Apples are grown throughout the country, including in Hawke's Bay, Gisborne, Waikato, Tasman-Nelson, Canterbury and Otago; and peaches are grown primarily in Otago and Hawke's Bay. Avocados are grown primarily in Northland, Auckland, Waikato and Bay of Plenty; wine grapes are grown throughout the country, including in Auckland, Gisborne, Hawke's Bay, Wellington, Tasman-Nelson, Marlborough, Canterbury and Otago (Plant & Food Research 2019)
- Therefore, potential hosts are likely to occur in climatically suitable areas for establishment.

Anastrepha fraterculus may not be detected until a population is established in New Zealand.

- No male lures have yet been identified for *Anastrepha* spp. (CPC 2020). Therefore, *A. fraterculus* is unlikely to be picked up in New Zealand's surveillance grid because it is not responsive to the lures used. As a result, there is unlikely to be early warning that *A. fraterculus* is present in New Zealand, and it may not be detected until a population has established.

There is uncertainty around the morphotypes and to what degree these vary in terms of plant hosts, geographic distribution, climatic requirements and tolerances. As a result, there is some uncertainty as to which taxa could establish, the extent that they could spread in New Zealand and what their host preferences would be.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impacts caused by *A. fraterculus* is likely to be high.

Damage and symptoms caused by *A. fraterculus* can reduce fruit quality.

- Attacked fruit can show signs of oviposition punctures, but much damage may occur inside the fruit before external symptoms are seen, often as networks of tunnels accompanied by rotting. Very sweet fruits may produce a sugary exudate (CPC 2020).

Anastrepha fraterculus is considered a serious pest of citrus and other crops with impacts on commercial production, including in areas with similar climate to New Zealand.

- Damage to crops through fruit loss can be considerable in areas where *A. fraterculus* is present. The state of São Paulo, Brazil, is a significant area for citrus production. In unsprayed citrus orchards, fruit drop caused by fruit flies has been estimated at 25–50% (Raga et al. 2004). These authors evaluated the natural infestations levels of fruit flies in different citrus varieties and hybrids collected across the state and found that about 78.1% of all adult Tephritoidea flies recovered from the fruit were Tephritidae (77.1% *Anastrepha* sp. and 1.0% *Ceratitidis capitata*) and 21.9% were Lonchaeidae (*Neosilba* spp.). All females of *Anastrepha* were identified as *A. fraterculus*.
- The state of São Paulo, Brazil, is a significant producer of guava (*Psidium guajava*) (Raga et al. 2005). Raga et al. (2005) carried out a field survey across the state of unsprayed guava and other species of Myrtaceae. For guava, some samples had infestations of up to 21.26 fruit fly puparia per fruit, with an overall estimate of 2.69 puparia per fruit of guava. *Anastrepha fraterculus* was the dominant fruit fly, reaching 87.74% of all *Anastrepha* females and 76.62% of all female fruit flies (Tephritoidea) from guavas (Raga et al. 2005).
- In Brazil, *A. fraterculus* is considered the main pest of temperate fruit trees and accounts for almost all pest species in orchards in southern Brazil (Poncio et al. 2016). Vacaria (0.9 CMI), located in the state of Rio Grande do Sul, Brazil, produces about 55% of the total harvest of apples in the state and around 20% of the apples in Brazil. Kovaleski et al. (1999) report that losses caused by *A. fraterculus* to the apple crop in Brazil are due primarily to ovipositing females rather than to larval development.
- In the northeastern region of Argentina, one of the main citrus-growing areas of the country, the fruit flies *A. fraterculus* and *C. capitata* together cause significant losses in orchards unless actively controlled by growers (Gullen and Sanchez 2007). The area most affected stretches from Monte Caseros (in Corrientes Province) to Colón (in Entre Ríos Province) where 954,000 tons of oranges, tangerines and grapefruits are produced for commercial markets. Due to fruit fly pests, about 143,000 tons of produce are lost every year, with a gross value estimated at US\$37 million (Gullen and Sanchez 2007). This area of Argentina has high climatic similarity to New Zealand (0.7–0.8 CMI), indicating the potential for impact on citrus production in New Zealand should *A. fraterculus* establish.
- *Anastrepha fraterculus* can infest many commercial crops including citrus, apple, stonefruit, berryfruit and grapevine. If *A. fraterculus* established in New Zealand, the losses could be considerable. Citrus is of economic importance to New Zealand (see Chapter 2, section 2.6), and apple exports alone were worth around NZ\$82.8 million in 2019 (Plant & Food Research 2019). The combined export value for fresh fruit was NZ\$3.39 billion in 2019 (Plant & Food Research 2019).
- Direct losses due to fruit fly damage on crops (citrus and other hosts, such as apples) would depend on how widely *A. fraterculus* established, with establishment more likely in the northern regions of New Zealand.

Establishment or an incursion of *A. fraterculus* is highly likely to cause trade impacts.

- The trade impact if *A. fraterculus* is detected in New Zealand is likely to be high due to export restrictions and/or extra phytosanitary measures being required by many trading partners.
- *Anastrepha fraterculus* is the subject of quarantine regulations in other countries, and detection in New Zealand could cause disruption of market access for any of its hosts, such as citrus, apple, pears, avocado, peach, passionfruit and persimmon, even if it did not establish. It is not present in existing or potential markets such as Europe, Australia, Asia and the USA. *Anastrepha fraterculus* is a quarantine pest in the European Union, to which exports of apples from New Zealand were worth NZ\$149 million in 2019 (Plant & Food Research 2019), for example. New Zealand currently has country freedom status from all fruit flies of economic importance, including *A. fraterculus*.
- Because *A. fraterculus* does not respond to lures used in New Zealand's fruit fly surveillance grid, it is likely to have an established population once detected.

If *A. fraterculus* is detected in New Zealand, the cost incurred by a response would be high.

- *Anastrepha fraterculus* is not responsive to current lures based on sex attractants. Therefore, once detected in New Zealand, eradication would be very difficult but is likely to be attempted. McPhail traps are usually used for the capture of *Anastrepha* spp. (White and Elson-Harris

1994) with baits such as ammonium acetate, casein hydrolysate and torula yeast (CPC 2020).

- The typical cost of a response is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).

It is likely that *A. fraterculus* will cause a low to moderate level of sociocultural impacts within a limited area in New Zealand.

- Many hosts of *A. fraterculus* are common amenity and home garden species and occur in parks and gardens throughout the country, for example, citrus, stonefruit, apple, pear, peach, avocado and blackberry. *Anastrepha fraterculus* are fruit feeders, and infested fruit are rendered inedible and drop prematurely.
- However, temperature is likely to restrict population growth, and establishment is more likely in northern regions of the country. Therefore, direct impact on plants may be within a limited area of the country.

It is likely that *A. fraterculus* will have a low level of impact on the environment.

- *Citrus* species are members of the Rutaceae family. There are two genera within Rutaceae endemic to New Zealand. These are *Melicope* and *Leionema*. Neither the *Leionema* nor *Melicope* species are considered threatened (NZPCN 2020).
- There are several genera of hosts with representatives in the same genus in New Zealand, for example, *Passiflora tetrandra*, *Rubus* spp. and *Syzygium maire*. The latter has threatened (nationally critical) status (NZPCN 2020).
- *Anastrepha fraterculus* are fruit pulp feeders so may not impact on the reproductive potential of infested plants, particularly those plants bearing small fruit with limited flesh. Additionally, temperature is likely to restrict population growth, and establishment is likely to be limited to northern New Zealand.

It is likely that *A. fraterculus* will have negligible impacts on human health.

- No evidence was found that *A. fraterculus* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Anastrepha fraterculus* may be considered for additional measures.

- *Anastrepha fraterculus* has a strong association with citrus fruit.
- Some infested fruits will not be detected, especially when the volume of commodities is large.
- As the larvae feed internally in the fruits, general handling (e.g., washing and brushing) cannot remove the larvae.
- The basic measures are likely to reduce the of entry of *A. fraterculus* on citrus fruit, by a moderate degree (with moderate uncertainty); consequently, the likelihood of entry is considered to be low (with moderate uncertainty)
- *Anastrepha fraterculus* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *A. fraterculus* to establish is considered moderate, within a limited area due to climate requirements.
- Citrus, and other hosts of *A. fraterculus*, such as avocados, apples, pears and peaches, are grown commercially in New Zealand and are common garden plants. Some are also environmental weeds.
- The level of impact caused by *A. fraterculus* is likely to be high to the overall economy of New Zealand, mainly due to stricter phytosanitary requirements for citrus and other horticultural crops.
- *Anastrepha fraterculus* is present in three citrus-exporting countries considered in this import risk analysis, Brazil, Peru and Mexico.

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8.2 *Anastrepha ludens* (Mexican fruit fly)

Anastrepha ludens is a polyphagous fruit fly. The larvae bore into and feed on fruit, and once infested, the fruit becomes inedible. It is a very serious pest of various fruits, particularly citrus and mango, in Mexico and Central America (Weems et al. 2015).

Scientific name: *Anastrepha ludens* (Loew, 1873)

Order/Family: Diptera/Tephritidae

Other names include: *Trypeta ludens*, *Acrotoxa ludens*, *Anastrepha lathana*

Summary of conclusions

Given the arguments and evidence presented:

- *Anastrepha ludens* meets the criteria to be a quarantine pest for New Zealand.
- *Anastrepha ludens* has a strong association with citrus fruit.
- Basic measures are likely to reduce the entry of *A. ludens* on citrus fruit by a moderate degree; consequently, the likelihood of entry is considered to be low to moderate.
- *Anastrepha ludens* has a moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *A. ludens* to establish is considered moderate.
- The level of impact by *A. ludens* is likely to be high, mainly due to stricter phytosanitary requirements for citrus and other horticultural crops.
- *Anastrepha ludens* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low–moderate
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	High	Low

8.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Anastrepha ludens* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest, relevant to this assessment, are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Anastrepha ludens is not known to be present in New Zealand:

- *Anastrepha ludens* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- The quarantine status of *A. ludens* in New Zealand is 'regulated', and it is a notifiable organism and unwanted organism (ONZPR 2020).

Anastrepha ludens has the potential to establish and spread in New Zealand:

- *Anastrepha ludens* is native to Mexico, and possibly Nicaragua and Costa Rica, and occurs in other parts of North and Central America (Molina-Nery et al. 2014; CPC 2020). It is widespread in Mexico which has areas with a climate match index (CMI) of 0.7 or greater with

New Zealand, indicating the potential for *A. ludens* to establish in parts of New Zealand (Phillips et al. 2018).

- *Anastrepha ludens* is a polyphagous species with a broad host range (CPC 2020, Liquido et al. 2017), including *Citrus* spp., *Malus domestica* (apple), *Passiflora edulis* (passionfruit), *Persea americana* (avocado), *Prunus persica* (peach), *Pyrus communis* (European pear) and *Syzygium jambos* (rose apple) (Weems et al. 2009; CPC 2020; Liquido et al. 2017).
- Host species are present in climatically suitable areas of New Zealand, indicating the potential for establishment.

Anastrepha ludens has the potential to cause impacts on *Citrus* and other horticultural crops in New Zealand:

- Host species, such as citrus *Citrus* spp., *Malus domestica* (apple), *Passiflora edulis* (passionfruit), *Persea americana* (avocado), *Prunus persica* (peach), *Pyrus communis* (European pear) are grown commercially in New Zealand and establishment of *A. ludens* could cause economic loss primarily due to a potential loss of pest-free status and subsequent restrictions on trade.

8.2.2 Hazard identification: commodity association

Anastrepha ludens is associated with citrus fruit.

Anastrepha ludens is reported from citrus fruit:

- Larvae of *A. ludens* develop in the fruit of *Citrus*, for example, *C. aurantiifolia*, *C. aurantium*, *C. limetta*, *C. maxima*, *C. medica*, *Citrus* x *paradisi*, *C. reticulata*, *C. sinensis* and *Citrus* x *tangelo* (White and Elson-Harris 1994).

8.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Anastrepha ludens* has a strong association with citrus fruit:

Eggs and larvae of *A. ludens* can be associated with citrus fruit commodities.

- Eggs of *A. ludens* are deposited under the skin of ripening fruit and, once hatched, larvae tunnel inside the fruit feeding on pulp (Weems et al. 2015; CPC 2020).
- Larvae have been recorded developing in the fruit of *Citrus*, for example, *C. aurantiifolia*, *C. aurantium*, *C. limon*, *C. maxima*, *C. medica*, *Citrus paradisi*, *C. reticulata*, *C. sinensis* and *Citrus reticulata* x *Citrus paradisi* (White and Elson-Harris 1994).
- Females begin to oviposit in fruit at the time when fruit begins to show colour. As many as 40 eggs are laid by each female at a time; however, eggs are usually laid in batches of 10 (Weems et al. 2015). A single female can produce over 1,000 eggs in her lifetime (Thomas et al. 2018). The egg stage lasts 6–12 days (Weems et al. 2015). Larvae are white and maggot-shaped, with the final instar about 9–12 mm long (Weems et al. 2015). The larval stage lasts approximately 3–4 weeks, with the rate of larval development determined by temperature and host fruit (Weems et al. 2015; Christenson and Foote 1960). Larvae go through three instars before leaving the fruit and burrowing into the ground, or other suitable substrate, to pupate (Aluja 1994).

Anastrepha ludens infests many citrus species and varieties.

- *Anastrepha ludens* has been recorded as infesting many citrus species and varieties under natural conditions (White and Elson-Harris 1994; Liquido et al. 2017):

- *Citrus aurantiifolia*, *C. aurantium*, *C. limon*, *C. maxima*, *C. medica*, *C. paradisi*, *C. reticulata* var. *austera*, *C. reticulata*, *C. sinensis*, *Citrus reticulata* × *Citrus paradisi*.
- According to Weems et al. (2015), all varieties of citrus except lemons and Mexican limes are attacked, with grapefruit the most preferred host and oranges the second.
- Arredondo et al. (2015) report that the 'Persian' lime (*C. latifolia* Tanaka) is not a host for *A. ludens*, with their study showing no natural infestation in the field or under forced infestation conditions on unharvested fruit. A very low rate of infestation of harvested fruit occurred under forced infestation conditions in the laboratory with very few immatures reaching adulthood. They conclude that because some adult flies emerged from the pupae obtained from harvested 'Persian' limes, after exposure to infestation, they should be considered a conditional host for *A. ludens* flies.
- According to Liquido et al. (2017), *C. paradisi*, *C. limon* and *C. reticulata* (as synonyms) have undetermined host status, that is, no valid record of infestation under natural conditions.

Anastrepha ludens is present in one citrus export country (and transient in another country) considered in this import risk analysis:

- *Anastrepha ludens* is present in Mexico (EPPO 2020), where it is widespread, being present in Aguascalientes, Baja California Sur, Campeche, Colima, Chiapas, Durango, Guanajuato, Guerrero, Hidalgo, Jalisco, México, Morelos, Nayarit, Nuevo León, Oaxaca, Puebla, Querétaro, Quintana Roo, San Luis Potosí, Sinaloa, Sonora, Tabasco, Tamaulipas, Veracruz, Yucatan and Zacatecas (EPPO 2020).
- *Anastrepha ludens* is currently considered "transient, under eradication" in the USA, in California and Texas (EPPO, 2020). It is considered "absent, no longer present" in Arizona and Florida (EPPO 2020).
- It is also found in the following Central American countries, which are not considered in this assessment: Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama (EPPO 2020).

Given the arguments and evidence below, basic measures are likely to reduce the entry of *A. ludens* on citrus fruit by a moderate degree. Consequently, the likelihood of entry is considered to be low to moderate, with low uncertainty.

Infested fruit may show signs of infestation and be removed from the consignment.

- Any *A. ludens* coming into New Zealand will likely be eggs or larvae inside infested fruit. Infested fruit may show signs of oviposition punctures, and these fruits would likely be culled. If fruit is at the later stage of infestation, then it will likely be culled during routine packing processes, as extensive internal damage may start to show as external symptoms, and infested fruit rots prematurely. Sugary exudates may also be produced in very sweet fruits (CPC 2010).

However, some infested fruit may go unnoticed during the export production process.

- If eggs and larvae are present inside fruit and are present at low density or at an early stage of infestation, the external signs such as oviposition punctures may not be visually obvious.
- Therefore, low levels of infestation may go undetected, especially at high volumes of the fruit commodity.

General handling and processing after harvesting are not likely to remove eggs and larvae of *A. ludens* from *Citrus* fruit.

- Eggs and larvae are found inside the fruit and so would not be removed by routine activities in the packhouse such as washing and brushing, which only treat the fruit's surface.
- Post-harvest treatments can effectively kill eggs or larvae of *A. ludens*. For example, the USDA approves vapor or high-temperature forced air treatments for fruit disinfestation of *Anastrepha* (pulp temperature of 44°C for 100 minutes) (USDA 2016) for *Citrus* types, including oranges, tangerines and grapefruit. However, such treatments are beyond basic measures, and so their impact is not taken into account here.

Larvae of *A. ludens* are likely to survive transit in some *Citrus* commodities.

- Transport of fruit from Mexico is likely to be by sea at low temperatures and may take up to three weeks. The larval stage lasts 21–28 days under optimal temperatures. Development

continues to occur at temperatures as low as 10°C. However, development will take considerably longer at low temperatures (Christenson and Foote 1960). Therefore, some larvae may survive under these conditions.

Likelihood of establishment:

Given the arguments and evidence below, *Anastrepha ludens* has a moderate ability (with low to moderate uncertainty) to move from imported fruit into a suitable environment to allow establishment, that is, onto a host plant.

Anastrepha ludens can survive and develop on discarded *Citrus* fruit and fruit pieces.

- Infested fruit may contain many eggs, as females usually lay them in batches of about 10, and multiple ovipositions by different females can take place in a single fruit (Aluja 1994). Once these eggs hatch, the larvae feed within the fruit. Larvae move from the fruit to pupate in the soil or other suitable substrates (Aluja 1994). Adult *A. ludens* can emerge from buried fruit (Christenson and Foote 1960).
- If infested *Citrus* fruit is discarded as whole fruit or fruit pieces, *A. ludens* may complete larval development in the waste and find a suitable location to pupate.

Most citrus fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any *A. ludens* present would either be killed or unable to escape from the *Citrus* host.

- In New Zealand, most waste is either bagged and sent to landfill or run through kitchen disposal units (see section 2.4.1, waste analysis). *Anastrepha ludens* in infested fruit is unlikely to survive in these circumstances.

However, some waste is likely to be disposed of using high risk methods, including composting in gardens, use as animal feed, or discarding directly into the environment.

- A small proportion of infested fruit is likely to be discarded in a home compost bin or open compost heap, or directly into the environment (see section 2.4.1, waste analysis).
- *Anastrepha ludens* larvae move from fruit to pupate in soil or other suitable substrate (Aluja 1994). Adults have been known to emerge from fruit buried more than 45 cm below the ground (Christenson and Foote 1960). Therefore, some larvae or pupae associated with discarded citrus may find suitable conditions to develop to adulthood.
- Before becoming sexually mature, adults go through a period where they need carbohydrates and water for survival and protein for gonad development (Aluja 1994). Adults emerging from the soil are likely to find suitable food in the environment, such as bird droppings, nectar and plant sap (Christenson and Foote 1960).
- *Anastrepha ludens* is a polyphagous species and can complete development on many unrelated species. It is associated with a total of 96 plant species/taxa. Of these, 45 taxa belonging to 24 genera in 17 families have validated record of infestation under natural field conditions (Liquido et al. 2017). Known host species are present in New Zealand in modified habitats, for example, citrus, avocado, guava, peach, apple, pear, persimmon, passionfruit, as are species within the same genus as known hosts, such as the native species *Passiflora tetrandra* and *Syzygium maire*. Therefore, host plants are likely to be present in areas where waste fruit has been disposed of.

Anastrepha ludens can disperse to find a suitable host.

- *Anastrepha ludens* adults emerging from pupae disperse to find a suitable host plant. The presence of host fruit (particularly *Citrus*) for oviposition in the landscape is associated with increased abundance of female *A. ludens* (Vanoye-Eligio et al. 2019a, Vanoye-Eligio et al. 2019b). This supports the potential for *A. ludens* to locate suitable hosts to establish a population.
- In climatically suitable locations where host plants are present, adults will not fly far from the site of emergence (the average dispersal distance is approximately 100 m (Hernández et al. 2007)).
- However, *A. ludens* is capable of long-distance dispersal if resources are scarce (Aluja 1994). The fruit fly regularly disperses up to 100 km from the site of emergence, and distances as far as 260 km have been recorded (Christenson and Foote 1960).

The level of uncertainty associated with this conclusion is low to moderate. Firstly, waste data may not be very accurate or up to date (see section 2.4.1, waste analysis). Secondly, it is uncertain what proportion of composting sites are exposed or uncovered (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *A. ludens* to establish is considered moderate.

New Zealand's climate in some fruit-growing regions is likely to be suitable for *A. ludens*.

- Given the current geographical range of *A. ludens*, which is widespread in Mexico, it is likely to establish in both the North and South Islands of New Zealand, especially in the warmer areas of northern New Zealand. Some of the Mexican states where it occurs have areas with a high climate match with New Zealand, with a climate match index (CMI) of 0.7 or greater (Phillips et al. 2018):
 - Aguascalientes (0.7 CMI), Durango (0.7–0.8 CMI), Guanajuato (0.7 CMI), Oaxaca (0.7–0.8 CMI), Puebla (0.7–0.8 CMI), San Luis Potosí (0.7–0.8 CMI), Tlaxcala (0.7–0.8 CMI), Zacatecas (0.7–0.8 CMI)
- Molina-Nery et al (2014) studied genetic diversity and structure of *A. ludens* populations from seven Mexican states (Chiapas, Yucatán, Morelos, Veracruz, San Luis Potosí, Tamaulipas and Durango). Some of the sites were at higher elevations and had mean annual temperatures below 20°C. For example, the collection site in Morelos was at 1,920 metres above sea level (masl), with a mean annual temperature of 15°C with warm humid climate; the site in Durango was at 2,500 masl, with a mean annual temperature of 14.6°C with warm subhumid climate; and the site at Chiapas was at 1,660 masl, with a mean annual temperature of 17.6°C with warm temperate subhumid climate. Mean annual temperatures in the north of New Zealand are within this range (NIWA 2020), and it is very likely other areas in both the North and South Islands are climatically suitable also.
- Vanoye-Eligio et al. (2017) studied *A. ludens* in the neighbouring municipalities of Miquihuana and Bustamante in the state of Tamaulipas, between 99°22'33"W, 23°38'06"N and 99°48'50"W, 22°58'07"N. Their sites extended over the highlands of the Sierra Madre Oriental in the southwestern part of the state with altitude ranges from 1,800 to 1,950 masl. Their study indicates that semi-arid ecosystems above 1,500 masl are native habitats of *A. ludens* populations in northeastern México. The authors note that *A. ludens* can occur in semi-arid ecosystems and temperate environments.
 - Miquihuana and Bustamante have a high climate match (0.7–0.8 CMI) with New Zealand.
- Wild populations can be self-sustaining under cool conditions although the rate of population growth is low (Thomas 2003). *Anastrepha ludens* is the dominant fruit fly in higher altitude (1100 m above sea level) regions of Mexico (Aluja 1994) and is localised to higher elevations within Central America (CPC 2010).
- *A. ludens* is multivoltine and a highly polyphagous species that can infest uncommon fruits under unfavourable climatic conditions (Vanoye-Eligio et al. 2017). In addition, adults have a long life-span and high fecundity. Vanoye-Eligio et al. (2015) and Aluja et al. (2014) note that *A. ludens* has a high degree of physiological and behavioural plasticity to adapt to varying environmental conditions. Therefore, individuals arriving in New Zealand from Mexico may not find the change in seasons a barrier to establishment.

Anastrepha ludens is likely to find mates and has a high reproductive rate.

- Multiple larvae are contained within a single fruit, and after emergence, adults can disperse to find a suitable host. Surviving pupae from the larvae contained within a single fruit would be enough to establish a population if that fruit were discarded within range of a suitable host plant. Therefore, it would be likely that there would be enough emerging adults to establish a viable population.
- *Anastrepha ludens* reproduces sexually. As multiple larvae are contained within a single fruit, both males and females are likely to be present in the same location.
- Males of *A. ludens* establish territories on the underside of leaves and emit pheromones to attract receptive females (Aluja 1994), enhancing the opportunity for mate-finding and therefore increasing the likelihood of establishment.
- Adults are long-lived and may live for up to 12 months in the field (Aluja 1994). A single female can produce over 1,000 eggs in her lifetime (Thomas et al. 2018).

Host availability is unlikely to be a barrier to establishment and spread of *A. ludens*.

- *Anastrepha ludens* is polyphagous on fruit from many different hosts (Weems et al. 2015; Liquido et al. 2017; CPC 2010). Potential host plants are available throughout New Zealand in climatically suitable areas in both commercial groves and home gardens. The main citrus-growing areas in New Zealand are Northland, Auckland, Bay of Plenty, Hawke's Bay and Gisborne. Apples are grown throughout the country, including in Hawke's Bay, Gisborne, Waikato, Tasman-Nelson, Canterbury and Otago; and peaches are grown primarily in Otago and Hawke's Bay. Avocados are grown primarily in Northland, Auckland, Waikato and Bay of Plenty (Plant & Food Research 2019). Some of the above commercial growing areas may be climatically suitable for *A. ludens*.

Anastrepha ludens may not be detected until a population is established in New Zealand.

- No male lures have yet been identified for *Anastrepha* spp. (CPC 2020). Therefore, *A. ludens* is unlikely to be detected in New Zealand's surveillance grid, because it is not responsive to the lures used (Tan et al. 2014). As a result, there is unlikely to be early warning that *A. ludens* is present in New Zealand, and it may not be detected until a population has established.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *A. ludens* is likely to be high.

Damage and symptoms caused by *A. ludens* reduces fruit quality.

- Attacked fruit can show signs of oviposition punctures, but much damage may occur inside the fruit before external symptoms are seen, often as networks of tunnels accompanied by rotting (CPC 2020).

Anastrepha ludens is considered a serious pest of citrus and other crops, with impacts on commercial production.

- Damage to crops through fruit loss is considerable in areas where *A. ludens* is present. In Mexico (areas not given) 20–40% of grapefruit is lost annually to damage by *A. ludens* (Birke et al. 2006). Damage to greater than 37% of grapefruit by *A. ludens* has been observed in Tamaulipas, which is one of the main citrus-growing regions (Vanoye-Eligio et al. 2015).
- *Anastrepha ludens* can infest many commercial crops, including *Citrus* species, apple, avocado, European pear and peach. If *A. ludens* became widespread in New Zealand, the losses could be considerable. *Citrus* is of economic importance to New Zealand (see Chapter 2, section 2.6), and apple exports alone were worth around NZ\$820.8 million in 2019 (Plant & Food Research 2019). The combined export value for fresh fruit was NZ\$3.39 billion in 2019 (Plant & Food Research 2019).
- Direct losses due to fruit fly damage on crops (citrus and other hosts, such as apples) may vary throughout New Zealand depending on factors such as the local climate and fruiting phenology of suitable hosts (Vanoye-Eligio et al. 2019a).

Establishment or an incursion of *Anastrepha ludens* is highly likely to cause trade impacts.

- The trade impact if *A. ludens* is detected in New Zealand is likely to be high due to export restrictions and/or extra phytosanitary measures being required by many trading partners.
- *Anastrepha ludens* is the subject of quarantine regulations in other countries, and detection in New Zealand could cause disruption of market access for any of its hosts, such as citrus, apple, pear, avocado, peach, passionfruit and persimmon, even if it did not establish. It is not present in existing or potential markets such as Europe, Australia, Asia and the USA. *Anastrepha ludens* is a quarantine pest in the European Union to which exports of apples from New Zealand were worth NZ\$149 million in 2019 (Plant & Food Research 2019), for example. New Zealand currently has country freedom status from all fruit flies of economic importance including *A. ludens*.
- Because *A. ludens* does not respond to lures used in New Zealand's fruit fly surveillance grid, it is likely to have an established population once detected.

If *A. ludens* is detected in New Zealand, the cost incurred by a response would be high.

- *Anastrepha ludens* is not responsive to lures based on sex attractants (Tan et al. 2014). Therefore, once detected in New Zealand, eradication would be very difficult but is likely to be attempted. Existing detection systems for pest *Anastrepha* species rely on the use of non-specific wet, protein-baited McPhail traps, which act as general food attractants (Weems et al. 2015).
- The typical cost of a response is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).

It is likely that *A. ludens* will cause a low level of sociocultural impacts in New Zealand.

- Many hosts of *A. ludens* are common amenity species and occur in gardens and parks in New Zealand, for example *Citrus* spp., peach, apple and pear. *Anastrepha ludens* are fruit feeders, and infested fruit are rendered inedible and drop prematurely. However, temperature is likely to restrict population growth, and therefore, direct losses may be variable in where they occur in the country.

It is likely that *A. ludens* will have a very low level of impact on the environment.

- *Citrus* are the primary hosts of *A. ludens*. *Citrus* species are members of the Rutaceae family. There are two genera within Rutaceae endemic to New Zealand; these are *Melicope* and *Leionema*. Neither the *Leionema* nor *Melicope* species are considered threatened (NZPCN 2020).
- New Zealand has one native species of *Passiflora* (*P. tetrandra*), which is not considered threatened, and one species of *Syzygium* (*S. maire*), which is considered threatened (nationally critical) (NZPCN 2020).
- *Anastrepha ludens* are fruit pulp feeders so may not impact on the reproductive potential of infested plants, particularly those plants bearing small fruit with limited flesh. Additionally, temperature is likely to restrict population growth and impacts may be variable as to where they occur in the country.

Anastrepha ludens is not known to have any impacts on human health.

Risk assessment summary:

Given the arguments and evidence below, *Anastrepha ludens* may be considered for additional measures.

- *Anastrepha ludens* has a strong association with fruits of some citrus species.
- Some infested fruits will not be detected, especially when the volume of commodities is large.
- As the larvae feed internally in the fruits, general handling (e.g. washing and brushing) cannot remove the larvae.
- *Anastrepha ludens* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *A. ludens* to establish is considered moderate.
- Citrus, and other hosts of *A. ludens*, such as avocados, apples, pears and peaches, are grown commercially in New Zealand and are common garden plants.
- The level of impact caused by *A. ludens* is likely to be high to the overall economy of New Zealand, mainly due to stricter phytosanitary requirements for citrus and other horticultural crops.
- *Anastrepha ludens* is present in one citrus-exporting country considered in this import risk analysis, Mexico, and considered “transient, under eradication” in the USA.

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8.3 *Bactrocera dorsalis* (Oriental fruit fly)

Bactrocera dorsalis is one of the most destructive insect pests of tropical and subtropical fruits and vegetables. It is highly polyphagous and highly adaptable to various climates, which has allowed it to spread to temperate areas.

Scientific name: *Bactrocera dorsalis* (Hendel, 1912)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera invadens*, *Bactrocera papayae*, *Bactrocera philippinensis*, *Bactrocera (Bactrocera) variabilis*, *Bactrocera ferruginea*, *Strumeta dorsalis*, *Chaetodacus dorsalis*, *Chaetodacus ferrugineus*, *Chaetodacus ferrugineus dorsalis*, *Chaetodacus ferrugineus okinawanus*, *Dacus dorsalis*, *Dacus ferrugineus*, *Dacus ferrugineus dorsalis*, *Dacus ferrugineus okinawanus*, *Dacus (Bactrocera) dorsalis*, *Dacus (Bactrocera) semifemoralis*, *Dacus (Bactrocera) vilanensis* (CPC 2020)

Taxonomic notes: CPC (2020) notes that *Bactrocera dorsalis* is a member of the Oriental fruit fly *Bactrocera dorsalis* species complex. *B. dorsalis* was originally treated as a single species, until it was split into several species, with the description of *B. carambolae*, *B. papayae* and *B. philippinensis* by Drew and Hancock (1994). Based on a total-evidence approach, *B. papayae*, *B. invadens* and *B. philippinensis* are now considered synonyms of *B. dorsalis*, but these names can still be found in numerous papers and internet website resources (Doorenweerd et al. 2018). *Bactrocera carambolae* was left as a distinct species by Schutze et al. (2014). *Bactrocera dorsalis* is known to hybridise with *B. carambolae*, and genetic evidence suggests that there is historic hybridisation with *B. kandiensis* (Schutze et al. 2015). Records of *B. pedestris* (Bezzi) from outside of the Philippines are mostly based on misidentifications of *B. dorsalis* (CPC 2020).

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera dorsalis* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera dorsalis* has a strong association with citrus fruit with low uncertainty.
- Basic measures are likely to reduce the likelihood of introduction of *B. dorsalis* by a low to moderate degree. Consequently, the likelihood of entry is considered to be moderate with low uncertainty.
- *Bactrocera dorsalis* has a moderate to high ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *B. dorsalis* to establish is considered moderate to high (with moderate uncertainty).
- The level of impact caused by *B. dorsalis* is likely to be high, with low uncertainty.
- *Bactrocera dorsalis* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate-high	moderate
Suitability of the New Zealand environment	Moderate-high	Low-moderate

Impacts on the New Zealand economy, environment, health and society	High	Low
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8.3.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera dorsalis* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁵⁷).

Bactrocera dorsalis is not known to be present in New Zealand:

- *Bactrocera dorsalis* is not recorded in NZInverts (2020) or NZOR (2020).
- *Bactrocera dorsalis* is not recorded in PPIN (2020).
- *Bactrocera dorsalis* is listed as 'Regulated' in ONZPR (2020).

Bactrocera dorsalis has the potential to establish and spread in New Zealand:

- *Bactrocera dorsalis* is distributed mainly in tropical areas (CPC 2020), but it also occurs in areas that have similar climate conditions to New Zealand.
- *Bactrocera dorsalis* is highly polyphagous, with over 300 species of commercial/edible and wild hosts (CPC 2020).
- Hosts commercially grown in New Zealand and commonly found in home gardens include, but are not limited to: apple (*Malus domestica*), cherries, apricot (*Prunus armeniaca*), avocado (*Persea americana*), capsicum (*Capsicum annuum*), citrus (*Citrus* spp.), cucumber (*Cucumis sativus*), grapevine (*Vitis vinifera*), guava (*Psidium guajava*), loquat (*Eriobotrya japonica*), peach (*Prunus persica*), pear (*Pyrus* spp.), persimmon (*Diospyros kaki*) and plum (*Prunus domestica*) (CPC 2020; EPPO 2020a).

Bactrocera dorsalis has the potential to cause impacts on the economy and environment of New Zealand:

- *Bactrocera dorsalis* has the potential to damage plant species that are of economic importance to New Zealand, such as citrus, apple, avocado, pear and grapevine.
- *Bactrocera dorsalis* has the potential to harm the New Zealand environment: *B. dorsalis* has been reported on plant species in genera that are present in New Zealand (NZPCN 2020).

8.3.2 Hazard identification: commodity association

Bactrocera dorsalis is associated with citrus fruit

Bactrocera dorsalis is reported from citrus fruit:

- *Bactrocera dorsalis* has been reported to infest citrus fruits (Cui et al. 2020).

8.3.3 Risk assessment

Likelihood of entry:

Bactrocera dorsalis has a strong association with citrus fruit with low uncertainty.

Bactrocera dorsalis has been reported to develop in various citrus species and cultivars.

- Larvae of *B. dorsalis* have been reported from various citrus cultivars, and adults of *B. dorsalis* have been reared from citrus fruits of different citrus cultivars (Leblanc et al. 2012;

⁵⁷ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining "harm".

Allwood et al. 1999). Citrus fruit host associations found in the literature are summarised in Table 9.3.1.

Table 9.3.1 Known citrus host association of *Bactrocera dorsalis*.

Citrus host scientific name	Citrus host common name from the reference	Reference	Notes
<i>Citrus aurantifolia</i>		Allwood et al. (1999)	Reared from field-collected fruit
<i>Citrus aurantifolia</i>	Lime	CPC (2020), Leblanc et al. (2013)	Field infestation
<i>Citrus aurantium</i>	Sour orange	CPC (2020)	
<i>Citrus reticulata</i>	Clementine	USDA (2016)*	
<i>Citrus reticulata</i>	Italian tangerine, Willow-leaf mandarin	USDA (2016)*	
<i>Citrus reticulata</i>		USDA (2016)*	
<i>Citrus maxima</i>		Allwood et al. (1999)	Reared from field-collected fruit
<i>Citrus hystrix</i>	Mauritius bitter orange	CPC (2020)	
<i>Citrus limon</i>	Bush lemon	Hancock et al. (2000)	Breeding in fruit
<i>Citrus reticulata</i>	Kabuchi, Keraji	USDA (2016)*	
<i>Citrus latifolia</i>	Tahiti lime	Leblanc et al. (2013)	Reared from field-collected fruit
<i>Citrus limon</i>	Sweet lime	USDA (2016)*	
<i>Citrus limon</i>	Indian sweet lime	USDA (2016)*	
<i>Citrus limon</i>	Lemon	White and Elson-Harris (1992)	Larvae develop in the fruit
<i>Citrus medica</i> var. Mata Kerbau		Ibrahim and Rahman (1982)	Experimental host (eggs were manually laid on fruit slice)
<i>Citrus maxima</i>	Pomelo	Leblanc et al. (2013)	Reared from field-collected fruit
<i>Citrus paradisi</i>	Japanese summer grapefruit, Natsudaidai	USDA (2016)*	
<i>Citrus reticulata</i>	King orange	USDA (2016)*	
<i>Citrus reticulata</i>		USDA (2016)*	
<i>Citrus paradisi</i>		Hancock et al. (2000) (CPC 2020; EPPO 2020a)	Breeding in fruit
<i>Citrus reticulata</i>	Mandarin	CPC (2020), Allwood et al. (1999)	Reared from field-collected fruit
<i>Citrus sinensis</i>	Navel orange	Leblanc et al. (2013)	Reared from field-collected fruit
<i>Fortunella swinglei</i>		CPC (2020)	
<i>Citrus</i> spp.	Tangerine, Orange, Grapefruit, Lemon	Loomans et al. (2019)	
<i>Poncirus trifoliata</i>	Trifoliolate orange	Leblanc et al. (2013)	Reared from field-collected fruit
<i>Citrus reticulata</i>	Sweet orange	Han et al. (2011)	Field infestation
<i>Citrus reticulata</i> x <i>Citrus paradisi</i>	Tangelo	EPPO (2020a)	

* For hosts listed in USDA (2016), USDA mentioned that, "The berries, fruit, nuts and vegetables of the listed plant species are now considered host articles for *B. dorsalis*. Unless proven otherwise, all cultivars, varieties, and hybrids of the plant species listed herein are considered suitable hosts of *B. dorsalis*." However, there were no original references cited.

Bactrocera dorsalis can be associated with citrus fruit commodities.

- *Bactrocera dorsalis* has been intercepted over 90 times at the New Zealand border. Among these records, *B. dorsalis* has been intercepted alive from fresh produce of limes (unknown life stage) and *C. reticulata* (larval stage) (LIMS 2019).
- *Bactrocera dorsalis* has been intercepted on *Citrus paradisi* and *C. maxima* in Europe (EPPO 2020b).
- In Hunan, China, the adult population peak of *B. dorsalis* coincided with the ripeness period of sweet oranges in October. Subsequently, larvae were found in sweet oranges between late September and early November (Han et al. 2011), suggesting that the fly is associated with mature fruits.
- Adult females of *B. dorsalis* lay eggs under the skin of the ripened or ripening fruits (Ye and Liu 2007).

Bactrocera dorsalis is present in a number of the citrus-exporting countries covered by this IRA:

- *Bactrocera dorsalis* is present in China, Viet Nam, the USA (California⁵⁸, Hawaii), and Australia (Torres Strait Islands)⁵⁹.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *B. dorsalis* by a low to moderate degree. Consequently, the likelihood of entry is considered to be moderate, with low uncertainty:

Some of the infested fruits may be detected and removed.

- Oviposition of *B. dorsalis* may cause necrosis around the puncture mark, followed by decomposition of the fruit (CPC 2020).
- If bagging and culling are used in the export countries, these practices are likely to reduce the likelihood to some extent. Xia et al. (2019) found that fruit bagging and packing house culling (including preliminary culling, washing, waxing, drying, intensive culling, sorting and final culling and box-packing) could contribute to risk mitigation of fruit flies in citrus in China. The study found few oviposition marks and an absence of living tephritid fruit flies in bagged pomelo fruits ($n=3,000$) (where n =sample size), while 129 fruit fly-infested fruits (containing 634 live larvae and 4 pupae of *B. dorsalis*) were found in the unbagged fruits ($n=3,040$). They also found that in fruit (*C. unshiu*) that received culling treatment ($n=10,000$), fruit flies were absent, and 10 fruits with oviposition marks (with no living fruit flies) were found, while in fruit that did not receive the culling treatment ($n=10,000$), one infested fruit with 7 larvae of *B. minax* and 25 fruits with fruit fly oviposition marks were found.
- *Bactrocera dorsalis* can cause rot and fruit drop (Jiang et al. 2011). Rotting fruit and fruit that drops on the ground is not likely to be picked up and exported.

However, eggs and larvae of *B. dorsalis* are unlikely to be visible in the course of general handling during and after harvest.

- Eggs of *B. dorsalis* are laid under the skin of the ripened or ripening fruits and the larvae feed inside the fruit (Ye and Liu 2007). Because general handling after harvesting (e.g. washing and brushing) only treats the surface of fruit, it is unlikely to remove the larvae of *B. dorsalis* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *B. dorsalis* inside, but eggs are harder to detect.

It is likely that some infested fruits will not be detected.

- A low level of infestation (fewer oviposition punctures in fruit) may not be obvious enough to be detected during general handling.

⁵⁸ California is recorded as "Present, Transient under eradication" in CPC (2020) and EPPO (2020a). CPC (2020) comments that as *B. dorsalis* is repeatedly trapped in California in small numbers, whether or not the fly is actually established in continental America is a hotly debated topic.

⁵⁹ Reported as *B. papaya* or *B. philippinensis*. The fly is present in the Torres Strait Islands, but it has been eradicated from mainland Australia (Hancock et al. 2000).

- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.
- *Bactrocera dorsalis* has been identified over 90 times at the New Zealand border. Among these records, *B. dorsalis* has been intercepted alive from fresh produce of limes (unknown life stage) and *C. reticulata* (larval stage) (LIMS 2019), suggesting that some infested fruit cannot be detected during general handling after harvest.

Larvae of *B. dorsalis* are likely to survive transit of some citrus commodities.

- Larvae of *Bactrocera dorsalis* have been intercepted alive in citrus fresh produce at the New Zealand border (LIMS 2019), suggesting that it can survive transit by air or sea in some citrus commodities.

Likelihood of establishment:

Given the arguments and evidence below, *Bactrocera dorsalis* has a moderate to high ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure).

Bactrocera dorsalis can survive and develop on the waste of citrus fruit (whole fruit or fruit pieces but probably not skin).

- Adult *B. dorsalis* have been reared from field-collected fruit of *Citrus aurantiifolia*, *C. latifolia*, *C. maxima*, *C. reticulata*, *C. sinensis*, *C. trifoliata* and *C. grandis* (Leblanc et al. 2012; Allwood et al. 1999).
- If citrus fruit is disposed of as whole fruit or fruit pieces, it is likely that *B. dorsalis* can survive in this waste. There is no evidence showing that *B. dorsalis* can complete development by feeding on citrus fruit skin.

Most of the waste in New Zealand would be disposed of using low-risk methods, so *B. dorsalis* would either be killed or unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills and run through kitchen disposal units, and in these situations, *B. dorsalis* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and use as animal feed.

- *Bactrocera dorsalis* is highly polyphagous. Many hosts (such as apple, apricot, avocado, capsicum, citrus, cucumber, grapevine, guava, loquat, passionfruit, peach, pear, persimmon and plum) are widely distributed in New Zealand and are commercially grown and/or commonly found in home gardens.
- Adults of *B. dorsalis* lay eggs below the skin of fruits, and eggs usually hatch within a day, but hatching can be delayed for up to 20 days in cool conditions. Larvae feed inside the fruit for 9–35 days depending on the season. The fly pupates in the soil under the host plant (Christenson and Foote 1960).
- An overwintering experiment in Hubei shows that while larvae and adults of *B. dorsalis* could not survive during the winter (around freezing temperature), a small proportion of pupae survived. Successful overwintering of pupae depended on the date and the depth at which the pupae were placed into the soil (Han et al. 2011). This suggests that pupae of *B. dorsalis* are cold-resistant and may be able to overwinter in the soil after leaving the fruit host.
- If hosts are not far from the composting site or animal feeding site (see the waste analysis in section 2.4.1), adult *B. dorsalis* is likely to locate a new host.

Adult *B. dorsalis* can fly for a moderate to long distance to food sources.

- According to a laboratory test with a flight-mill system, the maximum flight distance of *B. dorsalis* is 46 km (Liang et al. 2001).
- Mean dispersal distances from below 1 km to 3.6 km have been reported for *B. dorsalis*. However, the maximum dispersal distance reported in these studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014).
- Makumbe et al. (2020) investigated the tethered flight performance of *B. dorsalis*, showing that the longest total distance flown in 1 hour was about 15 km.

The longevity of adult *B. dorsalis* is likely to increase the likelihood for locating a suitable host.

- Adults of *B. dorsalis* normally live for 1 to 3 months, depending on diet and temperature. The lifespan can be up to 12 months in cool mountain locations (Christenson and Foote 1960). The longevity of adults is likely to increase the chance for locating a mate and a suitable host.

The level of uncertainty associated with the conclusion is low to moderate. Firstly, waste data may not be very accurate and up to date, and it is not known how frequently suitable hosts will be present near composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Secondly, it is uncertain what proportion of composting sites are exposed or enclosed (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *B. dorsalis* to establish is considered moderate to high (moderate uncertainty).

The current known distribution of *B. dorsalis* is mostly tropical and subtropical areas, but the current distribution also covers areas with similar climate conditions to New Zealand.

- *Bactrocera dorsalis* is native to Asia, and its current distribution is predominantly in the tropics and subtropics (Table 9.3.2).
- The current distribution includes countries and areas with a climate match index (CMI) (Phillips et al. 2018) of 0.7–0.8. These areas include Himachal Pradesh in India (CMI: 0.7–0.8), Anhui, Chongqing, Guizhou, Hubei, Hunan, Jiangsu, Shanghai, Yunnan, Zhejiang in China (CMI: 0.7) and Sichuan in China (CMI: 0.8). This suggests that *B. dorsalis*, or some populations of the species, can adapt to a colder, temperate climate.

Table 9.3.2 Known geographic distribution of *Bactrocera dorsalis*. Information compiled 11 September 2020 from CPC (2020) and EPPO (2020a). Country/area with “*” is only recorded in CPC (2020); country/area with “**” is only recorded in EPPO (2020a). Country/area in **bold** is included in the Citrus IHS project.

Continent/Region	Country/area
Africa	Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo, Democratic republic of the, Cote d'Ivoire, Equatorial Guinea, Eritrea, Eswatini**, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Mali, Mauritania, Mayotte, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, Senegal, Sierra Leone, Sudan, Swaziland*, Tanzania, Togo, Uganda, Zambia, Zimbabwe
Asia	Bangladesh, Bhutan, Brunei Darussalam, Cambodia, China (Anhui, Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hubei, Hunan, Jiangsu, Jiangxi, Shanghai, Sichuan, Tibet, Yunnan, Zhejiang, Hong Kong) , Christmas Island*, East Timor*, India, Indonesia, Lao, Malaysia, Myanmar, Nepal, Oman, Pakistan, Philippines, Singapore, Sri Lanka, Taiwan, Thailand, United Arab Emirates, Viet Nam
North America	The USA (California⁶⁰, Hawaii)
Oceania	Australia⁶¹ (Torres Strait islands) , French Polynesia, Nauru, Christmas Island**, Northern Mariana Islands, Palau, Papua, New Guinea, Timor-Leste**

Bactrocera dorsalis has a very broad host range, therefore, host availability is unlikely to be a limiting factor for it to establish in New Zealand.

- *Bactrocera dorsalis* is categorised by Vargas et al. (2015) as a Category A species (widespread invasive polyphagous generalists or highly destructive specialists that have

⁶⁰ California is recorded as “Present, Transient under eradication” in CPC (2020) and EPPO (2020a). CPC (2020) comments that as *B. dorsalis* is repeatedly trapped in California in small number, whether or not the fly is actually established in continental America is a hotly debated topic.

⁶¹ Reported as *B. papaya* or *B. philippinensis*. The fly is present in Torres Strait islands, but it has been eradicated from mainland Australia (Hancock et al. 2000).

become established outside their native ranges) and is highly polyphagous. It has over 300 species of commercial/edible and wild hosts (CPC 2020).

- Many hosts are commercially grown and commonly found in home gardens and parks, such as apple, apricot, avocado, capsicum, citrus, cucumber, grapevine, guava, loquat, peach, pear, persimmon and plum (CPC 2020; EPPO 2020a). Therefore, hosts are likely to be available in all seasons and present in most areas in New Zealand.

Bactrocera dorsalis has a rapid dispersal ability.

- *Bactrocera dorsalis* has strong flight capability. A laboratory test with a flight-mill system shows that the maximum flight distance of *B. dorsalis* is 46 km (Liang et al. 2001). According to Weldon et al. (2014), compared to other *Bactrocera* species, mean dispersal distances recorded for *B. dorsalis* in mark-release-recapture (MRR) studies are higher, ranging from below 1 km to 3.6 km, while mean dispersal distances for other *Bactrocera* species recorded are well under 1 km.
- Eggs and larvae of *B. dorsalis* are inside the fruits, therefore, they are unlikely to be visible. Therefore, transporting of infested fruits is a major means by which the fly can spread to areas that were not infested previously.

Bactrocera dorsalis has a high reproductive rate.

- A female of *B. dorsalis* can lay 3–30 eggs in each oviposition (Fletcher 1989, in Ye and Liu 2007) and more than 1,000 eggs during its lifespan (Zhou et al. 1996, in Ye and Liu 2007). Under laboratory conditions, a female can lay more than 1,000 eggs during its lifetime (Shelly 2000).
- Female *B. dorsalis* can release sex pheromones to attract males (Shen et al. 2019), which increases the probability of females finding mates.
- Female *B. dorsalis* re-mate, which implies that even if sperm reserves were depleted, egg laying would resume if the female found another male (Shelly 2000).

Bactrocera dorsalis has multiple overlapping generations in both warmer and colder climates.

- The number of generations per year and occurrence of *B. dorsalis* differ through its geographic distribution, but in general, *B. dorsalis* has 3–5 overlapping generations per year in most tropical areas in its distribution and may reach 10 generations per year under optimal conditions (Ye and Liu 2007).
- In Xishuangbana, Yunan, China (CMI: 0.6), *B. dorsalis* is present all year round (Ye and Liu 2007), while in Baoshanba, Yunan (CMI: 0.7–0.8), *B. dorsalis* occurs during April–November, with the population peak in August (Chen and Ye 2007). In Hubei, China (CMI: 0.7), where the typical climate is hot and wet in summer and freezing cold in winter, five generations per year were observed (Han et al. 2011).

Bactrocera dorsalis is a highly invasive species, both in its native and introduced range.

- *Bactrocera dorsalis* is highly invasive. The fly is native to Asia, but is now found in at least 65 countries. It is a serious pest of a wide range of fruit crops throughout its native and introduced range (CPC 2020).
- High genetic variability may facilitate the adaptation of *B. dorsalis* to a new habitat during invasion. High genetic diversity within the *B. dorsalis* population was observed in its native range, and multiple introductions and hybridisation among related populations in the introduced range may further enhance genetic diversity (Wan et al. 2012; Aketarawong et al. 2007).

The current national surveillance programme is likely to reduce the likelihood of *B. dorsalis* establishing a permanent population in New Zealand.

- *Bactrocera dorsalis* is one of the targeted fruit fly species in the National Fruit Fly Surveillance Programme in New Zealand (MacLellan et al. 2019). The male of *B. dorsalis* is attracted to methyl eugenol lure (Plant Health Australia 2001).

A modelling study indicates that many areas of New Zealand are likely to be suitable for the establishment and short-term population occurrence of *B. dorsalis*.

- A CLIMEX™ model of *B. dorsalis* indicates that under the reference climate (1961–1990), it could establish throughout much of the low-lying areas of the North Island, and most parts of

New Zealand could support short-term populations during the summer months (Kriticos et al. 2007).

Bactrocera dorsalis is a highly invasive pest in both its native and introduced range, and the species has the biological and ecological features to be invasive in new habitats (e.g. high productivity rate, high genetic variability and strong flight ability). Its current distribution includes areas with similar climate to New Zealand. However, its current distribution is predominantly in the tropics and subtropics, which are warmer than the overall climate of New Zealand. Due to the uncertainty around the suitability of all of New Zealand's climate for the fly, the level of uncertainty associated with the conclusion is moderate.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. dorsalis* is likely to be high, with low uncertainty.

Damage and symptoms caused by *B. dorsalis* can reduce fruit quality.

- Eggs of *B. dorsalis* were laid under the skin of the ripened or ripening fruits, and the larvae feed on the fruit pulp, which causes severe damage to the fruits. Necrosis may form around the oviposition puncture mark, followed by decomposition of the fruit (CPC 2020).
- Fruit infested with *B. dorsalis* become malformed, and larval feeding damage allows for infection by secondary pathogens, causing fruit to rot and ultimately fall from the plant (Tara et al. 2006).

Bactrocera dorsalis has been reported to cause severe damage to and production loss of a wide range of fruit crops in tropical and subtropical areas, and areas with a similar climate to New Zealand.

- *Bactrocera dorsalis* is a devastating pest of a wide variety of fruits and vegetables throughout its range, and damage levels can be up to 100% of unprotected fruit (CPC 2020).
- In Yunnan (CMI: 0.7), China, infestation rates by *B. dorsalis* of over 30% have been reported on mango (Zhou et al. 1996).
- In Sichuan (CMI: 0.8), infestations of *B. dorsalis* occur on pear, apple, mango, peach and guava. Infestation levels of fruit are usually 20% but can be as high as 50% (Zhang and Zhao 1994).
- In Hubei (CMI: 0.7), *B. dorsalis* changes feeding patterns depending on host availability. In a survey in the area, larvae were first found in pears, followed by jujube fruit and persimmons. The most serious damage occurred in the fourth generation in citrus orchards (Han et al. 2011).

Bactrocera dorsalis is likely to cause impact on many plants of economic importance in New Zealand, and is especially likely to impact the citrus, avocado and apple industries.

- Hosts commercially grown in New Zealand include, but are not limited to: apple, apricot, avocado, capsicum, citrus, cucumber, grapevine, peach, pear, persimmon and plum (CPC 2020; EPPO 2020a).
- Pears, apples and peaches have been reported to be severely damaged and infested by *B. dorsalis* in areas with a similar climate to New Zealand (Han et al. 2011; Zhang and Zhao 1994; Zhou et al. 1996). Follet et al. (2019) found that *B. dorsalis* could produce 269 puparia per kg in Scifresh apples.
- Pears, apples and peaches are important horticultural crops for New Zealand (FOB export values: pears NZ\$10.6 million, apples \$829 million; domestic and export value peaches \$9.4 million) (Plant & Food Research 2019).
- Kriticos et al. (2007) suggest that an incursion of *B. dorsalis* could have a major impact on the citrus and avocado industries in particular. Their model predicted that almost all areas where mandarins and avocados are cultivated are areas projected to be suitable for the establishment of *B. dorsalis*. In addition, *Citrus paradisi*, *C. reticulata*, *C. sinensis* and *C. x tangelo* are reported as major hosts in EPPO (2020a), and avocado is one of the most commonly attacked species (Weems et al. 2019).
- Sales values (export and domestic) for citrus and avocado in 2019 in New Zealand are NZ\$70.5 million and \$160.8 million respectively (Plant & Food Research 2019).

The impact on exports, including market access, is likely to be severe.

- Detection of a fruit fly in the surveillance programme would need to be reported internationally and would be expected to result in reduced market access for New Zealand host materials. In New Zealand, 80% of horticultural export value came from plants that are potential fruit fly host (MacLellan et al. 2019).
- The incursion of *B. dorsalis* (reported as *B. papayae*) in north Queensland was estimated to cause losses of nearly AU\$100 million, mostly due to loss of market access (Drew 1997, in Clark et al. 2005).
- If *B. dorsalis* established in New Zealand, additional post-harvest disinfestation costs would be necessary. In Australia in 1996, apples and citrus fruit underwent a cold treatment for fruit fly at a cost of approximately AU\$200/tonne, avocados were treated with hot forced air, costing approximately AU\$125/tonne, and stone fruit, cucurbits and tomatoes were treated with a dimethoate dip, which cost approximately AU\$100/tonne (MAF 1996).
- *Bactrocera dorsalis* is of quarantine significance to EPPO (European Plant Protection Organization), APPPC (Asia and Pacific Plant Protection Commission), COSAV (Comité de Sanidad Vegetal del Cono Sur), CPPC (Caribbean Plant Protection Commission), IAPSC (Inter-African Phytosanitary Council) and OIRSA (Organismo Internacional Regional de Sanidad Agropecuaria) countries (CPC 2020).

If *B. dorsalis* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 has cost approximately NZ\$18 million (MPI 2020).
- In Japan, eradication from the Ryukyu Islands has cost more than 200 million euros (Kiritani 1998, in CPC 2020). The cost for the eradication programme in northern Queensland (1995–1999) was AU\$33 million (Cantrell et al. 2002, in CPC 2020).

Bactrocera dorsalis is likely to have low to moderate impact on the environment in New Zealand, with moderate uncertainty.

- *Bactrocera dorsalis* hosts include plant genera with native New Zealand plant species. Some of the native species in these genera have “at risk” or “threatened” conservation status, including: *Piper excelsum* subsp. *peltatum*, *P. excelsum* subsp. *psittacorum*, *P. melchior*, *Planchonella costata*, *Solanum aviculare* var. *aviculare*, *S. aviculare* var. *latifolium*, *Streblus banksia*, *St. smithii*, *Syzygium maire*. However, the magnitude of the impact of *B. dorsalis* on the environment is uncertain.
- *Bactrocera dorsalis* has been reported to attack *Syzygium* overseas (Ranganath et al. 1994). Native *Syzygium maire* could become an alternative host if *B. dorsalis* established near native lowland forest where the tree species predominantly occurs (MAF 2009).

Bactrocera dorsalis may have impacts on the urban environment (sociocultural consequences).

- *Bactrocera dorsalis* is damaging to a number of plants grown in domestic gardens and parks, such as *Vitis* spp., *Prunus* spp., *Citrus* spp. and *Malus* spp. Therefore, it is a potential nuisance pest in urban environments.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera dorsalis* may be considered for additional measures.

- *Bactrocera dorsalis* has a strong association with fruit of a wide range of citrus species/cultivars.
- Some infested fruit will not be detected, especially when the volume of commodities is large.
- As the larvae feed internally in the fruit, general handling cannot remove the larvae, and citrus fruit needs to be cut open to reveal the larvae of *B. dorsalis*.
- *Bactrocera dorsalis* has moderate to high ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The suitability of the New Zealand environment for *B. dorsalis* to establish is considered moderate to high (moderate uncertainty).

- *Bactrocera dorsalis* has a very broad host range, and therefore, host availability is unlikely to be a limiting factor for it to establish in New Zealand.
- *Bactrocera dorsalis* is a highly invasive species, both in its native and introduced range.
- *Bactrocera dorsalis* has been reported to be one of the most devastating pests in the tropics and subtropics, and severe damage of crops of economic importance has been reported from colder areas with a similar climate to New Zealand.
- *Bactrocera dorsalis* is present in citrus-exporting countries in this IHS: China, Viet Nam and the USA (Hawaii and California; the presence/absence status of the fly in California is debatable) and Australia (Torres Strait Islands).

8.3.4 References

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8.4 *Bactrocera minax* (Chinese citrus fly)

Bactrocera minax is a fruit fly species that oviposits through the skin of fruit and causes internal feeding damage to fruit. Its only known hosts are citrus and the related genera of Rutaceae. *Bactrocera minax* is only known from Asia.

Scientific name: *Bactrocera minax* (Enderlein, 1920)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Tetradacus) minax*, *Bactrocera citri*, *Callantra minax*, *Dacus citri*, *Dacus minax*, *Mellessis citri*, *Polistomimetes minax*, *Tetradacus citri* (EPPO 2020; CPC 2019; Kapoor 2005)

Taxonomic notes: CPC (2019) reported that *Bactrocera citri* had been erroneously listed as a synonym of *B. tsuneonis* prior to the work of White and Wang (1992), and that confusion has caused some cataloguers to wrongly list *B. minax* and *B. tsuneonis* as synonyms. *Bactrocera minax* and *B. tsuneonis* can be distinguished through molecular diagnostic methods (Zheng et al. 2019).

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera minax* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera minax* has a strong association with citrus fruit, with low uncertainty.
- Basic measures are likely to reduce the likelihood of introduction of *B. minax* by a moderate degree. Consequently, the likelihood of entry is considered to be low to moderate, with low uncertainty.
- *Bactrocera minax* has moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment to for *B. minax* to establish is considered high, with low uncertainty, but establishment is likely to be limited by distribution of its hosts.
- The level of impact caused by *B. minax* is likely to be high, with low uncertainty.
- *Bactrocera minax* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low–moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	High	Low

8.4.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera minax* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Bactrocera minax is not known to be present in New Zealand:

- *Bactrocera minax* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020);
- *Bactrocera minax* is an unwanted organism (ONZPR 2020);
- *Bactrocera minax* is listed as 'Regulated' in ONZPR (2020).

Bactrocera minax has the potential to establish and spread in New Zealand:

- *Bactrocera minax* is present in Bhutan, China, Nepal (CPC 2019) and India (Xia et al. 2018). Some of the areas in China that are reported to have the pest have a similar climate to New Zealand.
- *Bactrocera minax* is a specialist of citrus and related genera of Rutaceae, which means that plant species in these genera are the only known hosts of *B. minax* (CPC 2019).
- Citrus is commercially grown in New Zealand and commonly grown in home gardens.

Bactrocera minax has the potential to cause impacts on the economy and environment of New Zealand:

- *Bactrocera minax* has the potential to harm citrus, which is of economic importance to New Zealand.
- *Bactrocera minax* has the potential to have sociocultural impacts: citrus is commonly planted in home gardens.

8.4.2 Hazard identification: commodity association

Bactrocera minax is associated with citrus fruit.

Bactrocera minax is reported from citrus fruit:

- *Bactrocera minax* oviposits through the skin of citrus fruit, and larvae feed inside the fruit (CPC 2019).

8.4.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera minax* has a strong association with citrus fruit, with low uncertainty.

Larvae of *B. minax* have been reported in citrus fruit.

- Adult females of *B. minax* lay eggs through the skin of young fruit of citrus with diameters of 2 to 4 cm. Navel orange, other early-ripening cultivars and pomelo are preferred hosts of the insect in China, although pomelo have thick skins and are typically 15–25 cm in size (Xia et al. 2018). CPC (2019) mentioned that *B. minax* has a telescopic and pointed ovipositor, and it is a large powerful insect presumably adapted to oviposition through the thick skin of oranges.
- After hatching from eggs, larvae feed inside the fruit until the third instar (Xia et al. 2018).

Larvae of *B. minax* are associated with citrus fruit commodities.

- Heavy infestation of *B. minax* causes fruit to drop prematurely (Xia et al. 2018).
- However, larvae can remain in citrus fruit during and after harvest. Low infestation in fruit may not cause premature drop, and this fruit could be harvested. There is a period of 18–52 days before larvae leave the fruit (Dorji et al. 2006).
- *Bactrocera minax* has frequently been found on citrus fruit during import inspections in Europe (Steffen et al. 2015). However, there is no interception record of *B. minax* in New Zealand (LIMS 2019). This is probably because New Zealand does not currently import host fruit from countries where the fly is present.

Citrus species/cultivars that are associated with *Bactrocera minax* are shown in Table 9.4.1.

Table 9.4.1 Known citrus host association of *Bactrocera minax*

Citrus host scientific name	Citrus host common name from the reference	Reference	Notes
All cultivated citrus species and cultivars in China		Xia et al. (2018)	
<i>Citrus aurantium</i>	Sour orange / Bitter orange	CPC (2019), Xia et al. (2018)	Field fruit infestations
<i>Citrus aurantiifolia</i>		EPPO (2020)	
<i>Citrus tachibana</i>		Xia et al. (2018)	Field fruit infestations
<i>Citrus maxima</i>		Allwood et al. (1999)	Reared from field-collected fruit
<i>Citrus ichang austera</i> hybrid		EPPO (2020), Xia et al. (2018)	'Cultivated host' in Xia et al. (2018)
<i>Citrus limon</i>	Lemon	Allwood et al. (1999)	Reared from field-collected fruit
<i>Citrus maxima</i>	Pummelo/Pomelo	CPC (2019), Xia et al. (2018)	Field fruit infestations
<i>Citrus medica</i>	Citron	CPC (2019), Xia et al. (2018)	Field fruit infestations
<i>Citrus macroptera</i>		Joint FAO/IAEA (2009)	Interception on fruit
<i>Citrus reticulata</i>	Ponkan	Xia et al. (2018)	Field fruit infestations
<i>Citrus reticulata</i>	Mandarin	Xia et al. (2018), Dorji et al. (2006)	Field fruit infestations
<i>Citrus sinensis</i>	Navel orange / Sweet orange	CPC (2019), Xia et al. (2018)	Field fruit infestations
<i>Citrus sinensis</i> × <i>Citrus maxima</i>		Xia et al. (2018)	'Cultivated host' in Xia et al. (2018)
<i>Citrus reticulata</i>		EPPO (2020), Xia et al. (2018)	Field fruit infestations
<i>Citrus reticulata</i>	Satsuma mandarin	EPPO (2020), Xia et al. (2018)	Field fruit infestations
<i>Citrus reticulata</i>		EPPO (2020)	
<i>Citrus paradisi</i>	Grapefruit	CPC (2019), EPPO (2020), Xia et al. (2018)	'Cultivated host' in Xia et al. (2018)
<i>Citrus sarcodactylis</i>		Zheng et al. (2019)	

Bactrocera minax is present in a citrus-exporting country in the citrus fresh produce IHS.

- *Bactrocera minax* is present in China (Xia et al. 2018).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *B. minax* by a moderate degree. Consequently, the likelihood of entry is considered low to moderate, with low uncertainty.

Infested fruits are usually easily detected and are likely to be removed.

- Infested fruits are easily recognised by dark colour and the small nodule caused by oviposition. The colour around the oviposition scars is quite distinct from that of healthy fruit skin (Zhang 1989). Fruit with multiple oviposition punctures and damage as described as above is likely to be removed during general handling.
- Xia et al. (2019) found that fruit bagging and packing house culling (including preliminary culling, washing, waxing, drying, intensive culling, sorting and final culling and box-packing) could contribute to risk mitigation of fruit flies in citrus in China. The study found few oviposition marks and an absence of living tephritid fruit flies in bagged pomelo fruits ($n=3,000$), while 129 fruit fly-infested fruits (containing 634 live larvae and 4 pupae of *B.*

dorsalis) were found in the unbagged fruits ($n=3,040$). They also found that in fruit (*C. unshiu*) that received culling treatment ($n=10,000$), fruit flies were absent, and 10 fruits with oviposition marks (with no living fruit flies) were found, while in fruit that did not receive the culling treatment ($n=10,000$), one infested fruit with seven larvae of *B. minax* and 25 fruits with fruit fly oviposition marks were found.

- Heavy infestation of *B. minax* causes fruit to drop prematurely (Xia et al. 2018). Dropped fruit is unlikely to be exported.

However, there is chance that a small quantity of infested fruit will not be detected.

- Low infestation (fewer oviposition punctures in fruit) may not be obvious enough to be detected during general handling. The fly can be transported in the larval stage with fruit or as puparia in packing cases (Zhang 1989).
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.
- *Bactrocera minax* has been frequently intercepted at the border in Europe (Steffen et al. 2015), suggesting that some infested fruit is not detected during general handling after harvesting.

General handling after harvesting is not likely to remove larvae of *B. minax* inside citrus fruit.

- As general handling after harvesting (e.g. washing and brushing) only treats the surface of fruit, it is unlikely to remove the larvae of *B. minax* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *B. minax* inside.

Larvae of *B. minax* are likely to survive transit of some citrus commodities.

- Transit of citrus fruits usually includes cold storage. *Bactrocera minax* is among the most cold-tolerant *Bactrocera* species. In a laboratory experiment, at 0°C, all third-instar larvae of *B. minax* survived until the 12th day of the experiment. Larval mortality reached 55% on day 22 and 93% on day 23 (Fan et al. 1994).

Likelihood of establishment:

Given the arguments and evidence below, *Bactrocera minax* has moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure).

Bactrocera minax can survive and develop on the waste of citrus fruit (whole fruit or fruit pieces but probably not skin).

- *Bactrocera minax* feeds exclusively on the fruit of citrus and related genera of Rutaceae. Adult females lay eggs on the fruit. The egg stage lasts for approximately one month, and the larvae feed inside the fruit until maturity (Xia et al. 2018).
- If citrus fruit is disposed of as whole fruit or fruit pieces, it is likely that *B. minax* can survive in this waste. There is no evidence to show that *B. minax* can complete development by feeding on citrus fruit skin.

Most of the waste in New Zealand would be disposed of using low-risk methods, so *B. minax* would either be killed or unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills and run through kitchen disposal units, and in these situations, *B. minax* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and use as animal feed.

- Adults of *B. minax* emerging from the soil are likely to be able to find food in the environment if citrus fruit waste is disposed of using high-risk methods. The mature larvae emerge from the fruits and drop into soil for overwintering and pupate (Xia et al. 2018). Sexually immature adults feed on honeydew from insects, nectar and sooty mould on non-host plants (Dong et al. 2014). Sexually mature adults lick sooty moulds, bird faeces and an unknown substance

on citrus leaves and fruits. These fruit sources are common in farms, parks and home gardens.

- It is reported that all cultivated *Citrus* species and cultivars are hosts of *B. minax* (Xia et al. 2018). It is also reported from *Fortunella* sp. and *Poncirus trifoliata* (CPC 2019).
- Hosts for oviposition and larval development are available in most areas of New Zealand. *Citrus* is commercially produced in both the North Island and the South Island, with most commercial production taking place in the North Island (See section 2.4.2). *Citrus* is also a common plant species grown in home gardens.
- If *Citrus* hosts are located near the composting site or animal feeding site (see the waste analysis in section 2.4.1), adult *B. minax* is likely to locate the *Citrus* host.

Adult *B. minax* can fly to food sources and locate *Citrus* hosts, although it is not known whether it is a strong flier.

- A field experiment (He et al. 2019) showed that emerging adults released from a citrus orchard could fly to the forest near the orchard. The mean straight-line distance from the release point to the third landing point was between 5 and 16 m. The total distance *B. minax* flew was longer than the mean straight-line distance, as it made two landings before flying to the third landing point.
- No study investigating the flight capability of *B. minax* has been found. However, studies on other tephritids reveal that the mean dispersal distance of tephritid flies is usually well below 1 km, except that mean dispersal distances from below 1 km to 3.6 km have been reported for *B. dorsalis*. However, the maximum dispersal distance reported in many studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014).

The level of uncertainty associated with the conclusion is low–moderate. First, waste data may not be very accurate and up to date, and it is not known how frequently suitable hosts would be present near composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Second, it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin). Third, although *B. minax* can fly to seek food sources and citrus hosts, its flight capability is uncertain. There is a lot of information for other tephritid flies, but the maximum dispersal distance reported from many studies was limited to the distance of the trap placed furthest from the release point.

Given the arguments and evidence below, the suitability of the New Zealand environment for *B. minax* to establish is considered high, with low uncertainty, but the area of establishment is likely to be limited by the distribution of its hosts.

Bactrocera minax appears to be a temperate species.

- *Bactrocera minax* is currently restricted to Bhutan, China, Nepal (CPC 2019) and northwest India bordering with China (Xia et al. 2018). In China, the known distribution is in areas between 24–33°N latitude, usually 230–1,500 m in altitude. It is present in Guangxi, Guizhou, Hubei, Hunan, Jiangxi, Shaanxi, Sichuan, Chongqing and Yunnan. Henan and Jiangsu provinces have reported *B. minax* previously, but the pest was either eradicated or disappeared by itself (Xia et al. 2018).
- Guizhou, Hubei, Hunan, Shaanxi, Sichuan, Chongqing, Yunnan and part of Northwest India have similar climate conditions to New Zealand, with Climate Match Index (CMI) between 0.7–0.8 (Phillips et al. 2018).
- Yunnan-Guizhou Plateau is believed to be the region of origin for *B. minax* (Xia et al. 2018). In spite of its low-latitude location, it has a CMI between 0.7 and 0.8.

Bactrocera minax is likely to survive cold temperature in New Zealand.

- *Bactrocera minax* is among the most cold-tolerant *Bactrocera* species. In a laboratory experiment, at 0°C, all third-instar larvae of *B. minax* survived until the 12th day of the experiment. Larval mortality reached 55% on day 22 and 93% on day 23 (Fan et al. 1994).

Bactrocera minax has a moderate reproduction rate.

- *Bactrocera minax* is univoltine (has one generation per year), unlike all other *Bactrocera* species (Dorji et al. 2006). A female adult lays 50 to 200 eggs (Xia et al. 2018) during its lifetime, and the average number of eggs produced is 48.33 per female (Zhang 1989). The average number of larvae in the infested fruit is 9.5 (Zhang 1989).

Host availability is unlikely to be a limiting factor for *B. minax* to establish in New Zealand, but establishment is likely to be limited by the distribution of its hosts.

- Eggs of *B. minax* are laid on citrus fruit, and the larvae develop in citrus fruit. Citrus is commercially produced in both the North Island and the South Island, with most commercial production taking place in the North Island (see section 2.4.2). Citrus is also commonly grown in home gardens.
- Adults of *B. minax* can feed on a wide range of food sources. Sexually immature adults feed on honeydew from insects (preferred food), nectar and sooty mould on non-host plants. Sexually mature adults lick sooty moulds, bird faeces and an unknown substance on citrus leaves and fruits (Dong et al. 2014; Zhang 1989).
- Current known hosts of *B. minax* are restricted to *Citrus*, *Poncirus* and *Fortunella*. Therefore, if the fly establishes in New Zealand, the area of establishment is likely to be limited by the distribution of its hosts (commercial citrus-growing areas, see section 2.4.2).

Bactrocera minax has become a major pest of citrus outside its native range.

- In Dhankuta, Ramechhap and Sindhuli (CMI: 0.5–0.6), Nepal, *B. minax* has been reported to be the major pest affecting citrus. At least 60% of fruit drops caused by *B. minax* have been reported from Sindhuli and Ramechhap. Up to 100% production loss has been reported from the eastern region of Nepal, and growers had to replace sweet orange and lemon (preferred hosts of *B. minax*) with mandarin (Acharya and Adhikari 2019).
- In Bhutan, *B. minax* is one of the major citrus pests and can cause over 50% fruit drop of mandarin (Dorji et al. 2006).
- *Bactrocera minax* has also been reported as a devastating pest of citrus in India (Wang et al. 2014), but details about damage and production loss in India were not found.

It is not known that there is any effective attractant for trapping *B. minax*, and it may not respond to lures in current fruit fly surveillance in New Zealand.

- Without an effective attractant for *B. minax*, the possibility of missing an incursion is higher compared to other species that respond to lures. Surveillance for fruit flies in New Zealand uses trimedlure, cuelure and methyl eugenol as lures (MacLellan et al. 2019). However, cuelure or methyl eugenol are not attractive to *B. minax* (Xia et al. 2018), and no evidence was found that trimedlure is attractive to *B. minax*.
- Hou et al. (2018) conducted a field trial to determine the efficacy of eight attractant traps⁶² for *B. minax* and showed that the effectiveness of these attractant traps is low.
- Food based lures are extensively used in citrus groves, and coloured sticky spheres are being used in recent years in limited groves in China, but they are primarily for mass-trapping efforts (Xia et al. 2018).

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. minax* is likely to be high, with low uncertainty.

Damage and symptoms caused by *B. minax* can reduce fruit quality.

- Oviposition of *B. minax* leaves scars (or puncture) on the skin of citrus fruit with small nodules. The colour around the oviposition scar is yellowish and distinct from that of healthy

⁶²“(1) sugar mixture: a homemade sugar solution with vinegar and wine mixture (10 g sugar, 5 g ethylic acid, and 3 mL alcohol in 100 mL water); (2) torula yeast: 3 pellets per 300 mL water (Chemtica Internacional S.A., Santa Rosa, Costa Rica); (3) Great bait: Great® fruit fly bait, a protein-based bait, 1:3 (vol:vol) solution at the recommended application rate (Hubei Great® Biotech Co. Ltd, Wuhan, China); (4) sticky sphere: a green-colored sticky sphere, 7 cm diam, green polystyrene sphere, with 1 mm thickness transparent sticky glue on the surface (Nongjie Technology Development Co. Ltd, Changsha, Hunan, China); (5) methyl eugenol: a solid sustained-release preparation (Chemtica Internacional S.A., Costa Rica); (6) cuelure: a solid sustained-release preparation (Chemtica Internacional S.A., Costa Rica); (7) 2-component: a 2-component fruit fly bait with a solid sustained-release preparation of ammonium acetate + putrescine (Scentry Biologicals, Inc., Billings, Montana, USA); and (8) 3-component: a 3-component fruit fly bait with a solid sustained-release preparation of ammonium acetate + putrescine + trimethylamine (Scentry Biologicals, Inc., Billings, Montana, USA).” Hou et al. (2018)

fruit skin. Oviposition puncture and internal feeding by the larvae can lead to distortion and rotting of fruit (Zhang 1989).

- Heavy infestation can cause premature fruit drop (Xia et al. 2018).

Bactrocera minax has been reported to cause severe damage and production loss of citrus in areas with a similar climate to New Zealand.

- *Bactrocera minax* is the most destructive citrus pest in south-central China. It can cause up to 100% fruit damage in severe infestation (Xia et al. 2018; Zhang 1989).
- Xia et al. (2018) summarises field fruit infestations by *B. minax* in different citrus orchards from the main citrus-producing provinces in China.
 - In Guizhou (CMI: 0.7–0.8), *B. minax* occurred in 68.8% (4,180 ha) of the surveyed area. Infestation varied from less than 1% to 100% between 1994 and 1996.
 - In Hubei (CMI: 0.7), most surveys from 1980 to 2012 indicated 20% or higher (up to 90%) of fruit infestations due to *B. minax*.
 - In Hunan (CMI: 0.7), surveys between 2010 to 2012 revealed over 50% to 100% fruit infestation in some orchards.
 - In Sichuan (CMI: 0.8), surveys between 1982 to 1992 and between 1997 and 2011 indicated average infestation caused by *B. minax* was between 20% and 30%.
- The pest has been also reported to cause severe damage in warmer areas. Van Schoubroeck (1999) reports that *B. minax* caused 35% to 75% fruit drop in citrus in mid- and high-altitude orchards (<1,100 masl) in Bhutan. A study in Sindhuli, Nepal found that *B. minax* caused 56.7% fruit loss in sweet orange orchards (Adhikari et al. 2020).
- *Citrus* is economically important in New Zealand (for the value of citrus in New Zealand, see section 2.5.2). As high infestation rates (up to 100%) have been recorded in areas with a similar climate to New Zealand, the likely impact of *B. minax* on the New Zealand citrus industry is likely to be high, but the impact to the overall economy of New Zealand is likely to be moderate.

If *B. minax* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 has cost approximately NZ\$18 million (MPI 2020).

Establishment of *B. minax* is likely to increase phytosanitary measures required for export to countries where the pest is absent, and therefore, the impact on exports, including market access, is likely to be severe.

- *Bactrocera minax* is only present in Bhutan, China, Nepal (CPC 2019) and India (Xia et al. 2018).
- Detection of a fruit fly in the surveillance programme would need to be reported internationally and would be expected to result in reduced market access for New Zealand host materials. In New Zealand, 80% of horticultural export value came from plants that are potential fruit fly hosts (MacLellan et al. 2019).
- The incursion of another fruit fly species, *B. dorsalis* (reported as *B. papayae*), in north Queensland was estimated to cause losses of nearly AU\$100 million, mostly due to loss of market access (Drew 1997, in Clark et al. 2005).
- If a fruit fly species established in New Zealand, additional post-harvest disinfestation costs would be necessary. In Australia in 1996, apples and citrus fruit underwent a cold treatment for fruit fly at a cost of approximately AU\$200/tonne, avocados were treated with hot forced air, costing approximately AU\$125/tonne, and stone fruit, cucurbits and tomatoes were treated with a dimethoate dip, which cost approximately AU\$100/tonne (MAF 1996).

Bactrocera minax is likely to cause sociocultural impacts on citrus in home gardens.

- Citrus is commonly grown in home gardens.

Since *B. minax* is a citrus specialist, and there are no native species of *Citrus* (or *Poncirus* or *Fortunella*), it seems likely that environmental impacts would be low.

There is no evidence found on the impact of *B. minax* on human health.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera minax* may be considered for additional measures.

- *Bactrocera minax* has a strong association with citrus fruit (all citrus cultivars in China);
- Low rates of infested fruit may not be detected during general handling, especially when the volume of commodities is large;
- As the larvae feed internally in the fruits, general handling cannot remove the larvae, and citrus fruits need to be cut open to reveal the larvae of *B. minax*;
- *Bactrocera minax* has moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment;
- New Zealand climate is likely to be suitable for the establishment of *B. minax*, but the area of establishment is likely to be limited by the distribution of its hosts.
- Hosts of the pest, citrus, are commercially grown in New Zealand and are common plants in home gardens;
- *Bactrocera minax* has been recorded to cause severe (up to 100%) production loss of citrus in areas with a similar climate to New Zealand, and therefore, it is likely to cause high impact on the citrus industry in New Zealand and moderate impact to the overall economy of New Zealand;
- *Bactrocera minax* is present in one of the citrus-exporting countries in the citrus fresh produce IHS (China).

8.4.4 References

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8.5 *Bactrocera trilineola* (Vanuatu fruit fly)

Bactrocera trilineola is a fruit fly species that has been reported to cause serious damage on fruit crops in Vanuatu. Main commercial host of *B. trilineola* is mango, although it has been reported in Rutaceae (Plant Health Australia 2011). Its current distribution is restricted to three Pacific Islands countries (Vanuatu, the Solomon Islands and New Caledonia).

Scientific name: *Bactrocera trilineola* Drew, 1989

Order/Family: Diptera/Tephritidae

Other names include: *Dacus triseriatus*, *Dacus (Strumeta) triseriatus*, *Bactrocera distotriseriata*

Taxonomic notes: *Bactrocera trilineola* belongs to the *frauenfeldi* complex (Plant Health Australia 2011). A specimen of *B. trilineola* from New Caledonia has been misidentified as *B. frauenfeldi* (Hancock 2008).

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera trilineola* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera trilineola* has a strong association with citrus fruit with low uncertainty.
- Basic measures are likely to reduce the likelihood of introduction of *B. trilineola* by a moderate degree (with moderate to high uncertainty). Consequently, the likelihood of entry is considered to be low to moderate.
- *Bactrocera trilineola* has low to moderate ability (with moderate to high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *B. trilineola* to establish is considered low to moderate (with moderate uncertainty), and its establishment is likely to be restricted to the warmer parts of the North Island, although short-term (seasonal) populations may occur in other areas during summer months.
- The level of impact caused by *B. trilineola* is likely to be high, with low uncertainty.
- *Bactrocera trilineola* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Moderate–high
The ability to move from the imported commodity onto a suitable host	Low–moderate	Moderate–high
Suitability of the New Zealand environment	Low–moderate	Moderate
Impacts on the New Zealand economy, environment, health and society	High	Low

8.5.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera trilineola* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁶³).

Bactrocera trilineola is not known to be present in New Zealand.

- *Bactrocera trilineola* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- *Bactrocera trilineola* is an unwanted organism (ONZPR 2020).
- *Bactrocera trilineola* is listed as 'regulated' in ONZPR (2020).

Bactrocera trilineola has the potential to establish and spread in New Zealand.

- *Bactrocera trilineola* is only reported as present in Vanuatu (Leblanc et al. 2013a), Solomon Islands (Vagalo et al. 1997) and New Caledonia (Loyalty Islands) (Hancock 2008). The fly may be able to establish in warmer areas in New Zealand.
- *Bactrocera trilineola* is polyphagous. It has been recorded from 32 fruit species from 18 plant families in Vanuatu (Allwood et al. 1996).
- Some hosts of *B. trilineola* are commercially grown or commonly found in home gardens, such as citrus, tomato, guava and avocado (Allwood 2000).

Bactrocera trilineola has the potential to cause impacts on the economy and environment of New Zealand.

- *Bactrocera trilineola* has the potential to harm to citrus and other hosts that are of economic importance to New Zealand.
- *Bactrocera trilineola* has the potential to have environmental impacts: *B. trilineola* has been reported on plant species in genera (such as *Syzygium*) that have native species in New Zealand (NZPCN 2020).
- *Bactrocera trilineola* has the potential to have sociocultural impacts: some hosts are commonly planted in home gardens, such as citrus and tomato.

8.5.2 Hazard identification: commodity association

Bactrocera trilineola is associated with citrus fruit.

Bactrocera trilineola is reported from citrus fruit:

- Citrus is a natural host of *B. trilineola*. *Bactrocera trilineola* has been reared from field-collected citrus fruits (Leblanc et al. 2013a).

8.5.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera trilineola* has a strong association with citrus fruit with low uncertainty.

Larvae of *B. trilineola* can be associated with citrus fruit commodities.

- Although no interception records of *B. trilineola* were found, like other *Bactrocera* spp., larvae of *B. trilineola* feed inside the fruit. Therefore, the larvae and eggs are unlikely to be visible.

⁶³ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining "harm".

Larvae of *B. trilineola* have been reported from fruits of various citrus species.

- Larvae of *B. trilineola* has been reared from field-collected fruit of various citrus species in Vanuatu (Leblanc et al. 2013).
- Citrus species/cultivars that are associated with *B. trilineola* are shown in Table 9.5.1.

Table 9.5.1 Known citrus fruit host association of *Bactrocera trilineola*.

Citrus host scientific name from the reference	Citrus host common name from the reference	Reference	Notes
<i>Fortunella japonica</i>	Round kumquat	Leblanc et al. (2013a)	Reared from field-collected fruit
<i>Citrus limon</i>	Lemon	Leblanc et al. (2013a)	Reared from field-collected fruit
<i>Citrus maxima</i>	Pomelo	Leblanc et al. (2013a)	Reared from field-collected fruit
<i>Citrus reticulata</i>	Tangerine	Leblanc et al. (2013a)	Reared from field-collected fruit
<i>Citrus sinensis</i>	Sweet orange	Leblanc et al. (2013a)	Reared from field-collected fruit

Bactrocera trilineola is reported as present in three citrus-exporting countries in this IHS:

- *Bactrocera trilineola* is reported as present in Vanuatu (Leblanc et al. 2013a), New Caledonia (Hancock 2008) and Solomon Islands (Vagalo et al. 1997).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *B. trilineola* by a moderate degree (with moderate to high uncertainty). Consequently, the likelihood of entry is considered low to moderate.

Some of the infested fruit may be easy to detect and will be removed.

- Although there is little information on damage to citrus fruit caused by *B. trilineola*, oviposition puncture/scars of *Bactrocera* spp. (e.g. *B. dorsalis*) maybe visible during general handling, especially for fruit with multiple oviposition punctures. This damage may cause necrosis around the puncture or even lead to decomposition of the fruit (CPC 2020).
- If bagging and culling are used in the export countries, these practices are likely to reduce the risk to some extent. Xia et al. (2019) found that fruit bagging and packing house culling (including preliminary culling, washing, waxing, drying, intensive culling, sorting and final culling and box-packing) could contribute to risk mitigation of fruit flies in citrus from China. The study found few oviposition marks and an absence of living tephritid fruit flies in bagged pomelo fruits ($n=3,000$), while 129 fruit fly-infested fruits (containing 634 live larvae and 4 pupae of *B. dorsalis*) were found in the unbagged fruits ($n=3,040$). They also found that in fruit (*C. unshiu*) that received culling treatment ($n=10,000$), fruit flies were absent, and 10 fruits with oviposition marks (with no living fruit flies) were found, while in fruit ($n=10,000$) that did not receive the culling treatment, 1 infested fruit with 7 larvae of *B. minax* and 25 fruits with fruit fly oviposition marks were found.

However, there is a chance that a small number of infested fruits will not be detected.

- Low infestation (fewer oviposition punctures in fruit) may not be obvious enough to be detected during general handling.
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.
- Although other *Bactrocera* fruit flies (e.g. *B. dorsalis* and *B. minax*) have been reported to cause fruit to drop prematurely in heavy infestation, and dropped fruit is unlikely to be exported, there is no evidence that *B. trilineola* can cause fruit to drop prematurely.

General handling after harvesting is not likely to remove eggs and larvae of *B. trilineola* inside citrus fruit.

- As general handling after harvesting (e.g. washing and brushing) only treats the surface of fruit, it is unlikely to remove the larvae of *B. trilineola* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *B. trilineola* inside.

Bactrocera trilineola may be able to survive air or sea transit in citrus fruit commodities, but the uncertainty associated with this is moderate to high.

- No interception records of *B. trilineola* on citrus fruits were found in EPPO (2020). It has been intercepted three times on fresh produce⁶⁴ commodities from Vanuatu (larvae, pupae and adults) and once on fresh avocado from Solomon Islands (eggs) (LIMS 2019). It is uncertain whether the small number of interceptions is due to existing measures on fruit fly hosts or whether *B. trilineola* cannot easily survive transit on existing pathways of citrus fruit.
- The transit process of fresh produce usually involves cold storage in various temperatures depending on the commodity. No study investigating the cold tolerance capability of *B. trilineola* was found, although it has been intercepted on fresh produce commodities (rather than citrus).
- Therefore, the uncertainty of whether *B. trilineola* can survive transit of citrus fruits is moderate to high.

The level of uncertainty associated with the conclusion is moderate to high. First, there is little information on the damage caused by *B. trilineola*. Information on damage used in this assessment is based on information from other *Bactrocera* spp. Second, the uncertainty about whether *B. trilineola* can survive transit of citrus fruits is moderate to high, because there are few interception records for the fly, the transit conditions of the interceptions are unknown, and no study investigating the cold tolerance of *B. trilineola* has been found.

Likelihood of establishment:

Given the arguments and evidence below, *Bactrocera trilineola* has a low to moderate ability (with moderate to high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure/ transfer).

Bactrocera trilineola may survive and develop on the waste of citrus fruit (whole fruit or fruit pieces, but probably not skin).

- Adult *B. trilineola* has been reared from field-collected fruit of different citrus species/cultivars (Leblanc et al. 2012), suggesting that the fly can survive and complete development in citrus fruit.
- Although the duration of larval development of *B. trilineola* in citrus fruit is not known, the life cycle is completed in approximately 21–22 days at 25°C using a papaya/torula yeast Nipagin artificial diet (Allwood et al. 1996). When the fly and the citrus host are disposed of, the development duration may be different from the duration when the fly was reared using the artificial diet. Previous importation records of citrus fresh produce from Vanuatu can be found from July to January (QuanCargo 2020). The development duration of the fly is likely to be longer in New Zealand during this period due to lower temperatures, but the fly is still likely to be able to survive and develop in the citrus host in warmer months.
- If citrus fruit is disposed of as whole fruit or fruit pieces, it is likely that *B. trilineola* can survive in this waste. There is no evidence showing that *B. trilineola* can complete development by feeding on citrus fruit skin.

Most of the kitchen waste in New Zealand would be disposed of using low-risk methods, so *B. trilineola* would either be killed or unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, *B. trilineola* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and use as animal feed.

- Mature larvae of fruit fly come out of the fruit host and drop to the ground to pupate in the soil. The pupae may be able to survive during summer months, but it is uncertain whether they can survive and develop in colder seasons.
- Adults of *B. trilineola* emerging from the soil are likely to be able to find food in the environment if citrus fruit waste is disposed of using high-risk methods and the temperature is

⁶⁴ Interception record shows that the fly was intercepted on Mango/Pacific Lychee/Pandanas/Hog Plum Fresh Produce, but it is not clear which commodity the fly was intercepted on.

suitable for the fly. Although not specifically reported from *B. trilineola*, adult fruit flies are reported to feed on various foods, including glandular secretions of plants; nectar; and plant sap exuding from trunk, stem, leaf or fruit injuries (Christenson and Foote 1960). These food sources are likely to be available in home gardens, parks and farms.

- Hosts for oviposition and larval development are available in warmer areas of New Zealand, and some are present in colder areas. *Bactrocera trilineola* is polyphagous. Hosts include commercially grown crops and crops commonly found in home gardens (e.g. citrus, avocado, guava and papaya). Citrus is commercially produced in both the North Island and the South Island, with most commercial production taking place in the North Island (see section 2.4.2), and the main production areas of avocado are Northland and Bay of Plenty (Plant & Food Research 2019).
- If hosts are located near the composting site or animal feeding site (see the waste analysis in section 2.4.1), adult *B. trilineola* is likely to locate the citrus host.

Adult *B. trilineola* can fly to food sources and locate citrus hosts, although it is not known whether it is a strong flier.

- No study investigating the flight capability of *B. trilineola* was found. However, studies on other tephritids reveal that the mean dispersal distance of tephritid flies is usually well below 1 km, except that mean dispersal distances from below 1 km to 3.6 km have been reported for *B. dorsalis*. However, the maximum dispersal distance reported in many studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014).

It is uncertain whether *B. trilineola* can survive cold temperatures if it arrives in New Zealand in cold seasons.

- The current known distribution of *B. trilineola* is restricted to three Pacific Island countries (Vanuatu, Solomon Islands and New Caledonia) located in tropical/subtropical areas.
- No study investigating the cold tolerance capability or lower development threshold of *B. trilineola* was found. Although there are many studies on these aspects on other *Bactrocera* spp., the cold tolerance of these species varies.
- Therefore, if *B. trilineola* arrives in New Zealand at a time with temperatures that are colder than its current distribution, it is uncertain whether it can survive and develop and then locate a new host outdoors.

The level of uncertainty associated with the conclusion is moderate to high. First, fruit waste data may not be very accurate and up to date, and it is not known how frequently suitable hosts would be present near composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Second, it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin). Third, although *B. trilineola* can fly to seek food sources and citrus hosts, its flight capability is uncertain. There is a lot of information for other tephritid flies, but the maximum dispersal distance reported from many studies was limited to the distance of the trap placed furthest from the release point. Fourth, since no study investigating the cold tolerance and development temperature threshold of *B. trilineola* was found, and its current distribution is restricted to tropical and subtropical areas, it is uncertain whether it could survive and find a new host if it arrived in New Zealand during colder seasons.

Given the arguments and evidence below, the suitability of the New Zealand environment for *B. trilineola* to establish is considered low to moderate (with moderate uncertainty), and its establishment is likely to be restricted to the warmer parts of the North Island and sheltered environments, although short-term populations may establish in other areas during summer months.

The current known distribution of *B. trilineola* is restricted to three Pacific Island countries located in tropical/subtropical areas.

- The current known distribution of *B. trilineola* is restricted to Vanuatu (Leblanc et al. 2013), Solomon Islands (Vagalo et al. 1997) and New Caledonia (Hancock 2008).
- Although the main island of New Caledonia has a climate match index (CMI) of 0.6–0.7 (Phillips et al. 2018), *B. trilineola* has only been detected on Loyalty Islands but not the main island. No CMI values are provided for Vanuatu, Solomon Islands and Loyalty Islands in the Phillips et al. (2018) climate tool. The lowest average monthly minimum temperatures of

Solomon Island, Vanuatu and Loyalty Islands are 22, 18 and 15°C respectively, and the highest average high monthly temperatures are 31, 29 and 29°C respectively (Weather Atlas 2020).

Based on the currently known geographic distribution of *B. trilineola*, establishment of *B. trilineola* in New Zealand is likely to be restricted to some areas of the North Island and in sheltered environments.

- *Bactrocera trilineola* may be able to establish in the northern part of the North Island (e.g. the Kaitiaki, Whangarei and Auckland regions). These areas have a lowest average monthly temperature of about 11–12°C⁶⁵, which are the warmest areas in New Zealand (NIWA 2001). It may be able to achieve short-term population establishment in the other areas during the summer season.
- *Bactrocera trilineola* has been detected in Maré, New Caledonia (Hancock 2008). A climate niche analysis (Figure 9.5.1) shows that some months in La Roche, Maré, have temperatures similar to New Zealand summers (Halloy 2020). The mean annual temperature, the lowest monthly minimum mean temperature and the absolute minimum temperature of La Roche are 22.2, 13.6 and 2.8°C respectively (Météo_France 2020). As *B. trilineola* adapts to these conditions, it is likely to tolerate cool temperatures over some areas of the North Island.
- *Bactrocera trilineola* may establish in sheltered environments with hosts present.

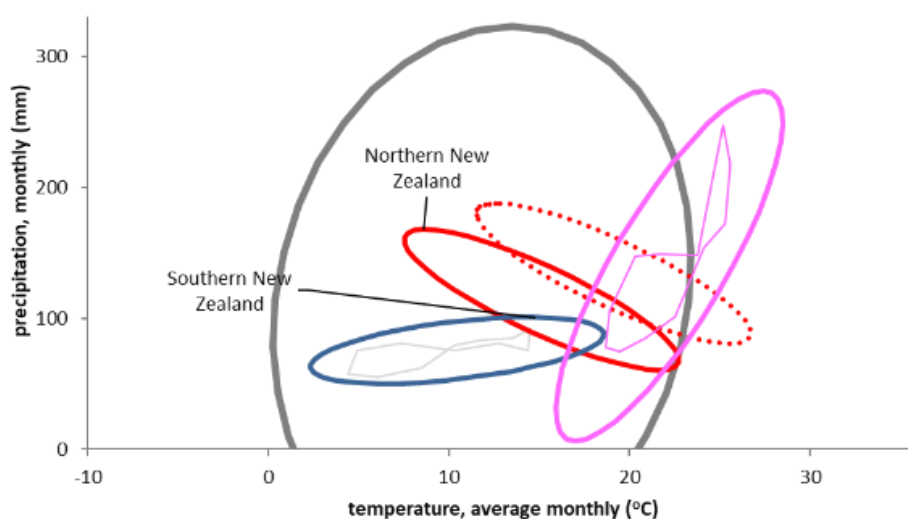


Figure 9.5.1 Climate niches (temperature and precipitation range) of New Zealand (grey ellipse), northern New Zealand (including Northland, Auckland, and Bay of plenty; red ellipse), La Roche (pink ellipse), and northern New Zealand in a +4°C climate change scenario (red dashes). These ellipses include 95% of climatic sites within the specific area. Northern New Zealand includes 68% of citrus productive area in New Zealand (Halloy 2020).

Hosts may not be a limiting factor for the establishment of *B. trilineola* in New Zealand.

- *Bactrocera trilineola* is listed in category B in Vargas et al. (2015), which are polyphagous fruit pests that are more restricted in distribution but at elevated risk of spreading to new locations.
- *Bactrocera trilineola* has been reported from 32 hosts belonging to 18 plant families in Vanuatu. Some of the hosts of economic importance in Vanuatu are present in New Zealand, such as avocado, guava, lemon, kumquat, orange, papaya and soursop (Allwood 2000). Watermelon, tomato and eggplant are conditional hosts (found in both laboratory and field cage tests) of *B. trilineola* (Heimoana et al. 1996). *Bactrocera trilineola* has also been reared from capsicum in laboratory conditions (Heimoana et al. 1996).
- Most commercial production of citrus takes place in the warmer part of New Zealand (including Northland regions) (see section 2.4.2), and the main growing regions of avocado are Northland and the Bay of Plenty (New Zealand Avocados 2020). These areas are the most suitable areas for the establishment of *B. trilineola* in New Zealand.

⁶⁵ The data are monthly averages for the period 1971–2000 for locations with at least five years of complete data.

- Citrus, avocado, capsicum, tomato and eggplant are commonly found in home gardens.

Bactrocera trilineola occurs year-round in Vanuatu.

- *Bactrocera trilineola* occurs year-round in Vanuatu, but tends to have population peaks in January–February and April–May, which coincides with the guava, mango and tropical almond fruiting times (Allwood 2000). This implies that if *B. trilineola* establishes in the warmer areas in New Zealand, it may be active during the warmer months (Figure 9.5.1).

Although *B. trilineola* is a serious pest of a wide range of economic hosts in Vanuatu, it has not been reported as an invasive species in other countries.

- No economic damage of *Bactrocera trilineola* has been reported from Solomon Islands and New Caledonia, although it is a serious pest in Vanuatu.

Bactrocera trilineola responds to cuelure, which is used in the national fruit fly surveillance programme.

- Three fruit fly lures, cuelure, trimedlure and methyl eugenol, are used in the national fruit fly surveillance programme in New Zealand (MacLellan et al. 2019). If a fruit fly species is responsive to any of these lures, it is likely to reduce the likelihood of its establishment in New Zealand.
- A male lure test was conducted in seven Pacific Island countries. This test indicated that *B. trilineola* responds to cuelure, but does not respond to methyl eugenol (Allwood 1996). It is not known whether *B. trilineola* responds to trimedlure.

The level of uncertainty associated with the conclusion is moderate. The current distribution of *B. trilineola* is restricted to the three Pacific Island countries located in tropical/subtropical areas. However, it is also detected in Maré, New Caledonia, where lower temperatures are well within the ranges of parts of the North Island. It is not known if its restricted distribution is due to geographic boundaries (i.e. islands) or if it is because not all the populations of the pest can establish in colder climates. In addition, no study has been found on the cold tolerance and development threshold (temperature) of *B. trilineola*, and therefore, it is uncertain whether it can survive or build up populations in colder areas.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. trilineola* is likely to be high, with low uncertainty.

Damage and symptoms caused by *B. trilineola* can reduce fruit quality.

- Larvae of *B. trilineola* feed inside the fruit of plant hosts. Although little information is found on the damage of *B. trilineola* specifically, oviposition of other *Bactrocera* spp. leaves scars (or punctures) on the skin of fruit, which may cause necrosis or darken the colour of fruit skin around the oviposition puncture. Oviposition punctures and internal feeding by the larvae of other *Bactrocera* spp. can lead to distortion and rotting of fruit (CPC 2020).
- Heavy infestation caused by other *Bactrocera* spp. can cause premature fruit drop (Xia et al. 2018; CPC 2020).

Bactrocera trilineola is a serious pest in Vanuatu, but economic damage has not been reported from other countries where it is present.

- *Bactrocera trilineola* has been recorded on 32 plant hosts, of which 22 are regarded as commercial or edible fruits (Allwood 2000). Severe damage has been reported from some commercially grown fruits. A 90% damage rate on guava has been recorded in Vanuatu when there were no control measures on the fruit fly, while the damage rate reduced to 15% with control measures (Allwood et al. 2001). It is also reported that *B. trilineola* attacks 64% of ripe Malay apples (*Syzygium malaccense*), 30% of breadfruit and 11% of ripe mangoes. However, these fruit crops are not commercially produced in New Zealand. Leblanc et al. (2012b) report that *B. trilineola* can also infest Suriname cherry (sample infested: 20%), Pacific almond

(40%), Tahiti chestnut (40%), avocado (23%), soursop (around 10%), papaya (around 5%), Pacific lychee (88%) and starfruit (50%).

- No damage records for *Citrus* have been reported from New Caledonia (Mille et al. 2012) and Solomon Islands.

Bactrocera trilineola may cause impact on citrus, avocado and other hosts grown in New Zealand.

- Leblanc et al. (2013) report infestation data of *B. trilineola* on citrus, avocado and banana/plantain (genus *Musa*):
 - 9.17 flies per kg of avocado (*Persea americana*);
 - 20.63 flies per kg of *C. reticulata*;
 - 8 flies per kg of *C. maxima*;
 - 7.59 flies per kg of *C. sinensis*;
 - 1.25 flies per kg of *Fortunella japonica*;
 - 0.63 flies per kg of *C. limon*;
 - 28.57 flies per kg of *Musa* sp.
- The main commercial production areas of citrus and avocado are in the northern part of the North Island. These areas are likely to be the most suitable areas for the establishment of *B. trilineola* in New Zealand.
- However, as there is no report found on quantifying the impact on citrus and avocado in areas with similar climate conditions to New Zealand, the impact on these two industries is uncertain.
- Leblanc et al. (2013) also report 28.57 flies per kg of *Musa* sp.
- *Bactrocera trilineola* may also cause impact on tomato, capsicum, eggplant and watermelon (Heimoana et al. 1996), but as tomato, eggplant and watermelon are conditional hosts (found in both laboratory and field cage test), and *B. trilineola* has only been known on capsicum in laboratory conditions, the uncertainty associated with the level of impact is high.

The impact on exports, including market access, is likely to be severe.

- Detection of a fruit fly in the surveillance programme would need to be reported internationally and would be expected to result in reduced market access for New Zealand host materials. In New Zealand, 80% of horticultural export value came from plants that are potential fruit fly hosts (MacLellan et al. 2019). The incursion of *B. dorsalis* (reported as *B. papaya*) in north Queensland, Australia, was estimated to cause losses of nearly AU\$100 million, and most of this was due to lost export markets (Drew 1997, in Clark et al. 2005).
- The current known distribution of *B. trilineola* is restricted to three Pacific Island countries. If *B. trilineola* establishes in New Zealand, other trading partners are likely to take measures on the host commodities or even limit market access of host commodities from New Zealand. Post-harvest disinfestation costs would be necessary, in particular for avocado and citrus. In Australia in 1996, apples and citrus fruit underwent a cold treatment for fruit fly at a cost of approximately AU\$200/tonne, avocados are treated with hot forced air, costing approximately AU\$125/tonne, and stone fruit, cucurbits and tomatoes were treated with a dimethoate dip, which cost approximately AU\$100/tonne (MAF 1996).

If *B. trilineola* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 has cost approximately NZ\$18 million (MPI 2020).
- In Japan, eradication of a fruit fly species from the Ryukyu Islands has cost more than 200 million euros (Kiritani 1998, cited in CPC 2020). The cost for the eradication programme in northern Queensland of the papaya fruit fly (*Bactrocera papayae*) (1995–1999) was AU\$33 million (Cantrell et al. 2002, in CPC 2020).

Bactrocera trilineola may cause low impact on the environment in New Zealand.

- *Bactrocera trilineola* has been reported to be a serious pest of *Syzygium malaccense* in Vanuatu (Allwood et al. 2000). New Zealand has native *Syzygium*, which is *S. maire*.
- *Bactrocera trilineola* may cause impact on the native *S. maire*. This native tree produces fruits and can be found in wet sites in warmer parts of New Zealand (e.g. in Northland) (NZPCN 2020).
- If *Bactrocera trilineola* establishes in New Zealand, *S. maire* may be an alternative host to those commercial fruit crops.

Bactrocera trilineola is likely to cause sociocultural impacts on citrus in home gardens.

- Some hosts are commonly grown in home gardens, such as citrus, avocado, capsicum, tomato and eggplants.

There is no evidence found on the impact of *B. trilineola* on human health.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera trilineola* may be considered for additional measures.

- *Bactrocera trilineola* has a strong association with fruits of some citrus species.
- Some infested fruit will not be detected, especially when the volume of commodities is large.
- As the larvae feed internally in the fruits, general handling cannot remove the larvae, and citrus fruit needs to be cut open to reveal the larvae of *B. trilineola*.
- *Bactrocera trilineola* has a low to moderate ability (moderate to high uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The suitability of the New Zealand environment for *B. trilineola* to establish is considered low to moderate (with moderate uncertainty), and its establishment is likely to be restricted to the North Island, although short-term populations may establish in other areas during summer months.
- Hosts may not be a limiting factor for the establishment of *B. trilineola* in New Zealand, as some hosts are commercially grown and commonly found in New Zealand.
- *Bactrocera trilineola* has been reported to cause severe impact on some tropical fruit crops and to attack citrus and avocado. However, economic damage is only known from lowland Vanuatu, not from areas with a similar climate to New Zealand.
- Although economic damage has not been reported in areas with similar climate to New Zealand, as a fruit fly species, if it is detected and/or establishes in New Zealand, the impact on export and market access of New Zealand's horticultural products (particularly citrus and avocado) is likely to be severe.
- *Bactrocera trilineola* is currently listed in the citrus fresh produce IHS in the following citrus exporting countries: Vanuatu, New Caledonia and Solomon Islands.

8.5.4 References

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8.6 *Bactrocera tryoni* (Queensland fruit fly, Qfly)

Bactrocera tryoni (Qfly) females lay their eggs through the skin of fruit. Maggots hatch from the eggs and feed within the fruit, causing damage and rotting. Qfly has a very wide host range, including many economically important horticultural crops in Australia. The fly is native to Queensland and is invasive in other parts of Australia and in New Caledonia, French Polynesia and the Pitcairn Islands. It has been detected in New Zealand on a number of occasions, including breeding populations, but has been successfully eradicated on each occasion.

Scientific name: *Bactrocera tryoni* (Froggatt, 1897)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera* (*Bactrocera*) *tryoni*, *Chaetodacus sarcocephali*, *Chaetodacus tryoni*, *Dacus ferrugineus tryoni*, *Dacus tryoni*, *Strumeta melas*, *Strumeta tryoni*, *Tephritis tryoni* (CPC 2020)

Taxonomic notes: *Bactrocera tryoni* is a member of the *B. tryoni* complex of species, which currently includes four named species: *B. tryoni*, *B. aquilonis*, *B. melas* and *B. neohumeralis*. The species status of *B. aquilonis* and *B. melas* is unclear; they may be junior synonyms of *B. tryoni* (Clarke et al. 2011).

Bactrocera aquilonis is distributed within northwestern Australia from Darwin across to northern Western Australia, and is completely allopatric to *B. tryoni* (Cameron et al. 2006, Sultana et al. 2020). However, *B. aquilonis* and *B. tryoni* cannot be separated reliably based on morphology or by using a population genetic approach with microsatellite data, leading Cameron et al. (2010) to conclude that “there is no genetic evidence supporting the separation of *B. aquilonis* and *B. tryoni* as distinct species”. Cameron et al. (2010) state “from a quarantine perspective, the genetic similarity between *B. tryoni* and the northwestern species [*B. aquilonis*] would suggest that control and disinfestation protocols should be similar in both regions”. More recent unpublished PhD research showed that *B. aquilonis* forms a defined clade within the species *tryoni* and is possibly a population of *tryoni* rather than a separate species (K. Armstrong, pers. comm.). Similarly, Popa-Báez et al. (2020) concluded that, based on whole genome analyses, the population of fruit flies in the Northern Territory is *B. tryoni*, but that genetic differentiation has occurred due to its geographic isolation from the parent population.

If *B. aquilonis* is synonymised under *B. tryoni*, host and distribution records for *B. aquilonis* should be attributed to *B. tryoni*. However the distribution of this putative species is very restricted. It has only been reported from the very north of Australia above 16° of latitude.

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera tryoni* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera tryoni* has a low to moderate association with citrus fruit, with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *B. tryoni* on the commodity by a moderate degree, with low uncertainty. Consequently the likelihood of entry is considered to be low, with low uncertainty.
- *Bactrocera tryoni* is considered to have a low to moderate ability (with moderate uncertainty) to move from imported citrus fruit and into an environment that is suitable for establishment.
- The suitability of the New Zealand environment for the establishment of *B. tryoni* is considered to be low to moderate, with low uncertainty.
- The level of impact caused by *B. tryoni* is likely to be high, with low uncertainty. Although its spread and economic impact may be limited by climate, even a temporary incursion is likely to be associated with significant trade barriers and eradication costs.
- *Bactrocera tryoni* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Low to moderate	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low to moderate	Moderate
Suitability of the New Zealand environment	Low to moderate	Low
Impacts on the New Zealand economy, environment, health and society	High	Low

8.6.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera tryoni* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the New Zealand, and of potential importance (able to establish and cause harm⁶⁶).

Bactrocera tryoni is not known to be present in New Zealand:

- NZOR (2020) reports *B. tryoni* as “eradicated/destroyed”, and PPIN (2020) reports it as absent.
- New Zealand has country freedom status for *B. tryoni* (MPI 2020a).
- *Bactrocera tryoni* is an unwanted and notifiable organism and a regulated pest (ONZPR 2020).

Bactrocera tryoni has the potential to establish and spread within the warmer parts of New Zealand:

- Climate modelling studies have concluded that *B. tryoni* is likely to be able to establish permanent populations in the warmer parts of New Zealand. It has established temporary populations in New Zealand on a number of occasions before being successfully eradicated.
- *Bactrocera tryoni* is a widely polyphagous fruit fly, and suitable host plants are readily available throughout New Zealand commercially, in home gardens and in natural areas.

The establishment of *Bactrocera tryoni* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. tryoni* has the potential to cause direct economic damage to many horticultural crops that are important to New Zealand. It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- The establishment of *B. tryoni* has the potential to have sociocultural impacts: many of its hosts are commonly planted in home gardens.
- Environmental and human health impacts caused by its establishment are likely to be very low or negligible.

8.6.2 Hazard identification: commodity association

Bactrocera tryoni is associated with citrus fruit

- *Bactrocera tryoni* oviposits through the fruit skin of many plant species, and its larvae feed inside the fruit (CPC 2020).
- There are validated records of infestation of many citrus species by *B. tryoni* that satisfy the definition of a host in accordance with international standards.

⁶⁶ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining “harm”.

8.6.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera tryoni* has a low to moderate association with citrus commodities.

Many citrus species are hosts of *B. tryoni*, but citrus is not a favoured host.

- Adult females of *B. tryoni* lay eggs below the skin of the host fruit. Eggs hatch within 2–3 days and the larvae feed within the fruit for another 10–31 days (time is dependent on the host and the environmental conditions, particularly temperature) before leaving the fruit to pupate (CPC 2020).
- There are validated records of infestation of many *Citrus* species by *B. tryoni* that satisfy the definition of a host in accordance with international standards, e.g. ISPM 37 (FAO 2016a)⁶⁷, RSPM 4 (2005) (Table 9.6.1).

Table 9.6.1 Citrus species reported to be hosts of *Bactrocera tryoni*

The scientific and common host names are the names cited in the reference given.

Host name	Common name	Reference (Country of record)
<i>Citrus aurantiifolia</i>	Lime; West Indian lime	Hancock et al. (2000); NTG (2013) (Australia)
<i>Citrus aurantiifolia</i>	Lime	Leblanc et al. (2013) (French Polynesia)
<i>Citrus aurantium</i>	Seville orange	Hancock et al. (2000) (Australia)
<i>Citrus maxima</i>	Pummelo	Hancock et al. (2000) (Australia)
<i>Citrus jambhiri</i>	Bush lemon	Hancock et al. (2000) (Australia)
<i>Fortunella japonica</i>	Round kumquat	Leblanc et al. (2013) (New Caledonia)
<i>Citrus latifolia</i>	Tahitian lime	Leblanc et al. (2013) (French Polynesia, New Caledonia)
<i>Citrus limon</i>	Sweet lemon	Hancock et al. (2000) (Australia)
<i>Citrus limon</i>	Lemon	Hancock et al. (2000) (Australia)
<i>Citrus limon</i>	Lemon	Lloyd et al. (2013) (Australia) Note: Lloyd et al. (2013) found lemons were poor hosts, especially green Eureka lemons. Conditional non-host status is a possibility for lemons.
<i>Citrus limon</i>	Meyer lemon	Hancock et al. (2000) (Australia)
<i>Citrus maxima</i>	Pomelo	Leblanc et al. (2013) (French Polynesia, New Caledonia)
<i>Citrus medica</i>	Citron	Hancock et al. (2000) (Australia)
<i>Citrus medica</i>	Citron, Tangor	NTG (2013) (Australia)
<i>Citrus paradisi</i>	Grapefruit	Leblanc et al. (2013) (New Caledonia)
<i>Citrus paradisi</i>	Grapefruit and Pink grapefruit	Hancock et al. (2000) (Australia)
<i>Citrus paradisi</i>	Grapefruit	White & Elson-Harris (1992) (Australia)
<i>Citrus reticulata</i>	Mandarin, Tangelo and Tangerine	Hancock et al. (2000) (Australia)
<i>Citrus reticulata</i>	Tangerine	Leblanc et al. (2013) (French Polynesia, New Caledonia)
<i>Citrus reticulata</i>	Imperial, Ellendale and Murcott mandarins	Lloyd et al. (2013) (Australia)
<i>Citrus limon</i>	Rangpur lime	DPIPWE (2011), NTG (2013) (Australia)

⁶⁷A host is a plant species or cultivar that has been scientifically found to be infested by the target fruit fly species under natural conditions and able to sustain its development to viable adults (ISPM 37, FAO 2016a).

Host name	Common name	Reference (Country of record)
<i>Citrus sinensis</i>	Navel and Valencia oranges	Lloyd et al. (2013) (Australia)
<i>Citrus sinensis</i>	Orange	Hancock et al. (2000) (Australia)
<i>Citrus sinensis</i>	Orange	Leblanc et al. (2012) (French Polynesia, New Caledonia)
<i>C. reticulata</i> × <i>C. paradisi</i>	Tangelo	NTG (2013) (Australia)

- However, *Citrus* species are generally considered to be relatively poor hosts of *B. tryoni*.
 - Field surveys of citrus hosts from unmanaged habitats have shown that the numbers of fruit flies produced per gram of fruit are much lower (usually an order of magnitude) than those of the more susceptible noncitrus hosts such as guava (*Psidium guajava*), cherry guava (*P. littorale*), mulberry (*Morus nigra*), loquat (*Eriobotrya japonica*), and pear (*Pyrus communis*) (Lloyd et al. 2013).
 - Hancock et al. (2000) do not report any species of *Citrus* as favoured hosts, though they report *B. tryoni* as a host of around 10 citrus taxa; and CPC (2020) do not list any *Citrus* species as “main” hosts (all *Citrus* species are categorised as “other”).
 - Muthuthantri (2013) reported that citrus fruit in general are poor hosts for *B. tryoni*, and that adult fly emergence from citrus was very low, while adult fly production from nectarine was very high.
 - According to Lloyd et al. (2013), the major citrus crops commercially cultivated in Australia have a relatively low susceptibility to *B. tryoni*, with Eureka lemons being a particularly poor host for this species (Table 9.6.2).

Table 9.6.2 Host susceptibility of *Citrus* species and other hosts of *Bactrocera tryoni*

The host susceptibility index is defined by Lloyd et al. (2013) as the number of adult flies produced per gram of fruit (infested at a calculated rate of one egg per gram of fruit).

Host common name (from reference)	Host scientific name (from reference)	Host susceptibility index
Citrus species		
Seville oranges	<i>Citrus aurantium</i>	0.237
Murcott mandarins	<i>Citrus reticulata</i>	0.083
Imperial mandarins	<i>Citrus reticulata</i>	0.052
Navel oranges	<i>Citrus sinensis</i>	0.026
Ellendale mandarins	<i>Citrus reticulata</i>	0.020
Valencia oranges	<i>Citrus sinensis</i>	0.008
Eureka (yellow) lemon	<i>Citrus limon</i>	0.002
Eureka (green) lemon	<i>Citrus limon</i>	0.000
Non-citrus species		
Guava	<i>Psidium guajava</i>	0.318
Cherry guava	<i>Psidium littorale</i>	0.226
Mulberry	<i>Morus nigra</i>	0.209
Loquat	<i>Eriobotrya japonica</i>	0.148
Pear	<i>Pyrus communis</i>	0.111

Bactrocera tryoni is present in countries that are included in the scope of this IRA:

- *Bactrocera tryoni* is present in eastern Australia and in New Caledonia (Table 9.6.3).

Table 9.6.3 Geographic distribution of *Bactrocera tryoni*

Areas in **bold** are potential exporting countries. Sources: EPPO (2020), Clarke et al. (2011)

Region	Country	Biostatus
Oceania	Australia	Native in Queensland, otherwise invasive. <i>Bactrocera tryoni</i> is considered to be a quarantine pest in Western Australia and Tasmania. In eastern Australia, only the Riverland Pest Free Area in South Australia is currently recognised as a pest free area for <i>B. tryoni</i> .
Oceania	French Polynesia (Austral Islands, Society Islands)	Invasive
Oceania	New Caledonia	Invasive
Oceania	Pitcairn Islands	Invasive

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *B. tryoni* by a moderate degree.

In Australia, in-field controls can reduce *B. tryoni* populations to a low level:

- In-field and area-wide controls can greatly reduce *B. tryoni* population levels in preferred host crops. Some untreated crops (e.g. peach in southeast Queensland) may have up to 100% infestation (Bull 2004), while production losses in treated crops in endemic areas range from 0.5–3% (Sultana et al. 2017).
- Lloyd et al. (2000, in DPIPWE 2011) estimated infestation levels in commercial citrus orchards in the central Burnett area that used bait spray consistently were in the order of 0.029–0.047% at the 95% confidence level.
- Subramaniam (2011) found that in-field control (field cover sprays and packhouse mitigation measures including washing, sorting and grading to remove defective and damaged fruit) and inspection in the packhouse was able to provide a high level of security in capsicum and tomato crops in Queensland.

Bactrocera tryoni infestations may be visually detectable in the field and/or packhouses, leading to the removal of infested produce, but some individuals are likely to be undetected:

- Larval feeding within fruit induces premature fruit drop and fungal decay (Clarke et al. 2011, PHA 2016). Infested fruit may therefore be detected and is not likely to be exported.
- However, low levels of infestation, or feeding by early instars, may not be detected during harvest, after harvest or in on-arrival inspection, particularly if the volume of commodities is large. Oviposition sites are not always noticeable. In mature citrus, tephritid sting marks may be small brown depressed spots, or the fruit may have an indistinct, bruised appearance. On green citrus fruit, the skin colours prematurely around the sting mark (PHA 2016). Therefore, infested fruit may not show any physical signs of oviposition or internal feeding, particularly those containing eggs or early instar larvae (DPIPWE 2011). Late instar larvae may also enter the country if there are few in the fruit and if the damage caused is not conspicuous.
- Internally feeding insects are difficult to detect by non-destructive inspection. Even using fruit dissection, Gould (1995) found that detection rates for Caribbean fruit fly (*Anastrepha suspensa*) could be as low as 17.9%. In this study, inspectors detected between 17.9% and 83.5% of fruit infested with Caribbean fruit fly. Variables influencing the detection rate were the fruit type, its ripeness and the inspector.
- Border detections in *Citrus* species: “*Bactrocera tryoni* complex” (see taxonomic note) has been identified at the New Zealand border in various *Citrus* species (LIMS and Quancargo databases):
 - Nine dead larvae (molecular identification of “*Bactrocera tryoni* complex”) were detected in a shipment of oranges from Australia in 2017 (consignment C2017/446874).

- Four live larvae (molecular identification of “*Bactrocera tryoni* complex”) were detected in lemons in 2016 (C16_00185, no further pathway information available).
- “*Bactrocera tryoni*” has also been identified alive in lemons seized from passengers in 1991, and also alive in *Citrus reticulata* (mandarin) and *Citrus limon* (lemon) in 2016 (accession numbers C16_01154 and C16_00185 respectively; no further pathway information available).
- *Bactrocera tryoni* and “*Bactrocera tryoni* complex” have been detected at the New Zealand border in other fruit species (for example, alive in irradiated mangoes and litchis from Australia, and alive in apples and chillis seized from passengers).
- EPPO has not reported any detections of *B. tryoni* in citrus fruit at the EU border (Steffen et al. 2015; EPPO 2020).

Bactrocera tryoni larvae may survive transit in some citrus commodities.

- Transport of fruit is likely to be by sea and may take a number of weeks. The optimum carrying temperature is variable depending on the fruit type (between 8 and 14°C for grapefruit, lemons and limes, and between 2 and 7°C for oranges; BMT 2020). Carrying temperatures are therefore generally cool, though not very low – grapefruit and mandarin exhibit chilling injury at 7 and 8°C, respectively and unconditioned lemons below 14.5°C (McGregor 1987). *Bactrocera tryoni* is considered to be a tropical species (Clarke et al. 2011) with an assumed low tolerance to cold. It is not known whether typical carrying temperatures affect its viability in citrus.

The overall likelihood of entry for *B. tryoni* on commercially produced citrus is considered to be low, with low uncertainty. Many commercially traded species of citrus are reported to be hosts of *B. tryoni*, though none are reported to be favoured hosts. There is evidence that in-field controls can be very effective in reducing, but not removing, *B. tryoni* infestations. Infested fruit is difficult to detect by inspection, particularly at low levels.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Bactrocera tryoni* to move from imported citrus fruit into a suitable environment to allow establishment is considered to be low to moderate, with moderate uncertainty.

Bactrocera tryoni is able to survive and develop on discarded fruit.

- *Bactrocera tryoni* is often reared on picked fruit in disinfestation experiments. In the field, fruit infested with fruit fly larvae often drop to the ground prematurely (Allwood and Leblanc 1997), where development continues until they leave the fruit to pupate. Pupation usually takes place in the soil (Weems and Fasulo 2002).
- Infested fruit is likely to be discarded. Infested fruit must remain in a suitable condition long enough for larvae to develop to maturity (this time is temperature dependent), and emerging larvae then need to find a suitable pupation site. Citrus fruit is relatively robust and not highly perishable, compared to commodities such as peaches or strawberries. Citrus is likely to remain in good condition long enough for larvae to emerge and pupate.
- However, *Citrus* species are not favoured hosts for *B. tryoni*. Developmental times are generally longer than in favoured hosts, and the number of flies emerging from citrus commodities is likely to be lower than for favoured hosts (Lloyd et al. 2013; Muthuthantri 2013; Table 2).

Most organic waste in New Zealand is likely to be disposed of using low-risk methods, meaning that fly larvae would die before completing development.

- The majority of waste in New Zealand is bagged and disposed of in landfills and into kitchen disposal units. In these situations, *B. tryoni* is unlikely to continue development to successful emergence of adults (see section 2.4.1).

However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, discarding into the environment (e.g. roadsides, parks) and use as animal feed, thus allowing larvae to successfully emerge from fruit, pupate and become adults.

- Adult *B. tryoni* emerging from the soil are likely to be able to find food in the environment. Like most tephritids, both male and female *B. tryoni* need protein in order to become sexually mature (Meats et al. 2004; Clarke et al. 2011). Adult flies are presumed to obtain the majority of their protein through feeding on leaf surface bacteria. Research suggests that no single bacterial species is involved in a primary symbiotic relationship with *B. tryoni* (Clarke et al. 2011), and it is assumed that these bacteria are widely available. Other food sources for adult tephritids include widely available substances such as bird droppings, nectar and plant sap (Christenson and Foote 1960).

Adult *B. tryoni* are mobile and can fly to food sources and locate hosts.

- Adults are highly mobile and capable of independent dispersal. Most MRR (mark, release, recapture) studies have concluded that the mean dispersal distance of tephritid flies is usually below 1 km. However, the maximum dispersal distance reported in many studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014). Long-distance dispersal is reported and has been linked to isolated favourable habitats separated by resource-poor country that forced dispersing flies to make longer flights (Dominiak 2012). Fletcher (1973, 1974) found that movement of *B. tryoni* into and away from an orchard was seasonal and associated with the availability of fruiting host trees, and Weldon (2005) found that flies dispersed further in spring than in autumn, noting that dispersal may be linked to habitat suitability, e.g. fewer fruiting hosts or other resources. It is therefore likely that flies will be able to disperse far enough to find the resources they require in New Zealand.

There is moderate uncertainty associated with the conclusion that the likelihood of exposure is moderate. Information about waste disposal may be inaccurate (section 2.4.1). The effect of seasonality on this likelihood is uncertain.

Given the arguments and evidence below, the suitability of New Zealand's environment for the establishment of *Bactrocera tryoni* is considered to be low to moderate, with low uncertainty.

Bactrocera tryoni is described as a tropical species (Clarke et al. 2011). The results of various climate models suggest that it is likely to establish permanently in at least some parts of New Zealand, predominantly the northern half of the North Island:

- Baker and Cowley (1988) predicted establishment of permanent populations in the northern North Island and the top of the South Island in Marlborough and Nelson. Summer populations were predicted around the coast of the southern North Island and down the east coast of the South Island.
- Sutherst and Maywald (1989) predicted colonisation of the northern and eastern parts of the North Island.
- Predictions by Kriticos (2007) using parameters from Yonow and Sutherst (1998) were more conservative. *Bactrocera tryoni* was projected to be capable of establishing persistent populations in New Zealand only as far south as the northern Waikato. This study also investigated a variety of climate-warming scenarios. Under these, *B. tryoni* was projected to be capable of spreading further south in the North Island, and under a warm scenario for the 2080s could even persist in the northern tip of the South Island.
- Kean and Stringer (2019) modelled seasonal dynamics of *B. tryoni* and concluded that it was unlikely to establish south of Napier (eastern North Island).

Bactrocera tryoni has a high reproductive rate and is capable of finding mates.

- Multiple larvae are contained within a single fruit. Forty *B. tryoni* larvae have been found in one peach, and 67 adults have been reared from one apple (Weems and Fasulo 2002), although fewer adults are likely to emerge from most citrus species (Lloyd et al. 2013, Muthuthantri 2013; Table 2).
- To found a population, a minimum of one male and one female must successfully emerge from imported fruit and survive long enough to locate each other and mate. Enough adults to establish a population may therefore emerge from a single or a few discarded fruit. Males use pheromones and acoustic signals to attract sexually receptive females at dusk (Dominiak et al. 2011). Mating takes place only if ambient temperatures are above 15°C–16°C (Dominiak et al. 2011, Meats and Fay 2000, in Meats 2006 respectively). This temperature requirement is likely to be a constraint on successful mating taking place in parts of New Zealand,

particularly since some citrus is imported from Australia during the colder months. Most orange fruit, for example, is imported from Australia from June through October. However, there is some trade in oranges virtually year round. In particular, importation of Australian oranges is not uncommon in the warmer months of November and December, although very few consignments are imported in January through to April (Quancargo database). Additionally, limes tend to be imported in the summer months. Immature adult flies (the overwintering stage in Australia) are long-lived. The longest known period of adult survival is 198 days (DPIPWE 2011). Flies may therefore survive until temperatures are suitable for mating. In addition, cold-acclimated flies show a much higher mating frequency at lower temperatures (Meats and Fay 1976).

- *Bactrocera tryoni* is a more prolific egg producer than many other tephritids. Egg production is variable, with upper limits ranging from 80 to 100–120 (maximum 160) eggs per female per day. The oviposition rate is likely to be influenced by host plant and environmental factors, particularly temperature (Clarke et al. 2011), so may be lower in New Zealand.

Host availability is unlikely to be a barrier to establishment and spread of *B. tryoni*.

- *Bactrocera tryoni* has a very broad host range of both commercial and wild fruit and vegetables, making it one of the most polyphagous of all the tephritids. The fly has been recorded from 117 hosts, including commercial crops such as citrus, nuts, stone and pome fruit and tomato (Clarke et al. 2011). Many suitable hosts are present in New Zealand in natural and managed habitats.
- Fruit is likely to be available at many times of the year, but in any case, immature adults are long-lived and if fruit is not present for oviposition, adults may survive until fruiting occurs. If incursions take place when fruit is scarce or unavailable, establishment would require the survival of at least one individual of both sexes, or a mated female, until suitable fruiting hosts are available for oviposition.
- Once established, *B. tryoni* is capable of dispersing naturally and is also likely to be spread by the distribution of infested host fruit.

Bactrocera tryoni is likely to be detected and eradicated in the event of an incursion.

- Surveillance for fruit flies in New Zealand uses trimedlure, cuelure and methyl eugenol as lures (MacLellan et al. 2019). Males are responsive to cuelure (IAEA 2003), and early detection and therefore eradication of incursions is very likely. An analysis of 211 eradication or emergency response programs against 17 species of fruit flies in 31 countries indicated that the failure rate for these fruit fly eradication programs was low (about 7%; McInnes et al. 2017).
- *Bactrocera tryoni* has been detected in New Zealand by the surveillance grid seven times since the mid-1990s (Kean et al. 2020). It has been successfully eradicated on all occasions, including when breeding populations were detected.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. tryoni* is likely to be high.

Damage caused by *B. tryoni* reduces fruit quality and can render it unmarketable.

- Oviposition can cause necrosis around the puncture mark. Internal feeding by the larvae induces decay and premature fruit drop (Clarke et al. 2011; CPC 2020).

Bactrocera tryoni has been reported to cause severe damage and production loss in many horticultural commodities that are economically important to New Zealand.

- DPIPWE (2011) lists stone fruit, citrus, pome, grape and tomato as major fruit industries affected by *B. tryoni* in Australia. Between 76 and 100% infestation may occur in untreated peach crops in southeast Queensland (Bull 2004).
- Fruit and vegetables grown commercially in New Zealand that are known hosts of *B. tryoni* include citrus, avocados, walnuts, pears, stonefruit, capsicum, cucurbits, tree tomatoes, grapes and tomatoes (Underwood 2007).

The economic impact of *B. tryoni* in Australia is high.

- The annual cost of pre-harvest bait and cover spraying over the period 2006–2009 was estimated to be around AU\$48 million, while post-harvest treatments necessary to transport produce interstate exceeded AU\$22 million p.a. Even with these treatments, production losses in fruit fly endemic regions range from 0.5–3% (Sultana et al. 2017). If fruit flies are not controlled, potential losses could reach AU\$100 million per year, most being attributable to *B. tryoni* (Lloyd et al. 2010). Production losses in New Zealand are likely to be lower than in Australia, as the climate is less favourable for the development of high *B. tryoni* population levels. However, since there are no pest tephritids currently present in New Zealand and therefore no existing management programmes, there would be high costs associated with implementing such systems.

The establishment or even an incursion of *B. tryoni* is highly likely to cause trade impacts;

- In addition to production losses, many trading partners are likely to impose export restrictions and/or extra phytosanitary measures if *B. tryoni* is present, even temporarily, in New Zealand. These may not be restricted to known host fruit and may be imposed for long periods. In response to the May 1996 incursion of *C. capitata*, trading partners imposed restrictions on produce from the Auckland area which lasted 8 to 12 months or longer (Underwood 2007). *Bactrocera tryoni* has a limited geographical distribution, meaning that the majority of our trading partners are likely to impose such sanctions.

If *B. tryoni* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020b).
- *Bactrocera tryoni* is considered a serious enough pest that many countries undertake eradication programmes following detections. Successful responses include those undertaken in Easter Island, Perth and Rarotonga (Kean et al. 2020).

Bactrocera tryoni is likely to cause socio-cultural impacts on home gardens.

- Many favoured hosts, as well as citrus, are commonly grown in home gardens. Some untreated crops (e.g. peach in southeast Queensland) may have up to 100% infestation (Bull 2004). Sultana et al. (2017) estimated that in Australia, 80% of the value of backyard fruit production is lost in the absence of eradication programmes.

Environmental impacts caused by the establishment of *Bactrocera tryoni* are likely to be low.

- *Bactrocera tryoni* attacks some plant species in genera that have New Zealand native representatives, e.g. *Passiflora*, *Solanum* and *Syzygium* (CPC 2020). The two varieties of *Solanum aviculare* present in New Zealand (neither endemic) and *Syzygium maire* all have some form of threatened status (NZPCN 2020), and where their distributions overlap with *B. tryoni*, they may be at risk. Other species of *Solanum* and *Passiflora* are reported as “main” hosts (CPC 2020). However:
 - The fly has an unprecedentedly wide host range, and Beever et al. (2007) have suggested that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater. While Beever et al. (2007) did suggest that *B. tryoni* was a potential (low) risk to *Solanum aviculare*, this conclusion was based on factors affecting the likelihood of this species becoming established, not just its anticipated impact.
 - The fruit of the native *Solanum* and *Passiflora* species are small and much less fleshy than the preferred hosts of *B. tryoni*.
 - Other susceptible native plants are likely to have populations in areas that are not suitable for the establishment of *B. tryoni*.
 - If the fly attacks only the flesh of ripe fruit, it is unlikely to impair seed development, number or viability.

Bactrocera tryoni is unlikely to cause unwanted impacts on human health.

- No evidence of such impacts has been found.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera tryoni* may be considered for additional measures.

- Many *Citrus* species are hosts, though none appear to be favoured hosts;
- low levels of fruit infestation may not be detected during general handling, especially when the volume of commodities is large;
- larvae feed internally in the fruit and cannot be removed by general handling; the fruit need to be cut open to reveal them;
- *Bactrocera tryoni* is capable of moving from imported fruit into a suitable environment to allow establishment;
- warmer parts of New Zealand are likely to be suitable for the establishment of *B. tryoni*;
- hosts are widely available; and
- the establishment or even an incursion of *B. tryoni* is likely to cause high economic impacts in New Zealand.

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8.7 *Bactrocera tsuneonis* (Japanese orange fly)

Bactrocera tsuneonis is a fruit fly that specialises on citrus and other closely related plants and can be a serious pest of citrus if uncontrolled.

Scientific name: *Bactrocera tsuneonis* (Miyake, 1919)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Tetradacus) tsuneonis* (Miyake), *Dacus cheni* Chao, *Dacus tsuneonis* Miyake, *Tetradacus tsuneonis* (Miyake), Japanese orange fly, citrus fruit fly, Japanese orange fruit fly

Taxonomic notes: *Bactrocera tsuneonis* belongs to the subgenus *Tetradacus*. Some workers in the past have mistakenly listed *B. citri* as a synonym of *B. tsuneonis*. However, *B. citri* is a synonym of *B. minax*, which is very similar in appearance to *B. tsuneonis* (White and Elson-Harris 1994).

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera tsuneonis* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera tsuneonis* has a strong association with citrus fruit.
- Basic measures are likely to reduce the likelihood of entry of *B. tsuneonis* by a moderate degree; consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty).
- *Bactrocera tsuneonis* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *B. tsuneonis* to establish is considered high, but the area of establishment is likely to be limited by the distribution of its hosts.
- The level of impact caused by *B. tsuneonis* is likely to be moderate.
- *Bactrocera tsuneonis* may be considered for additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Moderate
The ability to move from the imported commodity onto a suitable host	Moderate	Low–moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Moderate	Low

8.7.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera tsuneonis* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁶⁸).

Bactrocera tsuneonis is not known to be present in New Zealand:

- *Bactrocera tsuneonis* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020);

⁶⁸ Refer to [ISPM 5](#) for the definition of a quarantine pest under the IPPC, and the [Biosecurity Act 1993](#), for factors to consider when defining "harm".

- The quarantine status of *B. tsuneonis* in New Zealand is 'regulated', and it is an unwanted organism (ONZPR 2020).

Bactrocera tsuneonis has the potential to establish and spread in New Zealand:

- *Bactrocera tsuneonis* is recorded from Japan and China (EPPO 2020), both of which have areas with climatic similarity to New Zealand, and therefore may be able to establish in areas of New Zealand, particularly warmer areas in the north.
- *Bactrocera tsuneonis* is a specialist on *Citrus* spp. and closely related species in the Rutaceae family (CABI 2020).
- Citrus is grown in New Zealand both commercially and domestically (see Chapter 2).

Bactrocera tsuneonis has the potential to cause impacts on the New Zealand economy through impacts on the citrus industry:

- *Bactrocera tsuneonis* is a serious pest on *Citrus* spp. (White and Elson-Harris 1994) which are grown commercially in New Zealand (see section 2.5.2).

8.7.2 Hazard identification: commodity association

Bactrocera tsuneonis is associated with citrus fruit

Bactrocera tsuneonis is reported from citrus fruit:

- Larvae of *B. tsuneonis* develop in the fruit of *Citrus* species including *C. aurantium*, *C. reticulata*, *C. sinensis* and *C. tangerina* (White and Elson-Harris 1994).

8.7.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera tsuneonis* has a strong association with citrus fruit:

The eggs and larvae of *B. tsuneonis* can be associated with citrus fruit commodities.

- *Bactrocera tsuneonis* females lay their eggs below the rind of the fruit. Usually, a single oviposition puncture is made in a fruit, and two to six eggs are deposited in a puncture. Usually, only one larva develops in the fruit, where it feeds on the contents of from two to ten carpels (segments). Larvae, which are mature about the time fruit drops from the tree, leave the fruit to pupate in the soil (Weems and Fasulo 2015). Therefore, larvae may still be present in the commodity at harvest.
- Larvae of *B. tsuneonis* have been recorded developing in the fruit of several *Citrus* species including *C. aurantium* L. (sour orange), *C. reticulata* Blanco (tangerine), and *C. sinensis* (L.) Osbeck (sweet orange) (White and Elson-Harris 1994).

Bactrocera tsuneonis is found in multiple citrus species.

- *Bactrocera tsuneonis* has been recorded from species of *Citrus* and *Fortunella* in the family Rutaceae (White and Elson-Harris 1994; Allwood et al. 1999), and it is considered a citrus specialist (CABI 2020) (Table 9.7.1).
- Adults have been reared from fruit of *Citrus aurantium* (sour orange), *C. reticulata* (tangerine), *C. sinensis* (sweet orange), *C. tangerina* (*C. reticulata*), *Fortunella crassifolia* (meiwa kumquat), *F. japonica* (oval kumquat) and *F. margarita* (round kumquat) (White & Elson-Harris 1994; Allwood et al. 1999).
- Zhang (1989) records *Citrus unshiu* as a host.

- USDA (1995) lists grapefruit [*C. paradisi*], orange and mandarin orange as hosts of *B. tsuneonis* in a pest risk assessment for unshu orange fruits (*Citrus reticulata* Blanco var. *unshu* Swingle) from Japan.
- Other citrus names have been listed as hosts: *Citrus kikokuni*, *C. deliciosa* (Zheng et al. 2019); *C. sunki* (Gong et al. 2008); ponkan, komikan, tachibana (Biosecurity Australia 2009).

Table 9.7.1 Citrus species reported as hosts for *Bactrocera tsuneonis*.

Citrus host scientific name	Citrus host common name	Reference
<i>Citrus aurantium</i>	Sour orange	White and Elson-Harris 1994, Gong et al. 2008
<i>Citrus paradisi</i>	grapefruit	USDA 1995
<i>Citrus reticulata</i>	–	Zheng et al. 2019
<i>Citrus tachibana</i>	–	Zheng et al. 2019, Gong et al. 2008
<i>Citrus reticulata</i>	Mandarin	White and Elson-Harris 1994, Gong et al. 2008
<i>Citrus sinensis</i>	Sweet orange	White and Elson-Harris 1994, Gong et al. 2008
<i>Citrus reticulata</i> var. <i>austera</i>		Gong et al. 2008
<i>Citrus reticulata</i>	Tangerine	White and Elson-Harris 1994, Zhang 1989, Gong et al. 2008
<i>Citrus reticulata</i>	Unshu mandarin, Satsuma	Zhang 1989, Gong et al. 2008

Bactrocera tsuneonis is present in two citrus-exporting countries considered in this import risk assessment, China and Japan.

- *Bactrocera tsuneonis* is known to occur only in Asia, specifically in China (Zhang 1989; Hancock and Drew 2018; Hou et al. 2018) and Japan (Hancock and Drew 2018; EPPO 2020).
- Although some papers report *B. tsuneonis* as present in Viet Nam (which is also one of the countries under consideration), recent surveys have failed to find it (Leblanc et al. 2018), and it is considered absent from that country (EPPO 2020).

Given the arguments and evidence below, basic measures are likely to reduce likelihood of entry by a moderate degree; consequently, the likelihood of entry is considered low to moderate (with moderate uncertainty):

Infested fruits are usually easily detected and are likely to be removed.

- Attacked fruit usually shows signs of oviposition punctures, and sugary exudates from the puncture may solidify on the fruit surface. In oranges, the oviposition puncture initially discolours to whitish, after which a brownish gummy exudate is secreted by the fruit. The area around the puncture becomes yellowish (on otherwise green fruit) and spreads. It then turns reddish, often becoming a longitudinal mark along the infested carpel, although it may appear circular or irregular in shape (Miyake 1919, in CABI 2020).
- According to Zhang (1989), who describes both *B. tsuneonis* and *B. minax*, infested fruits are easily recognised by their dark colour, the small nodule of the oviposition scar and the colour around the oviposition scar, which is yellowish and distinct from healthy skin. Symptoms of infestation can include punctures in skin, winding tunnels beneath the fruit skin, distortion of fruit and rotting fruit. It is assumed this description applies to both species.
- Therefore, fruit showing obvious signs of infestation by *B. tsuneonis* is likely to be detected and removed from a line or consignment during packhouse activities and inspections.

However, infested fruit may be not be detected in some circumstances.

- Eggs and larvae are inside the fruit and are observed indirectly by signs on the fruit surface. Usually, only a single oviposition puncture is made in a fruit, and usually, a single larva develops within the fruit, damaging as few as two carpels or segments (Weems and Fasulo 2015).
- Therefore, low levels of infestation may go undetected, especially at high volumes of the fruit commodity.

General handling and processing after harvesting is not likely to remove eggs and larvae of *B. tsuneonis* from citrus fruit.

- Eggs and larvae are found inside the fruit and so would not be removed by routine activities in the packhouse, such as washing and brushing, which only treat the fruit surface.

Larvae of *B. tsuneonis* are likely to survive transit of some citrus commodities.

- Storage and transport of citrus consignments from exporting countries to New Zealand is likely to occur at cool temperatures, with the length of time for shipment varying depending on exporting country.
- *Bactrocera tsuneonis* and *B. minax* are widely regarded as the two most cold-tolerant species in the genus *Bactrocera* (Xia et al. 2019).
- In a study on the effect of different temperatures on pupariation and pupal development in *B. tsuneonis*, Yasuda et al. (1994) found that a small number of adults (2) emerged from pupae (10) exposed to 5°C for the first 45 days. These authors concluded that some development proceeds at 5°C.
- No interception records of *B. tsuneonis* in citrus fruits were found.
- There is some uncertainty around the ability of *B. tsuneonis* to survive storage and transport conditions, as little information was found on temperature requirements. No information was found to indicate that storage and transport conditions would have a detrimental effect on the survival of larvae.

The level of uncertainty associated with the conclusion is moderate, based on the lack of interception data for *B. tsuneonis* and the amount of information available on the impacts of low temperatures to inform the likelihood of *B. tsuneonis* larvae surviving standard storage and transport at low temperatures.

Likelihood of establishment:

Given the arguments and evidence below, *Bactrocera tsuneonis* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (transfer).

Bactrocera tsuneonis can survive and develop on discarded citrus fruits and fruit pieces.

- *Bactrocera tsuneonis* is univoltine (Zhang 1989). Eggs and larvae are found on only *Citrus* and the related genus *Fortunella* in the Rutaceae. Eggs are laid under the skin of the fruit and a single larva develops feeding inside the carpels (segments). Mature larvae leave the fruit to pupate when the fruit drops to ground, although sometimes larvae leave the fruit while it is still in the tree. Pupation, which takes place over winter, usually occurs in the soil but may take place in other situations such as packaging (Zhang 1989). *Bactrocera tsuneonis* may have a pupal diapause (Yasuda et al. 1994).
- Therefore, if infested citrus fruit is discarded as whole fruits or fruit pieces, *B. tsuneonis* may complete larval development in the waste and find a suitable location to pupate.

Most of the fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any *B. tsuneonis* present would either be killed or unable to escape from the citrus host.

- In New Zealand, the majority of kitchen waste is either bagged and sent to landfill or run through kitchen disposal units (see section 2.4.1, waste analysis). *Bactrocera tsuneonis* is unlikely to survive in these circumstances.

However, some of the waste would be disposed of using high-risk methods, including composting in gardens, use as animal feed or discarding directly into the environment.

- A small percentage of infested fruit is likely to be discarded in a home compost bin or open compost heap, or directly into the environment (see section 2.4.1, waste analysis).
- *Bactrocera tsuneonis* larvae move from citrus fruit to pupate in the soil (in the top two inches or 5 cm (Weems and Fasulo 2015) but may also pupate in other sheltered situations such as in packaging (Zhang 1989). Therefore, some larvae or pupae associated with discarded citrus may find suitable conditions to develop to adulthood.
- Adults emerging from the soil are likely to be able to find food in the environment. Sexually immature adults need supplementary nutrients, such as honeydew excreted from aphids, coccids and psyllids, before oviposition to enable health, longevity and egg production (Zhang 1989; Weems and Fasulo 2015).
- Hosts for oviposition and larval development are available in many areas of New Zealand, *Citrus* is commercially produced in many parts of the North Island and in parts of the South Island, with most production taking place in warmer northern regions (see section 2.4.2).

Citrus is also commonly grown in domestic gardens, although species favoured by *B. tsuneonis* are not likely to be grown in southern regions of New Zealand.

- If citrus hosts are located near the site for the citrus fruit waste, *B. tsuneonis* adults are likely to find them.

Adult *B. tsuneonis* can fly to food sources and locate hosts.

- *Bactrocera tsuneonis* is described as a large, powerful insect (CABI 2020). Adults are larger than those of most other species of *Bactrocera*: the adult female is approximately 11 mm long, excluding the ovipositor, with a wing expanse of about 10 mm; the male is slightly smaller (Weems and Fasulo 2015). Therefore, it is assumed that, like other *Bactrocera*, the adult can readily fly to food sources and locate citrus hosts.
- No information was found on flight capability or distances covered by *B. tsuneonis*. However, studies on other tephritids show that the mean dispersal distance of tephritid flies is usually well below 1 km, although mean dispersal distances from below 1 km to 3.6 km have been reported for *B. dorsalis*. However, the maximum dispersal distance reported in many studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014).

The level of uncertainty associated with this conclusion is low to moderate. Firstly, waste data may not be very accurate or up to date, and it is not known how frequently suitable hosts are available near composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Secondly, it is uncertain what proportion of composting sites are exposed or uncovered (e.g., in a compost bin). Thirdly, although *B. tsuneonis* can fly to seek food sources and citrus hosts, its flight capability is uncertain.

Given the arguments and evidence below, the suitability of the New Zealand environment for *B. tsuneonis* to establish is considered high, but the area of establishment is likely to be limited by the distribution of its hosts

Bactrocera tsuneonis is known to occur in subtropical and temperate areas.

- The known distribution for *B. tsuneonis* is China and southern parts of Japan (Kyushu, Ryukyu Islands) (EPPO 2020).
- *Bactrocera tsuneonis* occurs in temperate areas of China, such as the mountainous terrains of Guizhou, Guangxi, and Yunnan (Hou et al. 2018). In Guangdong, *B. tsuneonis* has recently been detected in Huaiji County on the northwest border, adjacent to Guangxi Province where *B. tsuneonis* is known to occur (Hou et al. 2018). The temperature in Huaiji County is lower than that of the coastal plain of Guangdong, which may contribute to the presence of *B. tsuneonis* there (Hou et al. 2018).
- In China, *B. tsuneonis* has been reported from the following provinces:
 - Guangxi (Hancock and Drew 2018; Hou et al. 2018; Zhang 1989)
 - Guizhou (Hancock and Drew 2018; Hou et al. 2018)
 - Hunan (Hancock and Drew 2018; Hou et al. 2018)
 - Jiangsu (Hancock and Drew 2018; Zhang 1989)
 - Sichuan (Hancock and Drew 2018; Hou et al. 2018; Zhang 1989)
 - Yunnan (Hou et al. 2018)
 - Guangdong (Hou et al. 2018)
- Some of these areas have similar climate conditions to New Zealand, with a climate match index (CMI) of 0.7 or greater (Phillips et al. 2018):
 - Guizhou (0.7–0.8 CMI), Hunan (0.7 CMI), Jiangsu (0.7 CMI), Sichuan (0.7–0.9 CMI), Yunnan (0.7–0.8 CMI).
- Therefore, based on the known geographic distribution and CMI values, *Bactrocera tsuneonis* is likely to find the climate suitable for it to establish in at least some regions of New Zealand where citrus is grown.

Bactrocera tsuneonis has a low reproductive rate.

- *Bactrocera tsuneonis* is univoltine (one generation per year). The ratio of males to females is approximately one to one (Weems and Fasulo 2015). A female may lay 30–40 eggs in its lifetime (Biosecurity Australia 2009), but only 2–6 eggs are laid in a single fruit via a single oviposition puncture. Frequent copulation apparently is necessary, as this occurs after each batch of eggs has been deposited (Weems and Fasulo 2015).

- Usually a single larva develops in a fruit, and therefore, mate-finding would be enhanced by more than one infested fruit being deposited in an area, either at the same spot or nearby.
- The production of sex pheromones would increase the ability of males and females to locate each other when present in low numbers and thereby improve mating success. Ono et al. (2020) have found that male *B. tsuneonis* biosynthesise a range of chemicals in the rectal gland that may represent sex pheromones and act to bring the sexes together, but their exact function remains unknown.

Host availability is unlikely to be a limiting factor for establishment, but the area of establishment is likely to be limited by the distribution of the hosts.

- *Bactrocera tsuneonis* has been recorded only from species of *Citrus* and *Fortunella* in the family Rutaceae. *Citrus* is commercially produced in both the North and South Island, with most commercial production taking place in the North Island (see section 2.4.2). *Citrus* is also commonly grown in domestic gardens, although species favoured by *B. tsuneonis* are not likely to be grown in southern regions of New Zealand.
- Therefore, if *B. tsuneonis* establishes in New Zealand, the area of establishment is likely to be limited by the distribution of its known hosts.

Bactrocera tsuneonis may not respond to lures used in current fruit fly surveillance in New Zealand.

- Males are not known to be attracted to any synthetic lures (White and Elson-Harris 1994; Hancock and Drew 2018; Plant Health Australia 2018; Zheng 2019; CABI 2020).
- Both sexes may be monitored using protein bait traps (either protein hydrolysate or protein autolysate) (CABI 2020).
- As a result, *B. tsuneonis* might not be discovered until after it has established in New Zealand.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. tsuneonis* is likely to be moderate, but the impact to the New Zealand citrus industry is likely to be high.

Damage and symptoms caused by *B. tsuneonis* can reduce fruit quality.

- Fruit quality and quantity are reduced as a result of larval feeding which takes place entirely inside the fruit (Weems and Fasulo 2015). The skin of the fruit may discolour around the oviposition scar and look unhealthy in comparison with the rest of the fruit.

Bactrocera tsuneonis is considered a serious pest of citrus with impacts on commercial production, including in areas with similar climate to New Zealand.

- In Japan, *B. tsuneonis* has been considered an important pest of citrus, with outbreaks where up to 60% of fruit have been infested occurring in some commercial citrus areas since 1947 (Weems and Fasulo 2015).
- Miyake (1919, in CABI 2020) noted that up to 50% of the harvest could be destroyed but that 10–20% was more typical.
- In China, Zhang (1989), Hou et al. (2018) and Xia et al. (2019) describe *B. tsuneonis* as a serious pest of citrus. Zhang et al. (2019) states that *B. tsuneonis* and *B. minax* are considered major pests of citrus crops, causing large-scale economic losses, doing great harm to the export of citrus, suppressing international trade and leading to trade barriers.
- *Bactrocera tsuneonis* mainly attacks *C. sunki*, *C. reticulata*, *C. unshiu*, *C. tangerina*, *C. aurantium*, *C. sinensis* and *C. kinokuni* in Ningming, Guangxi. The infestation rate is usually 30%, but as high as 86.92% has been observed (Gong et al. 2008). In Pingxiang, Guangxi, the infestation rate reached 75% in 2005 (Gong et al. 2008).
- *Bactrocera tsuneonis* was reported to infest 50% of oranges in Kiangtsin, in the Szechwan [Sichuan] Province of southwestern China, during 1940 (Weems and Fasulo 2015).
- Some of the areas in China where *B. tsuneonis* is a serious pest of citrus have similar climates to New Zealand. For example, the climate match index of Sichuan is 0.7–0.9.
- *Citrus* is of economic importance to New Zealand (see section 2.5.2). As infestation rates of around 50% have been recorded in areas with a similar climate to New Zealand, the impact of

B. tsuneonis on the New Zealand citrus industry is likely to be high, but the impact to the overall New Zealand economy is likely to be moderate.

If *B. tsuneonis* is detected in New Zealand, the cost incurred by a response would be expensive.

- The typical cost of a response is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).

Establishment of *B. tsuneonis* is likely to increase phytosanitary measures required for export of citrus fresh produce to countries where *B. tsuneonis* is not present.

- *Bactrocera tsuneonis* is recorded as present only in China and Japan.

It is likely that *B. tsuneonis* will cause a low level of sociocultural impacts in New Zealand.

- *Citrus* is grown domestically, particularly in warmer northern regions of the country.
- *Bactrocera tsuneonis* will affect fruit quality, although not the plants themselves.

It is likely that *B. tsuneonis* will have a very low level of impact on the environment.

- The host range of *B. tsuneonis* is confined to species of *Citrus* and the closely related *Fortunella* in the family Rutaceae.
- There are no *Citrus* or *Fortunella* species native to New Zealand. There are two genera within Rutaceae endemic to New Zealand: *Leionema* and *Melicope*. Neither the *Leionema* nor *Melicope* species are considered threatened (NZPCN 2020).

It is likely that *B. tsuneonis* will have negligible impacts on human health.

- No evidence was found that *B. tsuneonis* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera tsuneonis* meets the criteria to be considered for additional measures.

- *Bactrocera tsuneonis* has a strong association with fruits of some citrus species.
- Some infested fruits will not be detected, especially when the volume of commodities is large.
- As the larvae feed internally in the fruits, general handling (e.g. washing and brushing) cannot remove the larvae.
- *Bactrocera tsuneonis* has a moderate ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *B. tsuneonis* to establish is considered high, but the area of establishment is likely to be limited by the distribution of its hosts.
- The citrus hosts of *B. tsuneonis* are grown commercially in New Zealand and are common garden plants, especially in warmer northern regions of New Zealand.
- The level of impact caused by *B. tsuneonis* is likely to be moderate to the overall economy of New Zealand, but high for the citrus industry.
- *Bactrocera tsuneonis* is present in citrus-exporting countries considered in this import risk assessment: China, Japan.

8.7.4 References

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8.8 *Bactrocera xanthodes* (Pacific fruit fly)

Bactrocera xanthodes is a polyphagous, multivoltine (more than one generation per year) tropical/subtropical fruit fly. It has been recorded from 34 host species from 20 families, including citrus, and has been reported to cause serious damage to fruit crops.

Scientific name: *Bactrocera xanthodes* (Broun, 1904)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Notodacus) xanthodes*, *Chaetodacus xanthodes*, *Dacus xanthodes*, *Notodacus xanthodes*, *Tephritis xanthodes*

Taxonomic notes: *Bactrocera xanthodes* belongs to a species complex of closely related sibling species, based on morphological comparisons, host records, geographic distributions and DNA samples. Other species in the complex are *B. paraxanthodes* Drew and Hancock, present in New Caledonia, *B. neoxanthodes* Drew and Romig in Vanuatu (Drew and Romig 1997; Allwood et al. 1997a; Li et al. 2019) and an as yet undescribed species in Samoa (White and Elson-Harris 1994; Tunupopo Laiti et al. 2002; CPC 2020). Only *B. xanthodes* has been classified as a pest species.

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera xanthodes* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera xanthodes* has a strong association with citrus fruit.
- Basic measures are likely to reduce the likelihood of introduction of *Bactrocera xanthodes* by a moderate degree (with moderate to high uncertainty). Consequently the likelihood of entry is low to moderate (with moderate to high uncertainty).
- *Bactrocera xanthodes* has a low to moderate ability (with moderate to high uncertainty) to move from imported fruit and into a suitable environment, to allow for establishment.
- The suitability of the New Zealand environment for *Bactrocera xanthodes* to establish is considered low to moderate (with low to moderate uncertainty), and its establishment is likely to be restricted to the northern part of the North Island and sheltered environments, although short-term populations may appear in other areas during summer months.
- The level of impact caused by *Bactrocera xanthodes* is likely to be high (with low to moderate uncertainty).
- *Bactrocera xanthodes* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–Moderate	Moderate–high
The ability to move from the imported commodity onto a suitable host	Low–Moderate	Moderate–high
Suitability of the New Zealand environment	Low–moderate	Low–moderate
Impacts on the New Zealand economy, environment, health and society	High	Low–moderate

8.8.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera xanthodes* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: the pest is not present in New Zealand, and is of potential importance (able to establish and cause harm).

B. xanthodes is not known to be present in New Zealand:

- *B. xanthodes* is not recorded in NZInverts (2020) and NZOR (2020).
- *B. xanthodes* is recorded in PPIN (2020); however, it was entered for use in border, post-border and post-entry quarantine identification and has been classified as not present in New Zealand.
- *B. xanthodes* is listed as an unwanted organism in New Zealand (ONZPR 2020).
- *B. xanthodes* is listed as 'regulated' in New Zealand (ONZPR 2020).

B. xanthodes has the potential to establish and spread in New Zealand:

- *B. xanthodes* is only reported from areas with climates warmer than that of NZ; however, its restricted distribution may be a result of geographic barriers to dispersal (i.e. being present on remote islands) rather than strict climate requirements.
- Furthermore, while coastal climates of these islands are indeed warmer than New Zealand, montane areas do have cooler climates (Halloy 2020). As no information was found regarding specific distribution (i.e. if distribution is restricted to mountainous and/or coastal areas), there is a probability that *B. xanthodes* may have evolved some tolerance to cooler climates. Therefore, the climate of the species' current distribution may not be a good indicator of its potential distribution, and the fruit fly may be able to establish in some areas of New Zealand.

B. xanthodes is polyphagous and has been recorded from 34 hosts species in 20 plant families, including several species grown commercially and in home gardens in New Zealand.

B. xanthodes has the potential to cause impacts on the economy and environment of New Zealand:

- *B. xanthodes* has the potential to damage plant species that are of economic importance to New Zealand, such as citrus, tomato and avocado.
- *B. xanthodes* has the potential to harm the New Zealand environment, as it has been reported on plant species in genera that are present in New Zealand (NZPCN 2020).
- *B. xanthodes* has the potential to have sociocultural impacts, as some hosts, such as citrus, tomato and guava, are commonly planted in home gardens.

8.8.2 Hazard identification: commodity association

Bactrocera xanthodes is associated with citrus fruit.

B. xanthodes has been reported from citrus fruit:

- Adult *B. xanthodes* have been reared from field-collected fruit of different citrus species/cultivars (Leblanc et al. 2013), suggesting that the fruit fly can survive and complete development on citrus (Leblanc et al. 2012; Leblanc et al. 2013).

8.8.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera xanthodes* has a strong association with citrus fruit.

B. xanthodes has been reported to develop in various citrus species and cultivars.

- Larvae and adults of *B. xanthodes* have been reared from various citrus fruits and cultivars (Leblanc et al. 2013). Citrus fruit host associations found in the literature are summarised in Table 9.8.1.
- In Samoa, laboratory host status tests revealed that *B. xanthodes* adults can be reared from damaged grapefruit exposed to gravid females (Leblanc et al. 2013).

Table 9.8.1 Known citrus fruit host association of *Bactrocera xanthodes*. An asterisk indicates *B. xanthodes* was only bred on damaged fruits exposed to gravid females.

Citrus host scientific name from the reference	Citrus host common name from the reference	Reference
<i>Citrus latifolia</i>	Tahitian Lime*	Leblanc et al. (2013)
<i>Fortunella japonica</i>	Round kumquat	Leblanc et al. (2012; 2013)
<i>Citrus limon</i>	Lemon*	Leblanc et al. (2013)
<i>Citrus maxima</i>	Pomelo	Leblanc et al. (2012; 2013)
<i>Citrus paradisi</i>	Grapefruit*	Leblanc et al. (2013)
<i>Citrus reticulata</i>	Mandarin/Tangerine	Leblanc et al. (2012; 2013); CPC (2020)
<i>Citrus sinensis</i>	Navel orange	Leblanc et al. (2012; 2013)

B. xanthodes is present in three citrus-exporting countries in this IHS:

- *B. xanthodes* is present in the Cook Islands, Fiji and Samoa (Leblanc et al. 2013; CPC 2020; EPPO 2020a).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Bactrocera xanthodes* by a moderate degree (with moderate to high uncertainty). Consequently, the likelihood of entry is low to moderate.

Some of the infested fruits may be easy to detect and removed. Given the duration of each life stage of *B. xanthodes*, the likelihood of entry of eggs and larvae is moderate.

- Reproduction in *B. xanthodes* is biparental and females oviposit just under the skin of the fruit, usually at the start of ripening. The process of egg-laying introduces bacteria into the fruit, which becomes spoiled. The rotting flesh provides the developing larvae with a food source (Tunupopo Laiti et al. 2002).
- The fruit falls to the ground, and the larvae exit to pupate within the soil. Adults emerge from pupation and will immediately seek mates. The whole lifecycle from egg to egg at $26 \pm 1^\circ\text{C}$ (under laboratory rearing conditions) is a minimum of 35 days (Clare 1997).
- There do not appear to be records of how many eggs are laid at any one time by *B. xanthodes* in citrus. However, approximately 750 *B. xanthodes* larvae were found in a single breadfruit (*Artocarpus altilis*) from Niue (Baker and Cowley 1991), indicating several females had oviposited in the one fruit. Since the average egg to pupation period is 10 days, there is a higher likelihood of larvae entering in fruit arriving by air than by sea.
- As pupation occurs in the soil, it is considered unlikely pupae would enter with *Citrus* fruit.
- Adults have a lifespan of approximately 1–5 months (possibly longer in some cases), with females capable of laying about 1,000–1,300 eggs during their lifetime (Cowley et al. 1993).
- Xia et al. (2019) found that fruit bagging and packing house culling could mitigate risk from fruit flies to citrus commodities in China. The study found decreased oviposition marks and an absence of viable individuals in bagged pomelo fruit ($n=3,000$), while 129 fruit fly-infested fruits were found in unbagged fruit ($n=3,040$). They also found that in fruit (*C. unshiu*) that received culling treatments ($n=10,000$), fruit flies were absent, and only 10 fruits with oviposition marks were found, while in fruit ($n=10,000$) that did not receive the culling treatment, 1 infested fruit with 7 larvae of *B. minax* and 25 fruits with fruit fly oviposition marks were found.
- If bagging and culling are used in the export countries, these practices are likely to reduce the risk to some extent.

- Like other *Bactrocera* fruit flies (e.g. *B. dorsalis* and *B. minax*), heavy infestation of *B. xanthodes* may cause fruit to rot and drop prematurely, and dropped fruit is unlikely to be exported.

However, there is a chance that a small quantity of infested fruit will not be detected.

- Fruits with low infestation (fewer oviposition punctures) may not be obvious enough to be detected during general handling.
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may more difficult to detect.

General handling after harvesting is not likely to remove eggs and larvae of *B. xanthodes* inside citrus fruit.

- Because general handling after harvesting (e.g. washing and brushing) only treats the surface of fruit, it is unlikely to remove the larvae of *B. xanthodes* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *B. xanthodes* inside.

B. xanthodes has the potential to survive transit of fruit commodities.

- *B. xanthodes* has not been specifically identified on any commodities in Europe (EPPO 2020b).
- *B. xanthodes* has been identified 155 times at the New Zealand border between 1929 and 2019. In total, 1,097 specimens were intercepted (LIMS 2019).
 - 75.5% of specimens were either dead or non-viable, 18.5% were either alive or viable, and the status of 6% of specimens was unknown.
 - Approximately 99% of specimens were eggs (65.5%) or larvae (34.5%). The remaining specimens were recorded as adults, or their life stage was unknown.
 - 60% of interceptions were on passenger pathways, 25% did not record any details on the pathway, and 15% were on air/sea cargo.
 - The specimens were intercepted on:
 - Pomelo (*Citrus maxima*) and starfruit (*Averrhoa carambola*), 2% (fresh produce, live larvae from Fiji). The specimens were intercepted from two fresh produce consignments from Fiji (one including both pomelo and starfruit and the other importing only pomelo).
 - Breadfruit (*Artocarpus altilis*), 87% (fresh produce, cooked and peeled)
 - Mango (*Mangifera indica*), 3% (fresh produce)
 - Watermelon (*Citrullus lanatus*), 3% (fresh produce)
 - Avocado (*Persea americana*), 2% (fresh produce)
 - Fresh produce guava (*Psidium guajava*), pawpaw (*Asimina triloba*) and plantain plant material (*Musa* sp.), total 3% (fresh produce)
 - 52% of specimens were from Samoa, 34% from Tonga, 9% from Fiji and 3% from Niue, Tokelau and Tuvalu, and 2% of specimens did not record the country of origin or the country of origin was unknown.
 - Of the specimens from Samoa (a country included in the scope of this IRA) 10% were alive/viable, 31% were larvae, and 69% were eggs. Commodities the specimens were intercepted on included but were not limited to breadfruit, avocado and mango.
 - Of the specimens from Fiji (a country included in the scope of this IRA), 40% were alive/viable, 42% were larvae, and 57% were eggs. Commodities the specimens were intercepted on included but were not limited to breadfruit, avocados and pomelo.
- Transit of fresh produce usually involves cool storage. No study investigating the cold-tolerance capability of *B. xanthodes* has been found. However, of the interceptions recorded in LIMS (2019), all the specimens (eggs and larvae) on the air/sea cargo pathway (15%) were documented as dead, non-viable or unknown.
- Furthermore, it can be assumed if *B. xanthodes* distribution is restricted to coastal areas of tropical Pacific countries, then the fruit fly species is likely to be relatively susceptible to cold storage temperatures. However, Anthony (2008) states *B. xanthodes* has been recorded to breed in Tonga when minimum temperatures fell to 9°C in 1986.

The level of uncertainty associated with this conclusion is moderate to high.

1. Species-specific information about the detectability of *B. xanthodes* on citrus fruit is not available.
2. It is uncertain whether *B. xanthodes* can survive transit, as only 15% of interceptions were made on air/sea cargo pathways, and no study has been found investigating the cold tolerance of *B. xanthodes*.

Likelihood of establishment:

Given the arguments and evidence below, *Bactrocera xanthodes* has a low to moderate (with moderate to high uncertainty) to move from imported fruit and into a suitable environment to allow for establishment on a host plant.

B. xanthodes may survive and develop on citrus fruit waste.

- The duration of pupation for *B. xanthodes* is eight days at 30°C and 39 days at 14°C. The mean egg to adult development time is 23 days. Adult females begin oviposition at day 35 (at the adult age of 12 days) (Anthony 2008). Suboptimal humidity can prolong developmental rates of the immature stages and inhibit adult maturation (Fletcher 1987).
- The developmental time from egg to adult was found to be inversely proportional to temperature in *B. dorsalis* (Diptera: Tephritidae) (Rashmi et al. 2020). Thus, the development time of *B. xanthodes* is likely to be longer in New Zealand due to lower temperatures. Nevertheless, the fruit fly is expected to be able to survive and develop in *Citrus* spp. hosts in warmer months.
- In its native distribution, *B. xanthodes* is abundant between January and June, as this is when its primary host species (*Artocarpus altilis*, *Ochrosia oppositifolia* and *Barringtonia edulis*) is also available (Tora Vueti et al. 1997a). Previous importation records of citrus fresh produce from Vanuatu can be found from July to January (QuanCargo 2020).
- *B. xanthodes* have been observed ovipositing in fallen fruits (Allwood 1997a). They can also be reared successfully in artificial larval substrates of pawpaw and sugarcane bagasse, rehydrated carrot, and wheat (Tora Vueti et al. 1997a), illustrating the adaptability of the species to develop in various host environments.
- If citrus fruits are disposed of as whole fruits or fruit pieces, it is likely that *B. xanthodes* can survive in the resulting waste. There is no evidence to suggest *B. xanthodes* can complete development on citrus fruit skin.

Most of the citrus waste in New Zealand would be disposed of using low-risk methods. Thus, *B. xanthodes* would either be killed or unable to escape from the citrus host.

- Most of the kitchen waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units. In these situations, *B. xanthodes* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and use as animal feed.

- Mature fruit fly larvae emerge from host fruit and drop to the ground to pupate in soil. In New Zealand, the pupae may be able to survive during summer months, but it is uncertain whether they will survive and develop in colder seasons.
- Adults of *B. xanthodes* emerging from the soil are likely to be able to find food in the environment if citrus fruit waste is disposed of using high-risk methods and the temperature is suitable for the species.
- Although not specifically reported from *B. xanthodes*, adult fruit flies have been known to feed on various foods, including glandular secretions of plants, nectar and plant sap exuding from trunk, stem, leaf or fruit injuries (Christenson and Foote 1960). These food sources are likely to be available in household gardens, parks and farms.
- Hosts for oviposition and larval development are available in warmer areas of New Zealand, and some are present in colder areas. *B. xanthodes* is polyphagous, and hosts include species commonly grown commercially and in home gardens (e.g. citrus, avocado, guava and papaya). Citrus and avocados are commercially produced in multiple regions of New Zealand, with most commercial production taking place in the Gisborne (1,136 ha citrus planted) and

Northland regions (313 ha citrus, 1,647 ha avocados planted) (see section 2.4.2) (Plant & Food Research 2019).

- If citrus or other potential hosts are located near the composting site or animal feeding site (see the waste analysis, section 2.4.1), adult *B. xanthodes* are likely to locate the citrus host.

B. xanthodes can spread via adult flight and human-assisted movement of infested fruit (CPC 2020).

- Studies on other tephritids estimate that the mean dispersal distance of tephritid flies is usually under 1 km. The exception is the average dispersal distances of between 1 km and 3.6 km for *B. dorsalis*. However, the maximum dispersal distance reported in many studies was limited to the distance of the trap placed furthest from the release point (Weldon et al. 2014).
- While it is known that *B. xanthodes* are active fliers (Cowley et al. 1993), no information was found on the specific dispersal patterns and flight capabilities.
- As mentioned previously, 60% of *B. xanthodes* interceptions at New Zealand borders were on the passenger pathway (LIMS 2019).

It is uncertain if *B. xanthodes* would be able to establish if it arrived in New Zealand during colder months.

- The current known distribution of *B. xanthodes* is restricted to Pacific Island countries in tropical/subtropical areas, which may reflect the species' climate requirement. However, on some of these islands, there is a possibility of cooler montane climates (Halloy 2020).
- No research has been done to date on the cold tolerance capability of *B. xanthodes*. However, there are many studies on these aspects for other *Bactrocera* spp., which indicates variable cold tolerance for the genus.
- Thus, if *B. xanthodes* were to arrive in New Zealand at a time when temperatures are colder than regions where it is currently distributed, it is uncertain whether it will be able to survive and locate a suitable host to develop.

The level of uncertainty associated with this conclusion is moderate to high.

1. Waste data may not be accurate or current. Also, it is unknown how frequently suitable hosts are present near composting sites in gardens or animal feeding locations are (see section 2.4.1, waste analysis). Furthermore, when the fruit fly and citrus fresh produce hosts are disposed of, development time may vary from specimens reared on artificial diets.
2. It is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin).
3. Although *B. xanthodes* is an active flier, its exact flight capability is uncertain.
4. No specific studies were found investigating the cold tolerance of *B. xanthodes*. Its current distribution is restricted to tropical and subtropical areas, some of which have montane forests and reach average temperatures well within New Zealand ranges. Hence, there is uncertainty associated with whether *B. xanthodes* could survive and find a suitable host if it arrived in New Zealand during colder months and whether it would be able to establish a sustainable population due to the climate.

Given the arguments and evidence below, the suitability of the New Zealand environment for *Bactrocera xanthodes* to establish is considered low to moderate (low to moderate uncertainty). Establishment is likely to be restricted to northern parts of the North Island and sheltered environments, although short-term populations may establish in other areas during summer months.

- The current distribution of *B. xanthodes* is restricted to the tropical/subtropical Pacific Islands, found between 13 and 21°S (Table 9.8.2). It is classified as a major pest fruit fly species in the South Pacific region because of its ability to inflict heavy crop losses and the trade restrictions applied against crops grown in some countries due to its presence.
- In Broun's original species description, *B. xanthodes* was listed as being found in fruit imported into New Zealand from Rarotonga Island (Cook Islands), Suva and Tonga. According to Drew (1982), these records were based on occurrence of larvae in fruit and not on adults bred from the larvae. Drew reported that *B. xanthodes* had never subsequently been recorded from Rarotonga (Cook Islands) and so this record of *B. xanthodes* in

Rarotonga (Cook Islands) was likely incorrect. No other literature on *B. xanthodes* in Rarotonga (Cook Islands) has been found.

- The main islands of Fiji have a low climate similarity with New Zealand (climate match index (CMI) of 0.4, which is a poor match with New Zealand). While other countries where *B. xanthodes* has been found do not have a mapped CMI score (Phillips et al. 2018), there is considerable temperature overlap with equatorial mid-altitude regions of Pacific tropical island countries and the New Zealand climate (Halloy 2020).
- New Zealand's *Citrus* is mainly grown in the Gisborne and Northland regions (Plant & Food Research 2019).
- Comparing climate indicators of countries where *B. xanthodes* has established with the Gisborne and Northland regions shows that the average rainfall and sunshine hours are similar to Niue and Vanuatu (Table 9.8.3). However, the average monthly temperature in Niue and the average annual rainfall in Vanuatu is higher than in Gisborne or Northland.
- The Gisborne and Northland regions also produce significant quantities of avocados, squash and tomatoes, all of which are hosts of *B. xanthodes* (Leblanc et al 2013; Plant & Food Research 2019).
- Hence, establishment of *B. xanthodes* is likely to be restricted to northern regions of New Zealand and sheltered environments. Short-term populations of the fruit fly species may be able to establish in other areas during warmer months.
- *B. xanthodes* is also likely to establish in greenhouses where suitable hosts are present.

Table 9.8.2 Known geographic distribution of *bactrocera xanthodes*. Information compiled 21 September 2020. Countries/areas in bold are included in the citrus IHS project.

COUNTRY	Status	Reference
American Samoa	Present, no details	CPC 2020; EPPO 2020a
Cook Islands	Present, no details	CPC 2020; EPPO 2020a
Fiji	Present, no details	CPC 2020; EPPO 2020a
Nauru	Absent, eradicated	Drew, Allwood and Tau 1997; CPC 2020; EPPO 2020a
Niue	Present.	Heimoana et al. 1997; CPC 2020; EPPO 2020a
Tonga	Present, no details	CPC 2020; EPPO 2020a
Tuvalu	Present, restricted distribution	CPC 2020; EPPO 2020a
Vanuatu	Absent, no details	Allwood et al. 1997a; Drew and Romig 1997; Li et al. 2019
Wallis and Futuna	Present, no details	CPC 2020
Samoa	Present, no details	Leblanc et al. 2013

Table 9.8.3 Comparison of average Northland and Gisborne climate indicators.

REGION	Mean monthly temperature (°C)	Mean annual rainfall (mm)	Average annual sunshine hours	References
Niue	25.4	1,960	2,211	Statistics Niue 2020
Tonga	24	1,777	3,441	Weather and Climate 2020; Weather Atlas 2020
French Polynesia (Austral Islands)	23	2,005	1,925	NOAA 2018
Cook Islands	26	2,169	2,125	Weather and Climate 2020;
American Samoa	24.5	1,803	2,400	NOAA 2018
Northland	20	1,759	2,162	Plant & Food Research 2019, Chappell 2013
Gisborne	15–20	1,029	2,294	Plant & Food Research 2019; Chappell 2016

B. xanthodes has a broad host range, and therefore, host availability is unlikely to be a limiting factor for the species to establish in New Zealand.

- *B. xanthodes* is polyphagous in the countries it is established in (Table 9.8.2).
- *B. xanthodes* has been recorded on hosts from 20 families, in 24 genera and 34 species. Of these, there are over 22 which are commercial/edible host species (Leblanc et al. 2013).
- Several hosts of *B. xanthodes*, besides *Citrus* spp., are economically important to New Zealand (Table 9.8.4).
- Adult flight and the transport of infested fruit are the major means of movement and dispersal to areas previously not infested by the fruit fly (CPC 2020).
- Eggs and larvae of *B. xanthodes* are typically found inside fruit (Table 9.8.4). Thus, they are unlikely to be visible. Therefore, the transport of infested fruit is a significant means by which the species can spread to areas where it was not previously found.
- Little is known about the life cycle of *B. xanthodes* and its reproductive rate (CPC 2020).

B. xanthodes responds to methyl eugenol and so is likely to be detected in the National Fruit Fly Surveillance Programme.

- Three fruit fly lures, cuelure, trimedlure and methyl eugenol are used in the National Fruit Fly Surveillance Programme in New Zealand (MacLellan, Pather and King 2019). If a fruit fly species is responsive to one or more of these lures, early detection of an incursion is more likely, which will reduce the likelihood of its establishment in New Zealand.
- A male lure test was conducted in the Cook Islands, Vanuatu, Fiji, Tonga and Samoa, indicating that *B. xanthodes* responds to methyl eugenol (Allwood 1997b).
- Reponse to methyl eugenol was confirmed recently in a study by Royer et al. (2019), but the authors note that *B. xanthodes*'s attraction to methyl-isoeugenol is three times greater.

The level of uncertainty associated with the above conclusions is moderate to high.

1. *B. xanthodes* is currently distributed in various Pacific Island nations with tropical climates, which are predominantly warmer than New Zealand. However, if the species has evolved to adapt to cooler montane climates found in tropical Pacific islands, then establishment in the New Zealand climate is possible.
2. It is not known if the fruit fly's distribution is restricted by a geographic boundary (i.e. islands) or if it is unable to establish in colder climates.
3. Additionally, no research has been done to date on the cold tolerance of *B. xanthodes*.
4. However, the Northland and Gisborne regions have similar climate indicators to some Pacific Island countries where the fruit fly has established.

Table 9.8.4 Host range of *Bactrocera xanthodes*. Species names in **bold** are considered significant to New Zealand's economy by Plant & Food Research (2019).

Family	Species	Common Name	Country	Reference
Anacardiaceae	<i>Mangifera indica</i>	Mango	Cook Islands, Nauru (prior to eradication), Tonga	Leblanc et al. 2012
Annonaceae	<i>Annona cherimola</i>	Cherimoya	Cook Islands	Leblanc et al. 2012
	<i>Annona muricata</i>	Soursop	Samoa, Tonga	Leblanc et al. 2012
Apocynaceae	<i>Cerbera manghas</i>	Sea Mango	Tonga	Tora Vueti et al. 1997a; Leblanc et al. 2012
	<i>Ochrosia oppositifolia</i>		Fiji, Tonga	Leblanc et al. 2012
Bromeliaceae	<i>Ananas comosus</i> ⁶⁹	Pineapple		Leblanc et al. 2013
Calophyllaceae	<i>Calophyllum inophyllum</i>	Tamanu	Cook Islands	Leblanc et al. 2012
Caricaceae	<i>Carica papaya</i>	Papaya	Cook Islands, Fiji, Samoa, Tonga	Heimoana et al. 1997; Leblanc et al. 2012

⁶⁹ Reports of *B. xanthodes* in Tonga and in Fiji are dubious. *B. xanthodes* in Fiji were demonstrated not to breed on damaged pineapple exposed to gravid females in the laboratory. No fruit flies ever emerged from the 143 ripe pineapples sampled in the Pacific Islands during the RFFP surveys.

Family	Species	Common Name	Country	Reference
Combretaceae	<i>Terminalia catappa</i>	Tropical almond	Samoa, Tonga	Leblanc et al. 2012
	<i>Terminalia samoensis</i>		Samoa, Tonga	Leblanc et al. 2012
Convolvulaceae	<i>Stictocardia tiliifolia</i>	Spottedheart	Tonga	Leblanc et al. 2012
Cucurbitaceae	<i>Citrullus lanatus</i>	Watermelon ⁷⁰	Tonga	Heimoana et al. 1997; Leblanc et al. 2012; Leblanc et al. 2013
	<i>Cucumis sativus</i>	Cucumber ⁷¹	Tonga	Leblanc et al. 2013
	<i>Cucurbita pepo</i>	Squash ⁷²	Fiji	Leblanc et al. 2013
	<i>Luffa cylindrica</i>	Luffa ⁷³	Fiji	Leblanc et al. 2013
	<i>Mormordica charantia</i>	Bittergourd ⁹²	Fiji	Leblanc et al. 2013
Ebenaceae	<i>Diospyros vera</i>		Tonga	Leblanc et al. 2012
Euphorbiaceae	<i>Excoecaria agallocha</i>	Milky mangrove	Tonga	Leblanc et al. 2012
Lauraceae	<i>Persea americana</i>	Avocado	Cook Islands, Samoa, Tonga	Leblanc et al. 2012
Lecythidaceae	<i>Barringtonia edulis</i>		Fiji	Tora Vueti et al. 1997a; Leblanc et al. 2012
	<i>Barringtonia racemosa</i>		Fiji	Leblanc et al. 2012
	<i>Barringtonia seaturae</i>		Fiji	Leblanc et al. 2012
Leguminosae	<i>Inocarpus fagifer</i>	Tahitian chestnut	Cook Islands, Fiji, Wallis and Futuna	Leblanc et al. 2012
Malvaceae	<i>Hibiscus tiliaceus</i>	Sea hibiscus		Leblanc et al. 2013
	<i>Theobroma cacao</i>	Cacao tree	Fiji	Leblanc et al. 2012
Moraceae	<i>Artocarpus altilis</i>	Breadfruit	American Samoa, Cook Islands, Fiji, Nauru (prior to eradication) Samoa, Tonga, Wallis and Futuna	Tora Vueti et al. 1997a; Leblanc et al. 2012
	<i>Artocarpus heterophyllus</i>	Jackfruit	Cook Islands, Fiji, Samoa	Leblanc et al. 2012
Musaceae	<i>Musa × paradisiaca</i>	Banana	Samoa	Leblanc et al. 2013
Myrtaceae	<i>Psidium guajava</i>	Common guava ⁷⁴		Leblanc et al. 2013
Oxalidaceae	<i>Averrhoa carambola</i>	Starfruit ⁷⁵	Samoa	Leblanc et al. 2013
Passifloraceae	<i>Passiflora edulis</i>	Passion fruit	Tonga	Leblanc et al. 2012
	<i>Passiflora ligularis</i>	Sweet granadilla	Tonga	Leblanc et al. 2012
	<i>Passiflora quadrangularis</i>	Granadilla	Fiji, Tonga, Samoa	Leblanc et al. 2012

⁷⁰ Watermelon was observed to be infested by *B. xanthodes* in the field in Tonga. In laboratory host status tests in Tonga, *B. xanthodes* was bred from damaged but not from intact watermelons when exposed to gravid females.

Watermelon was observed to be infested by *B. xanthodes*, in the field, in Tonga. In laboratory host status tests, *B. xanthodes* was bred from damaged but not from intact watermelons, when exposed to gravid females in Tonga.

⁷¹ *B. xanthodes* was not bred from intact cucumber in Fiji. However, *B. xanthodes* was bred from damaged (but not from intact) cucumber in Tonga.

⁷² Bred from damaged fruit exposed to gravid females.

⁷³ Heimoana et al. (1997) reported that in Fiji, *B. xanthodes* was not bred from intact "spongy gourd" (likely *L. cylindrica*) exposed to gravid females, but *B. xanthodes* was bred from damaged fruits.

⁷⁴ The record of *B. xanthodes* on guava in Drew (1989) was not confirmed by subsequent surveys and is viewed as questionable.

⁷⁵ *B. xanthodes* was bred from damaged (but not from intact) fruit exposed to gravid females.

Family	Species	Common Name	Country	Reference
Rutaceae	<i>Fortunella japonica</i>	Kumquat	Fiji	Leblanc et al. 2012
	<i>Citrus latifolia</i>	Tahitian lime ⁸⁰	Samoa	Leblanc et al. 2013
	<i>Citrus limon</i>	Lemon ⁸⁰	Fiji	Leblanc et al. 2013
	<i>Citrus maxima</i>	Pomelo	Fiji, Tonga	Leblanc et al. 2012
	<i>Citrus paradisi</i>	Grapefruit ⁸⁰	Samoa	Leblanc et al. 2013
	<i>Citrus reticulata</i>	Mandarin ⁷⁶	Fiji, Tonga	Leblanc et al. 2013
	<i>Citrus sinensis</i>	Orange	Tonga	Leblanc et al. 2012
Santalaceae	<i>Santalum yasi</i>	Fijian sandalwood	Tonga	Leblanc et al. 2012
Sapindaceae	<i>Pometia pinnata</i>	Pacific lychee ⁷⁷		Leblanc et al. 2013
Sapotaceae	<i>Burckella richii</i>		Tonga	Leblanc et al. 2012
	<i>Chrysophyllum cainito</i>	Star apple	Tonga	Leblanc et al. 2012
	<i>Pouteria caimito</i>	Abiu	Samoa	Leblanc et al. 2012
Solanaceae	<i>Capsicum annuum</i>	Capsicum	Fiji, Samoa, Tonga	Leblanc et al. 2013
	<i>Solanum lycopersicum</i>	Tomato	Fiji, Tonga	Leblanc et al. 2012
	<i>Solanum mauritianum</i>	Bugweed	Cook Islands	Leblanc et al. 2012
	<i>Solanum melongena</i>	Eggplant	Tonga, Samoa, Vanuatu, Fiji	Leblanc et al. 2013

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *B. xanthodes* is likely to be high (low to moderate uncertainty).

Damage and symptoms caused by *B. xanthodes* can reduce fruit quality.

- Larvae of *B. xanthodes* feed inside fruit (fruit flesh, pod or seed) (Table 9.8.4). Although little information is available on the damage by *B. xanthodes* specifically, oviposition by *Bactrocera* spp. is known to leave scars (or punctures) on skin of fruits, which is likely to cause necrosis or darken the colour of fruit skin around the oviposition puncture. Larval feeding damage may also allow for infection by secondary pathogens, causing fruit rot (CPC 2020).
- Heavy infestation by other *Bactrocera* spp. can cause premature fruit drop (Xia et al. 2018; CPC 2020).

Bactrocera xanthodes attacks several commercially grown fruit species in several South Pacific islands. However, most collected individuals have either been trapped or reared in laboratory experiments (Leblanc et al. 2012; Leblanc et al. 2013; CPC 2020).

- Allwood and Leblanc (1997) report that *B. xanthodes* can cause between 19–37% fruit loss in a local variety of papaya, and 4–31% fruit loss in the Sunset variety of papaya.
- Although reports on quantifying the impact on commercially important crops in New Zealand were not found, the areas likely to be the most suitable for *B. xanthodes* establishment in New Zealand is northern regions. These regions have the highest hectares of planted *Citrus* spp. and avocados, both of which are economically important crops for New Zealand and confirmed hosts of *B. xanthodes*.
- *Bactrocera xanthodes* has been bred from pineapple, citrus, papaya, granadilla, guava and tomatoes. Hence, the species has the potential to become a very serious pest if introduced into areas where extensive horticulture is carried out and the climate is suitable (Drew 1982).
- Leblanc et al. (2013) showed that breadfruit, along with papaya, soursop and avocado are the host species with the highest flies per kg of fruit sampled and percentage of samples infested by *B. xanthodes*.

⁷⁶ Larvae develop in the fruit (fruit flesh, pod or seed).

⁷⁷ The confirmed records of host on Pacific lychee by White and Elson-Harris (1992) have not been confirmed by subsequent host fruit surveys and are therefore treated as unlikely.

- Avocados, along with several other hosts of *B. xanthodes*, are important horticultural crops (Table 9.8.4) (FOB export values: avocados NZ\$104.3 million, squash \$59.7 M, capsicums \$20.6 M, citrus \$12.0 M) (Plant & Food Research 2019). Sales values for avocado in 2019 in New Zealand were NZ\$56.5 million (domestic) and \$104.3 M (exports) (Plant & Food Research 2019).
- Other hosts commercially grown in New Zealand include, but are not limited to, passionfruit, eggplants, tomatoes, guava and cucumber (Leblanc et al. 2012; Leblanc et al. 2013; CPC 2020).
- However, as there is no report found on quantifying the impact on citrus and avocado in areas with similar climate conditions to New Zealand, the impact on these two industries is uncertain.
- *Bactrocera xanthodes* is likely to cause impact on hosts (e.g. tomato, capsicum, avocado, cherimoya) grown in greenhouses in New Zealand. Field infestations of capsicum crops have been observed in Tonga; however, these records are considered to be dubious as they have not been confirmed by recent host fruit surveys (Leblanc et al. 2013). Field infestations of tomatoes have been observed in Fiji.

The impact on exports, including market access, is likely to be severe.

- *Citrus* spp. grown in New Zealand is almost entirely sold on the domestic market with very limited export. However, a high-quality niche export market does exist, which includes Japan, the USA and China. A search of the Imported Country Phytosanitary Requirements (ICPR) (2020) revealed that *B. xanthodes* is a quarantine pest in Japan and China but is not regulated in the USA.
- New Zealand Avocado (2020) states avocados are exported between August and March to a predominantly Australian market. However, the exports to Asia are growing rapidly, where avocado exports amount to NZ\$22 million (Plant & Food Research 2019). Of the Asian countries where New Zealand avocados are exported, Thailand, China and Japan have listed *B. xanthodes* as a quarantine pest (ICPR 2020).
- Detection of a fruit fly in the surveillance programme would need to be reported internationally and would be expected to result in reduced market access for some of New Zealand's horticultural products. In New Zealand, 80% of horticultural export value came from plants that are potential fruit-fly host (MacLellan, Pather and King 2019). The incursion of *B. dorsalis* (reported as *B. papaya*) in north Queensland was estimated to cause losses of nearly AU\$100 million, most of this due to lost export markets (Clark et al. 2005).
- If *B. xanthodes* established in New Zealand, additional postharvest disinfestation costs would be necessary. In Australia in 1996, apples and citrus fruit underwent a cold treatment for fruit fly at a cost of approximately AU\$200/tonne, avocados were treated with hot forced air, costing approximately AU\$125/tonne, and stone fruit, cucurbits and tomatoes were treated with a dimethoate dip, which cost approximately AU\$100/tonne (MAF 1996).

If *B. xanthodes* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).
- In Japan, eradication of a fruit fly species from the Ryukyu Islands cost more than 200 million euros (Kiritani 1998). The cost for the eradication programme in northern Queensland (1995–1999) was AU\$33 million (Cantrell et al. 2002).

Bactrocera xanthodes is likely to have low impact on the environment in New Zealand.

- *Bactrocera xanthodes* hosts include, but are not limited to, species from the Myrtaceae, Passifloraceae and Lauraceae, which include New Zealand native species (NZPCN 2020). However, no New Zealand native species have been confirmed as hosts.

Bactrocera xanthodes may have impacts on the urban environment (sociocultural impacts).

- *Bactrocera xanthodes* is damaging to several plants grown in domestic gardens and parks, such as *Citrus* spp., *Passiflora* spp., *Hibiscus* spp., *Cucumis* spp. and *Psidium* spp. Therefore, it is a potential nuisance pest in urban environments.

There is no evidence found that *B. xanthodes* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera xanthodes* may be considered for additional measures.

- *Bactrocera xanthodes* has a strong association with fruits of some citrus species/cultivars.
- Some infested fruit will not be detected, especially when the volume of commodities is large.
- Because the larvae feed internally in the fruit, general handling cannot remove the larvae, and citrus fruit need to be cut open to reveal the larvae of *B. xanthodes*.
- *Bactrocera xanthodes* has a low to moderate ability (with moderate to high uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The suitability of the New Zealand environment for *B. xanthodes* to establish is considered low to moderate (low to moderate uncertainty), and its establishment is likely to be restricted to the northern part of the North Island and sheltered environments, although a short-term population may establish in other areas during summer months.
- *Bactrocera xanthodes* has a broad host range, which includes commonly grown domestic and commercial species, and therefore, host availability is unlikely to be a limiting factor for it to establish in New Zealand.
- *Bactrocera xanthodes* has been reported to cause impact on tropical fruit crops and attack citrus and avocado. However, damage is only known from some Pacific Island nations and not from areas with a similar climate to New Zealand.
- Nevertheless, as a fruit fly species, if it is detected and/or establishes in New Zealand, the impact on the export and market access of New Zealand's horticultural products (particularly of citrus and avocado) is likely to be severe.

8.8.4 References

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8.9 *Bactrocera zonata* (peach fruit fly)

Description: *Bactrocera zonata* is a polyphagous fruit fly species that oviposits through the skin of fruits and causes internal feeding damage to fruits. The main hosts are guava, mango and peach, but *B. zonata* has been recorded from over 50 wild and cultivated plant species, including citrus. Within its current range, it is considered a major economic pest.

Scientific name: *Bactrocera zonata* (Saunders, 1842)

Order/Family: Diptera/Tephritidae

Other names include: *Dasyneura zonatus*, *Dacus zonatus*, *Dasyneura zonata*, *Rivellia persicae*, *Strumeta zonata*, *B. maculigera*

Taxonomic notes: *Bactrocera maculigera* Doleschall was previously listed as a synonym of *B. zonata*. White and Evenhuis (1999) have shown that it is unrelated (EPPO 2005).

Summary of conclusions

Given the arguments and evidence presented:

- *Bactrocera zonata* meets the criteria to be a quarantine pest for New Zealand.
- *Bactrocera zonata* has a strong association with citrus fruit.
- Basic measures are likely to reduce the likelihood of introduction of *B. zonata* by a moderate degree (with moderate uncertainty). Consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty).
- *Bactrocera zonata* has a moderate to high ability (with moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The ability of *B. zonata* to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).
- The suitability of the New Zealand environment for *B. zonata* to establish in the short term is considered to be moderate to high (with moderate uncertainty), and in the long term low (with high uncertainty)
- The level of impact caused by *B. zonata* is likely to be high. Although its spread and economic impact may be limited by climate, even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- *Bactrocera zonata* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Moderate
The ability to move from the imported commodity onto a suitable host	Moderate–high	Moderate
Suitability of the New Zealand environment (short-term establishment)	Moderate–high	Moderate
Suitability of the New Zealand environment (long-term establishment)	Low	High
Impacts on the New Zealand economy, environment, health and society	High	Low

8.9.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Bactrocera zonata* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: the pest is not present in New Zealand, and is of potential importance (able to establish and cause harm).

Bactrocera zonata is not known to be present in New Zealand:

- *Bactrocera zonata* is not recorded in PPIN (2020), NZOR (2011) or NZInverts (2016).
- *Bactrocera zonata* is an unwanted organism (ONZPR 2020).
- *Bactrocera zonata* is listed as 'regulated' in ONZPR (2020).

Bactrocera zonata has the potential to establish and spread in New Zealand:

- Four records of *B. zonata* are from areas with a similar climate to New Zealand (Phillips et al. 2018; GBIF.org 2020), and modelling suggests that a large proportion of New Zealand has a climate suitable for the establishment of the species (Ni et al. 2012; EFSA et al. 2019).
- *Bactrocera zonata* is polyphagous with over 50 host species in 19 different families (EPPO 2010), the majority of which are grown in New Zealand commercially or in home gardens.

Bactrocera zonata has the potential to cause economic, environmental and sociocultural impacts in New Zealand:

- *Bactrocera zonata* has the potential to harm a number of horticultural crops of economic importance to New Zealand, including apples, avocados, lemons, apricots, oranges, peaches and mandarins. It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Bactrocera zonata* has the potential to harm several native species that belong to the same genus as known hosts. Two of these species are threatened or at risk (*Solanum aviculare* var. *aviculare* – threatened (nationally vulnerable); *S. a. var. latifolium* – at risk (naturally uncommon); and *Syzygium maire* – threatened (nationally critical)) (NZPCN 2020).
- *Bactrocera zonata* has the potential to harm plants traditionally used by Māori (*Elaeocarpus dentatus*, *E. hookerianus*, *S. aviculare*, *S. laciniatum* and *S. maire*).
- *Bactrocera zonata* has the potential to have sociocultural impacts, because its hosts include plants commonly grown in domestic gardens.
- Currently, there is no evidence that *B. zonata* could have a negative impact on human health.

8.9.2 Hazard identification: commodity association

Bactrocera zonata is associated with citrus fruit.

Bactrocera zonata has been reported from citrus fruit:

- *Bactrocera zonata* oviposits through the skin of citrus fruit, and larvae feed inside the fruit (Christenson and Foote 1960; Saafan et al. 2005).

8.9.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Bactrocera zonata* has a strong association with citrus fruit.

Larvae of *B. zonata* have been reported in citrus fruits.

- *Bactrocera zonata* larvae have been found infesting field-collected navel oranges (*C. sinensis*), Baladi oranges (*C. sinensis*), Valencia oranges (*C. sinensis*), mandarins (*C.*

reticulata), grapefruit (*C. paradisi*), sour oranges (*C. aurantium*), lemons (*C. limon*) (Saafan et al. 2005) and kinnow (*C. reticulata*) (Singh and Sharma 2013).

- Based on literature searches and communication with plant protection officials and research scientists, EPPO considers Mexican lime (*C. aurantiifolia*), sour orange (*C. aurantium*), lemon/ baramasi (*C. limon*), citron (*C. medica*), king orange/tangor (*C. reticulata* × *C. sinensis*), grapefruit (*C. paradisi*), mandarin/tangerine (*C. reticulata*) and sweet orange (*C. sinensis*) to be hosts of *B. zonata* (EPPO 2010).
- *Citrus* is considered a minor host by EPPO (2020a); however, *B. zonata* is considered a serious citrus pest in India, Pakistan and Egypt (Delrio and Cocco 2012; Ashfaq et al. 2020; CABI 2020).
- Substantial rates of infestation have been reported in Egypt in navel oranges (15.4%), Baladi oranges (10.2%), mandarins (8.8%), grapefruit (10.1%) and sour oranges (5.8%) (Saafan et al. 2005).
- Under the environmental conditions of countries within the current range of *B. zonata* (tropics and subtropics), eggs and larvae are likely to be within host fruit for a relatively short time (eggs 1–3 days, larvae 4–10 days) (Duyck et al. 2004). It is common, however, for larvae to overwinter within fruit (Syed 1968; Fletcher 1987).

Bactrocera zonata is present in citrus-exporting countries included in this IRA:

- *Bactrocera zonata* is present in Egypt and Viet Nam.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Bactrocera zonata* by a moderate degree (with moderate uncertainty). Consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty):

Bactrocera zonata infestations may be visually detectable in the field and/or packhouses, leading to the removal of infested produce.

- Signs of oviposition on citrus can be seen with the naked eye (Ashfaq et al. 2020). Larval feeding damage allows for infection by secondary pathogens, causing fruit rot (Delrio and Cocco 2012). Fruit with multiple oviposition punctures and feeding damage is likely to be removed during general handling.
- Fruit bagging and packhouse culling have been reported to be effective in reducing levels of infestation in some citrus commodities in China (Xia et al. 2019). Fruit bagging is not widely practiced due to its labour intensity.

However, there is a chance that a small quantity of infested fruit will not be detected.

- Fruit with low infestation (fewer oviposition punctures) may not be obvious enough to be detected during general handling, as puncture holes are difficult to see (European Food Safety Authority 2007).
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.

General handling after harvesting is not likely to remove larvae of *B. zonata* inside citrus fruit.

- General handling after harvesting (e.g. washing and brushing) only treats the surface of fruit. These procedures are therefore highly unlikely to remove the larvae of *B. zonata* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *B. zonata* inside. Internally feeding insects are likely to be particularly problematic to detect by non-destructive inspection. Even using fruit dissection, Gould (1995) found that detection rates for Caribbean fruit fly (*Anastrepha suspensa*) could be as low as 17.9%. In this study, inspectors detected between 17.9% and 83.5% of fruit infested with Caribbean fruit fly; variables influencing detection rate were the fruit type, its ripeness and the inspector (Gould 1995).

Larvae of *B. zonata* may survive transit in citrus commodities.

- The majority of interceptions of *B. zonata* on non-citrus hosts (guava, *Psidium guajava*) in New Zealand have been of live eggs or larvae (LIMS 2019).
- Transit of citrus fruit usually includes cold storage. Holding citrus fruit at a maximum of 1.7°C for a minimum of 18 days should result in no *B. zonata* survivors at the 95% level of

confidence (Hallman et al. 2013). However, it is not known whether usual storage temperatures and transit times from countries in this IRA where *B. zonata* is present will be sufficient to prevent survival of *B. zonata* larvae.

The level of uncertainty associated with both the degree to which basic measures reduce the likelihood of entry (moderate) and the consequent likelihood of entry (low to moderate) is moderate. Firstly, species specific information about the detectability of low levels of infestation of citrus fruits with *B. zonata* is not available. Secondly, there is uncertainty around whether standard transit times and storage temperatures of citrus commodities will be enough to prevent survival of *B. zonata* larvae.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Bactrocera zonata* to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).

Bactrocera zonata can survive and develop on waste of citrus fruit (whole fruit or fruit pieces but probably not skin).

- *Bactrocera zonata* females pierce the skin of host fruit and lay a batch of 2–9 eggs into the flesh. Upon hatching, larvae feed on the pulp of the fruit and drop to the ground upon maturity to pupate in the soil (Delrio and Cocco 2012).
- Larvae of *B. zonata* have been successfully reared to the pupal stage within field-collected fruit incubated in the laboratory. The resulting pupae reached adulthood (Saafan et al. 2005).
- Infested fruit is likely to be discarded. Infested fruit must remain in a suitable condition long enough for larvae to develop to maturity (this time is temperature-dependent), and emerging larvae then need to find a suitable pupation site. Citrus fruit is relatively robust and not highly perishable (compared to commodities such as peaches or strawberries). It is likely to remain in good condition long enough for larvae to emerge and pupate.
- If citrus fruit is disposed of as whole fruit or fruit pieces, it is likely that *B. zonata* can survive and reach adulthood in this waste. There is no evidence showing that *B. zonata* can complete development by feeding on citrus fruit skin.

Most of the fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any *B. zonata* present would either be killed or be unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, *B. zonata* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and being used as animal feed.

- Adults of *B. zonata* emerging from the soil are likely to be able to find food in the environment if citrus fruit wastes are disposed of using high risk methods. The mature larvae emerge from the fruits and drop into soil to pupate. Emerged adults feed on honeydew, plant exudates, bird faeces and bacteria on host plants (Delrio and Cocco 2012). These food sources are common in farms, parks and home gardens.
- Because *B. zonata* is polyphagous, hosts for oviposition and larval development are available in most areas of New Zealand, either in commercial plantations or in home gardens.
- If citrus hosts are located near composting sites or animal feeding sites, adult *B. zonata* are likely to locate them (see the waste analysis in section 2.4.1).

Adults of *B. zonata* are strong fliers and can fly moderate to long distances to food sources.

- Mark–recapture trapping experiments have shown that male *B. zonata* readily disperse 8–32 km and can travel up to 40 km. This experiment was limited to the distance of the trap placed furthest from the release point, therefore, the actual maximum dispersal distance may be larger. Additionally, only male dispersal was measured, and it is not certain how female dispersal differs (Qureshi et al. 1975).

- In Iran, low genetic structuring among *B. zonata* sampled from sites up to 420 km apart (Koochkanzadeh et al. 2019) indicates a high level of gene flow and confirms the dispersal ability of this species.

The level of uncertainty associated with the ability of *B. zonata* to move from imported fruit to a suitable host (moderate to high) is moderate. Firstly, waste data may not be very accurate or up to date, and it is not known how frequently suitable hosts are present near composting sites or animal feeding locations (see section 2.4.1, waste analysis). Secondly, it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin). Thirdly, although *B. zonata* can fly to seek food sources and hosts, and males can disperse up to 40 km, female dispersal distances are not known. Fourthly, the effect of seasonality on this likelihood is uncertain.

Given the arguments and evidence below, the suitability of the New Zealand environment for *Bactrocera zonata* to establish in the short term is considered moderate to high (with moderate uncertainty) and in the long term low (with high uncertainty).

The native range of *B. zonata* is tropical, but it has successfully established in a colder and more arid region.

- The native range of *B. zonata* is in tropical Asia, and much of its range expansion has been into other tropical areas in Asia, and also Mauritius and Réunion. The species has, however, successfully established in the colder and more arid, coastal areas of Egypt, indicating a degree of adaptability in the species (Delrio and Cocco 2012).

The current distribution of *B. zonata* is mainly in areas of low climate match with New Zealand, but modelling predicts that the species could establish in New Zealand, particularly in the north.

- Reliable records of *B. zonata* occurrence⁷⁸ are almost exclusively found in areas with a dissimilar climate to New Zealand (climate match index (CMI) <0.7). Five records (where species identity has been verified by experts), however, are from the foothills of the Himalayas in India and Pakistan, in areas with a similar climate to New Zealand (CMI = 0.7–0.8) (Phillips et al. 2018; GBIF.org 2020). It is not certain whether those records represent a one-off occurrence, or a transient or persistent population. It is also not known how much of this distribution is a result of host availability rather than climate.
- CLIMEX modelling predicts that, under current climate conditions, *B. zonata* should be able to establish in northern New Zealand and that the area suitable for establishment is likely to expand with climate change (Ni et al. 2012).
- Using climate comparisons between Egypt and southern Europe, and CLIMEX modelling in Cobos-Suárez et al. (2010), the European Food Safety Authority considered central and southern Spain, central and southern Portugal, Madeira, the Azores, Italy, Malta, Greece and Cyprus to be areas suitable for long-term establishment of *B. zonata* (EFSA et al. 2019). All of these regions are of a very high climate similarity with New Zealand (CMI 0.7–0.9). EFSA notes that, because of the difficulty in estimating overwintering survival, the northern limit of the potential range cannot be reliably delimited.

Bactrocera zonata is likely to establish a transient summer population across much of the North Island and the north of the South Island, and establishment of a persistent population in these areas may also be possible.

- Depending on the experiment, the lower developmental thresholds for *B. zonata* egg, larval and pupal stages are estimated to be 10–12.7°C, 10–12.6°C and 11.8–13.6°C, respectively (Mohamed 2000; Duyck et al. 2004; Choudhary et al. 2020). Many areas across New Zealand (as far south as Christchurch) have higher mean daily minimum temperatures than this from December to March, and some areas further north exceed these temperatures from October to May (NIWA data 1981–2010). However, minimum temperatures in all these areas are well below the lower developmental thresholds outside these months. This indicates that a persistent *B. zonata* population may not survive winter temperatures even in the north, unless individuals can successfully overwinter in New Zealand conditions. Detailed information about

⁷⁸ Records are from GBIF and only those based on material samples or preserved specimens were included in the analysis. All samples/specimens are lodged at the Royal Museum for Central Africa, Natural History Museum, London or held in the Barcode of Life Data System; therefore, species identity is likely to be reliable.

overwintering in *B. zonata* is not available; however, the species is capable of surviving winters with temperatures at or close to freezing in North Sinai in Egypt (European Food Safety Authority 2007). This indicates that the establishment of a persistent population across the North Island and the north of the South Island may be possible.

- The range of mean minimum daily temperatures across much of the North Island and the north of the South Island are suitable for the establishment of a transient summer population.

Bactrocera zonata has a high reproductive rate, which is likely to decrease, but still be relatively high, under conditions across most of New Zealand in summer.

- Under laboratory conditions, *B. zonata* can complete 8 consecutive generations in a year (Shehata et al. 2008), and a female can lay up to 93 eggs per day and as many as 564 in a lifetime (Qureshi et al. 1974; Duyck et al. 2004).
- Under laboratory conditions, optimal temperatures for egg hatch, and larval and pupal survival are 25–30°C. However, there is still substantial egg hatch (10–51%) at 15°C and egg hatch (54–89%), larval survival (63–88%) and pupal survival (87–96%) at 20°C (Qureshi et al. 1993; Mohamed 2000; Duyck et al. 2004; Choudhary et al. 2020). Females are unable to produce eggs at 15°C (Qureshi et al. 1993; Duyck et al. 2004; Choudhary et al. 2020). However, at 20°C, the average number of eggs produced per female in a lifetime is 91 (Choudhary et al. 2020).
- Mean daily maximum temperatures between 25 and 30°C are extremely rare in New Zealand, but mean daily maximum temperatures ranging between 20 and 25°C are common across much of the country during the spring and summer months (NIWA data 1981–2010). This indicates that many areas of New Zealand may be suitable for *B. zonata* to complete development during the summer months.

The biology of adult *B. zonata* means that they are likely to find mates if they are present.

- Adult female and male *B. zonata* emit volatile chemicals at dusk that are detected by each sex and likely play a role in mate location and sexual selection (Levi-Zada et al. 2020). This behaviour may increase the likelihood of encounters between the sexes to mate.

Host and food availability is unlikely to be a limiting factor for *B. zonata* to establish in New Zealand.

- *Bactrocera zonata* is polyphagous with over 50 host species in 19 different families (EPPO 2010), the majority of which are grown in New Zealand. Hosts for oviposition and larval development are available in most areas of New Zealand, either in commercial plantations or in home gardens.
- Emerged adults feed on honeydew, plant exudates, bird faeces and bacteria on host plants (Delrio and Cocco 2012). These food sources are common in farms, parks and home gardens.

Bactrocera zonata has become a major pest outside of its native range.

- In the years following its establishment in Egypt in the late 1990s, *B. zonata* caused an estimated US\$188 million of direct damage annually to citrus (Delrio and Cocco 2012).

Bactrocera zonata responds to methyl eugenol and so is likely to be detected in the National Fruit Fly Surveillance Programme.

- Three fruit fly lures, cuelure, trimedlure and methyl eugenol, are used in the National Fruit Fly Surveillance Programme in New Zealand (MacLellan et al. 2019). If a fruit fly species is responsive to one or more of these lures, early detection of an incursion is more likely, which reduces the likelihood of the species' establishment in New Zealand.
- Methyl eugenol is a potent attractant of *B. zonata* males (Qureshi et al. 1981) and has been used as an attractant in experimental (Qureshi et al. 1981) and real-world control programs using male annihilation techniques (Sookar et al. 2006) for the species.

The level of uncertainty associated with the likelihood of establishment of *B. zonata* in the short term (moderate to high) is moderate, and the level of uncertainty associated with the likelihood of establishment of *B. zonata* in the long term (low) is high. Firstly, the constant temperatures used in these studies do not reflect real-world daily temperature fluctuations, and it is not known how this would affect survivorship and fecundity in the wild. Secondly, the lower temperature thresholds for egg, larval and pupal survival are extrapolated from survivorship curves of *B. zonata* reared under

laboratory conditions, i.e. on an artificial diet and under constant temperature. Actual developmental thresholds in the wild may be substantially different to these estimates.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Bactrocera zonata* is likely to be high.

Damage and symptoms caused by *B. zonata* can reduce fruit quality.

- Oviposition puncture sites and larval feeding damage allows for infection by secondary pathogens, causing fruit rot (Delrio and Cocco 2012).

Bactrocera zonata has been reported to cause severe damage and production losses to a number of fruit crops.

- *Bactrocera zonata* is considered a serious fruit pest in India, Pakistan and Egypt (CABI 2020).
- In India, *B. zonata* has been reported to cause losses of 25–100% in peach (*Prunus persica*), apricot (*Prunus armeniaca*), guava (*Psidium guajava*) and figs (*Ficus carica*) (CABI 2020).
- In Pakistan, *B. zonata* has been reported as damaging 25–50% of guava fruit (CABI 2020) and causing yield losses of 18.9%, 9.7% and 4.0% in *C. reticulata*, *C. sinensis* and *C. paradisi* respectively (Ashfaq et al. 2020).
- Substantial rates of infestation have been reported in Egypt in navel oranges (15.4%), Baladi oranges (10.2%), mandarins (8.8%), grapefruit (10.1%) and sour oranges (5.8%) (Saafan et al. 2005). In the years following its establishment in Egypt in the late 1990s, *B. zonata* caused an estimated US\$188 million of direct damage annually to citrus (Delrio and Cocco 2012).

Bactrocera zonata is likely to negatively impact many plants of economic importance to New Zealand.

- *Bactrocera zonata* hosts include several important horticultural export crops: apple (*Malus domestica*, FOB export value: NZ\$828.8 million); avocado (*Persea americana*, FOB export value: \$104.3 M); lemon (*C. limon*, FOB export value: \$9.8 M); apricot (*Prunus armeniaca*, FOB export value: \$2 M); sweet orange (*C. sinensis*, FOB export value: \$1.7 M); peach (*Prunus persica*, FOB export value: \$0.4 M) and mandarin (*C. reticulata*, FOB export value: \$0.4 M) (Plant & Food Research 2019).
- Many of these crops are grown in the warmer areas of New Zealand, which coincides with the areas where *B. zonata* is most likely to establish.
- Using structured expert elicitation, EFSA estimated the percentage of yield losses due to *B. zonata* damage if the pest were to establish in the EU on a range of fruit commodities (EFSA et al. 2019). They estimated yield loss to be:
 - 18% on exotic fruit (in particular avocado, mango, guava and papaya);
 - 8.6% on citrus; and
 - 9% on peach (including both peaches and nectarines).

The area of the EU considered in these estimates is of a high climate match with New Zealand (CMI 0.7–0.9), so these estimates may be generalisable to the local horticulture industry.

- Even if *B. zonata* were to only establish for a single summer, the impact on a single growing season is likely to be high.
- Since there are no pest tephritids currently present in New Zealand, and therefore no existing management programmes, costs of control in the event of *B. zonata* establishment are likely to be high.

If *B. zonata* is detected in New Zealand, the cost incurred by a response would be expensive.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).

Establishment of *B. zonata* is likely to increase phytosanitary measures required for export to countries where the pest is absent.

- *B. zonata* is not present in any of the top 10 export destinations for New Zealand's horticultural produce (Plant & Food Research 2019).

Bactrocera zonata is likely to cause low to moderate sociocultural impacts on plants in home gardens, with moderate uncertainty.

- Several host species of *B. zonata* are commonly grown in home gardens (e.g. citrus, apple, apricot, peach, pear and tomato). If control measures become necessary in residential areas, this is likely to have a negative sociocultural impact.

Bactrocera zonata is likely to have very low impacts on the environment in New Zealand (with high uncertainty) and also very low impacts on Māori cultural values (with high uncertainty).

- *Bactrocera zonata* hosts include species in genera that also contain the following native species: *Elaeocarpus dentatus*, *E. hookerianus*, *Solanum americanum*, *S. aviculare*, *S. laciniatum*, *S. opacum* and *Syzygium maire*.
- *Solanum aviculare* var. *aviculare* is threatened (nationally vulnerable), *S. a.* var. *latifolium* is at risk (naturally uncommon), and *Syzygium maire* is threatened (nationally critical) (NZPCN 2020).
- Several native species in the same genera as *B. zonata* hosts have traditional Māori uses (Landcare Research 2020):
 - *E. dentatus* (hīnau) was an important cultivated crop for Māori, being used as a food source, as a mordant for fixing dyes, as medicine and for construction.
 - *E. hookerianus* (pōkākā) was traditionally used as a mordant for fixing dyes and as medicine.
 - *S. aviculare* and *S. laciniatum* (poroporo) was traditionally used as a food source, as medicine, as a tattoo dye and for making musical instruments.
 - *S. maire* (maire tawake) was traditionally used as a food source, as medicine and as a dye.
- The fruit of the native plant species are small and much less fleshy than those of the preferred hosts of *B. zonata*, so the native species may not make attractive hosts.
- If the fly attacks only the flesh of ripe fruit, it is unlikely to impair seed development, number or viability of native plant species.
- If the native plant species make suitable hosts for *B. zonata*, if the association has negative impacts on the hosts' biology and if the fly establishes in area near where these species are found, then *B. zonata* establishment could have a negative environmental impact and a negative impact on Māori cultural values.

There is no evidence found that *B. zonata* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Bactrocera zonata* may be considered for additional measures.

- *Bactrocera zonata* has a strong association with citrus fruit.
- Fruit with a low level of infestation may not be detected during general handling, especially when the volume of commodities is large.
- Because larvae feed internally inside fruit, general handling (e.g. washing and brushing) cannot remove the larvae, and citrus fruit need to be cut open to reveal the larvae of *B. zonata*.
- *Bactrocera zonata* has a moderate to high ability (with low to moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The suitability of the New Zealand environment for *B. zonata* to establish in the short term is considered to be moderate to high (with moderate uncertainty) and in the long term low (with high uncertainty).
- The establishment of *B. zonata* in New Zealand is likely to cause high economic impacts.

8.9.4 References

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8.10 *Ceratitidis capitata* (Mediterranean fruit fly, medfly)

Ceratitidis capitata (medfly) females lay their eggs through the skin of fruit. Maggots hatch from the eggs and feed within the fruit, causing damage and rotting. Medfly is extremely polyphagous and is a highly invasive pest of fruit crops, with a wide geographical distribution. It is endemic to sub-Saharan Africa but has been spread accidentally to many other regions.

Scientific name: *Ceratitidis capitata* (Wiedemann, 1824)

Order/ Family: Diptera/ Tephritidae

Other names include: *Ceratitidis citriperda*, *Ceratitidis hispanica*, *Pardalaspis asparagi*, *Tephritis capitata* (CPC 2020)

Summary of conclusions

Given the arguments and evidence presented:

- *Ceratitidis capitata* meets the criteria to be a quarantine pest for New Zealand.
- *Ceratitidis capitata* has a strong association with most citrus fruit, with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *C. capitata* on the commodity by a low to moderate degree with moderate uncertainty. Consequently, the likelihood of entry is considered to be low to moderate, with low uncertainty.
- *Ceratitidis capitata* is considered to have a moderate ability to move from imported citrus fruit and into an environment that is suitable for establishment, with moderate uncertainty.
- The suitability of the New Zealand environment for *C. capitata* to establish is considered to be moderate, with low uncertainty.
- The level of impact caused by *C. capitata* is likely to be high, with low uncertainty. Although its spread and economic impact may be somewhat limited by climate, even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- *Ceratitidis capitata* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Moderate
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	High	Low

8.10.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Ceratitidis capitata* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: the pest is not present in New Zealand, and is of potential importance (able to establish and cause harm⁷⁹).

Ceratitidis capitata is not known to be present in New Zealand:

- There are no records for *C. capitata* in NZOR (2020), and PPIN (2020) reports it as absent.
- New Zealand has country freedom status for *C. capitata* (MPI 2020a).
- *Ceratitidis capitata* is an unwanted and notifiable organism and a regulated pest (ONZPR 2020).

Ceratitidis capitata has the potential to establish and spread within the warmer parts of New Zealand:

- *Ceratitidis capitata* is established in parts of the world with climates similar to that of parts of New Zealand. It has previously established temporary populations in New Zealand before being successfully eradicated.
- *Ceratitidis capitata* is a widely polyphagous fruit fly, and suitable host plants are readily available throughout New Zealand commercially, in home gardens and in natural areas.

The establishment of *C. capitata* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *C. capitata* has the potential to cause direct economic damage to many horticultural crops that are important to New Zealand. It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- The establishment of *C. capitata* has the potential to have sociocultural impacts: many of its hosts are commonly planted in home gardens.
- Environmental and human health impacts are likely to be very low or negligible.

8.10.2 Hazard identification: commodity association

Ceratitidis capitata is associated with citrus fruit.

- *Ceratitidis capitata* oviposits through the fruit skin of many plant species, and its larvae feed inside the fruit (CPC 2020).
- There are validated records of infestation of many *Citrus* species by *C. capitata* that satisfy the definition of a host in accordance with international standards.

8.10.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Ceratitidis capitata* has a strong association with citrus commodities.

Many citrus species are hosts of *C. capitata*, and some are favoured hosts.

- Adult females lay eggs below the skin of the host fruit. Although they show a preference for discontinuities in the fruit surface such as cracks, bird pecks and insect damage (Bateman 1972), the fly is capable of ovipositing into sound citrus fruit (Papachristos and Papadopoulos 2009, DPIPWE 2011). Eggs usually hatch in 2–4 days (up to 18 days in cool weather) and the larvae feed for another 6–11 days (at 13–28°C) before leaving the fruit to pupate (CPC 2020).
- *C. capitata* is highly polyphagous and there are validated records of infestation of many citrus species by *C. capitata* which satisfy the definition of a host in accordance with international standards, e.g. ISPM 37⁸⁰, RSPM 4 (Table 9.10.1).

⁷⁹ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining “harm”.

⁸⁰ A host is a plant species or cultivar that has been scientifically found to be infested by the target fruit fly species under natural conditions and able to sustain its development to viable adults (ISPM 37, FAO 2016a).

Table 9.10.1 Citrus species reported to be hosts of *Ceratitidis capitata*
(The common hosts names are the names cited in the reference given).

Host name	Common name
<i>Citrus aurantiifolia</i>	Lime, West Indian lime (DPIPWE 2011); Lime (Thomas et al. 2019, CPC 2020); Sour lime (Mexican lime)(USDA 2017)
<i>Citrus aurantium</i>	Seville orange (DPIPWE); Sour orange (USDA 2017, CPC 2020); Sour orange, Seville orange, Bitter-sweet orange (Thomas et al. 2019)
<i>Citrus reticulata</i>	Mediterranean mandarin (USDA 2017)
<i>Citrus limon</i>	Rough lemon (USDA 2017)
<i>Citrus latifolia</i>	Tahitian lime (DPIPWE 2011); Persian lime (USDA 2017)
<i>Citrus limon</i>	Sweet lemon (USDA 2017; CPC 2020)
<i>Citrus aurantiifolia</i>	Palestine sweet lemon (USDA 2017)
<i>Citrus limon</i>	Lemon, Meyer lemon (DPIPWE 2011); lemon (USDA 2017; Thomas et al. 2019; CPC 2020) Note: Thomas et al. (2019) state that <i>C. limon</i> are heavily infested except 'Eureka', 'Lisbon', and 'Villa Franca' cultivars (smooth-skinned sour lemon).
<i>Citrus limon</i>	Canton lemon (USDA 2017); Mandarin lime (CPC 2020)
<i>Citrus maxima</i>	Pummelo (DPIPWE 2011, as <i>Citrus grandis</i>); Pummelo (USDA 2017; CPC 2020); Pummelo, Pomelmous shaddock, Pernambuco (Thomas et al. 2019)
<i>Citrus medica</i>	Citron, Tangor (DPIPWE 2011); Citron (USDA 2017, Thomas et al. 2019, CPC 2020)
<i>Citrus limon</i>	Meyer lemon (DPIPWE 2011, USDA 2017)
<i>Citrus aurantium</i>	Myrtle-leaf orange (USDA 2017)
<i>Citrus reticulata</i>	Tangor (CPC 2020); King orange (USDA 2017); King orange (Thomas et al. 2019, as <i>Citrus × nobilis</i>)
<i>Citrus paradisi</i>	Grapefruit (DPIPWE 2011; USDA 2017; CPC 2020 as <i>Citrus × paradisi</i>); Grapefruit, Pomelo (Thomas et al. 2019 as <i>Citrus × paradisi</i>)
<i>Citrus reticulata</i> var. <i>austera</i>	Cleopatra mandarin (USDA 2017)
<i>Citrus reticulata</i>	Mandarin, Tangelo, Tangerine (DPIPWE 2011); Mandarin (USDA 2017; CPC 2020); Mandarin, Tangerine (Thomas et al. 2019)
<i>Citrus reticulata</i> var. <i>austera</i>	Rangpur lime (DPIPWE 2011; NTG 2013)
<i>Citrus reticulata</i> × <i>Citrus paradisi</i>	Tangelo (CPC 2020)
<i>Citrus sinensis</i>	Sweet orange (DPIPWE 2011); Navel orange (CPC 2020); Orange (USDA 2017); 'Valencia' and 'Parson Brown' and 'Lue Gim Gong', Malta orange, Lambs summer orange (Thomas et al. 2019)
<i>Citrus reticulata</i>	Satsuma mandarin (USDA 2017)
<i>Citrus reticulata</i> × <i>Citrus paradisi</i>	Tangelo (DPIPWE 2011; USDA 2017)

Ceratitidis capitata is present in countries that are included in the Citrus IHS project (Tables 9.10.2 and 9.10.3).

- *Ceratitidis capitata* is present in Australia, Brazil, Egypt, Spain and Peru. The United States and Mexico are subject to recurrent incursions..

Table 9.10.2 General overview of geographic distribution of *Ceratitidis capitata*

Information is compiled at 22 September 2020 from EPPO (2020b) and CPC (2020). Countries marked* are only reported by CPC (2020). Potential exporting countries are **bolded**.

Continent /Region	Country/area
Africa	Algeria; Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Cape Verde; Comoros; Congo; Democratic Republic of the Congo; Cote d'Ivoire; Egypt ; Eritrea; Eswatini*; Ethiopia; Gabon; Ghana; Guinea; Kenya; Liberia; Libya; Madagascar; Malawi; Mali; Mauritius; Morocco; Mozambique; Namibia; Niger; Nigeria; Réunion; Saint Helena; São Tomé and Príncipe; Senegal; Seychelles; Sierra Leone; South Africa; Sudan; Swaziland; Tanzania; Togo; Tunisia; Uganda; Zambia; Zimbabwe

Continent /Region	Country/area
Asia	India (eradicated); Iran; Iraq; Israel; Jordan; Lebanon; Saudi Arabia; Syria; Turkey*; Yemen
The Americas	Argentina; Belize (under eradication); Bolivia; Brazil ; Chile (under eradication); Bermuda (eradicated); Colombia; Costa Rica; Dominican Republic (eradicated); Ecuador; El Salvador; Guatemala; Honduras; Jamaica (eradicated); Mexico (see Table 9.10.3); Nicaragua; Panama; Paraguay; Peru ; United States : California, Florida, Texas (under eradication or eradicated); United States: Hawaii; United States: Puerto Rico (under eradication); Uruguay; Venezuela
Europe	Albania; Belgium (eradicated); Bosnia and Herzegovina; Bulgaria; Croatia; Cyprus; France (including Corsica); Germany (under eradication); Greece (including Crete); Hungary (eradicated); Italy (including Sardinia and Sicily); Malta; Montenegro; Poland (transient); Portugal (including the Azores and Madeira); Romania; Russia (including Southern Russia); Serbia; Slovenia; Spain (including Balearic and Canary Islands); Switzerland; Turkey; Ukraine (under eradication); United Kingdom (transient)
Oceania	Australia (see Table 9.10.3); New Zealand (eradicated)

Table 9.10.3 Distribution of *Ceratitís capitata* in potential exporting countries

Source: EPPO (2020b), unless otherwise stated.

Country	Distribution in country
Australia	Localised distribution. Present in Western Australia. Occasional incursions in South Australia and Northern Territory but always subject to eradication measures. All other Australian states and territories are currently considered free from <i>C. capitata</i> (Sultana et al. 2020).
Brazil	Widespread. Present in: Acre (CPC 2020), Alagoas, Amapá, Bahia, Ceará, Distrito Federal, Espírito Santo, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraíba, Paraná, Pernambuco, Piauí, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, Rondônia, Roraima (CPC 2020), Santa Catarina, São Paulo, Tocantins
China	Absent, reported once in error from Hubei
Cook Islands	Not reported
Egypt	Widespread, present in all Governorates
Fiji	Not reported
Japan	Not reported
Korea	Absent
Mexico	Most of Mexico is designated “Pest Absent”, i.e. there are no records of the presence of the pest confirmed by surveys in 28 states of the 32 states. The southern border states of Chiapas, Tabasco and Campeche are subject to incursions (Enkerlin et al. 2015). In 2019 an outbreak was detected in Manzanillo, Colima, which was eradicated in April 2020.
New Caledonia	Not reported
Peru	Present, with no details
Samoa	Not reported
Spain	Present, widespread, including the Balearic and Canary Islands
Solomon Islands	Not reported
USA	<ul style="list-style-type: none"> • Present and widespread in Hawai‘i. • Recurrent incursions in California that are always subject to eradication measures. Some workers have suggested that despite numerous eradication attempts, <i>C. capitata</i> and other fruit fly species are now established and widespread in California at population levels that are too low to be detected by surveillance (e.g. Papadopoulos et al. 2013), however this opinion is not generally accepted (e.g. McInnes et al. 2017). • Historical eradications from Florida and Texas.

Country	Distribution in country
Vanuatu	Not reported
Viet Nam	Not reported

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *C. capitata* by a low to moderate degree (with moderate uncertainty). Consequently the likelihood of entry is considered to be low to moderate:

In-field controls may reduce *C. capitata* populations, but the extent is likely to be widely variable:

- *Citrus* spp. are favoured hosts for *C. capitata*. Losses for citrus crops vary by location and host species and cultivar, with thicker-skinned species being described as poor hosts. Reports of damage range from 7% to around 66% of fruit, and infestation rates appear to be determined by the level of in-field control.
 - Woods et al. (2005) reported 40% infestation of unmanaged grapefruit grown in parks, gardens and backyards in Australia.
 - In a commercial spray-free orchard study in the Azores (Portugal), infestation levels in oranges were recorded to be around 66% of fruit, with fruit yielding around seven pupae per fruit (Medeiros et al. 2007).
 - Studies in commercial grapefruit orchards in Gaza and Egypt reported infestation levels of around 26% and 28% respectively (Saleh and El-Hamalawii 2004; Lysandrou 2009).
 - Studies in commercial orange orchards in Gaza and Egypt reported infestation levels of around 24% and 7% respectively (Saleh and El-Hamalawii 2004; Lysandrou 2009).

Ceratitis capitata infestations may be visually detectable in the field and/or packhouses, leading to the removal of infested produce, but some individuals are likely to be undetected:

- Larval feeding within fruit induces decay, and females show a preference for ovipositing in cracked or otherwise damaged fruit. Infested fruit may therefore be detected and is not likely to be exported.
- However, females are able to oviposit into sound citrus fruit and oviposition sites are not always visible (Papachristos and Papadopoulos 2009, DPIPWE 2011). Infested fruit may show no outward signs, particularly at low levels of infestation. Feeding by early instars may not be detected during or after harvest or in on-arrival inspection, particularly if the volume of commodities is large.
- Internally feeding insects, and particularly those whose eggs are laid within fruit, are likely to be particularly problematic to detect by non-destructive inspection (Kendra et al. 2011). Even using fruit dissection, Gould (1995) found that detection rates for Caribbean fruit fly (*Anastrepha suspensa*) could be as low as 17.9%. In this study, inspectors detected between 17.9% and 83.5% of fruit infested with Caribbean fruit fly; variables influencing detection rate were the fruit type, its ripeness and the inspector.
- *Ceratitis capitata* has been identified at the New Zealand and European Union borders in various *Citrus* species⁸¹ (LIMS and Quancargo databases; EPPO 2020a):
 - Dead *C. capitata* larvae were identified at the New Zealand border in oranges from Spain in 2000 (Accession 19622), and in 2015, live larvae were detected in lemons carried by an air passenger (LIMS accession C15_00635).
 - In contrast to the few New Zealand border detections on citrus, *C. capitata* is frequently detected on citrus at EU borders (EPPO 2020a). Citrus commodities include (reported names): *Citrus aurantium*, *C. limon*, *C. paradisi*, *C. reticulata* (most common), and *C. sinensis* (EPPO 2020a).
 - Detections of *C. capitata* have been made at EU borders on citrus commodities originating from the following countries: Argentina, Brazil, Croatia, Egypt, France, Greece, Israel, Italy, Lebanon, Morocco, South Africa, Spain, Turkey and Uruguay (EPPO 2020a).

⁸¹ *Ceratitis capitata* has been detected at the New Zealand border on other hosts.

Ceratitis capitata larvae are likely to survive transit in some citrus commodities.

- Transport of fruit is likely to be by sea and may take a number of weeks. The optimum carrying temperature is variable depending on the fruit type (between 8 and 14°C for grapefruit, lemons and limes, and between 2 and 7°C for oranges; BMT 2020). Carrying temperatures are therefore generally cool, though not very low – grapefruit and mandarin exhibit chilling injury at 7 and 8°C, respectively, and unconditioned lemons below 14.5°C (McGregor 1987). *Ceratitis capitata* is considered to be a relatively temperate fruit fly species. Both eggs and larvae may survive cool temperatures during transport to New Zealand.

The level of uncertainty associated with the conclusion is moderate. Although infestation rates appear to be determined by the level of in-field control, the effectiveness of this control appears to be widely variable and not extremely high. The detectability of infested fruit is likely to be variable depending on a variety of factors. The impact of cool temperature transit⁸² on survival of *C. capitata* eggs and larvae is uncertain.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Ceratitis capitata* to move from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate.

Ceratitis capitata is able to survive and develop on discarded citrus fruit.

- *Ceratitis capitata* is often reared on picked fruit in disinfestation experiments. In the field, fruit infested with fruit fly larvae often drop to the ground prematurely (Allwood and Leblanc 1997), where development continues until they leave the fruit to pupate. Pupation usually takes place in the soil (CPC 2020).
- Infested fruit is likely to be discarded. Infested fruit must remain in a suitable condition long enough for larvae to develop to maturity (this time is temperature-dependent), and emerging larvae then need to find a suitable pupation site. Citrus fruit is relatively robust and not highly perishable (compared to commodities such as peaches or strawberries). It is likely to remain in good condition long enough for larvae to emerge and pupate.
- Many *Citrus* species are favoured hosts for *C. capitata*.

Most organic waste in New Zealand is likely to be disposed of using low-risk methods, meaning that fly larvae would die before completing development.

- The majority of waste in New Zealand is bagged and disposed of in landfills and into kitchen disposal units. In these situations, *C. capitata* is unlikely to continue development to successful emergence of adults (see section 2.4.1).

However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, discarding into the environment (e.g roadsides, parks) and use as animal feed, allowing larvae to successfully emerge from fruit, pupate and become adults.

- Adult *C. capitata* emerging from the soil are likely to be able to find food in the environment. Male and female tephritids need protein in order to become sexually mature, and they also need sugars for other behavioural activities (Meats et al. 2004, Farria et al. 2008; Clarke et al. 2011; Kouloussis 2017). Adult flies are presumed to obtain the majority of their protein through feeding on leaf surface bacteria (Clarke et al. 2011), and it is assumed that these bacteria are widely available. Other sources of food for adult tephritids include widely available substances such as bird droppings, nectar and plant sap (Christenson and Foote 1960).

Adult *C. capitata* are mobile and can fly to food sources and locate hosts.

- Adults are highly mobile and capable of independent dispersal. Meats and Smallridge (2007) showed that adult *C. capitata* are able to disperse over long distances (up to 9.5 km), but 90%

⁸² Cool storage differs from cold treatment, which usually involves a lower temperature for a shorter time period. Cold treatments are monitored by temperature probes to ensure the temperature does not increase beyond a certain set limit, e.g. 0.5°C.

of them remain within 400–700 m of the point of emergence. Long-distance dispersal may occur in response to scarce resources.

There is moderate uncertainty associated with the conclusion that the likelihood of exposure is moderate. Information about waste disposal may be inaccurate (section 2.4.1).

Given the arguments and evidence below, the suitability of New Zealand's environment for the establishment of *C. capitata* is moderate.

Ceratitis capitata is likely to establish permanently in at least some parts of New Zealand:

- *Ceratitis capitata* is found in some areas with similar climates to parts of New Zealand, for example, Switzerland (Table 9.10.2), and it was briefly established in Tasmania.
- Worner (1988) used climate modelling to predict sites suitable for establishment of *C. capitata* and concluded that the regions of Gisborne, Bay of Plenty and Northland were all climatically suitable for establishment. Other more marginal areas include the west coast of the North Island from Manawatu through to Taranaki and Marlborough in the South Island.
- Szyniszewska and Tatem (2014) used MaxEnt modelling to show that parts of the South Island, including the important fruit-growing region of Central Otago, could be considered environmentally suitable for the establishment of *C. capitata*.
- Kean and Stringer (2019) used daily air temperatures to predict that *C. capitata* might currently establish in the upper half of the North Island, though favourable microclimates may allow populations to establish even as far south as Alexandra.
- Breeding populations of *C. capitata* have been reported (and subsequently eradicated) in New Zealand on two occasions, providing some evidence of its potential to establish:
 - Cockayne (1907) reported *C. capitata* breeding populations in Napier and Blenheim in the summer of 1906/07.
 - *Ceratitis capitata* was detected in Auckland in 1996. Two males were found in a monitoring trap in Mt Roskill (Auckland). A further 41 adults were caught within the first 13 days of the response, and larval infestation of fruit (feijoa, grapefruit and tangelo) was detected in properties adjacent to the initial find (Holder et al. 2007; Kean et al. 2020).

Ceratitis capitata has a high reproduction rate, and mates are located using pheromones.

- Multiple larvae are contained within a single fruit. For example, Zeki et al. (2008) reported an average of 30 larvae per peach fruit (a preferred host; fewer adults are likely to emerge from some citrus species).
- A minimum of one male and one female is needed to successfully emerge from imported fruit and to survive long enough to locate each other and to mate. Enough adults may therefore emerge from a single or a few discarded fruit to establish a population. Males use pheromones to attract sexually receptive females (Baker et al. 1985).
- Females lay 1–14 eggs per fruit and can lay 300–1,000 eggs throughout life (Fletcher 1989). Oviposition rate is likely to be influenced by host plant and environmental factors, particularly temperature, so may be lower in New Zealand.

Host availability is unlikely to be a barrier to the establishment and spread of *C. capitata*.

- *Ceratitis capitata* is highly polyphagous on a wide range of hosts. Liquido et al. (2019) report over 400 plants species with validated records of infestation under natural field conditions. Potential host plants are available throughout New Zealand in climatically suitable areas in commercial groves, home gardens, parks and reserves.
- Suitable oviposition hosts are likely to be available at many times of the year.
- Once established, *C. capitata* is capable of dispersing naturally and is also likely to be spread by the distribution of infested host fruit.

Ceratitis capitata is likely to be detected and eradicated in the event of an incursion.

- Surveillance for fruit flies in New Zealand uses trimedlure, cuelure and methyl eugenol as lures (MacLellan et al. 2019). Male *C. capitata* are responsive to trimedlure (IAEA 2003) and early detection, and therefore, eradication of incursions is very likely. An analysis of 211 eradication or emergency response programs against 17 species of fruit flies in 31 countries

indicated that the failure rate for these fruit fly eradication programs was low (about 7%; McInnes et al. 2017).

- *Ceratitidis capitata* has been detected in New Zealand twice: in 1907 and in 1996 (Kean et al. 2020). On both occasions, larval infestations were detected (in 1996 subsequent to the detection of adult males in the surveillance grid), and on both occasions, the fly was successfully eradicated.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *C. capitata* is likely to be high.

Damage caused by *C. capitata* reduces fruit quality and can render it unmarketable.

- Attacked fruit usually shows signs of oviposition punctures. Larvae feed on the pulp of host fruit, sometimes tunneling through it and eventually reducing the whole fruit to a juicy, inedible mass (Thomas et al. 2019). Larval feeding also induces decay and premature fruit drop (CPC 2020; Allwood and Leblanc 1997).

Ceratitidis capitata has been reported to cause severe damage and production loss in many horticultural commodities that are economically important to New Zealand:

- *Ceratitidis capitata* is a major pest of citrus, though it is often a more serious pest in some deciduous fruits, such as peach, pear and apple. In some Mediterranean countries, only the earlier varieties of citrus are grown because the flies develop so rapidly that late-season fruits are too heavily infested to be marketable. Some infested areas in the Mediterranean have had almost 100% infestation in stone fruit (Thomas et al. 2019).
- Damage to crops through fruit loss is considerable in invaded areas. In Argentina, 143,000 tonnes of produce are lost annually to fruit fly damage caused by the two main pest species, *C. capitata* and *Anastrepha fratercula*, at an estimated value of US\$37 million (Guillén and Sánchez 2007). Fruit losses ranging from 15% for plums to 91% for peaches have been attributed to damage by *C. capitata* (Fischer-Colbrie and Busch-Petersen 1989). It has been estimated that the cost of controlling established medfly in California alone could range from US\$493 million to \$875 million, and the imposition of trade embargos from Asian countries would result in additional revenue losses of \$564 million and cost more than 14,000 jobs (Szyniszewska and Tatem 2014).
- Zeki et al. (2008) report infestation levels in commercial apple orchards of 1% of fruits on trees and 4% of fallen fruit, and a study in commercial orchards in Gaza reported infestation levels (based on emergence of adult flies from fruit) in oranges of around 24%.
- Over 90% of fresh fruit and vegetable exports by value are of produce that could host *C. capitata* (Underwood 2007), including apple and grapes (CPC 2020), which are among the top three export earners for horticultural produce (PFR 2019). The establishment of *C. capitata* would necessitate management programmes to be instated. Since there are no pest tephritids currently present in New Zealand and therefore no existing management programmes, the associated costs are likely to be high.

The establishment or even an incursion of *C. capitata* is likely to cause trade impacts.

- In addition to production losses, trading partners are likely to impose export restrictions and/or extra phytosanitary measures if *C. capitata* is present, even temporarily, in New Zealand. These may not be restricted to known host fruit and may last for long periods. In response to the May 1996 incursion of *C. capitata*, trading partners imposed restrictions on produce from the Auckland area, which lasted 8–12 months or longer (Underwood 2007). Although widely distributed in Europe, *C. capitata* is a quarantine pest for some of New Zealand's most important trading partners in Asia and eastern Australia.

If *C. capitata* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020b).

Ceratitidis capitata is likely to cause sociocultural impacts on home gardens.

- Many favoured hosts are commonly grown in home gardens. Some favoured hosts may have up to 90% infestation rates (e.g. peach in Jordan) (Fischer-Colbrie and Busch-Petersen 1989).

The likelihood of environmental impacts caused by the establishment of *C. capitata* is considered to be very low.

- *Ceratitidis capitata* attacks some plant species in genera that have New Zealand native representatives, e.g. *Passiflora*, *Solanum* and *Syzygium* (CPC 2020). The two varieties of *Solanum aviculare* present in New Zealand (neither endemic) and *Syzygium maire* all have some form of threatened status (NZPCN 2020), and where their distributions overlap with *C. ceratitidis*, they may be at risk. However:
 - neither genus contains species that have been reported as main hosts (CPC 2020);
 - the fly has an unprecedentedly wide host range and Beever et al. (2007) have suggested that highly damaging polyphagous species appear to be exceptional and that the impact of relatively specialised organisms is likely to be greater; and
 - the fruit of native *Solanum* and *Passiflora* species are small and much less fleshy than preferred hosts of *C. capitata*.
- Other susceptible native plants are likely to have populations in areas that are not suitable for the establishment of *C. capitata*.
- If the fly attacks only the flesh of ripe fruit, it is unlikely to impair seed development, number or viability.

Ceratitidis capitata is unlikely to cause unwanted impacts on human health.

- *Ceratitidis capitata* has been demonstrated to vector *Escheria coli* and coliform bacteria from damaged to intact apples (as has the vinegar fly *Drosophila melanogaster*, which is widespread in New Zealand). However, no direct evidence of human disease caused by medfly has been found.

Risk assessment summary:

Given the arguments and evidence below, *Ceratitidis capitata* may be considered for additional measures.

- Many citrus species are hosts, and some are favoured hosts.
- Low levels of fruit infestation may not be detected during general handling, especially when the volume of commodities is large.
- Larvae feed internally in fruit, and general handling cannot remove them; the fruit need to be cut open to reveal them.
- *Ceratitidis capitata* is capable of moving from imported fruit into a suitable environment to allow establishment.
- Warmer parts of New Zealand are likely to be suitable for the establishment of *C. capitata*.
- Hosts are widely available.
- The establishment or even an incursion of *C. capitata* is likely to cause high economic impacts in New Zealand.

8.10.4 References

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8.11 *Zeugodacus cucurbitae* (melon fly)

Description: *Zeugodacus cucurbitae* is a polyphagous fruit fly species that oviposits through the skin of fruits, causing internal feeding damage. The main hosts are all in the family Cucurbitaceae, but *Z. cucurbitae* has been recorded from field infestations in over 136 host taxa from 62 genera and 30 families. About 60% of the host species are from families other than Cucurbitaceae, including several citrus species (McQuate et al. 2017).

Scientific name: *Zeugodacus (Zeugodacus) cucurbitae* (Coquillett, 1899) (Virgilio et al. 2015)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Zeugodacus) cucurbitae*, *Dacus cucurbitae*, *Dacus yuiliensis*, *Dacus aureus*, *Chaetodacus cucurbitae*

Taxonomic notes: *Zeugodacus cucurbitae* was originally described as *Dacus cucurbitae*. The species was later placed in the subgenus *Zeugodacus*, firstly in the genus *Dacus* then subsequently in the genus *Bactrocera*. Recently, the systematic position of *Zeugodacus* was revised, and a new classification of *Zeugodacus (Zeugodacus) cucurbitae* was proposed (Virgilio et al. 2015). This classification is not yet universally accepted, so many publications and databases still refer to *Bactrocera cucurbitae*.

Summary of conclusions

Given the arguments and evidence presented:

- *Zeugodacus cucurbitae* meets the criteria to be a quarantine pest for New Zealand.
- *Zeugodacus cucurbitae* has a moderate association with citrus fruit.
- Basic measures are likely to reduce the likelihood of introduction of *Z. cucurbitae* by a moderate degree (with moderate uncertainty). Consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty).
- The ability of *Z. cucurbitae* to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).
- The suitability of the New Zealand environment for *Z. cucurbitae* to establish is considered to be moderate to high (with moderate uncertainty).
- The level of impact caused by *Z. cucurbitae* is likely to be high. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- *Zeugodacus cucurbitae* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Moderate	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Moderate
The ability to move from the imported commodity onto a suitable host	Moderate–high	Moderate
Suitability of the New Zealand environment	Moderate–high	Moderate
Impacts on the New Zealand economy, environment, health and society	High	Low

8.11.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Zeugodacus cucurbitae* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: the pest is not present in New Zealand, and is of potential importance (able to establish and cause harm⁸³).

Zeugodacus cucurbitae is not known to be present in New Zealand:

- *Zeugodacus cucurbitae* is not reported to be present in New Zealand (PPIN 2020) and is not recorded in NZOR (2011).
- New Zealand has country freedom status for *Z. cucurbitae* (listed as *B. cucurbitae*) (MPI 2020a).
- *Zeugodacus cucurbitae* is listed as a notifiable organism and a regulated pest (as *Bactrocera cucurbitae*) (ONZPR 2020).
- *Zeugodacus cucurbitae* is listed as 'regulated' in ONZPR (2020).

Zeugodacus cucurbitae has the potential to establish and spread in New Zealand:

- *Zeugodacus cucurbitae* is present in areas with a high climate similarity to New Zealand (Phillips et al. 2018; GBIF.org 2020), and species distribution models predict that *Z. cucurbitae* could establish in Europe in areas with a very similar climate to New Zealand (Godefroid et al. 2015; Phillips et al. 2018).
- Climate modelling shows that most of the North Island and the north of the South Island are suitable for *Z. cucurbitae* to establish (H. Narouei-Khandan pers. comm.)
- *Zeugodacus cucurbitae* is polyphagous with over 136 host taxa from 62 genera and 30 families, the majority of which are grown either in commercial plantations or in home gardens in New Zealand (McQuate et al. 2017).

Zeugodacus cucurbitae has the potential to cause economic, environmental, and sociocultural impacts in New Zealand:

- *Zeugodacus cucurbitae* has the potential to harm several horticultural crops of economic importance to New Zealand, including avocado, squash, beans, capsicum, sweet orange and mandarin. It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Zeugodacus cucurbitae* has the potential to harm several native species that belong to the same genus as known hosts. Varieties of one of these species are threatened or at risk (*Solanum aviculare* var. *aviculare* – threatened (nationally vulnerable); and *S. a.* var. *latifolium* – at risk (naturally uncommon)).
- *Zeugodacus cucurbitae* has the potential to harm plants traditionally used by Māori (*Solanum aviculare*, *S. laciniatum* and *Passiflora tetrandra*).
- *Zeugodacus cucurbitae* has the potential to have sociocultural impacts, because its hosts include plants commonly grown in domestic gardens.
- Currently, there is no evidence that *Z. cucurbitae* could have a negative impact on human health.

8.11.2 Hazard identification: commodity association

Zeugodacus cucurbitae is associated with citrus fruit.

Zeugodacus cucurbitae has been reported from citrus fruit:

- *Zeugodacus cucurbitae* oviposits through the skin of citrus fruit, and larvae feed inside the fruit (White and Elson-Harris 1994; Vayssières et al. 2007).

⁸³ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining "harm".

8.11.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Zeugodacus cucurbitae* has a moderate likelihood of entry with citrus fruit.

Larvae of *Z. cucurbitae* have been reported in citrus fruits.

- *Zeugodacus cucurbitae* larvae have been recorded from field infestation of various citrus cultivars (Table 9.11.1):
 - *Zeugodacus cucurbitae* larvae have been found infesting field-collected sweet oranges (*Citrus sinensis*) and tangerines (*C. reticulata*) in West Africa. Larvae within field-collected fruit were allowed to develop into pupae and adults in the laboratory, and infestation rates were calculated as the mean number of pupae per kg of fruit. Infestation rates were much lower in the *Citrus* species (1 to 25 pupae/kg of fruit) than the preferred hosts (Cucurbitaceae, 1 to over 100 pupae/kg of fruit) (Vayssières et al. 2007).
 - In Sudan, *Z. cucurbitae* have been found infesting field-collected sweet oranges (*C. sinensis*) at a rate of 3.2 individuals per kg of fruit (Ali et al. 2014, in McQuate et al. 2017).
 - *Zeugodacus cucurbitae* have been found infesting 13 of 52 field-collected citrons (*C. medica*) in India (Gupta and Verma 1978, in McQuate et al. 2015).
 - Other field-collected host records of *Z. cucurbitae* in citrus include: adults (number not given) reared from two makrut limes (*C. hystrix*) in Southeast Asia (Allwood et al. 1999); an infestation (number not given) of a single pomelo (*C. grandis*) in Malaysia (Keng-Hong and Soo-Lam 1982); a single adult reared from field-collected tangerine (*C. reticulata*) in Hawaii (McBride and Tanada 1949); an infestation of 10% of field-collected orange fruits (*C. sinensis*) in Pakistan (numbers of oranges and larvae not given) (Inayatullah et al. 1991, in McQuate et al. 2015); and a single adult reared from sweet orange (*C. sinensis*) in Hawaii (Ehrhorn 1910, in McQuate et al. 2015).

Table 9.11.1 Field infestation records of *Zeugodacus cucurbitae* in citrus, i.e. *Citrus* species that are natural hosts (Aluja and Mangan 2008)

Species name	Common name	Collection location	Reference
<i>Citrus sinensis</i>	Sweet orange	West Africa	Vayssières et al. 2007
		Pakistan	Inayatullah et al. 1991, in McQuate et al. 2015
		Hawaii	Ehrhorn 1910, in McQuate et al. 2015
		Sudan	Ali et al. 2014, in McQuate et al. 2017
<i>Citrus hystrix</i>	Makrut lime	Southeast Asia	Allwood et al. 1999
<i>Citrus maxima</i>	Pomelo	Malaysia	Keng-Hong and Soo-Lam 1982
<i>Citrus medica</i>	Citron	India	Gupta and Verma 1978, in McQuate et al. 2015
<i>Citrus reticulata</i>	Tangerine	West Africa	Vayssières et al. 2007
		Hawaii	McBride and Tanada 1949

- In addition to the natural hosts listed above, sour orange (*C. aurantium*) has been identified as a conditional (Aluja and Mangan 2008) host in a laboratory experiment (Rajamannar 1962 in McQuate et al. 2015).
- The following species have also been listed as hosts with no supporting data: Italian tangerine (*C. deliciosa*), lemon (*C. limon*), myrtle-leaf orange (*C. myrtifolia*), tangor (*C. nobilis*) and grapefruit (*C. paradisi*) (McQuate et al. 2015; McQuate et al. 2017). Lemon has been shown to be a non-host (Aluja and Mangan 2008), although this designation is currently only from a single study (Rajamannar 1962, in McQuate et al. 2015).

Zeugodacus cucurbitae is present in citrus-exporting countries in this IHS:

- *Zeugodacus cucurbitae* is present in: the USA (in Hawaii); China (in Fujian, Guangdong, Guangxi, Guizhou, Hainan, Jiangsu, Xianggang (Hong Kong), Yunnan, and Zhejiang); Viet Nam; Australia; and Solomon Islands (EPPO 2020a).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Zeugodacus cucurbitae* by a moderate degree (with moderate uncertainty). Consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty):

Zeugodacus cucurbitae infestations may be visually detectable in the field and/or packhouses, leading to the removal of infested produce.

- Puncture holes from oviposition are visible with the naked eye on citrus (Vayssières et al. 2007). The oviposition site often oozes fluid, which becomes a brown resinous deposit, and the surrounding tissue can become necrotic and slightly concave. Extensive larval feeding causes fruit rot or distortion (Dhillon et al. 2005). Fruit with multiple oviposition punctures and feeding damage is likely to be removed during general handling.
- Fruit bagging and packhouse culling have been reported to be effective in reducing levels of infestation in some citrus commodities in China (Xia et al. 2019). Fruit bagging is not widely practiced due to its labour intensity.

However, there is a chance that a small quantity of infested fruit will not be detected.

- Low levels of infestation (fewer oviposition punctures) may not be obvious enough to be detected during general handling. Low infestation levels may be more prevalent in less preferred hosts such as citrus.
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.
- *Zeugodacus cucurbitae* was intercepted over 70 times at the European border between 2003 and 2020 (EPPO 2020b), and over 200 times at the US border between 1923 and 2017 (McQuate et al. 2017) on a variety of (mainly cucurbit) host species.

General handling after harvesting is not likely to remove larvae of *Zeugodacus cucurbitae* inside citrus fruit.

- General handling after harvesting (e.g. washing and brushing) only treats the surface of fruit. These procedures are therefore highly unlikely to remove the larvae of *Z. cucurbitae* inside citrus fruit.
- Fruit will need to be cut open to reveal the larvae of *Z. cucurbitae* inside. Internally feeding insects are likely to be particularly problematic to detect by non-destructive inspection. Even using fruit dissection, Gould (1995) found that detection rates for Caribbean fruit fly (*Anastrepha suspensa*) could be as low as 17.9%. In this study, inspectors detected between 17.9% and 83.5% of fruit infested with Caribbean fruit fly; variables influencing detection rate were the fruit type, its ripeness and the inspector (Gould 1995).

Larvae of *Z. cucurbitae* may survive transit in citrus commodities.

- Between 1923 and 2017, live larvae, pupae or adults of *Z. cucurbitae* were intercepted at the US border over 100 times on a variety of (mainly cucurbit) host species. The only interception of *Z. cucurbitae* on citrus was of 22 live larvae from *Citrus* sp. being shipped domestically within Hawaii (McQuate et al. 2017).
- Viable eggs and live larvae of *Z. cucurbitae* have been intercepted at the New Zealand border in sea-shipped cucurbit from India (Keall 1981, in MAF 2007). There has also been an interception at the New Zealand border of two live *Z. cucurbitae* larvae on chillies (*Capsicum frutescens*) being carried by a passenger (LIMS 2019).
- Transit of citrus fruit usually includes cold storage. Eggs and larvae of *Z. cucurbitae* are very cold-tolerant. At 1.5–2°C within navel oranges (*C. sinensis*), eggs can survive for up to 6 days, first-instar larvae up to 10 days, second-instar larvae 14 days, and third-instar larvae up to 10 days (Follett et al. 2018). It is not known whether usual storage temperatures and transit times from countries in this IHS where *Z. cucurbitae* is present will be sufficient to prevent survival of *Z. cucurbitae* eggs and larvae.

The level of uncertainty associated with both the degree by which basic measures reduce the likelihood of entry (moderate) and the consequent likelihood of entry (low to moderate) is moderate. Firstly, species-specific information about the detectability of low levels of infestation of citrus fruit with *Z. cucurbitae* is not available. Secondly, there is uncertainty around whether standard transit times and storage temperatures of citrus commodities will be enough to prevent survival of *Z. cucurbitae* eggs and larvae.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Zeugodacus cucurbitae* to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).

Zeugodacus cucurbitae can survive and develop on the waste of citrus fruit (whole fruit or fruit pieces but probably not skin).

- In the laboratory, *Z. cucurbitae* can successfully develop to the adult stage in oranges (*C. sinensis*) and tangerines (*C. reticulata*) (McQuate et al. 2015)
- *Zeugodacus cucurbitae* females pierce the skin of host fruit and lay 1–40 eggs into the flesh. Upon hatching, larvae feed on the pulp of the fruit and drop to the ground upon maturity to pupate in the soil (Severin et al. 1914).
- Infested fruit is likely to be discarded and begin decaying. *Z. cucurbitae* larvae can develop on both decaying and non-decaying hosts (Severin et al. 1914).
- If citrus fruits are disposed of as whole fruit or fruit pieces, it is likely that *Z. cucurbitae* can survive and reach adulthood in this waste. There is no evidence showing that *Z. cucurbitae* can complete development by feeding on citrus fruit skin.

Most of the fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any *Z. cucurbitae* present would either be killed or be unable to escape from the citrus host.

- Most of the waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, *Z. cucurbitae* is unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some of the waste would be disposed of using high-risk methods, including composting in gardens and using as animal feed.

- Adults of *Z. cucurbitae* emerging from the soil are likely to be able to find food in the environment if citrus fruit waste is disposed of using high-risk methods. Emerged adults have been observed feeding on juice from decaying fruits and rotting caterpillars (Severin et al. 1914), and their diet is likely to be typical of other tephritid fruit fly adults, i.e. including plant exudates, honeydew, decaying insects and bird droppings (Christenson and Foote 1960). These food sources are common in farms, parks and home gardens.
- Because *Z. cucurbitae* is polyphagous, hosts for oviposition and larval development are available in most areas of New Zealand, either in commercial plantations or in home gardens.
- If citrus hosts are located near composting sites or animal feeding sites, adult *Z. cucurbitae* are likely to locate them (see the waste analysis in section 2.4.1).

Adults of *Z. cucurbitae* are strong fliers and can fly moderate to long distances to food sources.

- Mark-recapture trapping experiments during a sterile insect control programme have shown that sterile adult *Z. cucurbitae* can disperse up to 50 km over water (Kawai et al. 1978), and the maximum recorded distance is 256 km (also over water) (Waterhouse 1993). It is assumed that when hosts are plentiful, *Z. cucurbitae* adults become non-dispersive (Fletcher 1989).

The level of uncertainty associated with the ability of *Z. cucurbitae* to move from imported fruit to a suitable host (moderate to high) is moderate. Firstly, waste data may not be very accurate or up to date, and it is not known how frequently suitable hosts are present near composting sites or animal feeding locations (see the waste analysis in section 2.4.1). Secondly, it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin). Thirdly, the effect of seasonality on this likelihood is uncertain.

Given the arguments and evidence below, the suitability of the New Zealand environment for *Zeugodacus cucurbitae* to establish is considered to be moderate to high (with moderate uncertainty).

Zeugodacus cucurbitae is present in areas with a high climate similarity to New Zealand.

- Occurrence records within the native range (Pakistan, India and Bangladesh) (Virgilio et al. 2010) of *Z. cucurbitae* are found in areas with a dissimilar climate to New Zealand (climate match index (CMI) <0.7) (Phillips et al. 2018; GBIF.org 2020). However, the species has expanded its range into several areas with a similar climate to New Zealand (southern China, Taiwan, Ethiopia, Uganda and Kenya, CMI 0.7–0.8) (Phillips et al. 2018; GBIF.org 2020).

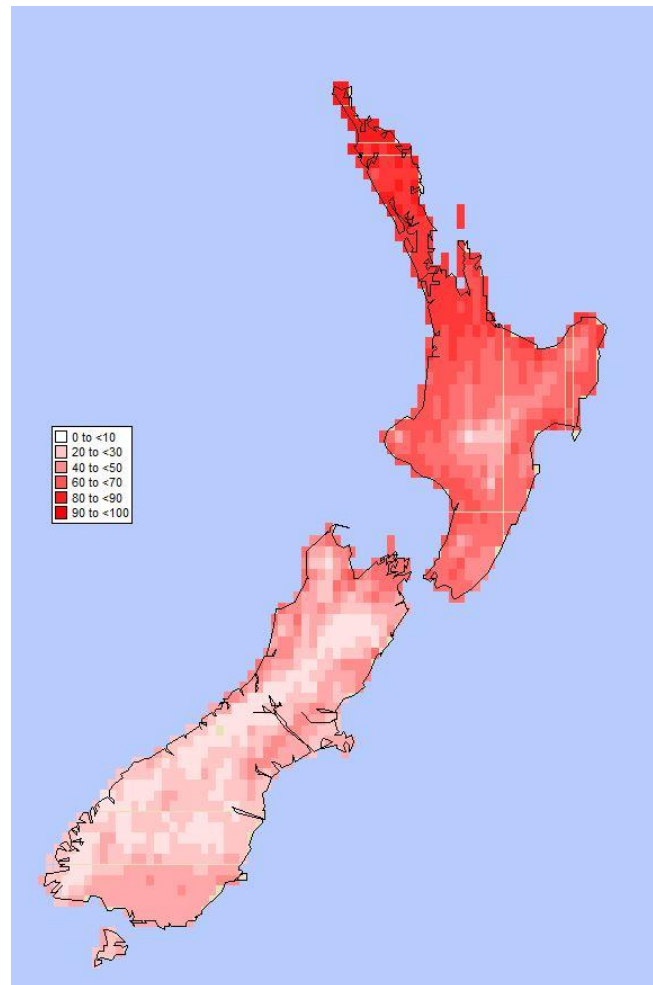
Modelling predicts that *Z. cucurbitae* could establish in Europe in areas with a very similar climate to New Zealand.

- Projections of climatic suitability for *Z. cucurbitae* establishment in Europe show that the areas where the species is highly likely to establish have a very similar climate (CMI 0.7–0.9) to New Zealand (Godefroid et al. 2015; Phillips et al. 2018).

Zeugodacus cucurbitae is likely to be capable of establishing across most of the North Island and the north of the South Island.

- Depending on the experiment, the lower developmental thresholds for *Z. cucurbitae* egg, larval and pupal stages are estimated to be 10–15.9°C, 6.6–13.4°C and 7.4–12.6°C, respectively (Vargas et al. 1996; Vayssières et al. 2008; Mkiga and Mwatawala 2015). The lower of these estimates has a higher likelihood of being more accurate, because they are based on experiments where development and survival of all life stages was recorded and measured at 15–16°C (Vargas et al. 1996; Vayssières et al. 2008).
- Under laboratory conditions, optimal temperatures for egg, larval and pupal survival are 24–29°C. However, there is still substantial egg hatch (93% at 16°C, 95% at 18°C), larval survival (84% at 16°C, 85% at 18°C) and pupal survival (95% at 16°C, 96% at 18°C) at 16°C and 18°C. Larval and pupal survival both decline at 32°C (88.7% and 62.0% respectively) (Vargas et al. 1996).
- Climate modelling, using 7.5°C as the lower temperature limit, 16–24°C as the optimum temperature range and 36°C as the upper temperature threshold, indicates that most of the North Island is highly suitable, and the north of the South Island is suitable, for the long-term establishment of *Z. cucurbitae* (Figure 9.11.1, H. Narouei-Khandan pers. comm.).

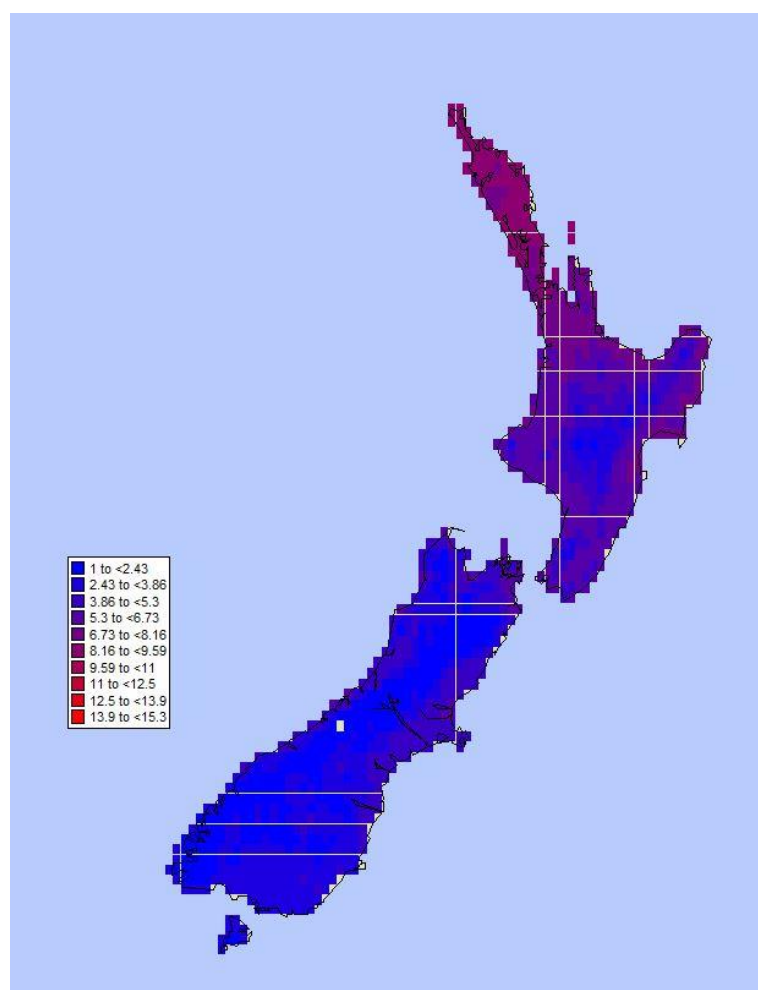
Figure 9.11.1 Map of the ecoclimatic index (Kriticos et al. 2015) for *Z. cucurbitae* showing the suitability of the New Zealand environment for establishment (lower temperature limit = 7.5°C, optimum temperature range = 16–24°C, upper temperature limit = 36°C). Values of 20 or over are considered suitable for establishment.



Zeugodacus cucurbitae has a high reproductive rate, which is likely to decrease, but still be high, under conditions across most of New Zealand in summer.

- Under laboratory conditions, *Z. cucurbitae* females can lay up to 578 fertile eggs in their lifetime at 24°C. This number decreases with decreasing temperature but remains high at both 18°C (364 fertile eggs/lifetime) and 16°C (142 fertile eggs/lifetime) (Vargas et al. 1997).
- Climate modelling using 322 degree days (the number of days of one degree above the developmental threshold required to complete development) per generation (Vayssières et al. 2008) shows that *Z. cucurbitae* can complete between 5 and 11 generations per year across most of the North Island and the north of the South Island (Figure 9.11.2, H. Narouei-Khandan pers. comm.).

Figure 9.11.2 Map of the number of generations *Z. cucurbitae* could complete given 322 degree days



Host and food availability are unlikely to be limiting factors for *Z. cucurbitae* to establish in New Zealand.

- *Zeugodacus cucurbitae* is polyphagous with over 136 host taxa from 62 genera and 30 families (McQuate et al. 2017), the majority of which are grown in New Zealand. Hosts for oviposition and larval development are available in most areas of New Zealand, either in commercial plantations or in home gardens.
- Emerged adults feed on juice from injured fruit and rotting caterpillars, and probably on honeydew, plant exudates, rotting insects and bird faeces (Severin et al. 1914; Christenson and Foote 1960). These food sources are common in farms, parks and home gardens.

Zeugodacus cucurbitae has become a major pest outside of its native range.

- *Zeugodacus cucurbitae* is considered a major pest of commercially grown cucurbits in Hawaii and Africa (De Meyer and Ekesi 2016).
- *Zeugodacus cucurbitae* is considered one of the most destructive “Category A” fruit fly species – “Category A” includes widespread invasive polyphagous generalists (species that use a wide range of resources) or highly destructive specialists (species that occupy a narrower ecological niche) that have become established outside their native range (Vargas et al. 2015).

Zeugodacus cucurbitae responds to cuelure and so is likely to be detected in the National Fruit Fly Surveillance Programme.

- Three fruit fly lures, cuelure, trimedlure and methyl eugenol are used in the National Fruit Fly Surveillance Programme in New Zealand (MacLellan et al. 2019). Melolure (raspberry ketone formate) was found to be a stronger attractant than cuelure in Hawaii (Casana-Giner et al. 2003). If a fruit fly species is responsive to one or more of these lures, early detection of an

incursion is more likely, which reduces the likelihood of the species' establishment in New Zealand.

- *Zeugodacus cucurbitae* adults are attracted to cuelure (Dhillon et al. 2005; Vayssières et al. 2007), although a mixture of cuelure with methyl eugenol may be more effective (Ramsamy et al. 1987).
- Cuelure has been used successfully for the monitoring and control of *Z. cucurbitae* (Dhillon et al. 2005; Sookar and Deguine 2016).

The level of uncertainty associated with the moderate to high likelihood of establishment of *Z. cucurbitae* is moderate. Firstly, the constant temperatures used in these studies do not reflect real-world daily temperature fluctuations, and it is not known how this would affect survivorship and fecundity in the wild. Secondly, the lower temperature thresholds for egg, larval and pupal survival are extrapolated from survivorship curves of *Z. cucurbitae* reared under laboratory conditions, i.e. on an artificial diet and under constant temperature. Actual developmental thresholds in the wild may be substantially different to these estimates.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Zeugodacus cucurbitae* is likely to be high.

Damage and symptoms caused by *Zeugodacus cucurbitae* can reduce yield.

- If *Z. cucurbitae* eggs are laid into fruits, then extensive larval feeding will cause fruit rot or distortion (Severin et al. 1914; Dhillon et al. 2005). Although *Z. cucurbitae* cannot oviposit into harder fruits such as pumpkins, or through thicker skin such as found in oranges, it will oviposit via injuries (Severin et al. 1914; McQuate et al. 2015).
- *Zeugodacus cucurbitae* also oviposits in stems, leaf petioles and flowers of cucurbits. Eggs laid into flowers can cause flower drop, preventing fruit production. If larvae develop in stems, they can penetrate the roots and destroy plants entirely (Severin et al. 1914; White and Elson-Harris 1994).

Zeugodacus cucurbitae has been reported to cause infestation, damage and production losses to several fruit and vegetable crops.

- Prior to the initiation of suppression activities of *Z. cucurbitae* on the southwestern islands of Japan in 1972, infestation rates of cucurbit hosts ranged up to 100% on some islands (McQuate and Teruya 2015).
- In Nepal, yield losses due to *Z. cucurbitae* damage have been estimated as 28.7–59.2% in pumpkin (*Cucurbita* sp.), 24.7–40.0% in bitter melon (*Momordica charantia*), 27.3–49.3% in bottle gourd (*Lagenaria siceraria*), 19.4–22.1% in cucumber (*Cucumis sativus*) and 0–26.2% in sponge gourd (*Luffa* sp.) (Pradhan 1977, in Sapkota et al. 2010)
- In squash (*Cucurbita pepo*) grown in Nepal, *Zeugodacus cucurbitae* caused the loss of 9.7% of female flowers and damage or loss of 26% of fruits (Sapkota et al. 2010).
- Damage by *Z. cucurbitae* of 28.6% and 31.3% has been reported on watermelon (*Citrullus lanatus*) and bitter melon (*Momordica charantia*) in India (Singh et al. 2000).
- In West Africa and on Réunion Island, infestation rates (measured as the mean number of pupae formed from larvae within field-collected fruits per kilogram of fruit) exceeded 100 in many cucurbit hosts and ranged between 1 and 25 for non-cucurbit hosts (Vayssières et al. 2007).

Zeugodacus cucurbitae is likely to negatively impact many plants of economic importance to New Zealand.

- *Zeugodacus cucurbitae* hosts include several important horticultural export crops: avocado (*Persea americana*, FOB export value: NZ\$104.3 million); squash (*Cucurbita* spp., FOB export value: \$59.7 M); beans (*Phaseolus vulgaris*, FOB export value: \$41.1 M); capsicum (*Capsicum annuum*, FOB export value: \$20.6 M); sweet orange (*Citrus sinensis*, FOB export value: \$1.7 M); and mandarin/tangerine (*Citrus reticulata*, FOB export value: \$0.4 M) (Plant & Food Research 2019).
- *Zeugodacus cucurbitae* has been shown to be capable of infesting intact and damaged gold kiwifruit and damaged green kiwifruit under laboratory conditions, and gold kiwifruit in the field

(in field experiments) (Follett et al. 2019a). *Z. cucurbitae* has also been shown to be capable of infesting intact and damaged apples under laboratory conditions but not in field experiments (Follett et al. 2019b). Although kiwifruit and apples make poor hosts when compared to papaya (*Carica papaya* – a preferred host), these two fruits are New Zealand's highest value export crops (kiwifruit, FOB export value: NZ\$2,302.2 million; apples, FOB export value: \$828.8 M). Additionally, even though kiwifruit are conditional hosts (Aluja and Mangan 2008), there is a risk that they could be infested in the absence of preferred hosts.

- Many of these crops are grown in the warmer areas of New Zealand, which coincides with the areas most suitable for *Z. cucurbitae* establishment.
- Even if *Z. cucurbitae* were to only establish for a single summer, the impact on a single growing season is likely to be high.
- Since there are no pest tephritids currently present in New Zealand and therefore no existing management programmes, costs of control in the event of *Z. cucurbitae* establishment are likely to be high.

If *Z. cucurbitae* is detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020b).

Establishment of *Z. cucurbitae* is likely to increase phytosanitary measures required for export to countries where the pest is absent.

- *Zeugodacus cucurbitae* is not present in five of the top 10 export destinations for New Zealand's horticultural produce (Plant & Food Research 2019) and is a quarantine pest in the top three destinations (Australia – National Priority Plant Pest No. 4; USA – quarantine pest; China – A2 list) (Department of Agriculture Water and the Environment 2019; EPPO 2020a).

Zeugodacus cucurbitae is likely to cause low to moderate sociocultural impacts on plants in home gardens with moderate uncertainty.

- Several host species of *Z. cucurbitae* are commonly grown in home gardens (e.g. pumpkins and squash, cucumbers, capsicums and chillies, and tomato). If control measures become necessary in residential areas, this is likely to have a negative sociocultural impact.

Zeugodacus cucurbitae is likely to have very low impacts on the environment in New Zealand (with high uncertainty), and very low impacts on Māori cultural values (with high uncertainty).

- *Zeugodacus cucurbitae* hosts include species in genera, which also contain the following native species: *Passiflora tetrandra*, *Solanum americanum*, *S. aviculare*, *S. laciniatum* and *S. opacum*.
- *Solanum aviculare* var. *aviculare* is threatened (nationally vulnerable) and *S. a.* var. *latifolium* is at risk (naturally uncommon) (NZPCN 2020).
- Several native species in the same genera as *Z. cucurbitae* hosts have traditional Māori uses (Landcare Research 2020):
 - *S. aviculare* and *S. laciniatum* (poroporo) was traditionally used as a food source, as medicine, as a tattoo dye and for making musical instruments.
 - *Passiflora tetrandra* (kōhia) was traditionally used as a medicine and as cable for making tools and anchors and for construction.
- The fruit of the native plant species are small and much less fleshy than those of preferred hosts of *Z. cucurbitae*, so the native species may not make attractive hosts. However, *Z. cucurbitae* has been reported infesting several wild *Solanum* species in the field at very low levels (e.g. *S. capsicoides* (0.33–0.39 pupae per fruit; *S. nigrum* – 1.14 larvae and pupae/kg fruit; and *S. pseudocapsicum* – 0.403 larvae and pupae/kg fruit) (Liquido et al. 1994; Harris et al. 2003; Jacquard et al. 2013).
- If *Z. cucurbitae* lays eggs into flowers or stems of these native species (as it does in cucurbit species), then it could impair their seed development, number or viability. It is not known whether *Z. cucurbitae* is capable of producing population-level effects in wild species.

There is no evidence that *Z. cucurbitae* could have a negative impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Zeugodacus cucurbitae* meets the criteria to be considered for additional measures.

- *Zeugodacus cucurbitae* has a moderate association with citrus fruit.
- Fruit with a low level of infestation may not be detected during general handling, especially when the volume of commodities is large.
- Because larvae feed internally inside fruit, general handling (e.g. washing and brushing) cannot remove the larvae, and citrus fruits need to be cut open to reveal the larvae of *Z. cucurbitae*;
- *Zeugodacus cucurbitae* has a moderate to high ability (with moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment;
- The suitability of the New Zealand environment for *Z. cucurbitae* to establish is considered to be moderate to high (with moderate uncertainty).
- The establishment of *Z. cucurbitae* in New Zealand is likely to cause high economic impacts.

8.11.4 References

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8.12 Other fruit flies

This hazard identification considers 23 species of fruit flies of economic significance. The earlier PRAs (Chapter 9, sections 9.1–9.11), carried out individually for 11 species from various geographic distributions, levels of host specificity and host range, showed several elements in common across all assessments. For this assessment, these elements have been addressed at a higher level for all fruit flies, and, where relevant, information particular to each fruit fly species has been considered separately to determine whether the potential impacts of an incursion or establishment warrant consideration of additional measures on the pathway.

The fruit fly species included here are:

- *Bactrocera aquilonis*
- *Bactrocera melas*
- *Bactrocera neohumeralis*
- *Bactrocera jarvisi*
- *Bactrocera kraussi*
- *Bactrocera trivialis*
- *Bactrocera frauenfeldi*
- *Bactrocera melanotus*
- *Bactrocera passiflorae*
- *Bactrocera* species near *passiflorae*
- *Bactrocera kirki*
- *Bactrocera curvipennis*
- *Bactrocera psidii*
- *Bactrocera distincta*
- *Bactrocera correcta*
- *Bactrocera latifrons*
- *Bactrocera carambolae*
- *Zeugodacus tau*
- *Anastrepha obliqua*
- *Anastrepha serpentina*
- *Anastrepha sororcula*
- *Anastrepha striata*
- *Anastrepha suspensa*

This section contains:

- Pest identity, hazard identification and host lists for each individual fruit fly species.
- A general assessment of:
 - The strength of association of each of the above species with citrus fruit;
 - The degree by which basic measures are likely to reduce the likelihood of entry of the above species and the consequent likelihood of entry;
 - The likelihood of establishment of the above species; and
 - The level of impact of the above species if they were to enter or establish in New Zealand.

Summary of conclusions

Given the arguments and evidence presented:

- The fruit fly species listed above meet the criteria to be quarantine pests for New Zealand.
- For the fruit flies in this assessment, the strength of association with citrus fruit ranges from weak to moderate–strong, depending on the species (with moderate to high uncertainty).

- Basic measures are likely to reduce the likelihood of entry of the fruit flies listed above by a moderate degree (with moderate to high uncertainty). Consequently, the likelihood of entry is considered to be low to moderate (with moderate uncertainty).
- The ability of the fruit fly species listed above to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).
- The suitability of the New Zealand environment for the fruit flies listed above to establish is considered to be:
 - Moderate to high (with low uncertainty) for *Bactrocera melas*, , *B. correcta*, *B. latifrons*, *A. obliqua*, *A. serpentina*, *A. sororcula*, *A. striata*, and *A. suspensa*;
 - Low (with low uncertainty) for *B. frauenfeldi*; and
 - Low (with moderate uncertainty) for the remaining species.
- The level of impact caused by the fruit flies listed above is likely to be high. Although their spread and economic impact may be limited by climate, even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- The fruit fly species listed above may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Weak to moderate–strong*	Moderate–high
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Moderate
The ability to move from the imported commodity onto a suitable host	Moderate–high	Moderate
Suitability of the New Zealand environment (<i>Bactrocera melas</i> , , <i>B. correcta</i> , <i>B. latifrons</i> , <i>Anastrepha obliqua</i> , <i>A. serpentina</i> , <i>A. sororcula</i> , <i>A. striata</i> and <i>A. suspensa</i>)	Moderate–high	Low
Suitability of the New Zealand environment (<i>Bactrocera frauenfeldi</i>)	Low	Low
Suitability of the New Zealand environment (all other fruit flies in this PRA)	Low	Moderate
Impacts on the New Zealand economy, environment, health and society	High	Low

* Rating is species specific, see likelihood of entry section below for details

8.12.1 *Bactrocera aquilonis* (Northern Territory fruit fly)

Scientific name: *Bactrocera aquilonis* (May, 1965)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera* (*Bactrocera*) *aquilonis*, *Dacus aquilonis*, *Strumeta aquilonis*

Taxonomic notes: *Bactrocera aquilonis* is a member of the *B. tryoni* complex of species, which currently includes four named species: *B. tryoni*, *B. aquilonis*, *B. melas* and *B. neohumeralis*. *Bactrocera aquilonis* may be a junior synonym of *B. tryoni* (Clarke et al. 2011); however, microsatellite and morphological data suggest that *B. aquilonis* is simply a western, allopatric population of *B. tryoni* (Cameron 2006; Cameron et al. 2010) (see taxonomic notes in *B. tryoni* PRA for full details).

Hazard identification

Bactrocera aquilonis meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera aquilonis is not known to be present in New Zealand:

- The putative species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera aquilonis* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera aquilonis has low potential to establish and spread within New Zealand; however, a transient summer population is possible, particularly in the north of New Zealand:

- The distribution of *B. aquilonis* is restricted to the north of the Northern Territory and of Western Australia (Sultana et al. 2020), which are areas of low climate similarity with New Zealand (climate match index, CMI, 0.4–0.5, Phillips et al. 2018). *Bactrocera aquilonis* is, therefore, unlikely to establish in New Zealand in the longer term; however, transient summer populations in the north of New Zealand are possible. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- The putative species is polyphagous and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.1).

The establishment of *B. aquilonis* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. aquilonis* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including apples (*Malus domestica*, FOB export value: \$828.8 million), avocados (*Persea americana*, FOB export value: \$104.3 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019).
- The establishment of *B. aquilonis* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. aquilonis* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (Hancock et al. 2000).

Lure: Cuelure (Hancock et al. 2000).

Table 9.12.1 *Bactrocera aquilonis* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus maxima</i>	Pomelo	Listing only	White and Elson-Harris (1994)
<i>Citrus limon</i>	Lemon	Listing only	White and Elson-Harris (1994)

<i>Citrus paradisi</i>	Grapefruit	Listing only	White and Elson-Harris (1994)
<i>Citrus reticulata</i>	Mandarin	Listing only	White and Elson-Harris (1994)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Hancock et al. (2000); CABI (2020)	
<i>Malus domestica</i>	Apple	Hancock et al. (2000); CABI (2020)	
<i>Prunus persica</i>	Peach	Hancock et al. (2000); CABI (2020)	
<i>Capsicum annuum</i>	Capsicum	Hancock et al. (2000); CABI (2020)	
<i>Solanum lycopersicum</i>	Tomato	Hancock et al. (2000); CABI (2020)	

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White, I M; Elson-Harris, M M (1994) *Fruit Flies of Economic Significance: Their Identification and Bionomics*. CAB International; Wallingford, UK.

8.12.2 *Bactrocera melas* (no common name)

Scientific name: *Bactrocera melas* (Perkins & May, 1949)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera* (*Bactrocera*) *melas*, *Strumeta melas*

Taxonomic notes: *Bactrocera melas* is a member of the *B. tryoni* complex of species, which currently includes four named species: *B. tryoni*, *B. aquilonis*, *B. melas* and *B. neohumeralis*. Although most Australian entomologists consider *Bactrocera melas* to be a junior synonym of *B. tryoni*, it continues to hold the status of a valid taxonomic species (Clarke et al. 2011).

Hazard identification

Bactrocera melas meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera melas is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera melas* is a regulated pest (ONZPR 2020).

Bactrocera melas has the potential to establish and spread within New Zealand:

- The distribution of *Bactrocera melas* includes southeast Queensland (Hancock et al. 2000), an area with a similar climate to all of New Zealand (CMI 0.7–0.8, Phillips et al. 2018).
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.2).

The establishment of *B. melas* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. melas* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and apples (*Malus domestica*, FOB export value: \$828.8 million) (Plant & Food Research 2019).
- The establishment of *B. melas* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. melas* was detected in New Zealand, the cost incurred by a response is likely to be high (see Impacts section below).

Distribution in countries considered in this IRA: Australia (Hancock et al. 2000).

Lure: Cuelure (Hancock et al. 2000).

Table 9.12.2 *Bactrocera melas* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. All hosts below are listed in White and Elson-Harris (1994) as being possible or likely hosts, but are only known from old records and not confirmed by surveys.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus paradisi</i>	Grapefruit	Listing only	White and Elson-Harris (1994)
<i>Citrus sinensis</i>	Orange	Listing only	White and Elson-Harris (1994)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Eriobotrya japonica</i>	Loquat	White and Elson-Harris (1994)	
<i>Malus domestica</i>	Apple	White and Elson-Harris (1994)	
<i>Prunus persica</i>	Peach	White and Elson-Harris (1994)	
<i>Prunus domestica</i>	Plum	White and Elson-Harris (1994)	
<i>Pyrus communis</i>	Pear	White and Elson-Harris (1994)	
<i>Fortunella japonica</i>	Kumquat	White and Elson-Harris (1994)	

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PPIN (2020) Plant Pest Information Network, Version 5.03.01. Ministry for Primary Industries internal database. Accessed 15 September 2020.

White, I M; Elson-Harris, M M (1994) *Fruit Flies of Economic Significance: Their Identification and Bionomics*. CAB International; Wallingford, UK.

8.12.3 *Bactrocera neohumeralis* (lesser Queensland fruit fly)

Scientific name: *Bactrocera neohumeralis* (Hardy, 1951)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera* (*Bactrocera*) *neohumeralis*, *Chaetodacus humeralis*, *Dacus tryoni* var. *neohumeralis*, *Dacus neohumeralis*

Taxonomic notes: *Bactrocera neohumeralis* is a member of the *B. tryoni* complex of species, which currently includes four named species: *B. tryoni*, *B. aquilonis*, *B. melas* and *B. neohumeralis*. Although the taxonomic status of *B. aquilonis* and *B. melas* is unclear, *B. neohumeralis* is accepted as a valid species; however, its populations in Papua New Guinea attributed to *B. neohumeralis* may constitute an unrecognised, additional species in the complex (Clarke et al. 2011).

Hazard identification

Bactrocera neohumeralis meets the criteria to be a quarantine pest for New Zealand

Criteria for being a quarantine pest relevant to this assessment are: the pest is not present in the PRA area (New Zealand), and the pest is of potential importance (able to establish and cause harm).

Bactrocera neohumeralis is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera neohumeralis* is a regulated pest and a notifiable organism (ONZPR 2020).
- New Zealand has country freedom status for *B. neohumeralis* (MPI 2020).

Bactrocera neohumeralis has the potential to establish and spread in New Zealand:

- The distribution of *B. neohumeralis* extends along eastern Australia, from Queensland to central New South Wales (Sultana et al. 2020) and with occasional detections as far south as Sydney (Dominiak and Worsley 2016). Dominiak (2021) considers Sydney to be free of *B. neohumeralis*, though low numbers are trapped in many years. Kriticos (2007) assessed the risk of establishment of fruit flies in New Zealand under climate change using CLIMEX modelling, and concluded that that, even under the warmest climate change scenarios considered (in the 2080s), *B. neohumeralis* would be barely able to persist even at the northernmost tip of Cape Reinga. According to Sultana et al. (2020), *B. neohumeralis* has a substantially narrower climate tolerance than *B. tryoni*. However Wan et al. (2020) used MAXENT to predict that most of the North Island and Central Otago were areas of high climate suitability for *B. neohumeralis*. It is likely that *B. neohumeralis* would be able to establish in warmer northern regions of New Zealand but there is a moderate to high level of uncertainty associated with this assessment.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.3).

The establishment of *B. neohumeralis* in New Zealand has the potential to cause unwanted impacts. Direct impacts may be limited by its likely restricted distribution, although there is a moderate to high level of uncertainty about how limited its distribution is likely to be since the outputs of climate models for this species are somewhat conflicting)

- The establishment of *B. neohumeralis* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), apples (*Malus domestica*, FOB export value: \$828.8 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. neohumeralis* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (Sultana et al. 2020).
Lure: Cuelure (Hancock et al. 2000)

Table 9.12.3 *Bactrocera neohumeralis* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Mexican lime	Listing only	Hancock et al. (2000)
<i>Citrus maxima</i>	Pomelo	Listing only	Hancock et al. (2000)
<i>Citrus limon</i>	Lemon, bush lemon, sweet lemon	Listing only	Hancock et al. (2000)
<i>Citrus paradisi</i>	Grapefruit	Listing only	Hancock et al. (2000)
<i>Citrus reticulata</i>	Mandarin	Listing only	Hancock et al. (2000)
<i>Citrus sinensis</i>	Sweet orange	Listing only	Hancock et al. (2000)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Passiflora edulis</i>	Passionfruit	Hancock et al. (2000)	
<i>Malus domestica</i>	Apple	Hancock et al. (2000)	
<i>Prunus persica</i>	Peach	Hancock et al. (2000)	
<i>Prunus armeniaca</i>	Apricot	Hancock et al. (2000)	
<i>Prunus domestica</i>	Plum	Hancock et al. (2000)	
<i>Prunus persica</i> var. <i>nucipersica</i>	Nectarine	Hancock et al. (2000)	
<i>Capsicum annuum</i>	Capsicum	Hancock et al. (2000)	
<i>Solanum lycopersicum</i>	Tomato	Hancock et al. (2000)	

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Dominiak, B C; Worsley, P (2016) Lesser Queensland fruit fly *Bactrocera neohumeralis* (Hardy) (Diptera: Tephritidae: Dacinae) not detected in inland New South Wales or south of Sydney. *General and Applied Entomology* 44: 9–15.

Dominiak, B C (2021) Surveillance for exotic fruit fly of the subfamily Dacinae (Insecta, Diptera, Tephritidae) and a review of the Dacinae established in Sydney, Australia, between 2010 and 2019, *New Zealand Entomologist*, DOI:10.1080/00779962.2021.1896061.

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Wan, J; Qi, G-J; Jun, M A; Ren, Y; Wang, R; McKirdy, S (2020) Predicting the potential geographic distribution of *Bactrocera bryoniae* and *Bactrocera neohumeralis* (Diptera: Tephritidae) in China using MaxEnt ecological niche modelling. *Journal of Integrative Agriculture* 19 (8): 2072–2082.

8.12.4 *Bactrocera jarvisi* (Jarvis' fruit fly)

Scientific name: *Bactrocera jarvisi* (Tryon, 1927)

Order/Family: Diptera/Tephritidae

Other names: *Chaetodacus jarvisi*, *Dacus jarvisi*

Hazard identification

Bactrocera jarvisi meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera jarvisi is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera jarvisi* is a regulated pest and a notifiable organism (ONZPR 2020).
- New Zealand has country freedom status for *B. jarvisi* (MPI 2020).

Bactrocera jarvisi has the potential to establish and spread in New Zealand:

- The distribution of *B. jarvisi* extends from northwest Western Australia, across the Northern Territory to northern Queensland (Sultana et al. 2020). Sultana et al. (2020) also report that in favourable years it may spread down the east coast of Australia into northern coastal New South Wales, an area with a similar climate to all of New Zealand (CMI 0.8–0.9, Phillips et al. 2018). However Dominiak and Worsley (2017) consider most records from NSW to be incursions, and that the southern boundary of the endemic range of *B. jarvisi* is somewhere north of the border between Queensland and NSW. Kriticos (2007) assessed the risk of establishment of fruit flies in New Zealand under climate change using CLIMEX modelling, and concluded that that, even under the warmest climate change scenarios considered (in the 2080s), *B. jarvisi* would be barely able to persist even at the northernmost tip of Cape Reinga. It is likely that *B. jarvisi* would be capable of establishing persistent populations only in the most northerly regions of New Zealand.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.4).

The establishment of *B. jarvisi* in New Zealand has the potential to cause unwanted impacts, though direct impacts would be limited by its likely restricted distribution:

- The establishment of *B. jarvisi* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and apples (*Malus domestica*, FOB export value: \$828.8 million) and avocados (*Persea americana*, FOB export value: \$104.3 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. jarvisi* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (New South Wales, Northern Territory, Queensland, Western Australia) (Hancock et al. 2000)

Lure: Weakly attracted to cuelure in northern Western Australia but not elsewhere (Drew 1989). Males are attracted to zingerone (Fay 2012).

Table 9.12.4 *Bactrocera jarvisi* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Mexican lime	Listing only	Hancock et al. (2000)
<i>Citrus maxima</i>	Pomelo	Listing only	Hancock et al. (2000)
<i>Citrus limon</i> *	Lemon	Listing only	Hancock et al. (2000)
<i>Citrus paradisi</i> *	Grapefruit	Listing only	Hancock et al. (2000)
<i>Citrus reticulata</i> *	Mandarin	Listing only	Hancock et al. (2000)
<i>Citrus sinensis</i> *	Sweet orange	Listing only	Hancock et al. (2000)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Hancock et al. (2000)	
<i>Malus domestica</i> [^]	Apple	Hancock et al. (2000)	
<i>Prunus persica</i>	Peach	Hancock et al. (2000)	
<i>Prunus armeniaca</i>	Apricot	Hancock et al. (2000)	
<i>Diospyros kaki</i> [^]	Persimmon	Hancock et al. (2000)	
<i>Pyrus communis</i> [^]	Pear	Hancock et al. (2000)	

* Occasional host

[^] Moderate host

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8.12.5 *Bactrocera kraussi* (Krauss's fruit fly)

Scientific name: *Bactrocera kraussi* (Hardy, 1951)

Order/Family: Diptera/Tephritidae

Other names: *Dacus kraussi*

Hazard identification

Bactrocera kraussi meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera kraussi is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera kraussi* is a regulated pest (ONZPR 2020).

Bactrocera kraussi has low potential to establish and spread within New Zealand; however, a transient summer population is possible, particularly in the north of New Zealand:

- The distribution of *B. kraussi* is restricted to the north of Australia (Torres Strait Islands and northeast Queensland as far south as Townsville, Sultana et al. 2020), an area of low climate similarity with New Zealand (CMI 0.4–0.6, Phillips et al. 2018). *Bactrocera kraussi* is, therefore, unlikely to establish in New Zealand in the longer term; however, the establishment of a transient summer population in the north of New Zealand is possible. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- The species is reported from multiple *Citrus* spp., which are grown in some regions of New Zealand both commercially and by home gardeners (Table 9.12.5).

The establishment of *B. kraussi* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. kraussi* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as citrus trees are commonly grown by home gardeners.
- If *B. kraussi* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (Torres Strait Islands and northeast Queensland as far south as Townsville) (Hancock et al. 2000)

Lure: Cuelure and isoeugenol (Hancock et al. 2000; Royer 2015)

Table 9.12.5 *Bactrocera kraussi* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Mexican lime	Listing only	Hancock et al. (2000)
<i>Citrus aurantium</i>	Sour orange	Listing only	Hancock et al. (2000)
<i>Citrus limon</i>	Lemon	Listing only	Hancock et al. (2000)
<i>Citrus paradisi</i>	Grapefruit	Listing only	Hancock et al. (2000)
<i>Citrus reticulata</i>	Mandarin	Listing only	Hancock et al. (2000)
<i>Citrus sinensis</i>	Sweet orange	Listing only	Hancock et al. (2000)
<i>Citrus limon</i>	Bush lemon	Listing only	Hancock et al. (2000)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Solanum lycopersicum</i>	Tomato	Hancock et al. (2000) only two records	
<i>Capsicum annum</i>	Capsicum	Hancock et al. (2000) only two records	

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8.12.6 *Bactrocera trivialis* (no common name)

Scientific name: *Bactrocera trivialis* (Drew, 1971)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera* (*Bactrocera*) *trivialis*, *Dacus trivialis*

Hazard identification

Bactrocera trivialis meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera trivialis is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera trivialis* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera trivialis has low potential to establish and spread within New Zealand; however, a transient summer population is possible, particularly in the north of New Zealand:

- *Bactrocera trivialis* is native to Papua New Guinea and West Papua, but it makes seasonal incursions into the Torres Strait Islands (Plant Health Australia 2018). All of these areas have a dissimilar climate to New Zealand (CMI 0.3–0.6, Phillips et al. 2018). *Bactrocera trivialis* is, therefore, unlikely to establish in New Zealand in the longer term; however, the establishment of a transient summer population in the north of New Zealand is possible. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- Hosts of the species include plants grown in regions of New Zealand both commercially and by home gardeners (Table 9.12.6).

The establishment of *B. trivialis* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. trivialis* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and peaches (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as citrus trees are commonly grown by home gardeners.
- If *B. trivialis* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (seasonal incursions into Torres Strait Islands) (Plant Health Australia 2018).

Lure: Cuelure (Leblanc et al. 2013)

Table 9.12.6 *Bactrocera trivialis* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus paradisi</i>	Grapefruit	Listing only	Leblanc et al. (2013); White and Elson-Harris (1994)
<i>Citrus sinensis</i>	Sweet orange	Field record (1/11)	Leblanc et al. (2013)
Other relevant hosts to New Zealand			
Host name	Common name	Reference	
<i>Prunus persica</i>	Peach	Leblanc et al. (2013)	
<i>Capsicum annuum</i>	Chilli	Leblanc et al. (2013)	

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Leblanc, L; Vueti, E; Allwood, A J (2013) Host plant records for fruit flies (Diptera: Tephritidae: Dacini) in the Pacific Islands: 2. Infestation statistics on economic hosts. *Proceedings of the Hawaiian Entomological Society*, 45: 83–177.

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8.12.7 *Bactrocera frauenfeldi* (mango fruit fly)

Scientific name: *Bactrocera frauenfeldi* (Schiner, 1868)

Order/Family: Diptera/Tephritidae

Other names: *Dacus frauenfeldi*, *Strumeta frauenfeldi*

Hazard identification

Bactrocera frauenfeldi meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera frauenfeldi is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera frauenfeldi* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera frauenfeldi has low potential to establish and spread within New Zealand; however, a transient summer population is possible, particularly in the north of New Zealand:

- The distribution of *B. frauenfeldi* is in northern Australia and the Pacific Islands – areas with a dissimilar average climate to New Zealand (Phillips et al. 2018).
- *Bactrocera frauenfeldi* has not expanded its range southward in Australia, despite the absence of any controls and an abundance of available hosts, and it is unlikely to be able to establish in areas that do not fulfil the following conditions:
 - a minimum temperature for the coldest month greater than 13.2°C;
 - an annual temperature range (the difference between the maximum temperature of the warmest month and the minimum temperature of the coldest month) less than 19.3°C;
 - a mean temperature of the driest quarter greater than 20.2°C;
 - precipitation of the wettest month greater than 268 mm;
 - precipitation of the wettest quarter greater than 697 mm;
 - temperature seasonality (the annual range in weekly mean temperature) less than 30.9°C (Royer et al. 2016).
- Given that no part of New Zealand fulfils the above climate requirements, *B. frauenfeldi* is unlikely to establish in New Zealand in the longer term; however, the formation of a transient summer population in the north of New Zealand is possible. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- The species is reported from multiple *Citrus* spp. and *Persea americana* (avocado), which are grown in some regions New Zealand both commercially and by home gardeners (Table 9.12.7). Therefore, suitable hosts would be present to support establishment.

The establishment of *B. frauenfeldi* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. frauenfeldi* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), avocado (*Persea americana*, FOB export value: \$104.3 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as citrus trees are commonly grown by home gardeners.
- If *B. frauenfeldi* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Australia (Hancock et al. 2000) and Solomon Islands (Leblanc et al. 2013)

Lure: Cuelure, Melolure (raspberry ketone formate) (Hancock et al. 2000)

Table 9.12.7 *Bactrocera frauenfeldi* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantium</i>	Sour orange	Field record (3/34)	Leblanc et al. (2012)
<i>Citrus maxima</i>	Pomelo	Field record (5/58)	Leblanc et al. (2012)
<i>Citrus limon</i>	Lemon	One field record	Hancock et al. (2000)
<i>Citrus paradisi</i>	Grapefruit	Field record (2/16)	Hancock et al. (2000); Leblanc et al. (2012)
<i>Citrus reticulata</i>	Mandarin	Field record (18/34)	Hancock et al. (2000); Leblanc et al. (2012)
<i>Citrus sinensis</i>	Sweet orange	Field record (10/33)	Hancock et al. (2000); Leblanc et al. (2012)
<i>Citrus reticulata</i>	Calamondin	Field record (5/20)	Leblanc et al. (2012)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Hancock et al. (2000); Leblanc et al. (2012)	
<i>Capsicum annuum</i>	Capsicum	Hancock et al. (2000); Leblanc et al. (2012)	

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8.12.8 *Bactrocera melanotus* (no common name)

Scientific name: *Bactrocera melanotus* (Coquillett, 1909)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera (Bactrocera) melanotus*, *Bactrocera melanota*, *Chaetodacus melanotus*, *Dacus melanotus*, *Dacus rarotongae*, *Strumeta melanota*

Hazard identification

Bactrocera melanotus meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera melanotus is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera melanotus* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera melanotus has the potential to establish and spread in New Zealand:

- The distribution of *B. melanotus* is restricted to the Cook Islands (Leblanc et al. 2012). The CMI of this island is not available (Phillips et al. 2018), but the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. melanotus* cannot be definitively ruled out, because a distribution on a single remote island may not be reflective of the fundamental niche of this species but rather of geographic isolation.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 12.9.8).

The establishment of *B. melanotus* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. melanotus* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and avocados (*Persea americana*, FOB export value: \$104.3 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. melanotus* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: the Cook Islands (Leblanc et al. 2012)

Lure: Cuelure (Leblanc et al. 2012)

Table 9.12.8 *Bactrocera melanotus* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the number in brackets indicates the numbers of fruit from which adults emerged (total number of samples not available).

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantium</i>	Sour orange	Listing only*	Leblanc et al. (2013)
<i>Citrus maxima</i>	Pomelo	Field record (4)	Leblanc et al. (2012)
<i>Citrus paradisi</i>	Grapefruit	Field record (4)	Leblanc et al. (2012)
<i>Citrus reticulata</i>	Mandarin	Field record (1)	Leblanc et al. (2012)
<i>Citrus sinensis</i>	Sweet orange	Field record (8)	Leblanc et al. (2012)
Other relevant hosts to New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Leblanc et al. (2012)	
<i>Solanum lycopersicum</i>	Tomato	Leblanc et al. (2012)	
<i>Solanum melongena</i>	Eggplant	Leblanc et al. (2012)	

* According to Leblanc et al. (2013), “there is a plausible record of *B. melanotus* on *C. aurantium* in Bezzi (1928), but cited by White and Elson-Harris (1992) as requiring confirmation”.

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8.12.9 *Bactrocera kirki* (no common name)

Scientific name: *Bactrocera kirki* (Froggatt, 1910)

Order/Family: Diptera/Tephritidae

Other names: *Dacus kirki*, *Strumeta kirki*

Hazard identification

Bactrocera kirki meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera kirki is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera kirki* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera kirki has the potential to establish and spread in New Zealand:

- *Bactrocera kirki* is present in several Pacific Islands (Leblanc et al. 2012) – all locations where a CMI is unavailable (Phillips et al. 2018) but where the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. kirki* cannot be definitively ruled out, because a distribution on remote islands may not be reflective of the fundamental niche of this species but rather of geographic isolation.
- The species is polyphagous and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.9).

The establishment of *B. kirki* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. kirki* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), avocados (*Persea americana*, FOB export value: \$104.3 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. kirki* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Fiji (Rotuma) and Samoa (Leblanc et al. 2012)

Lure: Cuelure (Leblanc et al. 2013)

Table 9.12.9 *Bactrocera kirki* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantifolia</i>	Mexican lime	Laboratory host*	Leblanc et al. (2013)
<i>Citrus latifolia</i>	Tahitian lime	Laboratory host*	Leblanc et al. (2013)
<i>Citrus maxima</i>	Pomelo	Field record (27/214)	Leblanc et al. (2013)
<i>Citrus paradisi</i>	Grapefruit	Laboratory host*	Leblanc et al. (2013)
<i>Citrus reticulata</i>	Mandarin	Field record (3/70)	White and Elson-Harris (1994); Leblanc et al. (2013)
<i>Citrus sinensis</i>	Sweet orange	Field record (5/119)	White and Elson-Harris (1994); Leblanc et al. (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Leblanc et al. (2013)	
<i>Passiflora edulis</i>	Passionfruit	Leblanc et al. (2013)	
<i>Prunus persica</i>	Peach	Leblanc et al. (2013)	
<i>Capsicum annum*</i>	Capsicum	Leblanc et al. (2013)	
<i>Solanum lycopersicum</i>	Tomato	Leblanc et al. (2013)	
<i>Solanum melongena</i>	Eggplant	Leblanc et al. (2013)	

* Flies have been bred from damaged fruits exposed to gravid females.

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Leblanc, L; Vueti, E; Allwood, A J (2013) Host plant records for fruit flies (Diptera: Tephritidae: Dacini) in the Pacific Islands: 2. Infestation statistics on economic hosts. *Proceedings of the Hawaiian Entomological Society*, 45: 83–177.

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8.12.10 *Bactrocera passiflorae* (Fijian fruit fly)

Scientific name: *Bactrocera passiflorae* (Froggatt, 1910)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera (Bactrocera) passiflorae*, *Dacus passiflorae*, *Strumeta passiflorae*

Hazard identification

Bactrocera passiflorae meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera passiflorae is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera passiflorae* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera passiflorae has the potential to establish and spread in New Zealand:

- *Bactrocera passiflorae* is found in Fiji (CMI 0.4) and two other Pacific Island countries (Niue, Wallis and Futuna) (Leblanc et al. 2012) where the CMI is unavailable (Phillips et al. 2018) but where the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. passiflorae* cannot be definitively ruled out, because the remote island distribution of this species may not be reflective of its fundamental niche but rather of geographic isolation.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.10).

The establishment of *B. passiflorae* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. passiflorae* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), avocados (*Persea americana*, FOB export value: \$104.3 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. passiflorae* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Fiji (Leblanc et al. 2013)

Lure: Cuelure (Leblanc et al. 2013)

Table 9.12.10 *Bactrocera passiflorae* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

<i>Citrus</i> spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantium</i>	Sour orange	Listing only	Leblanc et al. (2013)
<i>Citrus maxima</i>	Pomelo	Field record (21/79)	Leblanc et al. (2013)
<i>Citrus limon</i>	Lemon	Field record (9/219)	Leblanc et al. (2013)
<i>Citrus paradisi</i>	Grapefruit	Field record (13/96)	Leblanc et al. (2013)
<i>Citrus reticulata</i>	Mandarin	Field record (13/137)	Leblanc et al. (2013)
<i>Citrus sinensis</i>	Sweet orange	Field record (14/221)	Leblanc et al. (2013)
<i>Fortunella japonica</i>	Kumquat	Field record (40/146)	Leblanc et al. (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Leblanc et al. (2013)	
<i>Capsicum annuum</i>	Capsicum	Leblanc et al. (2013)	
<i>Solanum lycopersicum</i>	Tomato	Leblanc et al. (2013)	

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8.12.11 *Bactrocera* species near *passiflorae* (no common name)

Scientific name: *Bactrocera* species near *passiflorae* (sensu Drew and Hancock, 1995)

Order/Family: Diptera/Tephritidae

Other names: none

Taxonomic notes: Characterized by Drew and Hancock (1995) as the pale form of *B. passiflorae*, though not described, designated or named as a new species (Leblanc et al. 2012)

Hazard identification

Bactrocera sp. nr. *passiflorae* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera sp. nr. *passiflorae* is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera* sp. nr. *passiflorae* does not have an assigned regulatory status.

Bactrocera sp. nr. *passiflorae* has the potential to establish and spread in New Zealand:

- *Bactrocera* sp. nr. *passiflorae* is found in Fiji (CMI 0.4) and several Pacific Islands (Leblanc et al. 2012) where the CMI is unavailable (Phillips et al. 2018) but where the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. sp. nr. passiflorae* cannot be definitively ruled out, because the remote island distribution of this species may not be reflective of its fundamental niche but rather of geographic isolation.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.11).

The establishment of *B. sp. nr. passiflorae* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. sp. nr. passiflorae* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and avocado (*Persea americana*, FOB export value: \$104.3 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as citrus trees are commonly grown by home gardeners.
- If *B. sp. nr. passiflorae* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Fiji (Leblanc et al. 2013)

Lure: Cuelure (Leblanc et al. 2013)

Table 9.12.11 *Bactrocera* sp. nr. *passiflorae* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantifolia</i> *	Mexican lime	Listing only	Leblanc et al. (2013)
<i>Citrus reticulata</i>	Mandarin	Field record [^]	Leblanc et al. (2013)
<i>Citrus sinensis</i>	Sweet orange	Field record (3/14)	Leblanc et al. (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Persea americana</i>	Avocado	Leblanc et al. (2013)	

* Not confirmed

[^] Infestation rate not given

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8.12.12 *Bactrocera curvipennis* (banana fruit fly)

Scientific name: *Bactrocera curvipennis* (Froggatt, 1909)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera* (*Bactrocera*) *curvipennis*, *Chaetodacus curvipennis*, *Dacus curvipennis*, *Strumeta curvipennis*

Hazard identification

Bactrocera curvipennis meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera curvipennis is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera curvipennis* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera curvipennis has the potential to establish and spread in New Zealand:

- The distribution of *Bactrocera curvipennis* is restricted to New Caledonia and Vanuatu (Aneityum Island) (Leblanc et al. 2012). The CMIs of these islands are not available (Phillips et al. 2018), but the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. curvipennis* cannot be definitively ruled out, because a distribution on a single remote island may not be reflective of the fundamental niche of this species but rather of geographic isolation.
- The species is reported from multiple *Citrus* spp., which are grown in some regions of New Zealand both commercially and by home gardeners (Table 9.12.12).

The establishment of *B. curvipennis* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. curvipennis* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as citrus trees are commonly grown by home gardeners.
- If *B. curvipennis* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: New Caledonia (Amice and Sales 1996). There has also been a record from Aneityum in Vanuatu (three specimens collected in the 1930s), but this was unconfirmed and is not considered reliable (Allwood et al. 1996).

Lure: Only weakly attracted to cuelure. However, Royer et al. (2019) demonstrated that lures using isoeugenol resulted in 15 times more catches of flies compared to cuelure and four times more catches compared to dihydroeugenol.

Table 9.12.12 *Bactrocera curvipennis* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus latifolia</i>	Tahitian lime	Field record (1/33)	Leblanc et al. (2013)
<i>Citrus maxima</i>	Pomelo	Field record (1/28)	Leblanc et al. (2013)
<i>Citrus paradisi</i>	Grapefruit	Field record (1/18)	Leblanc et al. (2013)
<i>Citrus reticulata</i>	Mandarin	Field record (2/18)	Leblanc et al. (2013)
<i>Citrus sinensis</i>	Orange	Field record (1/35)	Leblanc et al. (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Capsicum annuum</i>	Capsicum	Amice and Sales (1996)	

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8.12.13 *Bactrocera psidii* (South Sea guava fruit fly)

Scientific name: *Bactrocera psidii* (Froggatt, 1899)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera (Bactrocera) psidii*, *Tephritis psidii*, *Dacus virgatus*, *Dacus ornatissimus*, *Strumeta psidii*

Hazard identification

Bactrocera psidii meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera psidii is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera psidii* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera psidii has the potential to establish and spread in New Zealand:

- The distribution of *Bactrocera psidii* is restricted to New Caledonia (Leblanc et al. 2012). The CMI of this island is not available (Phillips et al. 2018), but the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. psidii* cannot be definitively ruled out, because a distribution on a single remote island may not be reflective of the fundamental niche of this species but rather of geographic isolation.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.13).

The establishment of *B. psidii* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. psidii* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and grapes (*Vitis vinifera*, wine FOB export value: \$1.8 billion) (Plant & Food Research 2019). It also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. psidii* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: New Caledonia (Leblanc et al. 2013)

Lure: Cuelure (Amice and Sales 1996)

Table 9.12.13 *Bactrocera psidii* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus maxima</i>	Pomelo	Field record (1/28)	Leblanc et al. (2013)
<i>Citrus paradisi</i>	Grapefruit	Listing only	Margosian et al. (2007)
<i>Citrus limon</i>	Lemon	Listing only	Margosian et al. (2007)
<i>Citrus sinensis</i>	Orange	Listing only	Margosian et al. (2007)
<i>Citrus reticulata</i>	Mandarin	Listing only	Margosian et al. (2007)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Prunus persica</i> var. <i>nucipersica</i>	Nectarine	Leblanc et al. (2013)	
<i>Prunus domestica</i>	Plum	Leblanc et al. (2013)	
<i>Diospyros kaki</i>	Persimmon	Leblanc et al. (2013)	
<i>Vitis vinifera</i>	Grape	Leblanc et al. (2013)	

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8.12.14 *Bactrocera distincta* (no common name)

Scientific name: *Bactrocera distincta* (Malloch, 1931)

Order/Family: Diptera/Tephritidae

Other names: *Bactrocera* (*Bactrocera*) *distincta*, *Dacus distinctus*, *Strumeta distincta*, *Dacus* (*Strumeta*) *distinctus*

Hazard identification

Bactrocera distincta meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera distincta is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera distincta* is a regulated pest (ONZPR 2020).

Bactrocera distincta has the potential to establish and spread in New Zealand:

- *Bactrocera distincta* is found in Fiji (CMI 0.4) and several Pacific Islands (White and Elson-Harris 1994; Drew and Romig 1996; Leblanc et al. 2012) where the CMI is unavailable (Phillips et al. 2018) but where the average climate is likely to be dissimilar to that of New Zealand. The suitability of the New Zealand environment for establishment of *B. distincta* cannot be definitively ruled out, because the remote island distribution of this species may not be reflective of its fundamental niche but rather of geographic isolation.
- The species is oligophagous and suitable hosts include pomelo, a species grown in New Zealand by home gardeners (Table 9.12.14).

The establishment of *B. distincta* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. distincta* has the potential to cause economic impacts by directly damaging citrus crops (*Citrus* sp., FOB export value: NZ\$12.0 million) (Plant & Food Research 2019).
- The establishment of *B. distincta* has the potential to cause sociocultural impacts as host plants are grown by home gardeners.
- If *B. distincta* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Fiji and Samoa (Leblanc et al. 2012)

Lure: Cuelure (Leblanc et al. 2012)

Table 9.12.14 *Bactrocera distincta* citrus hosts. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the numbers in brackets indicate the numbers of fruit from which adults emerged out of the total number of samples collected for the host plant.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus maxima</i>	Pomelo	Field record (1/79)	Leblanc et al. (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
N/A	N/A	Leblanc et al. (2013)	

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8.12.15 *Bactrocera correcta* (guava fruit fly)

Scientific name: *Bactrocera correcta* (Bezzi, 1916)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Bactrocera) correcta*, *Chaetodacus correctus*, *Dacus correctus*

Hazard identification

Bactrocera correcta meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera correcta is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera correcta* is a regulated pest (ONZPR 2020).

Bactrocera correcta has the potential to establish and spread within New Zealand:

- The distribution of *B. correcta* includes areas with a similar climate to New Zealand – Yunnan (EPPO 2020) and Hebei (GBIF.org 2020) in China (CMI 0.7 for both, Phillips et al. 2018), Himachal Pradesh (EPPO 2020) in India (CMI 0.8, Phillips et al. 2018), Bhutan (0.4–0.7, Phillips et al. 2018; EPPO 2020), Myanmar (0.2–0.7, Phillips et al. 2018; EPPO 2020), Nepal (0.4–0.8, Phillips et al. 2018; EPPO 2020) and Pakistan (0.4–0.8, Phillips et al. 2018; EPPO 2020).
- The species is polyphagous and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.15).

The establishment of *B. correcta* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. correcta* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and peaches (*Prunus persica*, FOB export value:\$0.4 million) (Plant & Food Research 2019).
- The establishment of *B. correcta* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Bactrocera correcta* also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. correcta* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: China, Thailand and Viet Nam (Drew and Raghu 2002; Kamiji et al. 2014; EPPO 2020).

Lure: Methyl eugenol (White and Elson-Harris 1994) and beta-caryophyllene (a species-specific attractant that is more attractive than methyl eugenol) (Plant Health Australia 2018).

Table 9.12.15 *Bactrocera correcta* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the number in brackets indicates the numbers of fruit from which adults emerged (total number of samples not available).

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus maxima</i> *	Pomelo	Field record (1)	Allwood et al. (1999), Yan et al. (2016)
<i>Citrus sinensis</i> *	Orange	Field record	Yan et al. (2016)
<i>Citrus reticulata</i>	Mandarin	Field record (7)	Allwood et al. (1999)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Prunus persica</i>	Peach	White and Elson-Harris (1994)	
<i>Cucumis melo</i>	Muskmelon	Allwood et al. (1999)	

* Records from Yan et al. (2016) are for adults reared from field-collected fruits (numbers not available).

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8.12.16 *Bactrocera latifrons* (Malaysian fruit fly)

Scientific name: *Bactrocera latifrons* (Hendel, 1915)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera* (*Bactrocera*) *latifrons*, *Chaetodacus antennalis*, *Chaetodacus latifrons*, *Dacus latifrons*

Hazard identification

Bactrocera latifrons meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera latifrons is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera latifrons* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera latifrons has the potential to establish and spread within New Zealand:

- The distribution of *B. latifrons* includes areas with a similar climate to all of New Zealand – Gansu, Fujian, Guangdong, Guanhxi and Yunnan (EPPO 2020; GBIF.org 2020) in China (CMI 0.6–0.8, Phillips et al. 2018), Nairobi municipality (GBIF.org 2020) in Kenya (CMI 0.7, Phillips et al. 2018), Arusha and Kilimanjaro regions (GBIF.org 2020) in Tanzania (CMI 0.7 for both, Phillips et al. 2018), Pakistan (Phillips et al. 2018; EPPO 2020) and Himachal Pradesh (GBIF.org 2020) in India (CMI 0.8, Phillips et al. 2018).
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.16).

The establishment of *B. latifrons* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. latifrons* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019).
- The establishment of *B. latifrons* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Bactrocera latifrons* also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. latifrons* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: China, Japan, Viet Nam, USA (Hawaii) (EPPO 2020).

Lure: Not attracted to cuelure or methyl eugenol (White and Elson-Harris 1994). Alpha-ionol and cade oil is the best attractant for this species, though it is not as attractive as cuelure or methyl eugenol is to other species. It is, however, more attractive than a protein bait (McQuate et al. 2018).

Table 9.12.16 *Bactrocera latifrons* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the number in brackets indicates the numbers of fruit from which adults emerged (total number of samples not available).

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Lime	Field record (1)	Allwood et al. (1999)
<i>Citrus reticulata</i>	Mandarin	Laboratory host	McQuate et al. (2015)
<i>Citrus limon</i> *	Lemon	Listing only	McQuate and Liquido (2013)
<i>Citrus sinensis</i> *	Sweet orange	Listing only	McQuate and Liquido (2013)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Capsicum annuum</i>	Capsicum	Allwood et al. (1999), Liquido et al. (1994)	
<i>Solanum lycopersicum</i>	Tomato	Allwood et al. (1999), Liquido et al. (1994)	
<i>Cucumis sativus</i>	Cucumber	Allwood et al. (1999), Liquido et al. (1994)	

* Records for *C. limon* and *C. sinensis* described as “doubtful” in McQuate and Liquido (2013).

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8.12.17 *Bactrocera carambolae* (carambola fruit fly)

Scientific name: *Bactrocera carambolae* (Drew and Hancock, 1994)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera (Bactrocera) carambolae*, *Bactrocera* species A.

Taxonomic notes: *Bactrocera carambolae* belongs to the *B. dorsalis* species complex (Drew and Hancock 1994)

Hazard identification

Bactrocera carambolae meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Bactrocera carambolae is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Bactrocera carambolae* is a regulated pest and a notifiable organism (ONZPR 2020).

Bactrocera carambolae has low potential to establish and spread within New Zealand; however, a transient summer population is possible, particularly in the north of New Zealand:

- The distribution of *B. carambolae* is in southeast Asia, South America and Timor-Leste in areas of low climate similarity with New Zealand (see Table 9.12.24).
- *Bactrocera carambolae* is, therefore, unlikely to establish in New Zealand in the longer term; however, transient summer populations in the north of New Zealand are possible. Even a temporary incursion is likely to be associated with trade barriers and eradication costs.
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.17).

The establishment of *B. carambolae* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *B. carambolae* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), avocados (*Persea americana*, FOB export value: \$104.3 million) and capsicum (*Capsicum annuum*, FOB export value: \$20.6 million) (Plant & Food Research 2019).
- The establishment of *B. carambolae* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Bactrocera carambolae* also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *B. carambolae* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Viet Nam and Brazil (EPPO 2020).

Lure: Methyl eugenol (Plant Health Australia 2018).

Table 9.12.17 *Bactrocera carambolae* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts. For field records, the number in brackets indicates the numbers of fruit from which adults emerged either out of the total number of samples collected for the host plant, or (for single numbers) only the number of fruit from which adults emerged (total number of samples not available).

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Lime	Field record (1)	Allwood et al. (1999)
<i>Citrus reticulata</i>	Mandarin	Field record (15/140)	van Sauers-Muller (2005)
		Field record (1)	Allwood et al. (1999)
<i>Citrus limon</i>	Lemon	Field record (2)	Allwood et al. (1999)
<i>Citrus sinensis</i>	Sweet orange	Field record (8/640)	van Sauers-Muller (2005)
<i>Citrus paradisi</i>	Grapefruit	Field record (4/122.5)	van Sauers-Muller (2005)
<i>Citrus reticulata</i>	Calamansi	Listing only	Allwood et al. (1999)
<i>Citrus aurantium</i>	Bitter orange	Listing only	Allwood et al. (1999)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Capsicum annuum</i>	Capsicum	Allwood et al. (1999)	
<i>Solanum lycopersicum</i>	Tomato	Allwood et al. (1999)	
<i>Persea americana</i>	Avocado	Allwood et al. (1999)	

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8.12.18 *Zeugodacus tau* (no common name)

Scientific name: *Zeugodacus tau* (Walker, 1849)

Order/Family: Diptera/Tephritidae

Other names include: *Bactrocera tau*, *Chaetodacus tau*, *Dacus caudatus* var. *nubilus*, *Dacus hageni*, *Dacus nubilus*, *Dacus tau*, *Dasyneura tau*, *Zeugodacus nubilus*

Hazard identification

Zeugodacus tau meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Zeugodacus tau is not known to be present in New Zealand:

- The species is not recorded in NZOR (2011) or PPIN (2020).
- *Zeugodacus tau* is a regulated pest (ONZPR 2020).

Zeugodacus tau has the potential to establish and spread within New Zealand:

- The distribution of *Z. tau* includes areas with a similar climate to all of New Zealand – Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hubei, Shaanxi, Sichuan, Yunnan and Zhejiang (CABI 2020) in China (CMI 0.4–0.8, Phillips et al. 2018), Taiwan (CMI 0.4–0.8, Phillips et al. 2018; CABI 2020) and Bhutan (CMI 0.4–0.7, Phillips et al. 2018; CABI 2020).
- The species is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.18).

The establishment of *Z. tau* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *Z. tau* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and squash (*Cucurbita* sp., FOB export value: \$59.7 million) (Plant & Food Research 2019).
- The establishment of *Z. tau* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- *Zeugodacus tau* also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *Z. tau* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: China, Viet Nam (CABI 2020)

Lure: Cuelure (White and Elson-Harris 1994)

Table 9.12.18 *Zeugodacus tau* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus reticulata</i> *	Mandarin	Laboratory host	Wu et al. (2011); Lin et al. (2005)
<i>Citrus maxima</i> #	Pomelo	Listing	White and Elson-Harris (1994)
<i>Citrus sinensis</i> [^]	Sweet orange	Laboratory host	Lin et al. (2005)
<i>Citrus paradisi</i> [^]	Grapefruit	Laboratory host	Lin et al. (2005)
<i>Citrus reticulata</i> × <i>Citrus paradisi</i> [^]	Tangelo	Laboratory host	Lin et al. (2005)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Citrullus lanatus</i>	Watermelon	Liquido et al. (2016)	
<i>Cucumis melo</i>	Muskmelon	Liquido et al. (2016)	
<i>Cucumis sativus</i>	Cucumber	Liquido et al. (2016)	
<i>Cucurbita maxima</i>	Pumpkin	Liquido et al. (2016)	
<i>Cucurbita moschata</i>	Butternut pumpkin	Liquido et al. (2016)	
<i>Cucurbita pepo</i>	Squash	Liquido et al. (2016)	
<i>Pyrus communis</i>	Pear	Liquido et al. (2016)	
<i>Solanum lycopersicum</i>	Tomato	Liquido et al. (2016)	
* Choice experiments, <i>C. reticulata</i> least preferred host compared to four non-citrus hosts.			
# Unconfirmed record from 1968 for <i>Dacus hageni</i> , which was “probably <i>B. tau</i> rather than <i>B. caudata</i> ”.			
[^] Methodology not described in paper but likely to be no-choice tests.			

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8.12.19 *Anastrepha obliqua* (West Indian fruit fly)

Scientific name: *Anastrepha obliqua* (Macquart, 1835)

Order/Family: Diptera/Tephritidae

Other names include: *Tephritis obliqua*, *Acrotoxa obliqua*, *Anastrepha fraterculus* var. *mombinpraeoptans*, *Anastrepha fraterculus* var. *ligata*, *Anastrepha trinidadensis*, *Trypeta obliqua*, Antillean fruit fly

Hazard identification

Anastrepha obliqua meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Anastrepha obliqua is not known to be present in New Zealand:

- *Anastrepha obliqua* is not recorded in NZOR (2011) or PPIN (2020).
- *Anastrepha obliqua* is a regulated pest and a notifiable organism (ONZPR 2020).
- New Zealand has country freedom status for *A. obliqua* (MPI 2020).

Anastrepha obliqua has potential to establish and spread within New Zealand:

- *A. obliqua* has a tropical and subtropical distribution having been recorded from Florida and Texas, USA (now absent, eradicated (EPPO 2020), Southern and Central America and the West Indian islands. Some of the areas where *A. obliqua* is present (Zucchi and Moraes 2008; EPPO 2020) have high climate similarity with New Zealand (CMI 0.7–0.9 Phillips et al. 2018):
 - Brazil: Santa Catarina (CMI 0.7–0.9), Rio Grande do Sul (CMI 0.7–0.9), Paraná (CMI mostly 0.7–0.8), São Paulo (parts have CMI 0.7–0.8); Peru: Piura State (parts have CMI 0.7).
- *Anastrepha obliqua* is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.19).

The establishment of *Anastrepha obliqua* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *A. obliqua* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and peach (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019).
- The establishment of *A. obliqua* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *A. obliqua* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Brazil, Mexico, Peru, (absent, eradicated in the USA) (EPPO 2020)

Lure: No male lures have yet been identified, but *A. obliqua* can be captured in traps emitting ammonia (Plant Health Australia 2018; CABI 2020).

Table 9.12.19 *Anastrepha obliqua* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus limon</i>	Sweet lime	Listing only	White and Elson-Harris (1994)
<i>Citrus aurantium</i>	Sour orange	Listing only	White and Elson-Harris (1994)
<i>Citrus paradisi</i>	Grapefruit	Listing only	White and Elson-Harris (1994)
<i>Citrus sinensis</i>	Sweet orange	Listing only	White and Elson-Harris (1994)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Psidium guajava</i>	Guava	Zucchi and Moraes (2008)	
<i>Prunus persica</i>	Peach	Zucchi and Moraes (2008)	
<i>Pyrus communis</i>	Pear	White and Elson-Harris (1994), CABI (2020)	
<i>Mangifera indica</i>	Mango	CABI (2020), Zucchi and Moraes (2008)	
<i>Syzygium jambos</i>	Rose apple	White and Elson-Harris (1994), CABI (2020)	

References

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8.12.20 *Anastrepha serpentina* (sapodilla fruit fly)

Scientific name: *Anastrepha serpentina* (Wiedemann, 1830)

Order/Family: Diptera/Tephritidae

Other names include: *Urophora vittithorax*, *Acrotoxa serpentina*, *Dacus serpentinus*, *Leptoxys serpentina*, *Trypeta serpentina*, sapote fruit fly, serpentine fruit fly

Hazard identification

Anastrepha serpentina meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Anastrepha serpentina is not known to be present in New Zealand:

- *Anastrepha serpentina* is not recorded in NZOR (2011) or PPIN (2020).
- *Anastrepha serpentina* is a regulated pest and a notifiable organism (ONZPR 2020).
- New Zealand has country freedom status for *A. serpentina* (MPI 2020).

Anastrepha serpentina has potential to establish and spread within New Zealand:

- *Anastrepha serpentina* occurs in the Americas. Some of the areas where *A. serpentina* is present (Zucchi and Moraes 2008; EPPO 2020) have high climate similarity with New Zealand (CMI 0.7–0.9, Phillips et al. 2018):
 - Brazil: Santa Catarina (CMI 0.7–0.9), Paraná (CMI mostly 0.7–0.8), São Paulo (parts have CMI 0.7–0.8); Mexico: Coahuila (parts have CMI 0.7), Oaxaca (CMI 0.7), Puebla (CMI 0.7–0.8), San Luis Potosí (CMI 0.7).
- *Anastrepha serpentina* is polyphagous, and suitable hosts include species grown in New Zealand both commercially and by home gardeners (Table 9.12.20).

The establishment of *Anastrepha serpentina* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *A. serpentina* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), apple (*Malus domestica*, FOB export value \$828.8 million), avocado (*Persea americana*, FOB export value: \$104.3 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and peach (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019).
- The establishment of *A. serpentina* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *A. serpentina* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Brazil, Mexico, Peru (EPPO 2020). Confirmed eradicated from the USA in 2003 (NAPPO 2003, in CABI 2020), but sporadically captured in the Rio Grande Valley of Texas and California (CABI 2020; EPPO 2020).

Lure: No male lures have yet been identified, but *A. serpentina* can be captured using ammonia traps (Plant Health Australia 2018; CABI 2020).

Table 9.12.20 *Anastrepha serpentina* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantium</i>	Sour orange	Listing only	CABI (2020), White and Elson-Harris (1994)
<i>Citrus maxima</i>	Pummelo	Listing only	CABI (2020), White and Elson-Harris (1994)
<i>Citrus reticulata</i>	Mandarin	Listing only	CABI (2020), White and Elson-Harris (1994), Zucchi and Moraes (2008)
<i>Citrus sinensis</i>	Sweet orange	Listing only	CABI (2020), White and Elson-Harris (1994), Zucchi and Moraes (2008)
<i>Citrus paradisi</i>	Grapefruit	Listing only	CABI (2020), White and Elson-Harris (1994)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Cydonia oblonga</i>	Quince	CABI (2020), White and Elson-Harris (1994)	
<i>Malus domestica</i>	Apple	CABI 2020, EPPO (2020), White and Elson-Harris (1994)	
<i>Mangifera indica</i>	Mango	CABI (2020), EPPO (2020), White and Elson-Harris (1994)	
<i>Persea americana</i>	Avocado	CABI (2020), EPPO (2020), White and Elson-Harris (1994)	
<i>Prunus persica</i>	Peach	CABI (2020), White and Elson-Harris (1994)	
<i>Psidium guajava</i>	Guava	CABI (2020), White and Elson-Harris (1994)	
<i>Pyrus communis</i>	Pear	White and Elson-Harris (1994)	

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8.12.21 *Anastrepha sororcula* (no common name)

Scientific name: *Anastrepha sororcula* Zucchi, 1979

Order/Family: Diptera/Tephritidae

Other names include: None

Taxonomic notes: *Anastrepha sororcula* is a member of the *Anastrepha fraterculus* complex (White and Elson-Harris 1994).

Hazard identification

Anastrepha sororcula meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Anastrepha sororcula is not known to be present in New Zealand:

- *Anastrepha sororcula* is not recorded in NZOR (2011) or PPIN (2020); and
- The regulatory status of *Anastrepha sororcula* is unassessed (not listed in ONZPR 2020).

Anastrepha sororcula has potential to establish and spread within New Zealand:

- *Anastrepha sororcula* occurs in South America, recorded from Colombia, Paraguay and Brazil. Some of the areas where *A. sororcula* is present (Zucchi and Moraes 2008; CABI 2019) have a high climate similarity with New Zealand (Phillips et al. 2018):
 - Brazil: Santa Catarina (CMI 0.7–0.9), Paraná (CMI mostly 0.7–0.8), São Paulo (parts have CMI 0.7–0.8).
- *Anastrepha sororcula* hosts include species grown in New Zealand both commercially and by home gardeners (Table 9.12.21).

The establishment of *Anastrepha sororcula* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *A. sororcula* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million) and peach (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019).
- The establishment of *A. sororcula* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts as host plants are grown by home gardeners.
- If *A. sororcula* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Brazil (White and Elson-Harris 1994; Zucchi and Moraes 2008; CABI 2019; EPPO 2020).

Lure: No male lures have yet been identified for *Anastrepha* spp., but they can be captured using ammonia traps (CABI 2020).

Table 9.12.21 *Anastrepha sororcula* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus sinensis</i>	Sweet orange	Field record (2 females from 61 fruits)	Souza et al. (2008)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Prunus persica</i>	Peach	Zucchi and Moraes (2008)	
<i>Psidium guajava</i>	Guava	Zucchi and Moraes (2008)	

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8.12.22 *Anastrepha striata* (guava fruit fly)

Scientific name: *Anastrepha striata* Schiner, 1968

Order/Family: Diptera/Tephritidae

Other names include: *Dictya cancellaria*, *Trypeta cancellaria*

Hazard identification

Anastrepha striata meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Anastrepha striata is not known to be present in New Zealand:

- *Anastrepha striata* is not recorded in NZOR (2011) or PPIN (2020).
- *Anastrepha striata* is a regulated pest and a notifiable organism (ONZPR 2020).

Anastrepha striata has potential to establish and spread within New Zealand:

- *Anastrepha striata* is present in the Americas (White and Elson-Harris 1994; Plant Health Australia 2011). Some of the areas where *A. striata* is present (Zucchi and Moraes 2008; CABI 2020; EPPO 2020) have high climate similarity with New Zealand (Phillips et al. 2018):
 - Brazil: São Paulo (CMI 0.6–0.8); Mexico: Aguascalientes (CMI 0.7).
- Its presence in southern Brazil has been detected only recently, suggesting that human activities may have aided its spread. It has also been intercepted and trapped in the USA (Florida, California), indicating its potential for spread via infested fruits (Phillips et al. 2018).
- *Anastrepha striata* is polyphagous, recorded on hosts from a range of families, with a preference for Myrtaceae, and primarily a pest of guava, *Psidium guajava* (White and Elson-Harris 1994; Plant Health Australia 2011; Phillips et al. 2018). Suitable hosts include species grown in New Zealand both commercially and by home gardeners (Table 9.12.22).

The establishment of *Anastrepha striata* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *A. striata* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus (*Citrus* sp., FOB export value: NZ\$12.0 million), avocado (*Persea americana*, FOB export value: \$104.3 million) and peach (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019).
- The establishment of *A. striata* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *A. striata* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: Brazil, Mexico, Peru (EPPO 2020). Absent from the USA (CABI 2020), but sporadically captured in the Rio Grande Valley of Texas and California (CABI 2020; EPPO 2020).

Lure: No male lures have yet been identified, but the flies can be captured using ammonia traps (Plant Health Australia 2011; CABI 2020).

Table 9.12.22 *Anastrepha striata* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus sinensis</i>	Sweet orange	Listing only	CABI (2020), White and Elson-Harris (1994), Zucchi and Moraes (2008)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Psidium guajava</i>	Guava	CABI (2020), White and Elson-Harris (1994), Zucchi and Moraes (2008)	
<i>Mangifera indica</i>	Mango	CABI (2020), White and Elson-Harris (1994)	
<i>Passiflora edulis</i>	Passionfruit	CABI (2020), Zucchi and Moraes (2008)	
<i>Persea americana</i>	Avocado	CABI (2020), White and Elson-Harris (1994)	
<i>Prunus persica</i>	Peach	CABI (2020), White and Elson-Harris (1994)	
<i>Syzygium jambos</i>	Rose apple	CABI (2020), White and Elson-Harris (1994)	
<i>Manihot esculenta</i>	Cassava	CABI (2020), White and Elson-Harris (1994)	

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8.12.23 *Anastrepha suspensa* (Caribbean fruit fly)

Scientific name: *Anastrepha suspensa* (Loew, 1862)

Order/Family: Diptera/Tephritidae

Other names include: *Acrotoxa suspensa*, *Anastrepha longimacula*, *Anastrepha unipuncta*, *Trypeta suspensa*, greater Antillean fruit fly

Hazard identification

Anastrepha suspensa meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Anastrepha suspensa is not known to be present in New Zealand:

- *Anastrepha suspensa* is not recorded in NZOR (2011) or PPIN (2020).
- *Anastrepha suspensa* is a regulated pest and a notifiable organism (ONZPR 2020).
- New Zealand has country freedom status for *A. suspensa* (MPI 2020).

Anastrepha suspensa has potential to establish and spread within New Zealand:

- *A. suspensa* has a tropical and subtropical distribution having been recorded largely from the Caribbean (including Bahamas, British Virgin Islands, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico) and Florida in the USA (CABI 2020; EPPO 2020).
- *A. suspensa* is indigenous to the West Indies (Weems et al. 2012) and is considered invasive in Florida, USA (CABI 2020; EPPO 2020). According to Sutton and Steck (2005), *A. suspensa* was first detected in South Florida in the 1930s and apparently eradicated. It recolonised Dade county in 1965 and has since spread widely in Central and South Florida. It is occasionally found in northeastern Atlantic coastal counties in Florida (Sutton and Steck 2005). Weems et al. (2012) note isolated records north to Jacksonville (Florida).
- Some of the areas where *A. suspensa* is present have high climate similarity with New Zealand (Phillips et al. 2018):
 - North Florida, including Jacksonville, has a CMI of 0.7.
- *Anastrepha suspensa* is polyphagous, and suitable hosts include species grown throughout New Zealand both commercially and by home gardeners (Table 9.12.23).

The establishment of *Anastrepha suspensa* in New Zealand has the potential to cause unwanted impacts:

- The establishment of *A. suspensa* has the potential to cause economic impacts by directly damaging horticultural crops that are significant to New Zealand, including citrus, apple (*Malus domestica*, FOB export value NZ\$828.8 million), pear (*Pyrus communis*, FOB export value: \$10.6 million) and peach (*Prunus persica*, FOB export value: \$0.4 million) (Plant & Food Research 2019).
- The establishment of *A. suspensa* also has the potential to cause significant control costs and to impact negatively on national and international trade.
- It also has the potential to cause sociocultural impacts, as host plants are commonly grown by home gardeners.
- If *A. suspensa* was detected in New Zealand, the cost incurred by a response is likely to be high (see the Impacts section below).

Distribution in countries considered in this IRA: USA (Florida) (EPPO 2020)

Lure: No male lures have yet been identified but can be captured in traps emitting ammonia (Plant Health Australia 2011; CABI 2020).

Table 9.12.23: *Anastrepha suspensa* citrus hosts and other hosts grown in New Zealand. The type of record for the citrus hosts is given to indicate the strength of association with citrus hosts.

Citrus spp. hosts			
Host name	Common name	Type of record	Reference
<i>Citrus aurantiifolia</i>	Lime	Listing only	White and Elson-Harris (1994)
<i>Citrus aurantium</i>	Sour orange	Listing only	Weems et al. (2012), White and Elson-Harris (1994)
<i>Citrus maxima</i>	Pummelo	Listing only	Weems et al. (2012), White and Elson-Harris (1994)
<i>Citrus limon</i>	Sweet lime	Listing only	White and Elson-Harris (1994)
<i>Citrus limon</i>	Lemondarin	Listing only	White and Elson-Harris (1994)
<i>Citrus paradisi</i>	Grapefruit	Listing only	Weems et al. (2012), White and Elson-Harris (1994)
<i>Citrus reticulata</i>	–	Listing only	Weems et al. (2012), White and Elson-Harris (1994)
<i>Citrus reticulata</i>	Tangerine		White and Elson-Harris (1994)
<i>Citrus sinensis</i>	Sweet orange	Listing only	Weems et al. (2012), White and Elson-Harris (1994)
<i>Citrus reticulata</i> × <i>Citrus paradisi</i>	Tangelo	Listing only	White and Elson-Harris (1994)
Other hosts grown in New Zealand			
Host name	Common name	Reference	
<i>Psidium guajava</i>	Guava	Weems et al. (2012)	
<i>Prunus persica</i>	Peach	Weems et al. (2012), White and Elson-Harris (1994)	
<i>Pyrus communis</i>	Pear	CABI (2020), White and Elson-Harris (1994)	
<i>Mangifera indica</i>	Mango	Weems et al. (2012)	
<i>Malus domestica</i>	Apple	White and Elson-Harris (1994)	
<i>Capsicum annum</i>	Bell pepper	White and Elson-Harris (1994)	
<i>Diospyros kaki</i>	Japanese persimmon	White and Elson-Harris (1994)	

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8.12.24 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, for the fruit flies in this assessment, the likelihood of entry with citrus fruit ranges from low to moderate–high depending on the species (with high uncertainty).

All of the fruit fly species in this assessment have been recorded from citrus fruit.

- The fruit flies in this assessment have been recorded from between one and nine citrus species (see individual species sections above for details), although some of the associations are host listings only.

Internally feeding fruit pests have a stronger association with fruit than external pests.

- Fruit-feeding fruit flies complete egg and larval development within fruit flesh (White and Elson-Harris 1994).

The strength of association with citrus fruit for each species included in this assessment is given below. The strength of association depends on the number of citrus hosts a fruit fly species has been recorded from, whether those records were only host listings or field records, and the infestation rate (where available). Because of the small number of reliable, field-based host-range studies published for all of the species listed below, the uncertainty is rated as moderate to high in all cases.

- *Bactrocera aquilonis* – Weak to moderate
- *Bactrocera melas* – Weak
- *Bactrocera neohumeralis* – Moderate
- *Bactrocera jarvisi* – Moderate
- *Bactrocera kraussi* – Moderate
- *Bactrocera trivialis* – Weak
- *Bactrocera frauenfeldi* – Moderate to strong
- *Bactrocera melanotus* – Weak to moderate
- *Bactrocera passiflorae* – Moderate to strong
- *Bactrocera* species near *passiflorae* – Weak
- *Bactrocera kirki* – Moderate
- *Bactrocera curvipennis* – Moderate
- *Bactrocera psidii* – Weak
- *Bactrocera distincta* – Weak
- *Bactrocera correcta* – Weak
- *Bactrocera latifrons* – Weak
- *Bactrocera carambolae* – Moderate
- *Zeugodacus tau* – Weak
- *Anastrepha obliqua* – Weak to moderate
- *Anastrepha serpentina* – Weak to moderate
- *Anastrepha sororcula* – Weak
- *Anastrepha striata* – Weak
- *Anastrepha suspensa* – Moderate

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of fruit flies by a moderate degree (with moderate to high uncertainty). Consequently, the likelihood of entry is considered low to moderate (with moderate uncertainty).

Fruit fly infestations may be visually detectable in the field and/or packhouses, leading to the removal of infested produce.

- Puncture holes from oviposition are often visible with the naked eye (White and Elson-Harris 1994). Fruits with multiple oviposition punctures and external signs of feeding damage are likely to be removed during general handling.
- Fruit bagging and packhouse culling have been reported to be effective in reducing levels of infestation in some citrus commodities in China (Xia et al. 2019). Fruit bagging is not widely practiced due to its labour intensity.

However, there is a chance that a small quantity of infested fruit will not be detected.

- Low levels of infestation (fewer oviposition punctures and less external damage) may not be obvious enough to be detected during general handling. Low infestation levels may be more prevalent in less preferred hosts such as citrus, which is the case for most of the fruit fly species considered here.
- The volume of the commodities can also affect efficiency of detection. Low levels of infestation may not be easily detected, especially if the volume of commodities is large.

General handling after harvesting is not likely to remove fruit fly larvae inside citrus fruit.

- General handling after harvesting (e.g. washing and brushing) only treats the surface of fruit. These procedures are therefore highly unlikely to remove fruit fly larvae inside citrus fruit.
- Fruit will need to be cut open to reveal fruit fly larvae inside. Internally feeding insects are likely to be particularly problematic to detect by nondestructive inspection. Even using fruit dissection, Gould (1995) found that detection rates for Caribbean fruit fly (*Anastrepha suspensa*) could be as low as 17.9%. In this study, inspectors detected between 17.9% and 83.5% of fruit infested with Caribbean fruit fly; variables influencing detection rate were the fruit type, its ripeness and the inspector (Gould 1995).

Larvae of fruit flies may survive transit in citrus commodities.

- Between 1987 and 2019, live tephritid larvae, pupae or adults, or viable tephritid eggs, were intercepted over 1,000 times at the New Zealand border (LIMS 2019).

The level of uncertainty associated with both the degree by which basic measures reduce the likelihood of entry (moderate) and the consequent likelihood of entry (low to moderate) is moderate. Firstly, species-specific information about the detectability of low levels of infestation of citrus fruits with the fruit flies included in this grouped PRA is not available. Secondly, there is uncertainty around whether standard transit times and storage temperatures of citrus commodities will be enough to prevent survival of eggs and larvae of the fruit flies included in this grouped PRA.

Likelihood of establishment:

Given the arguments and evidence below, the ability of fruit flies to transfer from imported fruit into a suitable environment to allow establishment (exposure) is considered to be moderate to high (with moderate uncertainty).

Fruit flies can survive and develop on the waste of citrus fruit (whole fruit or fruit pieces but probably not skin).

- Fruit-feeding fruit flies complete egg and larval development within fruit flesh, and most drop to the ground to pupate in the soil (White and Elson-Harris 1994). If citrus fruit is disposed of as whole fruit or fruit pieces, it is likely that fruit fly eggs or larvae will survive and reach adulthood in this waste.

Most fruit waste in New Zealand is likely to be disposed of using low-risk methods, so any fruit flies present would either be killed or be unable to escape from the citrus host.

- Most of the waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, fruit flies are unlikely to reach a new host (see the waste analysis in section 2.4.1).

However, some fruit waste is disposed of using high-risk methods, including composting in gardens, using it as animal feed and discarding it directly into the environment.

- Adults fruit flies emerging from the soil are likely to be able to find food in the environment if citrus fruit waste is disposed of using high-risk methods. The typical tephritid adult diet includes plant exudates, honeydew, decaying insects and bird droppings (Christenson and Foote 1960). These food sources are common in farms, parks and home gardens, and adult fruit flies can fly to locate them.
- Because the fruit flies in this grouped PRA are polyphagous or (in the case of *B. distincta*) oligophagous, hosts for oviposition and larval development are available in most areas of New Zealand, either in commercial plantations or in home gardens.
- If citrus hosts are located near composting sites or animal feeding sites, adult fruit flies are likely to locate them (see the waste analysis in section 2.4.1).

The level of uncertainty associated with the ability of fruit flies to move from imported fruit to a suitable host (moderate to high) is moderate. Firstly, waste data may not be very accurate or up to date, and it is not known how frequently suitable hosts are present near composting sites or animal feeding locations (see waste analysis in section 2.4.1). Secondly, it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin). Thirdly, the effect of seasonality on this likelihood is uncertain.

Given the arguments and evidence below, the suitability of the New Zealand environment for all fruit flies considered in this assessment to establish is considered to be low (with high uncertainty), with the exception of *Bactrocera melas*, *B. correcta*, *B. latifrons*, *Anastrepha obliqua*, *A. serpentina*, *A. sororcula*, *A. striata* and *A. suspensa* where the suitability is moderate to high (with low uncertainty), and *B. frauenfeldi* where the suitability is low (with low uncertainty).

- Of the fruit flies in this assessment, *B. melas*, *B. correcta*, *B. latifrons*, *Anastrepha obliqua*, *A. serpentina*, *A. sororcula* and *A. striata* are found in locations with a climate similar to the whole of New Zealand (CMI greater than 0.7, Phillips et al. 2018) (Table 9.12.24).
 - The range of *B. melas* is in eastern Queensland, particularly in the southeast of the state (CMI 0.4–0.8).
 - *Bactrocera correcta* is found in Bhutan, Myanmar, Nepal, Pakistan, Sri Lanka, Thailand, and Viet Nam and several regions in India and China (CMI 0.2–0.8) (Drew and Raghu 2002; Kamiji et al. 2014; EPPO 2020; GBIF.org 2020).
 - *Bactrocera latifrons* has a broad distribution across southeastern Asia, as well as in Kenya, Tanzania and Hawaii (CMI 0.3–0.8)(EPPO 2020; GBIF.org 2020b).
 - *Anastrepha obliqua*, *A. serpentina* and *A. striata* have a broad distribution in South and Central America, whereas *A. sororcula* has a more restricted distribution in South America (Zucchi and Moraes 2008; CABI 2019, 2020b, 2020a; EPPO 2020). The distributions of these four species include areas with a similar climate to all of New Zealand (CMI greater than 0.7, Phillips et al. 2018).
 - *A. suspensa* is found in the West Indies and Florida, USA, and is recorded from the North of Florida, USA (CMI 0.5–0.7), as well as the Dominican Republic (CMI 0.5–0.7) (EPPO 2020).

- *B. aquilonis* and *B. kraussi* are restricted to the tropics of northern Australia (Sultana et al. 2020) – areas of low climate similarity with the whole of New Zealand (CMI 0.4–0.6, Table 9.12.24).
- *Bactrocera trivialis* is native to Papua New Guinea and West Papua, but it makes seasonal incursions into the Torres Strait Islands (Plant Health Australia 2018). All of these areas have a dissimilar climate to the whole of New Zealand (CMI 0.3–0.6, Table 9.12.24).
- The current distribution of *B. frauenfeldi* includes the Torres Strait Islands and northern Queensland, Australia (CMI 0.4–0.6), Papua New Guinea and West Papua (CMI 0.3–0.6) and Solomon Islands (CMI 0.4–0.5). The distribution also includes several Pacific islands where the CMI is unavailable; however, the average climate of these islands is likely to be dissimilar to that of New Zealand (Leblanc et al. 2012; Sultana et al. 2020) (Table 9.12.24).
- *Bactrocera passiflorae*, *B. sp. nr. passiflorae* and *B. distincta* are all found in Fiji (CMI 0.4) and several Pacific Islands where the CMI is unavailable but where the average climate is likely to be dissimilar to that of New Zealand (Leblanc et al. 2012) (Table 9.12.24).
- The distribution of *B. melanotus* is restricted to the Cook Islands, that of *B. curvipennis* and *B. psidii* to New Caledonia, whereas *B. kirki* is found in several Pacific Islands – all locations where the CMI is unavailable but where the average climate is likely to be dissimilar to that of New Zealand (Leblanc et al. 2012) (Table 9.12.24).
- *Bactrocera carambolae* is distributed in the north of South America, southeast Asia and East-Timor in areas of low climate similarity with the whole of New Zealand (CMI 0.3–0.5, Table 9.12.24)
- *Bactrocera melanotus*, *B. passiflorae*, *B. sp. nr. passiflorae*, *B. kirki*, *B. curvipennis* and *B. psidii* are distributed exclusively in the Pacific Islands. The suitability of the New Zealand environment for establishment of these species cannot be definitively ruled out, because remote island distributions may not be reflective of the fundamental niche of a species but rather of geographic isolation. Additionally, although the average temperature found on Pacific Islands shows no overlap with New Zealand, there can be considerable temperature overlap with equatorial mid-altitude regions, and some months have temperatures similar to New Zealand summers (Halloy 2020).
- *Bactrocera aquilonis*, *B. kraussi*, *B. trivialis*, *B. frauenfeldi* and *B. carambolae* are unlikely to establish in New Zealand in the longer term; however, the transient summer populations in the north of New Zealand are possible.

The level of uncertainty associated with the low suitability of the New Zealand environment for *Bactrocera aquilonis*, *B. kraussi*, *B. trivialis*, *B. melanotus*, *B. passiflorae*, *B. sp. nr. passiflorae*, *B. kirki*, *B. curvipennis*, *B. psidii*, *B. distincta* and *B. carambolae* is moderate, because a detailed assessment of the biology of these species and climate modelling were not carried out.

The level of uncertainty associated with the low suitability of the New Zealand environment for *B. neohumeralis* is moderate to high because the conclusions of different climate models (CLIMEX and MAXENT) are conflicting.

Table 9.12.24 Distribution and climate match index (CMI) (match to the whole of New Zealand) (Phillips et al. 2018) of the fruit flies included in this grouped PRA.

Species	Location	CMI	Reference for distribution
<i>Bactrocera aquilonis</i>	Australia – Top end of NT, northern areas of Western Australia	0.4–0.5	Sultana et al. (2020)
<i>Bactrocera melas</i>	Australia – Eastern Queensland, particularly the southeast	0.4–0.8	Hancock et al. (2000)
<i>Bactrocera neohumeralis</i>	Australia – Torres Strait Islands, eastern Queensland, northern New South Wales	0.4–0.9 ¹	Sultana et al. (2020)
	Papua New Guinea	0.3–0.6	Sultana et al. (2020)
<i>Bactrocera jarvisi</i>	Australia – NW Australia, Northern Territory, NW Queensland, eastern Australia from Cape York to its southern boundary near the Queensland-New South Wales border	0.4–0.8 ¹	Sultana et al. (2020), Dominiak and Worsley (2017)
<i>Bactrocera kraussi</i>	Australia – Torres Strait Islands, northeast Queensland as far south as Townsville	0.4–0.6	Sultana et al. (2020)
<i>Bactrocera trivialis</i>	Australia – Seasonal incursions into Torres Strait Islands	0.4	Plant Health Australia (2018)
	Indonesia – West Papua	0.3–0.6	
	Papua New Guinea	0.3–0.6	
<i>Bactrocera frauenfeldi</i>	Indonesia – West Papua	0.3–0.6	Sultana et al. (2020) and Leblanc et al. (2012)
	Australia – Torres Strait Islands and northern Queensland as far south as Townsville	0.4–0.6	
	Federated States of Micronesia	N/A	
	Kiribati	N/A	
	Marshall Islands	N/A	
	Nauru	N/A	
	Northern Mariana Islands	N/A	
	Palau	N/A	
	Papua New Guinea	0.3–0.6	
Solomon Islands	0.4–0.5		
<i>Bactrocera melanotus</i>	Cook Islands	N/A	Leblanc et al. (2012)
<i>Bactrocera passiflorae</i>	Fiji	0.4	Leblanc et al. (2012)
	Niue	N/A	
	Wallis and Futuna	N/A	
<i>Bactrocera sp. near passiflorae</i>	Fiji	0.4	Leblanc et al. (2012)
	Tokelau	N/A	
	Tonga	N/A	
	Tuvalu	N/A	
<i>Bactrocera kirki</i>	American Samoa	N/A	Leblanc et al. (2012)
	Fiji (Rotuma)	N/A	
	French Polynesia	N/A	
	Niue	N/A	
	Samoa	N/A	
	Tonga	N/A	
Wallis and Futuna	N/A		
<i>Bactrocera curvipennis</i>	New Caledonia	N/A	Leblanc et al. (2012)
<i>Bactrocera psidii</i>	New Caledonia	N/A	Leblanc et al. (2012)
<i>Bactrocera distincta</i>	Fiji	0.4	Leblanc et al. (2012), White and Elson Harris (1994) and Drew and Romig (1996)
	Niue	N/A	
	Tonga	N/A	
	Wallis and Futuna (Futuna)	N/A	
	Samoa	N/A	
	American Samoa	N/A	
<i>Bactrocera correcta</i>	Bhutan	0.4–0.7	Drew and Raghu (2002), Kamiji et al.
	China (Hebei, Yunnan)	0.7	

Species	Location	CMI	Reference for distribution
	India (Andhra Pradesh, Bihar, Goa, Gujarat, Haryana, Himachal Pradesh, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Mizoram, Punjab, Tamil Nadu, Uttar Pradesh, West Bengal)	0.3–0.8	(2014), EPPO (2020) and GBIF.org (2020a)
	Myanmar	0.2–0.7	
	Nepal	0.4–0.8	
	Pakistan	0.4–0.8	
	Sri Lanka	0.4–0.5	
	Thailand	0.3–0.5	
	Viet Nam	0.4–0.6	
<i>Bactrocera latifrons</i>	Kenya (Nairobi)	0.5–0.8	EPPO (2020) and GBIF.org (2020b)
	Tanzania (Arusha, Kilimanjaro)	0.6–0.7	
	United States (Hawaii)	0.5–0.8	
	Bangladesh	0.4–0.4	
	Brunei Darussalam	0.5	
	China (Gansu, Fujian, Guangdong, Guangxi, Hainan, Xianggang (Hong Kong), Yunnan)	0.4–0.8	
	East Timor	0.4–0.5	
	India (Himachal Pradesh, Karnataka, Kerala, Mizoram, Tamil Nadu, West Bengal)	0.3–0.8	
	Indonesia (Kalimantan, Sulawesi)	0.4–0.6	
	Japan (Ryukyu archipelago)	N/A	
	Laos	0.3–0.6	
	Malaysia (Sabah, West)	0.5	
	Myanmar	0.2–0.6	
	Pakistan	0.4–0.8	
	Singapore	0.5	
	Sri Lanka	0.4–0.5	
	Taiwan	0.4–0.8	
Thailand	0.3–0.5		
Viet Nam	0.6–0.4		
<i>Bactrocera carambolae</i>	Brazil (Amapá, Pará, Roraima)	0.4	EPPO (2020) and GBIF.org (2020c)
	French Guiana	0.4	
	Guyana	0.4–0.5	
	Suriname	0.4–0.5	
	Bangladesh	0.3–0.4	
	Brunei Darussalam	0.5	
	Cambodia	0.3–0.4	
	East Timor	0.4–0.5	
	India (West Bengal, Andaman and Nicobar Islands)	0.3–0.4	
	Indonesia (Java, Nusa Tenggara)	0.3–0.5	
	Malaysia (Sabah, Sarawak, West)	0.5	
	Myanmar	0.2–0.6	
	Singapore	0.5	
	Thailand	0.3–0.5	
Viet Nam	0.5		
<i>Zeugodacus tau</i>	Bangladesh	0.3–0.4	CABI (2020d)
	Bhutan	0.4–0.7	
	Brunei	0.5	
	Cambodia	0.3–0.4	
	China (Chongqing, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Hubei, Shaanxi, Sichuan, Yunnan, Zhejiang, Hong Kong)	0.4–0.8	
	India (Himachal Pradesh, Kerala, Uttar Pradesh, West Bengal)	0.3–0.8	
	Indonesia (Sumatra)	0.4	

Species	Location	CMI	Reference for distribution
	Laos	0.3–0.6	
	Malaysia (Sabah, Sarawak, West)	0.5	
	Myanmar	0.2–0.6	
	Singapore	0.5	
	Taiwan	0.4–0.8	
	Thailand	0.3–0.5	
	Viet Nam	0.6–0.4	
<i>Anastrepha obliqua</i>	Antigua and Barbuda	N/A	EPPO (2020) and Zucchi and Moraes (2008)
	Bahamas	0.5	
	Barbados	N/A	
	Belize	0.3–0.5	
	Brazil (Acre, Alagoas, Amapá, Amazonas, Bahia, Ceará, Distrito Federal, Espírito Santo, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraíba, Paraná, Pernambuco, Piauí, Rio de Janeiro, Rio Grande do Norte, Rio Grande do Sul, Rondônia, Roraima, Santa Catarina, São Paulo, Tocantins)	0.3–0.9	
	Colombia	0.3–0.8	
	Costa Rica	0.3–0.6	
	Cuba	0.5	
	Dominica	N/A	
	Dominican Republic	0.5–0.7	
	Ecuador	0.4–0.8	
	El Salvador	0.4–0.5	
	French Guiana	0.4	
	Grenada	N/A	
	Guadeloupe	N/A	
	Guatemala	0.3–0.6	
	Guyana	0.4–0.6	
	Haiti	0.5	
	Honduras	0.4–0.6	
	Jamaica	0.5–0.6	
	Martinique	N/A	
	Mexico	0.3–0.8	
	Montserrat	N/A	
	Netherlands Antilles	N/A	
	Nicaragua	0.4–0.6	
	Panama	0.4–0.5	
	Paraguay	0.5–0.6	
	Peru	0.4–0.8	
	Puerto Rico	0.5–0.6	
Saint Lucia	N/A		
St Kitts-Nevis	N/A		
St Vincent and the Grenadines	N/A		
Suriname	0.4–0.5		
Trinidad and Tobago	0.5		
Venezuela	0.3–0.8		
Virgin Islands (British)	N/A		
Virgin Islands (US)	N/A		
<i>Anastrepha serpentina</i>	Brazil (Amapá, Amazonas, Bahia, Espírito Santo, Goiás, Maranhão, Mato Grosso do Sul, Minas Gerais, Pará, Paraíba, Paraná, Pernambuco, Piauí, Rio de Janeiro, Rio Grande do Norte, Rondônia, Roraima, Santa Catarina, São Paulo)	0.3–0.9	EPPO (2020) and Zucchi and Moraes (2008)
	Colombia	0.3–0.8	
	Costa Rica	0.3–0.6	

Species	Location	CMI	Reference for distribution
	Dominica	N/A	
	Ecuador	0.4–0.8	
	French Guiana	0.4	
	Guatemala	0.3–0.6	
	Guyana	0.4–0.6	
	Mexico	0.3–0.8	
	Netherlands Antilles	N/A	
	Panama	0.4–0.5	
	Paraguay	0.5–0.6	
	Peru	0.4–0.8	
	Suriname	0.4–0.5	
	Trinidad and Tobago	0.5	
	United States of America (California, Texas) ⁸⁴	0.5–0.8	
	Venezuela	0.3–0.8	
<i>Anastrepha sororcula</i>	Brazil (Alagoas, Mato Grosso do Sul, Minas Gerais, Roraima, Tocantins, Santa Catarina, Paraná, São Paulo)	0.4–0.9	CABI (2020c) and Zucchi and Moraes (2008)
	Colombia	0.3–0.8	
	Paraguay	0.5–0.6	
<i>Anastrepha striata</i>	Bolivia	0.4–0.8	CABI (2020c) and Zucchi and Moraes (2008)
	Brazil (Acre, Amapá, Amazonas, Goiás, Maranhão, Mato Grosso do Sul, Pará, Piauí, Rondônia, Roraima, Tocantins, São Paulo)	0.3–0.9	
	Colombia	0.3–0.8	
	Costa Rica	0.3–0.6	
	Ecuador	0.4–0.8	
	French Guiana	0.4	
	Guatemala	0.3–0.6	
	Guyana	0.4–0.6	
	Honduras	0.4–0.6	
	Mexico (Sinaloa, Aguascalientes, Veracruz)	0.5–0.7	
	Netherlands Antilles	N/A	
	Nicaragua	0.4–0.6	
	Panama	0.4–0.5	
	Paraguay	0.5–0.6	
	Peru	0.4–0.8	
	Suriname	0.4–0.5	
	Trinidad and Tobago	0.5	
	United States of America ⁸⁴ (California, Texas)	0.5–0.8	
Venezuela	0.3–0.8		
<i>Anastrepha suspensa</i>	Bahamas	0.5	CABI (2020d)
	British Virgin Islands	N/A	
	Cuba	0.5	
	Dominican Republic	0.5–0.7	
	Haiti	0.5	
	Jamaica	0.5–0.6	
	Puerto Rico	0.5–0.6	
	USA (Florida)	0.5–0.7	

¹ These species have been reported in regions with high CMIs with all of New Zealand however more detailed climate models have produced conflicting predictions so there are moderate to high level of uncertainty.

⁸⁴ Confirmed eradicated from the USA in 2003 (NAPPO 2003, in CABI 2020b), but sporadically captured in the Rio Grande Valley of Texas and California (CABI 2020b; EPPO 2020).

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by fruit flies is likely to be high (low to moderate uncertainty).

Fruit flies can cause significant damage to fruit and vegetable commodities.

- Without control measures, direct damage of fruit and vegetable commodities by fruit flies ranges from 0–80% but can be as high as 100% depending on host species or variety, location and season (EFSA Panel on Plant Health et al. 2020).

Fruit flies can cause significant economic impacts due to direct damage and costs associated with control and management.

- Examples of significant economic impacts of fruit flies include (EFSA Panel on Plant Health et al. 2020):
 - Crop losses and control costs due to fruit flies have been estimated at over US\$7.5 million per annum in a single area of South Africa (West Cape).
 - In Brazil, annual economic losses may be as high as US\$242 million due to fruit fly activity.
 - In Hawaii, the economic losses associated with invasive fruit flies (due to the costs of spraying or, where this is ineffective, abandoning crops) exceed US\$300 million each year.

If fruit flies are detected in New Zealand, the cost incurred by a response would be high.

- The typical cost of responses is millions of dollars. For example:
 - The Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020).
 - The eradication of *Bactrocera cucurbitae* from the Okinawa prefecture of Japan took almost 20 years and reached a total cost of US\$177.2 million (EFSA Panel on Plant Health et al. 2020).
 - In the mid-1990s, the cost of eradicating Philippine fruit fly (*B. philippinensis*) in Darwin was estimated at AU\$7 million whereas the cost of eradicating *B. papayae* (Leblanc et al. 2012) from Cairns cost an estimated AU\$35 million (Abdalla et al. 2012).

The loss of market access due to fruit fly incursions can cause significant economic losses

- The direct financial impact to the horticultural industry nation-wide (revenue lost due to lost market access plus additional costs) of a successfully eradicated *Ceratitidis capitata* incursion in New Zealand's major fruit-growing regions has been estimated at between NZ\$24.4 million and \$71.4 million (Underwood 2007).
- The cost due to lost market access in the event of establishment of *C. capitata* in California was estimated at US\$564 million (Siebert and Cooper 1995).

8.12.25 References

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9. Insects: Hemiptera, Pseudococcidae (mealybugs)

9.1 *Nipaecoccus viridis* (spherical mealybug)

Nipaecoccus viridis is a polyphagous mealybug species. It is widespread throughout the tropics and subtropics, attacking numerous plant species and often causing considerable damage.

Scientific name: *Nipaecoccus viridis* (Newstead, 1894)

Order/Family: Hemiptera/Pseudococcidae

Other names include: *Dactylopius viridis*, *Dactylopius vastator*, *Pseudococcus vastator*, *Pseudococcus viridis*, *Dactylopius perniciosus*, *Ripersia theae*, *Pseudococcus solitaries*, *Pseudococcus perniciosus*, *Pseudococcus filamentosus corymbatus*, *Trionymus sericeus*, *Pseudococcus theae*, *Nipaecoccus vastator*, karoo thorn mealybug, lebbeck mealybug, cotton mealybug, globular coffee mealybug (García et al. 2016; EPPO 2019a)

Taxonomic notes: The name *N. vastator* was commonly used for *N. viridis* for many years. It was synonymised with *N. viridis* by Ali in 1970 (cited in CPC 2020), but some authors continue to use the name *N. vastator*. There are many records of *N. viridis* under the name *Pseudococcus filamentosus* (Cockerell) (it is now included in the genus *Nipaecoccus*), but these are based on misidentifications (Williams and Watson 1988).

Summary of conclusions

Given the arguments and evidence presented:

- *Nipaecoccus viridis* meets the criteria to be a quarantine pest for New Zealand.
- *Nipaecoccus viridis* has a strong association with citrus fruit, with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *N. viridis* by a moderate degree. Consequently, the likelihood of entry is considered to be low, with low uncertainty.
- *Nipaecoccus viridis* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment to for *N. viridis* to establish is considered low to moderate (with moderate uncertainty), but the likelihood of establishment in warmer areas and indoor environments, such as greenhouses, is considered moderate.
- The level of impact caused by *N. viridis* is likely to be low to moderate (with moderate uncertainty), but the level of impact to the citrus industry in northern New Zealand is likely to be moderate.
- *Nipaecoccus viridis* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low	High
Suitability of the New Zealand environment	Low–moderate	Moderate
Impacts on the New Zealand economy, environment, health and society	Low–Moderate	Moderate

9.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Nipaecoccus viridis* meets the criteria to be a quarantine pest for New Zealand

Criteria for being a quarantine pest, relevant to this assessment, are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Nipaecoccus viridis is not known to be present in New Zealand:

- It is not recorded in NZInverts (2020) and NZOR (2020).
- It is not recorded in PPIN (2020).
- It is listed as 'Regulated' in ONZPR (2020).

Nipaecoccus viridis has the potential to establish and spread in New Zealand:

- *Nipaecoccus viridis* is widespread throughout the tropics and subtropics, although it is also present in areas with similar or marginally similar climate conditions to New Zealand.
- *Nipaecoccus viridis* is polyphagous. It has been reported on 140 genera of plants in 52 families (García et al. 2016).
- Host plants include those commercially grown in New Zealand and those commonly grown in gardens and parks, such as *Citrus* spp., *Vitis* spp., *Solanum lycopersicum*, *Rosa* spp., *Camellia* spp. etc.

Nipaecoccus viridis has the potential to cause impacts to the economy and environment of New Zealand:

- *Nipaecoccus viridis* has the potential to harm plants of economic importance to New Zealand: Host plant species of the mealybug include important agricultural plants in New Zealand, such as citrus, grapevine, tomato, apple, pear, apricot and avocado.
- *Nipaecoccus viridis* has the potential to harm the New Zealand environment: The mealybug has been reported on plant species under genera (e.g. *Apium* and *Sonchus*) that are native to New Zealand.

9.1.2 Hazard identification: commodity association

Nipaecoccus viridis is associated with citrus fruit

Nipaecoccus viridis is reported from citrus fruit:

- *Nipaecoccus viridis* infests twigs, shoots, leaves, flower buds and fruit on citrus (García et al. 2016) and often settles in cryptic places, such as under sepals of citrus fruits (Figure 10.1.1).

9.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Nipaecoccus viridis* has a strong association with citrus fruit, with low uncertainty.

Many reports have recorded the damage of *N. viridis* on citrus fruits.

- *Nipaecoccus viridis* infests twigs, shoots, leaves, flower buds and fruit on citrus (García et al. 2016), primarily occurring on the foliage and fruit of hosts (Miller et al. 2014).
- *Nipaecoccus viridis* often settles in concealed places, such as under the sepals of citrus fruits (Figure 10.1.1) and under the calyx (CPC 2020).



Figure 10.1.1 A portion of the sepal of a citrus fruit is cut away to reveal the mealybugs (*N. viridis*) beneath. Sourced from Diepenbrock and Ahmed (2020).

Although there is a lack of interception data of *N. viridis* at the New Zealand border, it has been intercepted on citrus fruit in Australia.

- There are no identification records of *N. viridis* or its synonyms at the New Zealand border from 1929 to March 2019 (LIMS 2019) or in the EPPO interception database (EPPO 2020c), even though it is widespread in many tropical and subtropical areas.
- Adults of *Nipaecoccus filamentosus* (previously known as *Pseudococcus filamentosus* (Williams and Watson 1988) have been identified once on fresh orange fruit from Australia at the New Zealand border (LIMS 2019). It is suspected that this record is based on misidentification, as *N. filamentosus* is not present in Australia. Since *N. viridis* is present in Australia, and there are many records of *N. viridis* under the name *P. filamentosus*, it is possible that this identification record is actually *N. viridis*.
- It is uncertain whether the lack of interception records for *N. viridis* is a result of the difficulty in detection or because *N. viridis* may not be able to survive transit on most commodities. Host commodities of fruit flies may have measures that could possibly kill the mealybug, which may also contribute to the lack of interception records for *N. viridis* in New Zealand.
- *Nipaecoccus viridis* has been intercepted on *Citrus tangerina* and pomelo fruits at the Australian border (DAWE 2019).
- *Nipaecoccus viridis* has been intercepted 37 times at the US border between 1995 and 2012 (records without commodity types) with specimens originating from Bangladesh, Cambodia, China, Costa Rica, India, Indonesia, Italy, Laos, Pakistan, the Philippines, Puerto Rico, South Africa, Taiwan, Thailand and Viet Nam (Millers et al. 2014).

Citrus species/cultivars that are associated with *N. viridis* are shown in Table 10.1.1.

Table 10.1.1 Known citrus plant host association of *Nipaecoccus viridis*.

Citrus host scientific name	Citrus host common name from the reference	Reference	Notes
<i>Citrus aurantiifolia</i>	Lime	García et al. (2016), CPC (2020)	
<i>Citrus aurantium</i>	Sour orange	García et al. (2016), CPC (2020)	
<i>Citrus aurantium</i> subsp. <i>bergamia</i>		García et al. (2016)	
<i>Citrus aurantium</i> var. <i>sinensis</i>		García et al. (2016)	
<i>Citrus limon</i>	Lemon	García et al. (2016), CPC (2020)	
<i>Citrus maxima</i>	Pummelo	García et al. (2016), CPC (2020)	
<i>Citrus maxima</i>		García et al. (2016)	
<i>Citrus medica</i>		García et al. (2016)	
<i>Citrus paradisi</i>		García et al. (2016)	
<i>Citrus reticulata</i>		García et al. (2016)	
<i>Citrus sinensis</i>	Navels and Valencias	Bedford (1978)	Field fruit infestation

Citrus host scientific name	Citrus host common name from the reference	Reference	Notes
<i>Citrus</i> sp.	Tangelo Orlando	Germain et al. (2014)	
<i>Citrus reticulata</i>		DAWR (2019)	Interception on fruit
<i>Citrus paradisi</i>	Grapefruit	CPC (2020)	
<i>Citrus maxima</i>	Pomelo	DAWR (2019)	Interception on fruit

Nipaecoccus viridis is present in citrus-exporting countries in this IHS:

- *Nipaecoccus viridis* is present in the following citrus-exporting countries in this IHS: Egypt, China, Japan, Viet Nam, Mexico, the USA, Australia, New Caledonia and Solomon Islands (García et al. 2016).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *N. viridis* by a moderate degree. Consequently, the likelihood of entry is considered to be low, with low uncertainty.

Visual inspection can usually detect infestations of *N. viridis* on citrus fruit.

- Some typical signs can indicate the presence of *N. viridis* on fruit, such as green marks occurring on ripe fruit at the point where the mealybugs pierce with their mouthparts, sooty mould, ovisac, male cocoon and waxy material produced by the mealybug. Females produce an ovisac with a wax that is sticky when touched. At high levels of infestation, waxy secretions may appear as a continuous layer of wax which obscures individual mealybugs (Stocks and Hodges 2010; Levi-Zada et al. 2019).
- The reproducing females are covered by the buff or whitish, fluffy and stringy ovisac, protecting the eggs inside (Bartlett 1987). As such, reproducing adult females and eggs that are within the ovisac are likely to be detected.

However, in low population densities or as individuals, or if the commodities have a complex structure, detection of *N. viridis* citrus fruits can be difficult.

- *Nipaecoccus viridis* often settle in concealed places, such as under sepals of citrus fruits and under the calyx (Figure 10.1.1; CPC 2020). This distribution is likely to be the result of behaviours such as thigmotaxis and negative phototaxis that have been reported in crawlers of other coccoid species (diaspidids and other pseudococcids) (Nestel et al. 1995, Geiger and Daane 2001).
- *Nipaecoccus viridis* is small. Adult females and males are up to 4 mm and 2.5 mm long respectively (Williams 2004), and nymphs and eggs are even smaller (crawlers are 0.4–0.5 mm long; Sharaf and Meyerdirk 1987). Adult males are up to 2.5 mm long and are winged, so they are unlikely to be associated with commodities (Sharaf and Meyerdirk 1987). Reproducing females and egg masses are more likely to be detected due to the cottony appearance of the ovisac. Nymphs are likely to be more difficult to detect, as they are smaller, especially when they are in sheltered places, such as under the sepals and in the calyx. As such, detection of *N. viridis* requires careful inspection with a good eye or magnifier.

As citrus fruit may have protected places for *N. viridis* to hide, general handling after harvesting may not be able to remove/kill all mealybugs.

- *Nipaecoccus viridis* is very difficult to control with insecticides due to its wax-covered body, cryptic behaviour, egg masses and male cocoon, along with overlapping generations (Sharaf and Meyerdirk 1987). The wax covering over a mealybug's body can repel aqueous solutions, which reduces the effectiveness of insecticides and the likelihood of removal by washing (Hollingsworth and Hamnett 2009).
- Although early instar nymphs have less wax covering to protect them from insecticide and washing, it is easier for them to hide in sheltered places (e.g. under sepal or calyx and in the navel of navel orange) because of their smaller size and higher mobility than other life stages (except male adults).
- In general, except for adult males and the first instar nymphs, other life stages of mealybugs tend to be stationary (Koszarab and Kozár 2012). As such, they are less likely to get off the commodity during handling, especially when they are in sheltered places.

Likelihood of establishment:

Given the arguments and evidence below, *Nipaecoccus viridis* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant. (exposure/transfer)

Nipaecoccus viridis may survive and develop on the waste of citrus fruit (whole fruit or fruit pieces).

- Although there is no specific study on the development of *N. viridis* on citrus fruit, a laboratory study in New Zealand (Whyte et al. 1994) showed that the longtailed mealybug, *Pseudococcus longispinus*, survived up to 49 days on oranges (if whole fruit was not consumed or decayed). In contrast, desiccation renders orange peel unsuitable as a host.
- On lemon seedlings at 25±2°C, female and male *N. viridis* nymphs completed development in about 19.3 and 20.3 days (Sharaf and Meyerdirk 1987). Sharaf and Meyerdirk (1987) did not mention which part the mealybug was reared on. There is a moderate to high uncertainty that *N. viridis* can survive and develop on citrus fruits.

Most of the kitchen waste in New Zealand is disposed of using methods that pose a low risk of transfer to a new host, so the mealybug would either be killed or unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, the mealybug is unlikely to reach a new host (see waste analysis, section 2.4.1).

However, some of the waste would be disposed of using methods that pose a higher risk of transfer to a new host, including composting in gardens and using it as animal feed.

- *Nipaecoccus viridis* is rather polyphagous, and some host plants are commonly planted in home gardens and parks, such as citrus, grapevines, tomatoes, apples, pears, figs, celery, cucumbers, asparagus, roses and camellias (García et al. 2016).
- *Nipaecoccus viridis* has been reported on common weed species, including *Cynodon dactylon* (Bermuda grass), *Sonchus* spp. and *Lantana camara* (García et al. 2016). *Cynodon dactylon* is both a lawn grass and weed species (Breitwieser et al. 2020), common in warmer coastal areas of the North Island and some warmer parts of the South Island; *Sonchus oleraceus* and *S. asper* (sow thistle) are common weeds throughout New Zealand (iNaturalist 2020); *Lantana camara* is abundant on the northwest shore of Hokianga Harbour and occasionally grows elsewhere in north Auckland and the Bay of Plenty (RNZIH 2014). If these hosts are located near a composting site (see the waste analysis, section 2.4.1), *N. viridis* may be able to transfer from the citrus host to the new host.

Mealybug species have relatively limited mobility, and except for the first-instar nymphs (crawlers) and adult males, life stages tend to be sessile, meaning they prefer not to move if they are in a suitable location.

- All stages of *N. viridis* can move freely, but the crawler is the only life stage that moves readily, and they usually settle on the same host (Sharaf and Meyerdirk 1987). This implies that dispersal via walking can only result in short-distance dispersal (i.e. within the original host plants or nearby plants). The ovipositing females often remain sedentary (Wakgari and Giliomee 2005). If citrus fruit waste is disposed of in an environment with suitable hosts nearby, for example composting and animal feeding, the crawlers may be able to walk to the nearby host.

Mealybug species can be dispersed passively, which is also considered an important mechanism contributing to the spread of mealybugs, and the polyphagous nature of *N. viridis* is likely to increase the likelihood of landing on a suitable host.

- Mealybugs can be passively dispersed by wind, water, fallen leaves, phoresy (attached to birds, ants, other insects, etc.) and movement of farm equipment, soil and infested plant material (although no specific study has been carried out on *N. viridis*). However, long-distance movement of mealybugs is most likely due to the movement of infested nursery stock and agricultural commodities (Mani and Shivaraju 2016).
- Passive dispersal by wind is considered to be an important mechanism contributing to the colonisation of new areas by mealybugs (Lo et al. 2006). Nymphs (mainly first instars) and

adult males (only in insignificant numbers) have been reported as able to disperse by wind, for short, moderate and presumably long distances:

- The first- and second-instar nymphs, as well as adult males, of the grape mealybug, *Pseudococcus maritimus*, can be dispersed by wind, but there is a marked decline in numbers with increasing distance from the source plant (Grasswitz et al. 2008). The crawlers were dispersed up to 8 m in this study. Among the mealybugs being dispersed by wind, 86.3% were crawlers, 10.8% were second instars, and 2.9% third instars.
- Lo et al. (2006) conducted a field trial using aerial trapping to catch mealybugs that were dispersed by wind in a New Zealand vineyard. Crawlers and a small number of adult males were caught in these traps, and they found that mealybugs can be blown at least 5 m and up to 15 m.
- Based on 24-hr wind-run values, Barrass et al. (1994) presumed that the crawlers of *Pseudococcus longispinus* could disperse across distances greater than 50 km, although this has not been tested in scientific studies.
- Barrass et al. (1994) also found that the survival rate for the crawlers of *Ps. longispinus* held at 20°C and 32% relative humidity for 48 hours was 75%, suggesting that the crawlers are capable of surviving desiccation for long enough to make wind currents a viable method of dispersal.
- In Lo et al. (2006), they also estimated that in the 6 weeks leading up to mid-April, there were 2.5 million crawlers/ha in the air above the mealybug-infested vineyard.
- Barrass et al. (1994) also found that number of mealybugs caught in aerial traps increased directly with wind speed and with the square of the daily temperature maximum, which implies that dispersal by winds of mealybugs in areas with high wind speeds and temperature are likely to be more frequent.
- Some coccoid species are known to deliberately move to high points of their host plants in order to disperse (Brown 1958, Beardsley and Gonzalez 1975, Greathead 1990, Lo et al. 2006). Washburn and Washburn (1984) showed that crawlers of the coccid *Pulvinariella mesembryanthemi* (Vallot) deliberately entered the air, not only by moving up the plant but by orienting their bodies most favourably to the air current and standing on their hind legs. However it is important to note that most studies of crawler dispersal have been carried out using insects on their host plants, and that information about dispersal of crawlers from situations comparable to a piece of discarded fruit is scarce.
- Rapid and widespread dispersal of mealybugs may also occur due to the sticky and stringy ovisac, which is well adapted to adhere to the feet of birds (Bartlett et al. 1978).
- Passive dispersal cannot guarantee *N. viridis* will land on a suitable host, but the polyphagous nature of *N. viridis* is likely to increase the likelihood of landing on a suitable host.
- However, passive dispersal also means that successful transfer will depend not only on whether hosts are present, but also on other factors such as wind speed, whether animals are present (i.e. hitchhiking) and the survival rates of the mealybug during passive dispersal, which are considered uncertain at this stage.

Nipaecoccus viridis reproduces sexually (Ross et al. 2012, Mendel and Blumberg 2015). Sharaf and Meyerdirk (1987) cited one report of asexual reproduction by parthenogenesis in Iraq (Al-Ani et al. 1974) but this is considered to be doubtful (Mendel and Blumberg 2015).

- Mealybugs are able to mate with their siblings in the laboratory (e.g. Ross et al. 2012, García de la Filia et al. 2019) and it is assumed this also occurs in the field, though there may be behavioural or other constraints against sibling mating (Müller and Müller 2016, Collet et al. 2019).
- Virgin females of *N. viridis* can produce a sex pheromone to attract males (Levi-Zada et al. 2019). It is uncertain how far adult males can fly to locate a mature female, but it is noted that the adult males of some well-known mealybug pests are weak fliers (Barrass et al. 1984; Chen et al. 2012).
- Adult male mealybugs only live for a few days (Williams 2004).

The level of uncertainty associated with the conclusion on the transfer ability of *N. viridis* is high. First, waste data and information may not be very accurate and up to date, and it is not known how frequently suitable hosts would be near composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Second, it is reported that dispersal by wind is an important

mechanism for the spread of mealybugs, but it is not known how efficient (compared to dispersal by walking) this dispersal method is, and it is uncertain what proportion of composting sites are exposed or covered (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *N. viridis* to establish is considered low to moderate (with moderate uncertainty), but the likelihood of establishment in warmer areas and indoor environments, such as greenhouses, is considered moderate.

Nipaecoccus viridis has a wide distribution that includes areas with a similar climate to New Zealand.

- *Nipaecoccus viridis* is present in Africa, Asia, North America and Oceania (Table 10.1.2).

Table 10.1.2 Known geographic distribution of *Nipaecoccus viridis*. Information compiled 29 May 2020 from García et al. (2016) and EPPO (2020a). Country/area with underline is only recorded in García et al. (2016). Country/area in **bold** is included in the Citrus IHS project.

Continent /Region	Country/area
Africa	Algeria, Angola, Benin, Burkina Faso, Comoros, Cote d'Ivoire, Egypt , Eritrea, Kenya, Madagascar, Malawi, Mali, Mauritius, Niger, Nigeria, Réunion, Rwanda, Senegal, Seychelles, South Africa, Sudan, Tanzania, Togo, Uganda, <u>Zanzibar</u> , Zimbabwe
Asia	Afghanistan, Bangladesh, <u>Bhutan</u> , <u>Myanmar</u> , China (<u>Hainan</u> , Hong Kong, Hunan, <u>Henan</u> , <u>Inner Mongolia</u>), <u>Christmas Island</u> , India, Indonesia, Iran, Iraq, Israel, Japan , Jordan, Cambodia, Malaysia, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, <u>Singapore</u> , Sri Lanka, <u>Syria</u> , Taiwan, Thailand, Viet Nam
North America	Bahamas, Mexico , United States (Florida, Hawaii)
Oceania	Australia (Northern Territory, Queensland), Guam, Kiribati, New Caledonia , Northern Mariana Islands, Papua New Guinea, Solomon Islands , Tuvalu

Climatically, the distribution of *N. viridis* is mainly in the tropics and subtropics.

- *Nipaecoccus viridis* is widely distributed in tropical and subtropical areas (Table 10.1.2).

However, *N. viridis* is also present in areas with similar climate conditions to New Zealand, although these areas only occupy a very small portion of the distribution areas.

- The current distribution includes a small number of countries/areas with a climate match index (CMI) (Phillips et al. 2018) over 0.7, which means these areas have 70%–100% similarity of climate to the general New Zealand climate. These areas include Henan in China (CMI: 0.7–0.8), Hunan in China (CMI: 0.7), Northern Cape of South Africa (CMI: 0.6–0.8), Himachal Pradesh in India (CMI: 0.8) and Rwanda (CMI: 0.7) (García et al. 2016; Phillips et al. 2018; CPC 2020).

It is uncertain if the mealybug can survive or complete development in the colder areas of New Zealand.

- Some mealybugs have been reported to be able to survive transit, including cold storage, on some commodities (e.g. *Pseudococcus longispinus* and *Pseudococcus calceolariae* (Smith et al. 1997), implying that these mealybugs are likely to survive cold conditions. However, no study on the lower temperature developmental threshold or cold tolerance of *N. viridis* was found.

Nipaecoccus viridis has multiple, overlapping generations in its distribution and a high reproductive rate.

- *Nipaecoccus viridis* can quickly develop large populations in its current distribution due to multiple and overlapping generations (Bartlett 1978).
- On lemon seedlings at 25±2°C, adult females laid an average of 667 eggs during the oviposition period, which lasted from 21–37 days (Sharaf and Meyerdirk 1987). Bartlett (1978) reported that the fecundity of a large female can exceed 1,100 eggs.

Host availability is unlikely to be a limiting factor for *N. viridis* to establish in New Zealand.

- *Nipaecoccus viridis* is polyphagous. It has been reported from 140 genera of plants in 52 families (García et al. 2016).
- Host plants include those commercially grown in New Zealand and those commonly grown in gardens and parks, such as citrus, grapevines, tomatoes, apples, pears, figs, celery, cucumbers, asparagus, *Rosa* and *Camellia*. etc. Common weed species, *C. dactylon* (Bermuda grass), *Sonchus* spp. and *L. camara*, are also reported as hosts (García et al. 2016).

Nipaecoccus viridis is predominantly distributed in the tropics and subtropics, but it is also present in areas/countries (Hunan and Henan in China, Northern Cape of South Africa, Taipei in Taiwan, Himachal Pradesh in India and Rwanda) with similar or marginally similar climate conditions to New Zealand. This suggests that *N. viridis* or some populations of the pest may adapt to some areas of New Zealand with a colder climate. Also, the lower development threshold and cold tolerance of *N. viridis* is unknown. Therefore, the level of uncertainty associated with the conclusion is moderate.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *N. viridis* is likely to be low–moderate (with moderate uncertainty), but the level of impact to the citrus industry in northern New Zealand is likely to be moderate.

Damage and symptoms caused by *N. viridis* can reduce yield and plant or fruit quality.

- *Nipaecoccus viridis* can feed on the host's branches, twigs, shoots, leaves, flower buds, fruits and root. It sucks up the plant sap, causing curling and dwarfing of the terminal growth, abortion of flowers, yellowing of leaves, fruit distortion and dropping of fruits. Severe infestations can lead to wilt and death of plants (Sharaf and Meyerdirk 1987).
- *Nipaecoccus viridis* injects toxic substances into plant tissues, which can lead to dieback of the terminal growth. It secretes large amounts of honeydew on the host, which can lead to the growth of sooty mould affecting plant photosynthesis. Fruits with sooty mould contamination or dust accumulated due to honeydew become soiled and unmarketable (Sharaf and Meyerdirk 1987).
- The damage caused by *N. viridis* on fruits also includes lumpy outgrowths or raised shoulders near the stem end. Fruits with this damage have to be culled in the packinghouse (Hattingh et al. 1998, in CPC 2020).

Nipaecoccus viridis has been reported as a severe pest on a range of economically important plants, some of which are also important in New Zealand, such as citrus and grapevine.

- *Nipaecoccus viridis* is a pest on a range of plants that are of economic importance to New Zealand, such as citrus, grapevine, soybean and many ornamental plants (Sharaf and Meyerdirk 1987; Thomas and Leppla 2008).
- In 2019, the domestic and export value of citrus in New Zealand were NZ\$58.5 million and \$12 million respectively (Plant & Food Research 2019).
- Grapes are high-value crops in New Zealand. In 2019, the export value of New Zealand wine was NZ\$1.825 billion (Plant & Food Research 2019).

However, while most reports on its impacts were from the tropics and subtropics, severe production loss has been reported from South Africa.

- Citrus:
 - *Nipaecoccus viridis* has been reported to cause heavy infestations in citrus orchards (e.g. orange, acid lime, pomelo, etc.) in South Africa, Hawaii, Egypt, Jordan, Iraq, India and Israel (Bartlett 1978; Thomas and Leppla 2008; Mani and Shivaraju 2016).
 - In South Africa, *N. viridis* is sometimes a serious pest in poorly managed citrus orchards in Rustenburg (CMI: 0.7) (Bedford et al. 1978), and it has been reported to cause more than 50% crop loss of navel orange (Hattingh et al. 1998, in Thomas and Leppla 2008). In Rustenburg, *N. viridis* (reported as *N. vastator*) has three generations from September to around April (Bedford et al. 1978). A climate niche approach (Halloy 2020) reveals that *N. viridis* is active in the wet and warm seasons in Rustenburg, with a temperature range overlapping with the temperature range of

the summer months of northern New Zealand (Figure 10.1.2), which is New Zealand's main citrus production area. Climate change is likely to increase the similarity of the climate between northern New Zealand and Rustenburg (Figure 10.1.2). In addition, many mealybug species are cold-resistant (DAWR 2019) and *N. viridis* is present in colder areas with similar climate to the overall New Zealand climate, suggesting that it may be able to overwinter in northern New Zealand. Therefore, the consequences of introducing *N. viridis* could potentially be compared to the consequences of introduction in South Africa.

- Other crops:
 - *Nipaecoccus viridis* has been reported to be a pest of grapes in India (Levi-Zada et al. 2019). It is reported that *N. viridis* caused up to 5% damage on grape bunches in two vineyards in Bangalore, India (Mani and Thontadarya 1987, in CPC 2020). *Nipaecoccus viridis* is not known to occur on grapes in temperate areas.
 - *Nipaecoccus viridis* has also been recorded as a pest of soybeans in India. *Nipaecoccus viridis* feeds on leaves, stems and pods of soybean. An average of 30–35 mealybugs per soybean plant has been recorded in Rajasthan, India (Babu 2016). There is no report of its impact on soybeans in temperate areas. Soybean is commercially grown in New Zealand, although it is a small industry.

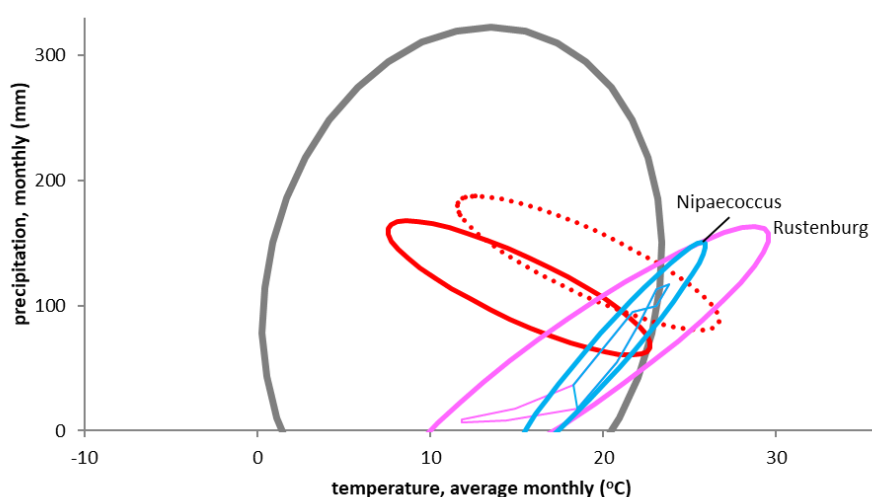


Figure 10.1.2 Climate niches (temperature and precipitation range) of New Zealand (grey ellipse), northern New Zealand (including Northland, Auckland and Bay of Plenty; red ellipse), Rustenburg (pink ellipse), active period of *N. viridis* in Rustenburg (blue ellipse) and northern New Zealand in a +4°C climate change scenario (red dashes). These ellipses include 95% of climatic sites within the specific area. Northern New Zealand includes 68% of the citrus productive area in New Zealand (Halloy 2020).

The introduction of biological control agents has successfully controlled *N. viridis* in some areas, and one agent (the mealybug ladybird) that is reported to have effectively controlled the pest is present in New Zealand. However, the effectiveness of biological control in New Zealand is uncertain.

- *Nipaecoccus viridis* is very difficult to control with insecticides due to the wax covering, cryptic behaviours, the protection of ovisacs and cocoons, and overlapping generations (Sharaf and Meyerdirk 1987). However, *N. viridis* has a long list of natural enemies (García et al. 2016), and introduction of biological agents has successfully controlled the pest in some areas, such as the introduction of *Anagyrus dactylopii* (encyrtid wasp) in Hawaii, the introduction of *A. aegyptiacus* and *Leptomastix phenacocci* in Egypt, and the introduction of *Cryptolaemus montrouzieri* in India (CPC 2020; Sharaf and Meyerdirk 1987).
- *Cryptolaemus montrouzieri* (mealybug ladybird) is present in warmer areas in New Zealand, mainly in Auckland and Northland (Martin 2018), and it is commercially produced in New Zealand (Bioforce 2012). However, it is hard to know the effectiveness of this biological control agent on *N. viridis* in New Zealand due to the complexity and differences of the ecological system in New Zealand compared with other locations.

The establishment of *N. viridis* may result in increased phytosanitary measures required for export to countries where the pest is absent and regulated.

- Most countries in temperate areas and some areas in the tropics and subtropics have not been reported to have the mealybug, such as the whole European area, South America, and most areas in North America (Table 10.1.1).
- *Nipaecoccus viridis* is a quarantine pest in South Korea (Thomas and Leppla 2008), East Africa, Southern Africa, Brazil, Chile, Bahrain and Turday (EPPO 2020).

Nipaecoccus viridis may cause environmental impacts on native plant species, as it has hosts in plant genera with native New Zealand plant species, and plant species under some of these genera have 'at risk' or 'threatened' conservation status.

- Usually, if a pest attacks species under a genus, it is assumed that the pest may attack other species under the same genus. *Nipaecoccus viridis* has been recorded on host species belonging to genera that have species native to New Zealand. These genera included: *Avicennia*, *Apium*, *Schefflera*, *Sonchus*, *Ipomoea*, *Euphorbia*, *Geranium*, *Pelargonium*, *Vitex*, *Hibiscus*, *Streblus* and *Solanum* (NZPCN 2020; García et al. 2016). It is uncertain what level of damage can be caused by the pest on these species.
- Some of the species under these genera have 'at risk' or 'threatened' conservation status in New Zealand, including: *Apium prostratum* subsp. *denticulatum*, *Sonchus grandifolius*, *Sonchus kirkii*, *Sonchus novae-zelandiae*, *Ipomoea pes-caprae* subsp. *brasiliensis*, *Euphorbia glauca*, *Geranium retrorsum*, *Geranium sessiliflorum* var. *arenarium*, *Geranium socolatum*, *Geranium solanderi*, *Geranium traversii*, *Hibiscus diversifolius* subsp. *diversifolius*, *Hibiscus richardsonii*, *Streblus banksia*, *Streblus smithii*, *Solanum aviculare* var. *aviculare*, *Solanum aviculare* var. *latifolium* (NZPCN 2020).
- however it should be noted that relatively few non-indigenous invertebrates and pathogens have been recognised as causing serious damage to terrestrial natural ecosystems globally (Phillips et al. 2008), and in the New Zealand context only a few substantial pest and disease outbreaks affecting native plants have been documented (Beever et al. 2007).

Nipaecoccus viridis may have impacts on the urban environment and may have indirect health impacts to humans.

- *Nipaecoccus viridis* is damaging to a number of plants grown in domestic gardens and parks, such as *Vitis* spp., *Prunus* spp., *Citrus* spp., *Malus* spp., roses and camellias. Therefore, it is a potential nuisance pest in urban environments. Also, it could be more problematic in protected environments (e.g. houseplants) where parasitoids do not have easy access to them.
- *Nipaecoccus viridis* may indirectly have some impact on human activities. *Vespula* wasps are attracted to honeydew excreted by some insects, and high numbers of wasps in recreational, urban or other areas may adversely impact on health (painful stings or allergy to stings) and social activities (MAF 2008). However, as many sap-sucking insects that can produce honeydew are already present in New Zealand, the impact may be minor to negligible.

Most reports on economic or sociocultural impacts of *N. viridis* are from the tropics and subtropics, except for the report on poorly managed citrus orchards from Rustenburg, South Africa, where the climate conditions are similar to New Zealand. There is a lack of reports on the environmental impacts of *N. viridis*, but plant genera that have related native species and have 'at risk' and "threatened" conservation status in New Zealand have been attacked by *N. viridis* overseas. Therefore, the level of uncertainty associated with the conclusion is moderate.

Risk assessment summary:

Given the arguments and evidence below, *Nipaecoccus viridis* may be considered for additional measures.

- *Nipaecoccus viridis* has a strong host association with citrus fruits.
- *Nipaecoccus viridis* is present in several exporting countries.

- *Nipaecoccus viridis* is small and cryptic (especially nymphs). As such, in low population densities or as individuals, detection can be difficult if the commodities have sheltered places (e.g. under the sepals or calyx of fruits, in the navel of navel oranges) for them to hide.
- *Nipaecoccus viridis* has relatively limited mobility, but it can disperse passively. It is reported that dispersal of mealybugs by wind is an important mechanism for their spread.
- Passive dispersal cannot guarantee *N. viridis* will land on a suitable host, but the polyphagous nature of *N. viridis* increases the likelihood of it landing on a suitable host.
- Disposal to landfill, which is a low-risk disposal method, is the primary way of disposing of kitchen waste in New Zealand, while disposal using high-risk methods (composting and animal feeding) is less common.
- Some kitchen waste is likely to be disposed of using high-risk methods, and the mealybug is polyphagous, which increases the probability that suitable hosts would be present in the surrounding environment.
- *Nipaecoccus viridis* is widespread in the tropics and subtropics, but a very small portion of the distribution areas have similar climate conditions to New Zealand.
- Host availability is unlikely to be a limiting factor for *N. viridis* to establish in New Zealand.
- The economic impact is considered low to moderate with moderate uncertainty, because there is a lack of reports found on the economic impacts of *N. viridis* in temperate areas, except for South Africa.
- In South Africa, this mealybug caused more than 50% crop loss in heavily infested navel orange orchards in Rustenburg. The climate conditions of Rustenburg are similar to those of New Zealand based on a climate niche approach.
- *Nipaecoccus viridis* may cause environmental impacts on native plant species, as it has hosts in plant genera with native New Zealand plant species, and plant species under some of these genera have an 'at risk' or 'threatened' conservation status.

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9.2 *Planococcus kraunhiae* (Japanese mealybug)

Planococcus kraunhiae is a species of mealybug. It is believed to be of eastern Asian origin, and it is found in a number of countries. It damages a variety of fruits (e.g. grapes, pears, figs, citrus etc.), especially persimmons in western Japan.

Scientific name: *Planococcus kraunhiae* (Kuwana, 1902)

Order/Family: Hemiptera/Pseudococcidae

Other names include: *Dactylopius kraunhiae*, *Pseudococcus kraunhiae*, *Planococcus kraunhiae*, *Planococcus siakwanensis* (García et al. 2016)

Summary of conclusions

Given the arguments and evidence presented:

- *Planococcus kraunhiae* meets the criteria to be a quarantine pest for New Zealand.
- *Planococcus kraunhiae* has a strong association with citrus fruit with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *P. kraunhiae* to New Zealand by a moderate degree. Consequently, the likelihood of entry is considered low, with low uncertainty.
- *Planococcus kraunhiae* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *P. kraunhiae* to establish is considered high, with low uncertainty.
- The level of impact caused by *P. kraunhiae* is likely to be moderate (with moderate uncertainty).
- *Planococcus kraunhiae* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low	High
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Moderate	Moderate

9.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Planococcus kraunhiae* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Planococcus kraunhiae is not known to be present in New Zealand:

- It is not recorded in NZInverts (2020) or NZOR (2020).
- It is not recorded in PPIN (2020).
- It is listed as 'regulated' in ONZPR (2020).

Planococcus kraunhiae has the potential to establish and spread in New Zealand:

- *Planococcus kraunhiae* is present in China (Shanxi, Yunnan), India, Iran, Japan, Madeira Islands, Philippines, South Korea, Taiwan, Viet Nam and the United States (California) (Cox 1989; Hembram et al. 2007; Thuy et al. 2011; García et al. 2016; Wang et al. 2018).
- The current distribution of the pest includes areas with similar climate conditions to New Zealand: Shanxi (climate match index (CMI) = 0.7), Yunnan (0.6–0.8), Japan (0.7–0.8), South Korea (0.6–0.7) and California (0.5–0.8) (Phillips et al. 2018).
- *Planococcus kraunhiae* is polyphagous. It has been reported on 32 genera of plants in 26 families (García et al. 2016).
- The host list includes species that are commercially planted in New Zealand, including kiwifruit (*Actinidia* spp.), pumpkin (*Cucurbita moschata*), persimmon (*Diospyros kaki*), fig (*Ficus carica*), olive (*Olea europaea*), grapevine (*Vitis vinifera*) and citrus (*Citrus* spp.).

Planococcus kraunhiae has the potential to cause impacts to the economy and environment of New Zealand:

- *Planococcus kraunhiae* has the potential to harm plants of economic importance to New Zealand. Host species of *P. kraunhiae* include important crops in New Zealand, such as *Citrus*, *Actinidia* and *Vitis* (García et al. 2016; USDA 1995).
- *Planococcus kraunhiae* has the potential to harm the New Zealand environment. The mealybug has been reported on plant species in genera that are native to New Zealand (NZPCN 2020).

9.2.2 Hazard identification: commodity association

Planococcus kraunhiae is associated with citrus fruit.

Planococcus kraunhiae is reported from citrus fruit:

- It has been reported on citrus fruit in Japan (Miyashita et al. 2013; Boujo 2020).
- At US ports-of-entry, *P. kraunhiae* is most often taken into quarantine on *Citrus* and *Diospyros* spp. (persimmons) from Japan (Miller et al. 2014), although the authors did not mention whether the commodities were fresh fruit or plants for planting.

9.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Planococcus kraunhiae* has a strong association with citrus fruit with low uncertainty:

Planococcus kraunhiae has been reported on citrus fruits.

- Boujo (2020) reported that *P. kraunhiae* is often found on peduncles, branches, fruits and leaves of citrus.
- Miyashita et al. (2013) conducted a study on the effectiveness of different chemical control methods in controlling *P. kraunhiae* in lemon orchards, using mealybugs per fruit as one of the indices, indicating that *P. kraunhiae* can be found on lemon fruits.
- *Planococcus kraunhiae* is reported as an important pest that infests many kinds of fruits, including *Citrus* species in Japan (Kawai 1980; Ben-Dov 1994, in Tabata 2013).
- Quarantine specimens of *P. kraunhiae* on oranges from Japan to the USA have been reported (Miller et al. 2014).
- At US ports-of-entry, *P. kraunhiae* is most often taken into quarantine on *Citrus* and *Diospyros* (persimmons) from Japan (Miller et al. 2014), although the authors did not mention whether the commodities were fresh fruit or plants for planting.
- There has been only one interception of *P. kraunhiae* since 1986 to date at the New Zealand border (LIMS interception data). However, there have been 161 interceptions of *Planococcus* spp. (the identity of species is not always determined), which may or may not include some *P. kraunhiae*.

Nymphs of *Planococcus kraunhiae* may survive cold storage.

- *Planococcus kraunhiae* can overwinter as first and second-instar nymphs on persimmon in Japan (Morishita 2005), which means that they are likely to survive cold storage during transit.

Citrus species/cultivars found to be associated with *P. kraunhiae* are shown in Table 10.2.1.

Table 10.2.1 Known citrus plant host association with *Planococcus kraunhiae*.

Citrus host scientific name	Citrus host common name (from the reference)	Reference
<i>Citrus aurantium</i>		García et al. (2016)
<i>Citrus ichang austera</i> hybrid	<i>Citrus junos</i>	García et al. (2016)
<i>Citrus maxima</i>		García et al. (2016)
<i>Citrus paradisi</i> *	grapefruit	Chen et al. (2003)
<i>Citrus reticulata</i>	Unshu orange	USDA (1995)
<i>Citrus limon</i>	lemon	Miyashita et al. (2013)
<i>Citrus reticulata</i>	mandarin	Venkatesan et al. (2016)
<i>Citrus sinensis</i>	orange	Miller et al. (2014)

* Reference is in Chinese, with the English scientific and common names not provided. It is assumed that 葡萄柚 refers to *C. paradisi* (grapefruit).

Planococcus kraunhiae is present in citrus exporting countries in this IHS:

- *Planococcus kraunhiae* is present in the following citrus exporting countries: China, Japan, South Korea, Viet Nam and the USA.

Given the arguments and evidence below, Basic measures are likely to reduce the likelihood of entry of *P. kraunhiae* by a moderate degree, consequently the likelihood of entry is considered to be low with low uncertainty:

Usually, visual inspection can detect infestations of *P. kraunhiae* on citrus fruits.

- Some typical signs can indicate the presence of *P. kraunhiae* on fruits, such as sooty mould on fruits and waxy material produced by the mealybug (Thuy et al. 2011).

However, in low population densities or as individuals, detection can be difficult if the commodities have sheltered places for them to hide.

- *Planococcus kraunhiae* is small. Adult females are approximately 2.0–3.3 mm in length and 2.2–2.0 mm in width, and nymphs and eggs are even smaller than the adult female (Cox 1989). Early instar nymphs are likely to be more difficult to be detected, as they are smaller and have less of the waxy covering. As such, detection of *P. kraunhiae* will require careful inspection with a good eye or magnifier.
- Mealybugs are cryptic and are commonly found in protected places on the plant, such as in plant nodes, overlapping leaves, bracts and bark crevices (Mani and Shivaraju, 2016). As such, *P. kraunhiae* may be able to hide in the calyx of fruits, underneath sepals, wrinkles around the calyx or in the navel of navel oranges if navel orange is a suitable host (The pest has been intercepted on orange from Japan (Miller et al. 2014), but it is not known whether it was navel orange). This reduces the likelihood of detection.

As citrus fruit may have protected places for *P. kraunhiae* to hide, general handling after harvesting may not be able to remove/kill all mealybugs.

- Mealybugs are commonly found in protected/sheltered places (Mani and Shivaraju 2016). This distribution is likely to be the result of behaviours such as thigmotaxis and negative phototaxis that have been reported in crawlers of other coccoid species (diaspidids and other pseudococcids) (Nestel et al. 1995, Geiger and Daane 2001).

- The wax covering over a mealybug's body can repel aqueous solutions, which reduces the effectiveness of insecticides and the likelihood of removal by washing (Hollingsworth and Hamnett 2009; Teshiba et al. 2015; Venkatesan et al. 2016).
- Although early instar nymphs have less of the wax covering to protect them from washing and insecticides, it is easier for them to hide in sheltered places (such as the calyx and the navel of navel oranges) because of their smaller size and higher mobility than other life stages.
- Except for adult males and the first-instar nymphs, *P. kraunhia* life stages have limited mobility (Kosztarab and Kozár 2012). As such, they are less likely to get off the commodity during handling.

Likelihood of establishment:

Given the arguments and evidence below, *Planococcus kraunhia* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure).

Planococcus kraunhia is likely to survive and develop on the waste of citrus fruit.

- Although there is no specific study on the development of *P. kraunhia* on citrus fruit, a laboratory study in New Zealand (Whyte et al. 1994) showed that the longtailed mealybug, *Pseudococcus longispinus*, survived up to 49 days on oranges (if whole fruit was not consumed or decayed). In contrast, desiccation renders orange peels unsuitable as hosts.

Most of the kitchen waste in New Zealand is disposed of using methods that pose a low risk of transfer to a new host such that the mealybug would either be killed or unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is disposed of in landfills and run through kitchen disposal units, and in these situations, the mealybug is unlikely to reach a new host (see section 2.4.1, waste analysis).

However, some of the waste would be disposed of using methods that pose a higher risk of transfer to a new host including composting in gardens and using as animal feed.

- *Planococcus kraunhia* is polyphagous, and some host plants are commonly planted in home gardens, such as *Citrus*, *Pyrus* and fig. It has been reported on a weed species, *Digitaria sanguinalis* (summer grass) (García et al. 2016), which is very common in northern and coastal regions of the North Island of New Zealand (AgPest 2020). If these hosts are located near the composting site or animal feeding site (see section 2.4.1, waste analysis), some life stages of *P. kraunhia* may be able to transfer from the citrus host to the new host.

Mealybug species have relatively limited mobility, and other than the first-instar nymphs (crawlers) and adult males, life stages tend to be sessile.

- The primary dispersal stage of mealybug species is the crawlers. Crawlers have been found to possess characteristics that are considered adaptations for dispersal behaviour, including relatively well-developed legs and antennae (Gullan and Kosztarab 1997). This implies that dispersal via walking can result in short-distance dispersal (i.e. within the original host plants or nearby plants). While other life stages of mealybugs are usually mobile, they tend to be stationary or may only move limited distances (Kosztarab and Kozár 2012). For *P. kraunhia*, it is reported that all life stages can walk and move (Boujo 2020), but no reports have been found mentioning how far the different life stages of *P. kraunhia* can move specifically. If citrus fruit waste is disposed of in an open environment with suitable hosts nearby (for example, composting and animal feeding), the crawlers may be able to walk to the nearby host.

Mealybug species can be dispersed passively, which is also considered an important mechanism contributing to the spread of mealybugs, and the polyphagous nature of *P. kraunhia* is likely to increase the likelihood of landing on a suitable host.

- Mealybugs can be passively dispersed by wind, water, fallen leaves, phoresy (attached to birds, ants, other insects, etc.) and movement of farm equipment, soil and infested plant material (although no specific study has been carried on *P. kraunhia*). However, long-distance movement of mealybugs is most likely due to the movement of infested nursery stock and agricultural commodities (Mani and Shivaraju 2016).

- Passive dispersal by wind is considered an important mechanism contributing to the colonisation of new areas by mealybugs (Lo et al. 2006). Nymphs (mainly first instars) and adult males (only in insignificant number) of mealybugs have been reported to be able to disperse by wind for short, moderate and presumably long distances:
 - The first- and second-instar nymphs, as well as adult males, of the grape mealybug, *Pseudococcus maritimus*, can be dispersed by wind, but there is a marked decline in numbers with increasing distance from the source plant (Grasswitz et al. 2008). The crawlers were dispersed up to 8 m in this study. Among the mealybugs being dispersed by wind, 86.3% were crawlers, 10.8% were second instars, and 2.9% third instars.
 - Lo et al. (2006) conducted a field trial using aerial trapping to catch mealybugs in a New Zealand vineyard that were dispersed by wind. Crawlers and a small number of adult males were caught in these traps, and they found that mealybugs can be blown at least 5 m and up to 15 m.
 - Based on 24-hr wind-run values, Barrass et al. (1994) presumed that the crawlers of *Pseudococcus longispinus* could disperse across distances greater than 50 km, although this has not been tested in scientific studies.
 - Barrass et al. (1994) also found that the survival rate for the crawlers of *Ps. longispinus* held at 20°C and 32% relative humidity for 48 hours was 75%, suggesting that the crawlers are capable of surviving desiccation for long enough to make wind currents a viable method of dispersal.
 - In Lo et al. (2006), they also estimated that in the 6 weeks leading up to mid-April, there were 2.5 million crawlers/ha in the air above the mealybug-infested vineyard.
 - Barrass et al. (1994) also found that number of mealybugs caught in aerial traps increased directly with wind speed and with the square of the daily temperature maximum, which implies that dispersal by winds of mealybugs in areas with high wind speeds and temperature are likely to be more frequent.
 - Some coccoid species are known to deliberately move to high points of their host plants in order to disperse (Brown 1958, Beardsley and Gonzalez 1975, Greathead 1990, Lo et al. 2006). Washburn and Washburn (1984) showed that crawlers of the coccid *Pulvinariella mesembryanthemi* (Vallot) deliberately entered the air, not only by moving up the plant but by orienting their bodies most favourably to the air current and standing on their hind legs. However it is important to note that most studies of crawler dispersal have been carried out using insects on their host plants, and that information about dispersal of crawlers from situations comparable to a piece of discarded fruit is scarce.
- Passive dispersal cannot guarantee *P. kraunhiae* will land on a suitable host, but the polyphagous nature of *P. kraunhiae* is likely to increase the likelihood of landing on a suitable host.
- However, passive dispersal also means that the successful transfer will depend not only on whether hosts are present, but also on other factors, such as wind speed, whether animals are present (i.e. hitchhiking) and the survival rates of the mealybug during passive dispersal, which are considered uncertain at this stage.

Successful establishment of *P. kraunhiae* requires at least one mature female and one male successfully transferring to the same host, or a female carrying fertilised eggs.

- *Planococcus* species are able to mate with their siblings in the laboratory (e.g. Ross et al. 2012, García de la Filia et al. 2019) and it is assumed this also occurs in the field, though there may be behavioural or other constraints against sibling mating (Müller and Müller 2016, Collet et al. 2019).
- *Planococcus kraunhiae* is known to be biparental (Teshiba 2013), which means successful establishment requires at least one female and one male located at the same host or in a close distance, or a female carrying fertilised eggs.
- Females can produce sex pheromone to attract males (Sugie et al. 2008), but it is uncertain how far an adult male can fly to locate a mature female.
- Parthenogenesis (reproduction without a male) has not been observed in this species.
- Adult males of mealybug species can only live for a few days (Williams 2004).

The level of uncertainty associated with the conclusion is high. First, waste data and information may not be very accurate and up to date, and it is not known how frequently suitable hosts would be near

composting sites in gardens or animal feeding locations (see section 2.4.1, waste analysis). Second, it is reported that all life stages of *P. kraunhia* can walk and move, but no reports have studied the mobility of this species specifically. Third, it is reported that dispersal by winds is an important mechanism for the spread of mealybugs, but it is not known how efficient (compared to dispersal by walking) this dispersal method is, and it is uncertain what proportion of composting sites are exposed or concealed (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *P. kraunhia* to establish is considered high with low uncertainty.

Planococcus kraunhia lives in both tropical and temperate areas with similar climate conditions to New Zealand.

- *Planococcus kraunhia* is present in both tropical and temperate areas. It has been reported in China (Shanxi, Yunnan), Iran, Japan, Madeira Islands, Philippines, South Korea, Taiwan, Viet Nam (Thuy et al. 2011), United States (California) (García et al. 2016) and India (Hemram et al. 2007).
- Its current distribution includes areas with similar climate conditions to New Zealand: Shanxi (CMI = 0.7), Yunnan (0.6–0.8), Japan (0.7–0.8), South Korea (0.6–0.7) and California (0.5–0.8) (Phillips et al. 2018).
- It is common in Japan, China and Korea, and it is known in the USA on numerous host plants (Williams 2004).

Multiple generations of *P. kraunhia* occur per year in areas with similar climate conditions to New Zealand.

- Three to four generations of *P. kraunhia* per year have been reported in the Shimane, Hiroshima, Gifu and Fukuoka prefectures in Japan (Sawamura et al. 2015). Except for the Fukuoka prefecture, which has a CMI ranging from 0.6–0.7, other named prefectures have CMI = 0.7.

Development temperature thresholds of *P. kraunhia* implies that it is likely to survive and develop at least in the North Island.

- *Planococcus kraunhia* was reared on citrus leaves in Japan at five constant-temperature regimes to determine developmental thresholds (Arai 1996). The upper developmental threshold was estimated to be around 30°C, as no mealybugs developed to oviposition at 30°C. Lower developmental threshold for the entire nymphal stage and preovipositional period were 8°C and 11.7°C respectively. The other study which reared *P. kraunhia* on germinated broad bean seeds found that the estimated lower developmental threshold for the nymphal developmental period (from egg-hatching to adult) and the preovipositional period were 12.2°C and 8.1°C (Sawamura and Narai 2008).
- Monthly average data for the period 1971–2000 (NIWA 2016) show that most areas of the North Island have monthly mean temperatures higher than 8°C, including northern areas (Kaitaia, Whangarei, Auckland and Tauranga), Hamilton in the central North Island, the southwest North Island (New Plymouth, Palmerston North and Wellington), and Gisborne and Napier in the eastern North Island, indicating that *P. kraunhia* is likely to survive, or even develop, in winter in these areas.

Host availability is unlikely to be a limiting factor for the mealybug to establish in New Zealand.

- *Planococcus kraunhia* is polyphagous. It has been reported on 26 families and 32 genera of plants (García et al. 2016).
- The host list includes those that are commercially planted in New Zealand, including kiwifruit, squash/pumpkin, persimmon, fig, olive, pear (*Pyrus* spp.), grapevine and citrus. Many of these hosts are also common in home gardens.
- Some ornamental plants that can be found in parks and gardens are hosts of *P. kraunhia*, such as holly (*Ilex* sp.) and southern magnolia (*Magnolia grandiflora*). Summer grass (*Digitaria sanguinalis*), which is very common in northern and coastal regions of the North Island of New Zealand (AgPest 2020), is also a host of *P. kraunhia*.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *P. kraunhia* is likely to be moderate (with moderate uncertainty).

Damage and symptoms caused by *P. kraunhia* can reduce yield and plant or fruit quality.

- Like other mealybug species, *P. kraunhia* is a sap-sucking insect. Nymphs and adult females feed on branches, leaves and fruits (Boujo 2020).
- *Planococcus kraunhia* excretes honeydew that can lead to the growth of sooty moulds, which build up on the leaves, shoots and fruits. These moulds interfere with the plant's normal photosynthetic activity, which affects plant growth. If the infestation level is high, it can stop new growth of shoots, and branches can die (Boujo 2020).

Production loss caused by *P. kraunhia* has been reported from countries with similar climate conditions to New Zealand, and yield losses associated with *P. kraunhia* have been observed overseas in a variety of fruit crops that are also grown commercially in New Zealand.

- Impact on persimmons:
 - Many studies from Japan, especially in the last decade, have reported the damage of and control methods for *P. kraunhia* on persimmon plants and fruits (e.g. Morishita 2005; Miyashita et al. 2013; Teshiba and Tabata 2017; Teshiba 2018), implying that it is a serious pest on persimmons in Japan.
 - A field experiment conducted in Ukiha city, Fukuoka Prefecture, Japan, to investigate the effectiveness of mating disruption (mating dispensers containing a sex pheromone component) in controlling *P. kraunhia*, revealed that the mean injured fruit rate of persimmon ranged from approximately 1% to 2% in field trials with mating disruption, while 13% to 20% injured fruit rate was observed for the control treatment (Teshiba 2018).
 - Three to four generations of *P. kraunhia* per year have been reported in Shimane, Hiroshima, Gifu and Fukuoka prefectures in Japan (Sawamura et al. 2015). Except for Fukuoka prefecture which has a CMI ranging from 0.6 – 0.7, other named prefectures have CMI = 0.7.
 - In New Zealand, the domestic value (2018/19) of persimmons is NZ\$1.5 million, and the export value (2019) is \$10 million (Plant & Food Research 2019).
- Impact on pears:
 - A survey on three mealybug species, *P. kraunhia*, *Pseudococcus comstocki* and *Crisicoccus matsumotoi*, in Korea in 1990–1991 found that 80.6% of the mealybugs collected from pears were *P. kraunhia*. The degree⁸⁵ of damage caused by these mealybugs on different pear varieties, Singo, Poongsoo and Haengsoo, were 21.2, 18.2 and 13.3%. The population density of the pests began to increase from mid-June and peaked in mid-July (with 48% damage), mid-August (with 50.6% damage) and early October (Park and Hong 1992).
 - In New Zealand, the export value of pear in 2019 was NZ\$10.6 million (Plant & Food Research 2019).
- Impact on other plant species that are of economic importance in New Zealand.
 - *Planococcus kraunhia* has been reported as one of the most harmful mealybugs that attack many kinds of fruit crops in Japan, including persimmons, grapes, pears, citrus and figs (Kawai 1980; Shibao and Tanaka 2000; Ueno 1963, in Teshiba and Tabata 2017). However, reports on the economic impact on grapes, citrus and figs could not be found or the full text of the report was not accessible (e.g. Shibao 2000 on *P. kraunhia* on figs in Japan).

Cryptolaemus montrouzieri (mealybug ladybird), one of the natural enemies of *P. kraunhia*, is present in New Zealand, but the effectiveness of control by this natural enemy in New Zealand is unknown.

- Smith and Armitage (1931, in Mani and Shivaraju 2016) reported that an isolated infestation of *P. kraunhia* on citrus disappeared following the release of *Cryptolaemus montrouzieri* (mealybug ladybird) in Southern California. *Cryptolaemus montrouzieri* is present in New Zealand as an exotic species (NZOR 2020). However, it is hard to know the effectiveness of this biological control agent on *P. kraunhia* in New Zealand due to the complexity of the

⁸⁵ In Park and Hong (1992), Degree of damages (%) = 100[(4A + 3C + 2B + D)/4(total fruits investigated)], where A: above 16, B: 11–15, C: 6–10, D: 1–5 individuals per pear fruit.

ecological system in New Zealand and how different New Zealand's ecosystem is from other locations.

Establishment of *P. kraunhia* may result in increased phytosanitary measures required for export to countries where the pest is absent and regulated.

- The known distribution of *P. kraunhia* includes China (Shanxi, Yunnan), Iran, Japan, Madeira Islands, Philippines, South Korea, Taiwan, United States (California) (García et al. 2016) and India (Hembram et al. 2007).
- *Planococcus kraunhia* is considered a quarantine pest in Australia (Department of Agriculture and Water Resources 2019).
- Although it is recorded that *P. kraunhia* is present in California (Ben-Dov 1994), Park et al. (2010) reported that due to strict quarantine controls, fruit could not enter the USA if *P. kraunhia* was discovered, and *P. kraunhia* was a regulated pest at the time of this assessment (USDA 2020).
- *Planococcus kraunhia* is absent in European countries, but it is not in the EPPO A1 or A2 list of pests recommended for regulation as quarantine pests (EPPO 2020a and 2020b).

Planococcus kraunhia has been reported on a plant species under a genus that has a native representative in New Zealand (NZPCN 2020); the native species under this genus has an 'at risk' conservation status.

- *Digitaria sanguinalis* (family: Poaceae) is a host of *P. kraunhia* (García et al. 2016). In New Zealand, the indigenous plant species *Digitaria setigera*, has 'at risk-naturally uncommon' conservation status (NZPCN 2020). It is locally common in the northern Kermadec Islands, but has only been collected on the mainland islands once some time between 1838 and 1840 from the Bay of Islands. The impact of *P. kraunhia* on this plant species is likely to be low.

Planococcus kraunhia may have an impact on the urban environment and may have indirect health impacts for humans.

- *Planococcus kraunhia* is damaging to a number of plants grown in domestic gardens (e.g. *Vitis* spp., *Citrus* spp., persimmons, figs) and ornamentals in parks. Therefore, it is a potential nuisance pest in the urban environment. Also, it could be more problematic in protected environments (e.g. houseplants and nurseries) where parasitoids do not have easy access to them. Parasitoids known to affect *P. kraunhia* are not known to be released in nurseries in New Zealand.
- *Planococcus kraunhia* may indirectly have some impact on human activities. *Vespula* wasps are attracted to honeydew excreted by some insects, and high numbers of wasps in recreational, urban or other areas may adversely impact on health (painful stings or allergy to stings) and social activities (MAF 2008). However, as many sap-sucking insects are already present in New Zealand that can produce honeydew, the impact maybe minor to negligible.

The level of uncertainty associated with the conclusion is considered moderate. Many studies from Japan have reported its impacts on persimmons, and low to moderate fruit damage has been reported. There is one report from 2010 from South Korea on its severe impact on pears. Most of these reports are either in Japanese/Korean or not accessible. Although most key information was extracted from English abstracts, machine translation (Google Translate) has been used to interpret the content of some texts, and as such, very high accuracy in interpretation cannot be guaranteed.

Risk assessment summary:

Given the arguments and evidence below, *Planococcus kraunhia* may be considered for additional measures.

- *Planococcus kraunhia* has a strong host association with citrus fruit.
- *Planococcus kraunhia* is present in exporting countries.
- *Planococcus kraunhia* is small and cryptic. As such, in low population densities or as individuals, detection can be difficult if the commodities have sheltered places for them to hide (e.g. under the calyx or potentially in the navel of navel oranges).

- The ability of *P. kraunhiae* to move from imported fruit and into a suitable environment to allow establishment is limited.
- Disposal to landfill, which is a low-risk disposal method, is the major way of disposing of kitchen waste in New Zealand, while disposal using high-risk methods (composting and animal feeding) is less common.
- Some kitchen waste is likely to be disposed of using high-risk methods, and the mealybug is polyphagous, which increases the probability that suitable hosts would be present in the surrounding environment.
- *Planococcus kraunhiae* is distributed in both tropical and temperate areas including areas with similar climate conditions to New Zealand.
- The climate suitability of the New Zealand environment for the establishment of *P. kraunhiae* is high.
- The level of impact is considered moderate, because there are many reports on its damage and control methods in persimmon orchards in Japan, and a low-to-moderate level of fruit damage on pears has been reported from Korea. No report has been found on production loss of citrus due to this mealybug species.

9.2.4 References

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9.3 *Planococcus minor* (Pacific mealybug)

Planococcus minor is a species of mealybug of Asian origin, but it is the most widespread mealybug in the South Pacific area as an exotic species. Adult females are wingless and oval, about 1.3–3.2 mm long and 0.8–1.9 mm wide, and they are covered in a white, powdery, waxy secretion. Males are minute and winged, without functional mouthparts.

Scientific name: *Planococcus minor* (Maskell, 1897)

Order/Family: Hemiptera/Pseudococcidae

Other names include: *Dactylopius calceolariae minor*, *Pseudococcus calceolariae minor*, *Planococcus pacificus*, *Planococcus psidii*, passionvine mealybug, guava mealybug (EPPO 2020; García et al. 2016)

Taxonomic notes: *Planococcus minor* is very similar to *P. citri* and has been routinely misidentified due to similarity in appearance, host plant range and geographic distribution (Roda et al. 2013). Distinction usually requires the expertise of a taxonomist, and good preparations are needed to count the oral collar tubular ducts at the anterior end of the body (Williams 2004). Williams (1982, in Cox 1989) comments that most records of *P. citri* from the South Pacific Islands are misidentifications of *P. minor*.

Summary of conclusions

Given the arguments and evidence presented:

- *Planococcus minor* meets the criteria to be a quarantine pest for New Zealand.
- *Planococcus minor* has a strong association with citrus fruit with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *P. minor* by a moderate degree. Consequently, the likelihood of entry is considered to be low with low uncertainty.
- *Planococcus minor* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.
- The suitability of the New Zealand environment for *P. minor* to establish is considered low–moderate (with moderate–high uncertainty), and establishment is likely to be limited to warmer areas.
- The level of impact caused by *P. minor* is likely to be low to moderate (with high uncertainty).
- *Planococcus minor* may be considered for requiring additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low	High
Suitability of the New Zealand environment	Low–moderate	Moderate–high
Impacts on the New Zealand economy, environment, health and society	Low–moderate	High

9.3.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Planococcus minor* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁸⁶).

Planococcus minor is not known to be present in New Zealand:

- It is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- It is listed as 'Regulated' in ONZPR (2020).

Planococcus minor has the potential to establish and spread in New Zealand:

- *Planococcus minor* is present in Africa, Asia, North America, Central America and Caribbean, South America, Europe (only Madeira, Portugal) and Oceania (CPC 2020).
- *Planococcus minor* is predominantly distributed in tropical and subtropical areas, but its distribution has extended to temperate areas. The current distribution includes areas (e.g. Uruguay and New South Wales, Australia) with similar climatic conditions to New Zealand.
- *Planococcus minor* is polyphagous. It has been reported on 73 families and 196 genera of plants (García et al. 2016).
- Host plants include those commercially grown in New Zealand and those commonly grown in gardens and parks, which include but are not limited to citrus (*Citrus* spp.), capsicums (*Capsicum* spp.), tomatoes (*Solanum lycopersicum*), potato (*S. tuberosum*), sweet corn (*Zea mays*), cucumber (*Cucumis sativus*), fig (*Ficus carica*), camellias (*Camellia sinensis*) (CPC 2020; García et al. 2016)

Planococcus minor has the potential to cause impacts on the economy and environment of New Zealand:

- *Planococcus minor* has the potential to harm plants of economic importance to New Zealand. Host plant species of the mealybug include important agricultural plants in New Zealand, such as citrus, sweet corn, tomato, potato, cucumber, squash and grapevine.
- *Planococcus minor* has the potential to harm the New Zealand environment. The mealybug has been reported on plant species in genera that are native to New Zealand.

9.3.2 Hazard identification: commodity association

Planococcus minor is associated with citrus fruit.

Planococcus minor is reported from citrus fruit:

- It has been intercepted on citrus fruit 44 times (38 live) at the New Zealand border (LIMS 2019).
- *Planococcus minor* is considered a major pest on *Citrus* in Taiwan (Ho et al. 2007).

9.3.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Planococcus minor* has a strong association with citrus fruit, with low uncertainty:

Planococcus minor has been intercepted on citrus fruit at the border.

- It has been identified 321 times at the New Zealand border, among these records, 44 records were on citrus fresh produce (lime, Tahitian lime, orange, grapefruit and pomelo) from various exporting countries (Australia, Ecuador, New Caledonia, Samoa, the USA and Vanuatu) from 1929 to March 2019 (LIMS 2019). Of these 44 records, 29 records were from the last decade.
- Of these 44 border identifications on citrus fresh produce, 38 identifications were live *P. minor*, indicating that it can survive post-harvest and transit processes on these citrus fruits.

⁸⁶ Refer to ISPM 5 for the definition of a quarantine pest under the IPPC, and the Biosecurity Act 1993, for factors to consider when defining "harm".

- The most intercepted life stage is adults, but eggs and nymphs have also been intercepted at the border.

Planococcus minor has been recorded as a major pest of *Citrus*.

- It has been recorded as a major pest of a range of crops in Taiwan, including *Citrus* (Ho et al. 2007), although the reference does not mention whether the pest was on fruit.

Citrus species/cultivars found to be associated with *P. minor* are shown in Table 10.3.1.

Table 10.3.1 Known citrus fruit host association with *Planococcus minor*

Citrus host scientific name	Citrus host common name from the reference	Reference	Notes
<i>Citrus aurantiifolia</i>		García et al. (2016)	
<i>Citrus aurantium</i>		García et al. (2016)	
<i>Citrus reticulata</i>	Mediterranean mandarin	CPC (2020)	
<i>Citrus hystrix</i>		Chen et al. (2013)	
<i>Citrus latifolia</i>		LIMS (2019)	Interception on fruit
<i>Citrus limon</i>		García et al. (2016)	
<i>Citrus maxima</i>		García et al. (2016)	
<i>Citrus reticulata</i>		García et al. (2016)	
<i>Citrus paradisi</i>		LIMS (2019)	Interception on fruit
<i>Citrus maxima</i>	Pomelo	LIMS (2019)	Interception on fruit
<i>Citrus sinensis</i>	Orange / Navel orange	LIMS (2019)	Interception on fruit
<i>Citrus paradisi</i>	Grapefruit	LIMS (2019)	Interception on fruit

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *P. minor* by a moderate degree. Consequently, the likelihood of entry is considered low, with low uncertainty:

Usually, visual inspection can detect infestations of *P. minor* on citrus fruits.

- Some typical signs that indicate the presence of *P. minor* on fruit can be wet patches (of honeydew) and sooty mould, and waxy material produced by the mealybug (Roda et al. 2013).

However, in low population densities or as individuals, if the commodities have a complex structure, detection of *P. minor* on citrus fruit can be difficult.

- *Planococcus minor* is small. Adult females are approximately 1.3–3.2 mm, and nymphs and eggs are even smaller than the adult female (Roda et al. 2013). Early instar nymphs are pinkish and likely to be more difficult to detect as they have less waxy covering. As such, detection of *P. minor* will require careful inspection with a good eye or magnifier.
- Mealybugs are cryptic. In the field, *Planococcus minor* are rarely found in direct sunlight, and they are often found on the underside of leaves, inside the calyx of sepals, in axils or under bark (Roda et al. 2013). As such, *P. minor* may be able to hide in the calyx of fruit, wrinkles around the calyx or in the navel of navel oranges.

General handling after harvesting may not be able to remove and detect all mealybugs if commodities have protected places for *P. minor* to hide.

- *Planococcus minor* is commonly found in protected places (Mani and Shivaraju 2016), which reduces the likelihood of detection and the effectiveness of insecticides. This distribution is likely to be the result of behaviours such as thigmotaxis and negative phototaxis that have been reported in crawlers of other coccoid species (diaspidids and other pseudococcids) (Nestel et al. 1995, Geiger and Daane 2001).

- The wax covering over a mealybug's body can repel aqueous solutions, which reduces the likelihood of removal of the mealybug during commodity handling (e.g. washing and pesticides) (Hollingsworth and Hamnett 2009).
- Although early instar nymphs have less of the wax covering to protect them from insecticides and washing, it is easier for them to hide in sheltered places because of their smaller size and higher mobility than other life stages (except male adults, which are winged (Roda et al. 2013)).
- Adult males are winged and the first instar nymphs are very mobile. Other life stages are less mobile when they are on suitable food sources (Williams 2004). As such, they are less likely to get off the commodity during handling.
- *Planococcus minor* has been identified over 44 times at the New Zealand border on citrus fresh produce (LIMS 2019). It has also been identified over 1990 times on various hosts from over 30 countries between 1995 and 2012 at the US border (Wistermann et al. 2016).

Likelihood of establishment:

Given the arguments and evidence below, *Planococcus minor* has low ability (with high uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure).

Planococcus minor may survive on the waste of citrus fruits (whole fruit or fruit pieces).

- A laboratory experiment showed that *P. minor* can survive when reared on oranges. The duration of the nymphal stage of female *P. minor* is approximately 22.8 days at approximately 25°C; the number of eggs per adult female is approximately 49.4; nymphal mortality is 33.3% (de Souza et al. 2018).
- Although not specifically for *P. minor*, other mealybug species have been reported to be able to resist desiccation and starvation (Abbs 2010; Barrass et al. 1994).

Most of the kitchen waste in New Zealand would be disposed of using low-risk methods, so the mealybug would either be killed or be unable to escape from the citrus host.

- The majority of kitchen waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units, and in these situations, the mealybug is unlikely to reach a new host (see the waste analysis, section 2.4.1).

However, some waste is disposed of using high-risk methods, including composting in gardens and using as animal feed.

- *Planococcus minor* is polyphagous, and some host plants are commonly planted in home gardens, such as tomato, citrus, grapevine and pear. *Planococcus minor* has been reported on a common weed species, *Saccharum officinarum* (García et al. 2016). If these hosts are located near the composting site (see the waste analysis, section 2.4.1), some life stages of *P. minor* may be able to transfer from the citrus host to the new host.

Planococcus minor has relatively limited mobility, and except for the first-instar nymphs (crawlers) and adult males, life stages tend to be sessile while they are on a suitable food source.

- The primary dispersal stage of *P. minor* is the crawlers. Crawlers of *P. minor* are very mobile, and may disperse over the plant host, especially toward tender, growing parts. This implies that dispersal via walking can only result in short-distance dispersal (Roda et al. 2013) (i.e. within original host plants or nearby plants). While other life stages are able to move, they tend to be stationary or may move limited distances (Kosztarab and Kozár 2012). If citrus fruit waste (whole fruit or fruit pieces) (see the waste analysis, section 2.4.1) is disposed of in an environment with suitable living hosts nearby, for example compost and animal feed, the crawlers may be able to walk to the nearby host after the fruit is no longer a suitable food source.

Mealybug species can be dispersed passively, which is also considered an important mechanism contributing to the spread of mealybugs, and the polyphagous nature of *P. minor* is likely to increase the likelihood of landing on a suitable host. No species specific data are available for *P. minor*, but its dispersal capacity is likely to be similar to other Pseudococcidae.

- Mealybugs can be passively dispersed by winds, water, fallen leaves, phoresy (attached to birds, ants, other insects, etc.) and movement of farm equipment, soil and infested plant material (although no specific study has been carried on *P. minor*). However, long-distance movement of the mealybug is most likely due to the movement of infested nursery stock and agricultural commodities (Mani and Shivaraju 2016).
- Passive dispersal by wind is considered an important mechanism contributing to the colonisation of new areas by mealybugs (Lo et al. 2006). Nymphs (mainly first instars) and adult males (only in insignificant numbers) of mealybugs have been recorded to be able to disperse by wind for short, moderate and presumably long distances:
 - The first- and second-instar nymphs, as well as adult males, of the grape mealybug, *Pseudococcus maritimus*, can be dispersed by wind, but there is a marked decline in numbers with increasing distance from the source plant (Grasswitz et al. 2008). The crawlers can be dispersed up to 8 m in this study. Among the mealybugs being dispersed by winds, 86.3% were crawlers, 10.8% were second instars and 2.9% third instars.
 - Lo et al. (2006) conducted a field trial using aerial trapping to catch mealybugs in a New Zealand vineyard that were dispersed by wind. Crawlers and a small number of adult males were caught in these traps, and they found that mealybugs can be blown at least 5 m and up to 15 m.
 - Based on 24-hour wind-run values, Barrass et al. (1994) presumed that the crawlers of *Pseudococcus longispinus* could disperse across distances greater than 50 km, although it has not been tested in scientific studies.
 - Barrass et al. (1994) also found that the survival rate for the crawlers of *Ps. longispinus* held at 20°C and 32% relative humidity for 48 hours was 75%, suggesting that the crawlers are capable of surviving desiccation for long enough to make wind currents a viable method of dispersal.
 - Lo et al. (2006) also estimated that in the six weeks before mid-April, there were 2.5 million crawlers/ha in the air above the mealybug-infested vineyard.
 - Barrass et al. (1994) also found that the numbers of mealybugs caught in aerial traps increased directly with wind speed and with the square of the daily temperature maximum, which implies that dispersal of mealybugs by wind in areas with high wind speeds and temperature is likely to be more frequent.
 - Some coccoid species are known to deliberately move to high points of their host plants in order to disperse (Brown 1958, Beardsley and Gonzalez 1975, Greathead 1990, Lo et al. 2006). Washburn and Washburn (1984) showed that crawlers of the coccid *Pulvinariella mesembryanthemi* (Vallot) deliberately entered the air, not only by moving up the plant but by orienting their bodies most favourably to the air current and standing on their hind legs. However it is important to note that most studies of crawler dispersal have been carried out using insects on their host plants, and that information about dispersal of crawlers from situations comparable to a piece of discarded fruit is scarce.
- Passive dispersal cannot guarantee *P. minor* will land on a suitable host, but the polyphagous nature of *P. minor* is likely to increase the likelihood of landing on a suitable host.
- However, passive dispersal also means that successful transfer will depend on other factors in addition to the presence of hosts, such as wind speed, whether animals are present and the survival rates of the mealybug during passive dispersal, which are considered uncertain at this stage.

Successful establishment of *P. minor* requires at least one mature female and one male successfully transferring to the same host, or a female carrying fertilised eggs.

- *Planococcus* species are able to mate with their siblings in the laboratory (e.g. Ross et al. 2012, García de la Filia et al. 2019) and it is assumed this also occurs in the field, though there may be behavioural or other constraints against sibling mating (Müller and Müller 2016, Collet et al. 2019).
- *Planococcus minor* is known to be biparental (CPC 2020), which means successful establishment requires at least one female and one male located at the same host or in a close distance, or a female carrying fertilised eggs.
- Females can produce sex pheromone to attract males (Ho et al. 2007), but it is uncertain how far adult males can fly to locate a mature female.
- Adult males of mealybug species only live for a few days (Williams 2004).

The level of uncertainty associated with the conclusion is high. First, waste data may not be very accurate and up to date, and it is not known how frequently suitable hosts would be present near composting sites in gardens or animal feeding locations (see Chapter 2 waste analysis). Second, it is reported that dispersal by wind is an important mechanism for the spread of mealybugs, but it is not known how efficient (compared to dispersal by walking) this dispersal method is, and it is uncertain what proportion of composting sites are exposed or concealed (e.g. in a compost bin).

Given the arguments and evidence below, the suitability of the New Zealand environment for *P. minor* to establish is considered low to moderate (with moderate to high uncertainty), and establishment is likely to be limited to warmer areas.

Planococcus minor is mainly distributed in tropical and subtropical areas, but its distribution has extended to temperate areas.

- *Planococcus minor* is predominantly distributed in tropical and subtropical areas (Table 10.3.2).

Table 10.3.2 Known geographic distribution of *Planococcus minor*. Information compiled 29 May 2020 from García et al. (2016) and EPPO (2020), unless specified. Country/area with underline is only recorded in García et al. (2016). Country/area in **bold** is included in the *Citrus* IHS project.

Continent /Region	Country/area
Africa	<u>Ascension Island</u> , Comoros, Madagascar, Mauritius, Seychelles
Asia ^a	<u>Bangladesh</u> , Brit. Indian Ocean Terr., Brunei, Burma (=Myanmar), China (Hong Kong) , <u>Christmas Island</u> , Hong Kong, <u>India</u> , <u>Indonesia</u> , <u>Kampuchea</u> , <u>Malaysia</u> , <u>Maldives</u> , <u>Philippines</u> , Singapore, Sri Lanka, Taiwan, Thailand, Viet Nam
North America	Bermuda, Guadeloupe, Mexico , United States (Florida, California ^b)
Central America and Caribbean	<u>Barbuda</u> , <u>Bahamas</u> , <u>Costa Rica</u> , <u>Cuba</u> , <u>Dominica</u> , <u>Grenada</u> , <u>Guatemala</u> , <u>Guadeloupe</u> , <u>Haiti</u> , <u>Honduras</u> , <u>Jamaica</u> , <u>Saint Lucia</u> , <u>Trinidad and Tobago</u> , <u>United States Virgin Islands</u>
South America	<u>Argentina</u> , Brazil , <u>Colombia</u> , <u>Ecuador</u> (Galapagos Islands), <u>Guyana</u> , <u>Suriname</u> , <u>Uruguay</u>
Europe	Portugal (Madeira)
Oceania	<u>American Samoa</u> , Australia (New South Wales , Northern Territory , Queensland , South Australia (including Adelaide ^c), Australian Capital Territory ^c), Cook Islands , <u>Fiji</u> , <u>French Polynesia</u> , <u>Kiribati</u> , New Caledonia , <u>Papua New Guinea</u> , Samoa , Solomon Islands , Tokelau, <u>Tonga</u> , Vanuatu , <u>Wallis and Futuna Islands</u>

^a Japan is recorded as “CABI Data Mining (Undated)” (CPC 2020) but is not recorded in García et al (2016) and EPPO (2020). A search was conducted in CAB Abstract, no report indicates that *P. minor* is present in Japan. There is one literature reporting that *P. minor* was intercepted in Japan during import inspection (Suqimoto 1994).

^b This record is from Wistermann et al. (2013).

^c The records of Adelaide and Australian Capital Territory are from ALA (2020).

- *Planococcus minor* is of Asian origin, and it is the most widespread mealybug in the South Pacific area.
- The current distribution includes countries and areas with climate match index (CMI) (Phillips et al. 2018) of 0.7–1, which means these areas have a 70%–100% similarity of climate to the general New Zealand climate. These areas include Argentina (CMI ranges from 0.6 to 0.9), Uruguay (0.7–0.9), California (0.6–0.8), New South Wales (0.7–1), Adelaide (0.8–0.9), Australian Capital Territory (0.9) and South Australia (0.5–0.8). This implies that the mealybug species or some populations of the mealybug may adapt to colder temperate climates.

It is uncertain if the mealybug can survive or complete development in the colder areas in New Zealand.

- Cold tolerance and overwintering mechanisms for *P. minor* are uncertain. The only information found on it is a laboratory experiment, which reported that no eggs of *P. minor* hatched at 15°C (Francis et al. 2012).

- As *P. minor* is present in areas with similar climate conditions to New Zealand, it may have an overwintering strategy. *Planococcus minor* is very similar to *P. citri* in terms of appearance, host plant range and geographic distribution. *Planococcus citri* overwinters primarily as eggs on the upper roots, trunk and lower branches of the host plant. Some mealybug species are known to overwinter in the soil or on the host plant (Roda et al. 2013). In addition, many mealybug species are cold-resistant (DAWR 2019).

Host availability is unlikely to be a limiting factor for the mealybug to establish in New Zealand.

- *Planococcus minor* is polyphagous. It has been reported from 73 families and 196 genera of plants (García et al. 2016).
- Host plants include those commercially grown in New Zealand and those commonly grown in gardens and parks, such as citrus, capsicums, tomato, potato, pears, sweet corn, cucumber, grapevine, fig, camellias, eucalypts (*Eucalyptus* spp.), roses (*Rosa* spp.). Common weed, *Saccharum officinarum*, is also a reported host (García et al. 2016).

Planococcus minor is predominantly distributed in warmer areas, but it is also present in areas/countries (Argentina, New South Wales, Adelaide and Australian Capital Territory) with similar climate conditions to New Zealand. These areas occupy a very small proportion of the known distribution. Also, the cold tolerance and overwintering strategy of *P. minor* is unknown. Therefore, the level of uncertainty associated with the conclusion is moderate to high.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *P. minor* is likely to be low to moderate (with high uncertainty).

Damage caused by *P. minor* can reduce yield and plant or fruit quality.

- *Planococcus minor* is sap-sucking insect. Damage due to the feeding can reduce yield and plant or fruit quality and causes stunted growth, discoloration/yellowing and leaf loss (Venette and Davis 2004, in Roda 2013). High density of the mealybug can even kill perennial plants (Krishnamoorthy and Singh 1987; Walton et al. 2006 in Roda 2013; Ben-Dov 1994). However, high density of *P. minor* is less likely to occur in cooler areas such as much of New Zealand.
- During low infestation, the mealybug can still be a serious pest, as it is a vector of virus diseases (e.g. *Piper yellow mottle virus* and *Banana streak virus*) that could cause plant death (Cox 1989; de Sousa et al. 2011; Francis 2011). *Piper yellow mottle virus* and *Banana streak virus* are badnaviruses that are transmitted by mealybugs in a semi-persistent manner (Bhat et al. 2016).
- *Planococcus minor* excretes honeydew, which can lead to growth of sooty mould that builds up on the leaves, shoots, fruits and other plant parts (Mittler and Douglas 2003, in Roda 2013). These moulds interfere with the plant's normal photosynthetic activity, which affects plant growth. Honeydew and sooty mould also cause cosmetic defects to plants and their fruits.

Reports on the economic impact or damage caused by *P. minor* are focused on crops grown in warmer areas, while there is a lack of reports on the quantified economic impact of *P. minor* in temperate areas or countries with similar climate conditions to New Zealand or quantifying the impact.

- Reports on the economic impact or damage caused by *P. minor* are focused on crops grown in warmer areas, such as coffee (*Coffea* sp.), cacao, cotton and custard apple from Brazil, Taiwan, Papua New Guinea, Trinidad and India. Stevens (1996, in Williams and Watson 1988) recorded *P. minor* as *P. citri*, which formed over 90% of a mixed population of Coccoidea, caused a 70–75% reduction in yield on coffee.
- It is considered as a major pest of banana, citrus, mango, celery, guava, melon (*Benincasa* spp.), pumpkin (*Cucurbita* spp.) and passionvine (*Passiflora* spp.) in Taiwan (Ho et al. 2007), where has CMI from 0.4–0.8. It is also found on grapevine in Uruguay (CMI: 0.7–0.9) (Wistermann et al. 2016). It is also reported as a serious pest of grapevine in California and occasional pest of citrus (Wistermann et al. 2016). However, no reports have been found quantifying the incidence and yield loss due to the mealybug on these hosts.

- Some of the hosts are important commercial crops planted in New Zealand, such as citrus, grapevine, tomato and pear.
- A couple of predatory ladybird beetles (*Cryptolaemus* and *Scymnus*) that can prey on *P. minor* are present in New Zealand.

Planococcus minor can transmit *Banana streak virus* (BSV) (absent from New Zealand), which can cause serious damage to banana crops, which in turn may cause impact on bananas grown in New Zealand. BSV may also attack *Heliconia* in gardens and parks.

- A banana plantation is under development in Northland, New Zealand (Kissun 2019), but no reports were found on the potential value of this crop in New Zealand, although it is likely to be low in terms of the overall economy.
- BSV is absent from New Zealand (PPIN; Veerakone et al. 2015). The transmission efficiency of *P. minor* is 17.2% (Arias and Miranda 2002).
- In Australia, infection of BSV can result in an 18-day delay in harvest and a 6% loss of yield annually (Daniells et al. 2001).
- BSV has the potential to impact *Heliconia* in gardens and parks (CPC 2019).

Establishment of *P. minor* may result in increased phytosanitary measures required for export to countries where the pest is absent.

- Most of the countries in temperate areas have not been reported to have the mealybug.

Planococcus minor has hosts in plant genera with native New Zealand plant species, and plant species under some of these genera have at risk or threatened conservation status.

- Some of the species in these genera are native to New Zealand, such as *Apium prostratum* subsp. *prostratum* var. *filiforme*, *Schefflera digitata*, *Cyperus ustulatus*, *Isolepis prolifera*, *Pelargonium inodorum*, *Vitex lucens*, *Dysoxylum spectabile*, *Piper excelsum* subsp. *excelsum* and *Solanum opacum* (NZPCN 2020).
- Some of the species in these genera have 'at risk' or 'threatened' conservation status in New Zealand, including *Apium prostratum* subsp. *denticulatum*, *Ipomoea cairica*, *Ipomoea pescaprae* subsp. *brasiliensis*, *Corynocarpus laevigatus*, *Cyperus insularis*, *Euphorbia glauca*, *Hibiscus diversifolius* subsp. *diversifolius*, *Hibiscus richardsonii*, *Syzygium maire*, *Piper excelsum* subsp. *delangei*, *Piper excelsum* subsp. *peltatum*, *Piper excelsum* subsp. *psittacorum*, *Piper melchior*, *Solanum americanum*, *Solanum aviculare* var. *aviculare*, *Solanum aviculare* var. *latifolium* and *Solanum laciniatum* (NZPCN 2020).
- As no report was found on the impact of the mealybug on native plants, the damage level on New Zealand native plant species is uncertain. It should be noted that relatively few non-indigenous invertebrates and pathogens have been recognised as causing serious damage to terrestrial natural ecosystems globally (Phillips et al. 2008), and in the New Zealand context only a few substantial pest and disease outbreaks affecting native plants have been documented (Beever et al. 2007).

Planococcus minor may have sociocultural and human health consequences.

- *Planococcus minor* is damaging to a number of plants grown in domestic gardens and parks, such as *Vitis* spp., *Prunus* spp., *Citrus* spp. and *Malus* spp. Therefore, it is a potential nuisance pest in urban environment. Also, it could be more problematic in protected environments (e.g. houseplants and nurseries) where parasitoids do not have easy access to them.
- *Planococcus minor* may indirectly have some impact on human activities. *Vespula* wasps are attracted to honeydew excreted by some insects, and high numbers of wasps in recreational, urban or other areas may adversely impact on health (painful stings or allergy to stings) and social activities (MAF 2008). However, as many sap-sucking insects are already present in New Zealand that can produce honeydew, the impact may be minor to negligible.

Due to the lack of reports quantifying the economic and environmental impact of *P. minor*, and the uncertainty of whether the pest is present outdoors or indoors in those areas with similar climate condition to New Zealand, the level of uncertainty associated with the conclusion is high.

Risk assessment summary:

Given the arguments and evidence below, *Planococcus minor* may be considered for additional measures.

- *Planococcus minor* has a strong host association with citrus fruit.
- *Planococcus minor* is present in several exporting countries.
- *Planococcus minor* is small and cryptic. As such, low infestation would be difficult to detect.
- The ability of *P. minor* to move from imported fruit and into a suitable environment to allow establishment is low, but with high uncertainty.
- *Planococcus minor* have relatively low mobility: except for the crawler stage and male adult, life stages tend to be stationary.
- Disposal to landfill, which is a low-risk disposal method, is the primary way of disposing of kitchen waste in New Zealand, while disposing using high-risk methods (composting and animal feeding) is less common.
- Some kitchen waste is likely to be disposed of using high-risk methods, and the mealybug is polyphagous, which increases the probability that suitable hosts would be present in the surrounding environment.
- *Planococcus minor* is predominantly distributed in tropical/subtropical areas, but also present in areas with similar climate conditions to New Zealand. The suitability of the New Zealand environment for *P. minor* to establish is considered low to moderate, with moderate to high uncertainty, and establishment is likely to be limited to warmer areas.
- The economic impact is considered low to moderate with high uncertainty, because there is a lack of reports found on quantified economic impact of *P. minor* in temperate areas.

9.3.4 References

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10. Insects: Hemiptera, Psylloidea (psyllids)

10.1 *Diaphorina citri* (Asian citrus psyllid)

Diaphorina citri is a small (around 3 mm long) psyllid that damages plant tissues directly through its feeding activities and indirectly through vectoring '*Candidatus Liberibacter asiaticus*' and other liberibacter species that cause huanglongbing (HLB) (also known as citrus greening) (Grafton-Cardwell et al. 2006, CABI 2020).

Scientific name: *Diaphorina citri* Kuwayama, 1908

Order/Family: Hemiptera/Liviidae

Other names include: Asian citrus psyllid (ACP), citrus psyllid

Taxonomic information: *Diaphorina citri* is one of the psyllid vectors of the causal agents of the serious citrus disease HLB, also known as citrus greening.

HLB is associated with three liberibacter species, '*Candidatus Liberibacter africanus*', '*Ca. americanus*' and '*Ca. L. asiaticus*' (Gottwald 2010). '*Ca. L. asiaticus*', which is the most prevalent bacteria, is associated with Asian HLB which is the most widespread form of the disease. '*Ca. L. africanus*' is associated with the African form of HLB and '*Ca. L. americanus*' with the American form of HLB. Recently, a new strain provisionally named '*Ca. L. caribbeanus*' has been reported that may cause HLB-like symptoms in citrus (Keremane et al. 2015). The liberibacter are found in the phloem of the plant host. They are transmitted naturally by two psyllid vectors: *Diaphorina citri* and *Trioza erytreae* (Bove 2006). *D. citri* vectors '*Ca. L. americanus*' and '*Ca. L. asiaticus*' naturally and is capable of transmitting '*Ca. L. africanus*', experimentally at least (Gottwald 2010; Bove 2006). *Trioza erytreae* transmits '*Ca. L. africanus*' under natural conditions, and it has been shown experimentally that *T. erytreae* is able to transmit '*Ca. L. asiaticus*' (Gottwald 2010).

Note:

A related species, *Diaphorina communis* (Mathur 1975) occurs occasionally on citrus (Halbert and Manjunath 2004). It was first described from *Murraya koenigi* in Uttar Pradesh in northern India and has since been reported in Bhutan, where it was found on mandarin trees that showed symptoms of huanglongbing (HLB) caused by '*Candidatus Liberibacter asiaticus*' (Donovan et al. 2012). The presence of '*Ca. L. asiaticus*' in adult *D. communis* was confirmed by conventional and real-time PCR, indicating the potential for this species to act as a vector of the disease, but transmission has not yet been confirmed (Donovan et al. 2012). However, this psyllid species is not known to occur in any of the potential citrus-exporting countries considered in this import risk assessment.

Summary of conclusions

Given the arguments and evidence presented:

- *Diaphorina citri* meets the criteria to be a quarantine pest for New Zealand.
- *Diaphorina citri* has a strong association with citrus, but a weak association with citrus fruit (with low uncertainty).
- Basic measures are likely to reduce the likelihood of entry by a high degree (with low uncertainty); consequently, the likelihood of entry is considered to be low (with low uncertainty).
- The ability of *D. citri* to move from imported fruit to a suitable host plant is high (with low uncertainty).
- The suitability of the New Zealand environment for *D. citri* to establish is considered moderate (with low uncertainty).
- The level of impact caused by *D. citri* is likely to be low to moderate for New Zealand overall (with low uncertainty), but moderate to high for the citrus industry (with low uncertainty), depending on the presence of the citrus disease HLB, with at least two of the causal agents being vectored by *D. citri*.
- *Diaphorina citri* may be considered for additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Weak	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	High	Low
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society, depending on presence of HLB	Low-moderate	Low

10.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Diaphorina citri* meets the criteria to be a quarantine pest for New Zealand

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Diaphorina citri is not known to be present in New Zealand.

- *Diaphorina citri* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- The quarantine status of *D. citri* in New Zealand is 'regulated', and it is an unwanted organism (ONZPR 2020).

Diaphorina citri has the potential to establish and spread in New Zealand.

- *Diaphorina citri* is widespread throughout Asia and occurs in North, Central and South America, Africa and Oceania (Table 11.1.2) (Halbert and Nunez 2004; Grafton-Cardwell et al. 2006; EPPO 2020; CABI 2020).
- Some of the areas where *D. citri* occurs have a high climate match with New Zealand, with a climate match index (CMI) of 0.7 or greater (Phillips et al. 2018), indicating the potential to establish in New Zealand:
 - For example, Yunnan and Sichuan (mostly 0.7-0.8 CMI) in China; Uruguay (0.8–0.9 CMI).
- There are suitable host species (*Citrus* spp.) present in areas of New Zealand that are likely to be climatically suitable for *D. citri*.

Diaphorina citri has the potential to cause economic impacts in New Zealand.

- *Diaphorina citri* has the potential to damage citrus, which is of economic importance to New Zealand, both through direct feeding damage and by vectoring liberibacter species that cause the citrus disease huanglongbing (HLB).
- Losses relating to establishment of *D. citri* are likely to result from loss of market access for *Citrus* in those countries free from HLB.

10.1.2 Hazard identification: commodity association

Diaphorina citri is associated with citrus fruit.

Diaphorina citri is reported from citrus fruit:

- A study by Halbert et al. (2010) showed that *D. citri* can be transported with harvested citrus fruit. Live adults (509 psyllids) were collected from seven trailers, from the tops and sides of the loads up to 30 cm below the surface of the oranges, suggesting they were distributed throughout the loads. The psyllids were seen resting on the fruit itself rather than on the minimal amount of foliage that was present (Halbert et al. 2010).

- High numbers of *D. citri* adults were intercepted in boxes of fresh unprocessed citrus fruit (grapefruit) picked in the Bahamas and shipped to Ft. Pierce, Florida, for processing in 2001 (Halbert and Nunez 2004).

10.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Diaphorina citri* has a strong association with citrus, but a weak association with citrus fruit.

Although the life stages of *D. citri* feed on young tender foliage, adults that have been disturbed may seek refuge on citrus fruit.

- All life stages of *D. citri* are found on foliage. Females oviposit within 2-cm lengths of the terminal tissue in leaf folds, on petioles, axillary buds, upper and lower surfaces of young leaves and tender stems (Tsai and Liu 2000). Nymphs undergo five instar stages, feed only on soft, young plant tissue and excrete wax and honeydew. They are found on immature leaves, stems and flowers of citrus and are sedentary, but will move if disturbed or overcrowded. Adults feed on both new growth and mature citrus flush (Grafton-Cardwell and Daugherty 2018; Childers and Rogers 2005). Mature fruits are not considered suitable feeding sites for any life stage of *D. citri*.
- Adults are easily disturbed and will jump or fly a short distance (Tsai and Liu 2000). Adults of *D. citri* that have been disturbed may seek refuge on citrus fruit. Live adults have been intercepted on harvested citrus fruit being transported by trailer and by ship for processing (Halbert and Nunez 2004; Halbert et al. 2010).

Diaphorina citri infests many citrus species and varieties:

- Host plants for *D. citri* are confined to the Rutaceae and include *Citrus* spp. (Table 11.1.1) and many close citrus relatives. Well-known hosts include *Murraya paniculata* (orange jasmine) and *Murraya koenigii* (curry leaf) (Halbert and Manjunath 2004).
- Based on Aubert (1987), there are at least 21 species on which *D. citri* can feed, but egg-laying and nymphal development are restricted to 15 and 14 hosts, respectively (Biosecurity Australia 2011).

Table 11.1.1. *Citrus* spp. recorded as hosts for *Diaphorina citri* by EPPO (2020) and Halbert and Manjunath (2004)

Botanical name	English common name as given in EPPO (2020)	Reference
<i>Citrus reticulata</i>	Djeruk lime, Nasnaran mandarin	EPPO 2020: Westbrook et al. 2011
<i>Citrus aurantiifolia</i>	Key lime, Lime, Mexican lime, West Indian lime	EPPO 2020: Aubert 1990; Westbrook et al. 2011
<i>Citrus aurantium</i>	Bigarade, Bitter orange, Seville orange, Sour orange	EPPO 2020: Tsai and Liu 2000; Westbrook et al. 2011
<i>Citrus australasica</i>	Australian finger lime	EPPO 2020: Westbrook et al. 2011
<i>Citrus australis</i>	Australian round lime	EPPO 2020: Westbrook et al. 2011
<i>Citrus reticulata</i>	–	Halbert and Manjunath 2004
<i>Citrus halimii</i>	–	EPPO 2020: Westbrook et al. 2011
<i>Citrus paradisi</i>	Hassaku orange	EPPO 2020: Westbrook et al. 2011
<i>Citrus hystrix</i>	Kaffir lime, Kieffer lime, Leech lime, Limau purut, Mauritius bitter orange	EPPO 2020: Aubert 1990
<i>Citrus inodora</i>	Russel river lime	EPPO 2020: Westbrook et al. 2011
<i>Citrus latifolia</i>	Persian lime, Tahiti lime	Ramirez-Godoy et al. 2018; Casique-Valdes et al. 2015

Botanical name	English common name as given in EPPO (2020)	Reference
<i>Citrus limon</i>	Rough lemon	EPPO 2020: Tsai and Liu 2000; Westbrook et al. 2011
<i>Citrus latipes</i>	-	EPPO 2020: Westbrook et al. 2011
<i>Citrus limon</i>	Palestine sweet lime	EPPO 2020: Westbrook et al. 2011
<i>Citrus limon</i>	Lemon	EPPO 2020: Westbrook et al. 2011
<i>Citrus aurantiifolia</i>	Alemow, Colo	EPPO 2020: Westbrook et al. 2011
<i>Citrus reticulata</i>		Halbert and Manjunath 2004
<i>Citrus maxima</i>	Bali lemon, Pummelo, Shaddock	EPPO 2020: Westbrook et al. 2011
<i>Citrus medica</i>	Buddha's hand, Cidran, Citron, Etrog	EPPO 2020: Westbrook et al. 2011
<i>Citrus limon</i>	-	Halbert and Manjunath 2004
<i>Citrus paradisi</i>	Kinkoji	Halbert and Manjunath 2004
<i>Citrus paradisi</i>	Grapefruit, Pomelo	EPPO 2020: Tsai and Liu 2000; Westbrook et al. 2011
<i>Citrus reticulata</i> var. <i>austera</i>	Cleopatra mandarin	EPPO 2020: Tsagkarakis et al. 2010
<i>Citrus reticulata</i>	Clementine, Mandarin, Tangerine	EPPO 2020: Westbrook et al. 2011
<i>Citrus sinensis</i>	Sweet orange	EPPO 2020: Westbrook et al. 2011
<i>Citrus reticulata</i> var. <i>austera</i>	Sour mandarin	EPPO 2020: Westbrook et al. 2011
<i>Citrus aurantium</i>	-	EPPO 2020: Westbrook et al. 2011
<i>Citrus limon</i>	Volkameriana	EPPO 2020: Westbrook et al. 2011
<i>Citrus aurantiifolia</i>	Kalpi	EPPO 2020: Westbrook et al. 2011
<i>Citrus limon</i>	Canton lemon, Mandarin lime, Rangpur lime	EPPO 2020: Westbrook et al. 2011
<i>Citrus reticulata</i>	Kjing orange, Tangor	EPPO 2020: Westbrook et al. 2011

Diaphorina citri is present in several citrus-exporting countries considered in this import risk assessment.

- *Diaphorina citri* is widespread throughout Asia and occurs in North, Central and South America, Africa and Oceania (Table 11.1.2) (Halbert and Nunez 2004, Grafton-Cardwell et al. 2006; EPPO 2020; CABI 2020).
- *Diaphorina citri* is present in the following citrus-exporting countries under consideration for this assessment:
 - Brazil, China, Japan, Mexico, USA, Viet Nam (EPPO 2020) and Samoa (MPI 2020a).

Table 11.1.2. Known geographic distribution of *Diaphorina citri*. Information is compiled as at 31 August 2020 (from EPPO 2020, except where indicated). Countries in **bold** are included in the scope of this risk assessment.

Continent/Region	Country (province/state)
Africa	Ethiopia, Kenya, Mauritius, Nigeria, Réunion, Tanzania
North America	Mexico, USA (Alabama, Arizona, California, Florida, Georgia, Hawaii, Louisiana, Mississippi, South Carolina, Texas)
Central America and Caribbean	Antigua and Barbuda, Bahamas, Barbados, Belize, Cayman Islands, Costa Rica, Cuba, Dominica, Dominican Republic, Guadeloupe, Haiti, Jamaica, Martinique, Puerto Rico, Saint Lucia, St Vincent and the Grenadines, US Virgin Islands
South America	Argentina, Brazil (Amazonas, Bahia, Ceará, Pará, Pernambuco, Rio de Janeiro, Santa Catarina, São Paulo), Colombia, Paraguay, Uruguay, Venezuela

Continent/Region	Country (province/state)
Asia	Afghanistan, Bangladesh, Bhutan, Cambodia, China (Aomen, Fujian, Guangdong, Guangxi, Guizhou, Hainan, Henan, Hunan, Jiangxi, Sichuan, Xianggang, Yunnan, Zhejiang), East Timor, India, Indonesia, Iran, Japan (Kyushu, Ryukyu Archipelago), Laos, Malaysia, Maldives, Myanmar, Nepal, Oman, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Taiwan, Thailand, United Arab Emirates, Viet Nam , Yemen
Oceania ¹	American Samoa, Samoa (MPI 2020), Guam, Northern Mariana Islands, Papua New Guinea

¹ **Australia** – absent, pest no longer present

Given the arguments and evidence below, basic measures are likely to reduce the of entry of *D. citri* by a high degree; consequently, the likelihood of entry is considered to be low.

General handling after harvesting is expected to remove the majority of small mobile external organisms such as adult *D. citri*.

- Eggs and immature stages of *D. citri* are unlikely to be associated with the harvested fruit commodity in the packhouse as they feed on young, soft plant tissues and tend not to move from their feeding sites. However, any leaf material contaminating the commodity may carry eggs or larvae.
- Although adult *D. citri* do not feed on citrus fruit, they are very mobile and have been recorded on unprocessed harvested citrus fruit that is being transported for processing. Therefore, adults may be associated with the commodity when it reaches the packhouse.
- Washing, brushing and other activities in packhouse are expected to remove most contaminants and small mobile organisms from the outside of the fruit.
- Adults are brownish in colour and around 3 mm in length (the average size was 3.3 mm in length and 1.0 mm in width for adult females, 2.7 mm long and 0.8 mm wide for adult males in a study by Tsai and Liu, 2000) and are therefore visually detectable on the commodity.

The export production system may not remove all *D. citri* present on the fruit commodity.

- Adults move readily if disturbed and can fly and resetttle. They are also attracted to bright lights, which may be used in the packhouse. There is potential for adult *D. citri* to settle on fruit again after disturbance, and fruit may be infested during packhouse processing or if not stored separately from fruit that has not yet been through the export production system.
- Small amounts of leaf contaminants harbouring life stages of *D. citri* may be overlooked during routine inspection.
- There is potential for *D. citri* adults or other life stages to become hidden in crevices such as the navel of an orange.
- There have been previous interceptions at the New Zealand border of other mobile Hemiptera (e.g. Aphididae) on fruit of *Citrus* spp. (MPI LIMS 2014–2016), indicating that packhouse systems may not always remove all organisms present on fruit.

Diaphorina citri can survive transit in citrus commodities.

- Storage and transport of citrus consignments from exporting countries to New Zealand are likely to occur at cool temperatures, with the length of time for shipment depending on the exporting country. For example, transport of fruit by sea may take up to three weeks from Korea and more than three weeks from Brazil.
- Overwintering adults, especially females, have a much longer lifespan than females in other generations and can live for 8–9 months. There is no complete diapause or dormancy. Some overwintering adults are able to survive temperatures as low as -12°C for short periods of time (Yang et al. 2006).
- *D. citri* can survive, without food or water, for increasing periods as temperature decreases and humidity increases. Under laboratory conditions, adult *D. citri* are able to survive up to 94.5 hours at 25°C without feeding if suitable foliage is not available (McFarland and Hoy 2001). Therefore, psyllids packed with fruit could survive for longer periods at lower temperatures (Biosecurity Australia 2011).
- Interceptions of live psyllids on unprocessed fruit (Halbert and Nunez 2004) show that *D. citri* can survive transportation and storage in some conditions.

Likelihood of establishment:

Given the arguments and evidence below, *Diaphorina citri* has a high ability (with low uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.

Diaphorina citri is easily disturbed and may disperse to a host plant:

- Adults are easily disturbed and will jump a short distance or fly (Tsai and Liu 2000; Grafton-Cardwell et al. 2006). Therefore, an adult *D. citri* is able to fly off the fruit at any stage in the pathway to consumption or disposal.
- *Diaphorina citri* uses both olfactory and visual cues to orient to host plants (Wenninger et al. 2009).
- *D. citri* has been recorded dispersing away from host plants to nearby citrus groves (Boina et al. 2009). Arakawa and Miyamoto (2007) calculated flight distances of up to 978 m for females and 1,241 m for males using a flight mill.

Most *D. citri* are likely to be disturbed off fruit in an environment with limited access to host plants.

- Most imported citrus fruit is displayed and handled inside retail buildings, and therefore, any adults that fly off fruit in these settings would fly into an environment with limited access to host plants. Nymphs and pupae associated with imported citrus fruit may also be dislodged during fruit handling; however, unless they are near suitable host plants, there is no opportunity for exposure.
- Potential for transfer exists if infested fruit is unpackaged in an environment containing suitable host plants or if adults can easily reach environments containing host plants. In these instances, adult *D. citri* may be able to disperse to a new host.

Citrus spp. are present throughout New Zealand, especially in residential environments.

- *Citrus* spp. are present in commercial groves throughout Northland, Auckland, Bay of Plenty, and Gisborne, and in domestic gardens in warmer regions. *C. limon* (one of the main hosts of *D. citri*) is particularly prevalent in domestic gardens through much of the country. Therefore, if disturbed off fruit in or near an outdoor environment, *D. citri* could reach a suitable host plant particularly in a residential environment with *Citrus* present.

Given the arguments and evidence below, the suitability of the New Zealand environment for *D. citri* to establish is considered moderate.

New Zealand's climate in some citrus-growing regions is likely to be suitable for *D. citri* to establish, especially in the north of New Zealand.

- Some of the areas where *D. citri* has been recorded (Table 11.1.2) have similar climate to New Zealand, as indicated by climate match index (CMI) values ≥ 7 (Phillips et al. 2018), for example:
 - Argentina (0.7–0.9); Brazil: Santa Catarina (0.7–0.9), São Paulo (parts are 0.7–0.8); China: Sichuan (0.7–0.8), Yunnan (0.7–0.8); Uruguay (0.8–0.9); USA: Alabama (0.7–0.8), Georgia (0.7–0.8), South Carolina (0.7–0.8), Texas (mostly 0.7–0.8)
- Two models to assess the global climate suitability of citrus huanglongbing and its vector *D. citri* predict that the northern North Island (both models) and southern North Island (one model) are climatically suitable for the establishment of *D. citri* (Narouei-Khandan et al. 2016).
- Therefore, *D. citri* is likely to be able to establish in warmer areas of northern New Zealand.

Potential hosts are available, especially in warmer northern regions, where most commercial citrus is grown.

- *Citrus* is commercially produced in both the North and South Island, with most production taking place in the North Island (see section 2.4.2). The main citrus-growing areas in New Zealand are Northland, Auckland, Bay of Plenty, Hawke's Bay and Gisborne (Plant & Food

Research 2019). *Citrus* is also commonly grown in domestic gardens in warmer regions. Lemon (*C. limon*), one of the main hosts of *D. citri*, is grown in domestic gardens through much of the country.

- Other hosts, such as *Murraya paniculata* (a preferred host), *M. koenigi* and *Choisya ternata*, are cultivated in gardens.

Diaphorina citri is likely to find mates and has a high reproductive rate.

- *D. citri* reproduces sexually, and adults locate mates through pheromones (Wenninger et al. 2008) and vibrational communication (Wenninger et al. 2009b). If several individuals were to be disturbed off fruit in the same environment, either outdoors or near outdoors, males and females would be capable of locating each other.
- *D. citri* mate and lay eggs almost exclusively on young foliage (Wenninger and Hall 2007) and the timing of reproduction in *D. citri* is related to the emergence of new growth on the host plants (Halbert and Manjunath 2004).
- The number of eggs laid by *D. citri* females varies in the literature, with as many as 1,000–2,000 eggs laid by a female psyllid in three weeks (Aubert 2008) to as few as 180–520 eggs (Pande 1971). Egg-laying capacity may vary on different hosts (Tsai and Liu 2000).
- There are multiple generations per year, the number depending on regional climates, with up to 11–12 generations possible when suitable flush growth is present (Husain and Nath 1927).
- Adults of *D. citri* can live for several months. They do not diapause but are able to overwinter on vegetation to wait for more favourable breeding conditions (Gottwald et al. 2007).

Diaphorina citri can disperse locally to enable initial establishment.

- Adult psyllids are very mobile and can move from tree to tree in the field. *D. citri* uses both olfactory and visual cues to orientate to host plants and has been recorded dispersing away from host plants to nearby citrus orchards (Boina et al. 2009; Wenninger et al. 2009a).

Diaphorina citri can spread over longer distances.

- There is some evidence that high winds and storms can move psyllids considerable distances (Gottwald 2010).
- An important means of long-distance dispersal to new areas is through the movement of infested host plant material (Halbert and Manjunath 2004).
- Adults can hitchhike on unprocessed fruit consignments (Halbert and Manjunath 2004, Halbert et al. 2010) and, in the absence of fruit, are likely to hitchhike with various forms of transport to new locations.

Impacts in New Zealand

Given the arguments and evidence below, the level of impact caused by *D. citri* is likely to be low to moderate for New Zealand overall but moderate to high for the citrus industry, depending on the presence of HLB in New Zealand.

The potential economic consequences of *D. citri* are considered low to moderate for New Zealand, but moderate to high for the citrus industry, depending on the presence of HLB.

- *D. citri* typically causes defoliation and dieback. Serious damage to growing points can occur, which can lead to dwarfing, as well as lack of juice and taste in fruit. Heavy *D. citri* populations can cause blossom and fruitlet drop. The honeydew excreted by *D. citri* promotes the growth of sooty mould, which affects the photosynthetic activity of the tree (CABI 2000).

- Little direct economic loss has been reported as a result of *D. citri* alone (Biosecurity Australia 2011).
- However, the main economic impact of *D. citri* is as a vector of huanglongbing (HLB) disease, also referred to as citrus greening. HLB is regarded as one of the most devastating diseases of citrus in the world. Premature fruit drop on infected trees results in decreased production. Infected fruit that remains on the tree can be small, hard, discoloured and misshapen with a bitter unpleasant taste that makes it commercially useless. Trees become stunted and have a much shorter life. Nearly all commercial citrus species and cultivars are susceptible to the disease, regardless of rootstock (Bove 2006). HLB is associated with three liberibacter species, '*Candidatus Liberibacter africanus*', '*Ca. L. americanus*' and '*Ca. L. asiaticus*'. The liberibacter are found in the phloem of the plant host. They are transmitted naturally by two psyllid vectors: *Diaphorina citri* and *Trioza erytreae* (Bove 2006). *D. citri* vectors '*Ca. L. americanus*' and '*Ca. L. asiaticus*' naturally and is capable of transmitting '*Ca. L. africanus*', experimentally at least (Gottwald 2010; Bove 2006). The liberibacter can be found in the salivary glands and haemolymph of *D. citri* (da Graca 1991; Gottwald 2010), and once the psyllid has acquired the bacteria, as a nymph or adult, it is maintained in the psyllid for its lifetime.
 - '*Candidatus Liberibacter africanus*' is not known to be present in any of the countries in the IRA (EPPO 2020). It has been recorded as absent, confirmed by survey in Spain (EPPO 2020);
 - '*Candidatus Liberibacter americanus*' is known to be present in one of the IRA countries: Brazil (EPPO 2020);
 - '*Candidatus liberibacter asiaticus*' is known to be present in several of the IRA countries: Brazil, China, Japan, Mexico, USA, Viet Nam (EPPO 2020). It has been recorded as absent, confirmed by survey, in Fiji, Cook Islands, Samoa and Spain, and absent (invalid record) in Egypt (EPPO 2020).
- The introduction of *D. citri* to New Zealand is very likely to mean the introduction of HLB if infected psyllids come from a location where the disease is present. On the other hand, if *D. citri* arrives in New Zealand in the absence of the disease, then establishment of psyllid populations that are capable of vectoring HLB would be of concern should the disease be introduced at a later date.
- In areas where both the vector and HLB are present, the damage to citrus production can be very high (Biosecurity Australia 2011). For example, HLB destroys 10–15% of tangerine trees in Thailand annually (Bové 2006). In Réunion, an eight-year survey conducted in the 1980s and 1990s determined that 65% of trees were infected and became unproductive within seven years of planting (Gottwald et al. 1989; Gottwald et al. 2007).
- Both *D. citri* and HLB affect many *Citrus* species and commercial citrus varieties including those in the New Zealand citrus industry (see section 2.5.2).
- The discovery of the presence of *D. citri* in New Zealand as an incursion or an established population is likely to have an immediate impact on exports of citrus countries free from huanglongbing and *D. citri*.
- If *D. citri* were detected in New Zealand, the cost incurred by a response would be high. It is likely that a response would be undertaken given the ability of *D. citri* to vector HLB, regardless of the presence of HLB. The typical cost of a response is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020b).
- Establishment of *D. citri* is likely to increase phytosanitary measures required for export of citrus fresh produce to countries where *D. citri* and HLB are not present, such as the European Union.
- Models predict that the climate in the northern North Island (both models) and southern North Island (one model) are climatically suitable for the establishment of *D. citri* (Narouei-Khandan et al. 2016). Therefore, *D. citri* is likely to be able to establish in warmer areas of northern New Zealand where much of the country's commercial *Citrus* production takes place, especially in areas such as Northland, where it could have a large impact on the local economy.

It is likely that *D. citri* will cause a low to moderate level of sociocultural impacts in New Zealand, depending on the presence of HLB.

- *Citrus* spp. and *Murraya paniculata* are common in domestic gardens in New Zealand, especially in the northern regions, although *C. limon* is grown more widely throughout the country. If *D. citri* became established in New Zealand, it could impact home gardeners directly through feeding damage to host plants, which can result in leaf distortion and abscission, and blossom and fruit drop. Excreted honeydew promotes the growth of sooty mould, affecting both appearance and photosynthetic activity of the plant (CABI 2000).
- Greater impacts would occur if any of the liberibacter species that cause HLB were present in New Zealand, given the role of *D. citri* as a vector for HLB. Symptomatic infected citrus trees would have blotchy mottled and yellowing leaves, small lopsided and bitter-tasting fruit with aborted seeds, with branches and eventually whole plants dying after a few years (Garnier and Bove 2000; CABI 2000). Symptoms of HLB may not be expressed on *Murraya paniculata*, but there is potential for this species to act as a reservoir for the disease (Darmsteegt et al. 2010).

It is likely that *D. citri* will have a very low level of impact on the environment.

- *Citrus* species are members of the Rutaceae family. There are two endemic genera within Rutaceae in New Zealand (NZPCN 2020), *Melicope* and *Leionema*. Neither genus is considered threatened (NZPCN 2020), and they are usually restricted to native forest environments. Although neither of these genera are known to be hosts for *D. citri*, heavy psyllid infestations can cause leaf, blossom and fruit abscission; however, the main risk associated with *D. citri* is from transmission of the disease HLB, which only affects Rutaceae, primarily *Citrus* spp.

It is likely that *D. citri* will have negligible impacts on human health.

- No evidence was found that *D. citri* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below, *Diaphorina citri* may be considered for additional measures.

- *Diaphorina citri* has a strong association with citrus, but a weak association with citrus fruit.
- Basic measures are likely to reduce the entry of *D. citri* by a high degree (with low uncertainty). Consequently, the likelihood of entry is considered low (with low uncertainty).
- The ability of *D. citri* to move from imported fruit to a suitable host plant is high (with low uncertainty).
- The suitability of the New Zealand environment for *D. citri* to establish is considered moderate (with low uncertainty).
- The level of impact caused by *D. citri* is likely to be low to moderate (with low uncertainty) for New Zealand overall but moderate to high (with low uncertainty) for the citrus industry, depending on the presence of HLB in New Zealand, with at least two of the causal agents being vectored by *D. citri*.
- *Diaphorina citri* is present in the following citrus-exporting countries under consideration for this assessment: Brazil, China, Japan, Mexico, the USA, Viet Nam and Samoa.

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10.2 *Trioza erytreae* (African citrus psyllid)

Trioza erytreae is a small psyllid (about 2 mm long) that damages plant tissues directly through its feeding activities and indirectly through vectoring liberibacter that cause huanglongbing (HLB), a very destructive disease of citrus (van den Berg 1990; CABI 2020).

Scientific name: *Trioza erytreae* (Del Guercio, 1918)

Order/Family: Hemiptera/Trioziidae

Other names include: *Aleurodes erytreae*, *Spanioza eritreae*, *Spanioza erythrae*, *Spanioza erytreae*, *Spanioza merwei*, *Trioza citri*, *Trioza erythrae*, *Trioza merwei*, African citrus psyllid, citrus psylla, African citrus psylla, two-spotted citrus psyllid

Note:

Trioza erytreae is one of the psyllid vectors of the causal agents of the serious citrus disease HLB, also known as citrus greening.

HLB is associated with three liberibacter species, '*Candidatus Liberibacter africanus*', '*Ca. americanus*' and '*Ca. L. asiaticus*' (Gottwald 2010). '*Ca. L. asiaticus*', which is the most prevalent bacteria, is associated with Asian HLB, which is the most widespread form of the disease. '*Ca. L. africanus*' is associated with the African form of HLB and '*Ca. L. americanus*' with the American form of HLB. Recently, a new strain provisionally named '*Ca. L. caribbeanus*' has been reported that may cause HLB-like symptoms in citrus (Keremane et al. 2015). The liberibacter are found in the phloem of the plant host. They are transmitted naturally by two psyllid vectors: *Diaphorina citri* and *Trioza erytreae* (Bove 2006). *D. citri* vectors '*Ca. L. americanus*' and '*Ca. L. asiaticus*' naturally and is capable of transmitting '*Ca. L. africanus*', experimentally at least (Gottwald 2010, Bove 2006). *Trioza erytreae* transmits '*Ca. L. africanus*' under natural conditions, and it has been shown experimentally that *T. erytreae* is able to transmit '*Ca. L. asiaticus*' (Gottwald 2010).

Summary of conclusions

Given the arguments and evidence presented:

- *Trioza erytreae* meets the criteria to be a quarantine pest for New Zealand.
- *Trioza erytreae* has strong association with citrus, but a weak association with citrus fruit (with low uncertainty).
- Basic measures are likely to reduce the likelihood of entry by a high degree (with low uncertainty). consequently, the likelihood of entry is considered low (with moderate uncertainty).
- The ability of *T. erytreae* to transfer from imported fruit to suitable host plants is high (with low uncertainty).
- The suitability of the New Zealand environment for *T. erytreae* to establish is considered high (with moderate uncertainty).
- The level of impact caused by *T. erytreae* is likely to be low to moderate for New Zealand overall (with low uncertainty), but moderate to high for the citrus industry (with low uncertainty), depending on the presence of the citrus disease HLB, with a least one of the causal agents being vectored by *T. erytreae*.
- *Trioza erytreae* may be considered for additional measures.

Summary of risk assessment against criteria:

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Weak	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Moderate
The ability to move from the imported commodity onto a suitable host	High	Low
Suitability of the New Zealand environment	High	Moderate
Impacts on the New Zealand economy, environment, health and society, depending on presence of HLB	Low-moderate	Low

10.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Trioza erytreae* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Trioza erytreae is not known to be present in New Zealand.

- *Trioza erytreae* is not recorded in NZInverts (2020), NZOR (2020) or PPIN (2020).
- The quarantine status of *T. erytreae* in New Zealand is 'regulated', and it is an unwanted organism (ONZPR 2020).

Trioza erytreae has the potential to establish and spread in New Zealand.

- *T. erytreae* largely occurs in Africa and nearby Asian countries, Saudi Arabia and Yemen. However, it has been recently recorded in Europe (Portugal and Spain) (EPPO 2020; CABI 2020) (Table 11.2.2).
- Some of the areas where *T. erytreae* occurs have a high climate match with New Zealand, with a climate match index (CMI) of 0.7 or greater (Phillips et al. 2018), indicating the potential to establish in New Zealand, for example:
 - Spain (0.7–0.9) and Portugal (0.8–0.9).
- There are suitable host species (*Citrus* spp.) present in areas of New Zealand that are likely to be climatically suitable for *T. erytreae*.

Trioza erytreae has the potential to cause economic impacts in New Zealand.

- *T. erytreae* has the potential to damage citrus, which is of economic importance to New Zealand, both through direct feeding damage and by vectoring liberibacter species that cause the citrus disease huanglongbing (HLB).
- Establishment of *T. erytreae* is likely to affect market access for *Citrus* to those countries free from *T. erytreae* and HLB.

10.2.2 Hazard identification: commodity association

Trioza erytreae is associated with citrus fruit

- *Trioza erytreae* (African citrus psyllid) is a similar organism to *Diaphorina citri* (Asian citrus psyllid), which also has a host range confined to the Rutaceae, including *Citrus* and other close relatives (Halbert and Manjunath 2004), and is also a vector for at least two of the pathogens that cause HLB.
- A study by Halbert et al. (2010) showed that *D. citri* can be transported with harvested citrus fruit. Live adults (509 psyllids) were collected from seven trailers, from the tops and sides of the loads up to 30 cm below the surface of the oranges, suggesting they were distributed throughout the loads. The psyllids were seen resting on the fruit itself rather than on the minimal amount of foliage that was present (Halbert et al. 2010).
- High numbers of *D. citri* adults were intercepted in boxes of fresh unprocessed citrus fruit (grapefruit) picked in the Bahamas and shipped to Ft. Pierce, Florida, for processing in 2001 (Halbert and Nunez 2004).
- Therefore, it is assumed that adults of *T. erytreae* can similarly be associated with citrus fruit as hitchhikers.

10.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Trioza erytreae* has a strong association with citrus but a weak association with citrus fruit.

Although the life stages of *T. erytrae* feed on foliage, adults that have been disturbed may seek refuge on citrus fruit.

- All life stages of *T. erytrae* are found on citrus host foliage (van den Berg 1990). Eggs are laid on the margins of actively growing leaves. Nymphs live in individual depressions or open galls they produce on the undersides of leaves and remain there until they become adults. Nymphs and adults prefer to feed on young plant tissues, generally foliage (van den Berg 1990). They are not known to feed on mature fruit (Biosecurity Australia 2011).
- *T. erytrae* adults wander leaves and fly readily to areas of citrus flush (van den Berg 1990). It is assumed here that, in a similar fashion to *D. citri*, adult *T. erytrae* will jump or fly short distances and seek refuge on citrus fruit when disturbed.
- Live *D. citri* adults have been intercepted on harvested citrus fruits being transported by trailer and by ship, in boxes of unprocessed fruit shipped from the Bahamas to Florida, USA, for processing (Halbert and Nunez 2004, Halbert et al. 2010).

Trioza erytrae infests many citrus species and varieties.

- All known hosts of *T. erytrae* are members of the Rutaceae. The original hosts are probably *Vepris lanceolata* (=undulata) and *Clausena anisata*, with *Citrus* spp., and other close relatives such as *Murraya paniculata* and *Poncirus trifoliata* recorded as hosts (Cocuzza et al. 2017).
- *T. erytrae* has been recorded infesting many citrus species and varieties. Table 11.2.1 lists *Citrus* species/taxa that are confirmed hosts (EPPO 2020). Some of these hosts are preferred over others (Biosecurity Australia 2011).

Table 11.2.1. Citrus host plant records for *Trioza erytrae*

Botanical name	Common name	Comments
<i>Citrus aurantiifolia</i>	Lime	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a preferred host plant
<i>Citrus australasica</i> (<i>Microcitrus australasica</i>)	Australian finger lime	EPPO 2020: confirmed host, incidental (Aubert 1987) Aubert (1987): an occasional host plant
<i>Citrus reticulata</i>	–	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a common host plant
<i>Citrus limon</i>	Rough lemon	EPPO 2020: confirmed host (Aidoo et al. 2019)
<i>Citrus limon</i>	Lemon	EPPO 2020: confirmed host (Moran 1968) Aubert (1987): a preferred host plant
<i>Citrus maxima</i>	Pummelo	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a common host plant
<i>Citrus medica</i>	Citron	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a preferred host plant
<i>Citrus reticulata</i>	Tangor	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a common host plant
<i>Citrus paradisi</i>	Grapefruit	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a common host plant
<i>Citrus reticulata</i>	Mandarin	EPPO 2020: confirmed host (Aubert 1987) Aubert (1987): a common host plant
<i>Citrus sinensis</i>	Sweet orange	EPPO 2020: confirmed host (Aubert 1987. Aidoo et al 2019) Aubert (1987): a common host plant
<i>Citrus reticulata</i>	Tangerine	EPPO 2020: confirmed host (Aidoo et al. 2019)

Trioza erytrae is present in one citrus-exporting country considered in this import risk assessment.

- The geographic range of *T. erytrae* is largely African, but it occurs in some nearby Asian countries and more recently in Europe (Table 11.2.2).

- *T. erytraeae* is present in the following citrus-exporting country under consideration:
 - Spain (EPPO 2020)

Table 11.2.2. Known geographic distribution of *Trioza erytraeae*. Information compiled 31 October 2020 from EPPO (2020). Countries in **bold** are included in the scope of this risk assessment.

Continent/Region	Country/State
Africa	Angola, Cameroon, Comoros, Congo (Democratic Republic of the), Eritrea, Eswatini, Ethiopia, Gabon, Kenya, Madagascar, Malawi, Mauritius, Réunion, Rwanda, Saint Helena, São Tomé and Príncipe, South Africa, Sudan, Tanzania, Uganda, Zambia, Zimbabwe
Asia	Saudi Arabia, Yemen
Europe	Portugal (mainland and Madeira), Spain (mainland and Canary Islands)

Given the arguments and evidence below, basic measures are likely to reduce likelihood of entry of *T. erytraeae* by a high degree. Consequently, the likelihood of entry is considered to be low (with moderate uncertainty).

General handling after harvesting is expected to remove the majority of small mobile external organisms, such as adult *T. erytraeae*.

- Eggs and immature stages of *T. erytraeae* are unlikely to be associated with the harvested fruit commodity in the packhouse as they feed on young, soft plant tissues and tend not to move from their feeding sites. However, any leaf material contaminating the commodity may carry eggs or larvae.
- Although adult *T. erytraeae* don't feed on citrus fruit, they are mobile. Given *D. citri* has been recorded as hitchhiker on unprocessed harvested citrus fruit that is being transported for processing, it is assumed that *T. erytraeae* could also hitchhike on fruit. Therefore, adults may be associated with the commodity when it reaches the packhouse.
- Washing, brushing and other activities in packhouse are expected to remove most contaminants and small mobile organisms from the outside of the fruit.
- Adults are brownish in colour and around 2 mm in length (adult males 2.17 mm, adult females 2.24 mm (van den Berg 1990)) and are therefore visually detectable on the commodity.

The export production system may not remove all *T. erytraeae* present on fruit.

- Adults move if disturbed and can fly and resettle. They are also attracted to bright lights that may be used in the packhouse (Biosecurity Australia 2011). There is potential for adult *T. erytraeae* to settle on fruit again after a disturbance, and fruit may be infested during packhouse processing or if not stored separately from fruit that has not yet been through the export production system.
- Small amounts of leaf contaminants harbouring life stages of *T. erytraeae* may be overlooked during routine inspection.
- There is potential for *T. erytraeae* adults or other life stages to become hidden in crevices such as the navel of an orange.
- There have been previous interceptions at the New Zealand border of other mobile Hemiptera (e.g. Aphididae) on fruit of *Citrus* spp. (MPI LIMS 2014–2016), indicating that packhouse systems may not always remove all organisms present on fruit.

Adult *T. erytraeae* may be able to survive transport times and temperatures for some citrus commodities.

- Storage and transport of citrus consignments from exporting countries to New Zealand are likely to occur at cool temperatures, with the length of time for shipment depending on the exporting country. For example, transport of fruit by sea may take up to three weeks from Korea and more than three weeks from Brazil.
- The threshold the temperature for nymphal development is between 10°C and 12°C, and the psyllid overwinters as an adult (van den Berg 1990).
- *Trioza erytraeae* adults can live up to 55 hours without feeding if suitable foliage is not available or 85 hours in the absence of a suitable host plant in the field. The death of the psyllids under field conditions, where temperatures reached 27°C and relative humidity dropped to 37%, was attributed to desiccation rather than starvation (van den Berg and Deacon 1988). Therefore, psyllids associated with fruit could survive for longer periods during

transportation and storage under low temperatures and high humidity (Biosecurity Australia 2011).

The level of uncertainty in relation to entry is rated as moderate, because it has been assumed that *T. erytreae* will behave in a similar manner to *D. citri*, there is no specific information on the conditions of transit, including temperature and duration, and there is a lack of interception data for *T. erytreae*.

Likelihood of establishment:

Given the arguments and evidence below, *Trioza erytreae* has a high ability (with low uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant.

Trioza erytreae is mobile and may disperse from fruit to a new host.

- Adult *T. erytreae* associated with imported fruit are able to move independently from imported fruit to a suitable host.
- Adults can readily locate and invade isolated areas of flush over several hundred metres (van den Berg 1990)
- *T. erytreae* able to disperse via wind currents up to 1.5 km (van den Berg and Deacon 1988).

Most *T. erytreae* are likely to be disturbed off fruit in an environment with limited access to host plants.

- Most imported citrus fruit is displayed and handled inside retail buildings, and therefore, any adults that fly off fruit in these settings would fly into an environment with limited access to host plants. Nymphs and pupae associated with imported citrus fruit may also be dislodged during fruit handling; however, unless they are near suitable host plants, there is no opportunity for exposure.
- Potential for transfer exists if infested fruit is unpackaged in an environment containing suitable host plants or if adults can easily reach environments containing host plants. In these instances, adult *T. erytreae* may be able to disperse to a new host.

Citrus spp. are present throughout New Zealand, especially in residential environments.

- *Citrus* plants are present in commercial groves throughout Northland, Auckland, Bay of Plenty and Gisborne, and in domestic gardens in warmer regions. *C. limon* (a preferred host of *T. erytreae*) is particularly prevalent in domestic gardens throughout much of the country. Therefore, if disturbed off fruit in or near an outdoor environment, *T. erytreae* could reach a suitable host plant, particularly in a residential environment with *Citrus* present.

Given the arguments and evidence below, the suitability of the New Zealand environment for *T. erytreae* to establish is considered high (with moderate uncertainty).

New Zealand's climate is likely to be suitable for establishment of *T. erytreae*.

- *Trioza erytreae* is adapted to relatively cool environments, often at higher altitudes, and is sensitive to high temperatures combined with low humidity (Bove 2006).
- The distribution of the psyllid in Africa, Saudi Arabia and Yemen show that it has been able to adapt and settle under a variety of ecological conditions such as in equatorial, arid, and warm temperate climates with different temperatures and rainfall (Cocuzza et al. 2017).
- Some of the areas where *T. erytreae* has been recorded (Table 11.2.2) have similar climate to New Zealand, as indicated by climate match index (CMI) values ≥ 0.7 (Phillips et al. 2018), for example:
 - Spain (0.7–0.9): location records in Galicia (0.9) (EPPO 2020)
 - Portugal (0.8–0.9): mainland Norte (0.9) and Centro (0.8–0.9) regions, Porto (0.9), Area Metropolitana de Lisboa (0.8) (EPPO 2020)
 - Eswatini (Swaziland) (0.7–0.8 CMI): found in cool moist upland regions (EPPO 2020)
- New Zealand's climate is likely to be more suitable for *T. erytreae* than *D. citri*, which is more heat tolerant (Bove 2006). Two models to assess the global climate suitability of citrus huanglongbing and the vector *D. citri* predict that the northern North Island (both models) and

southern North Island (one model) are climatically suitable for the establishment of *D. citri* (Narouei-Khandan et al. 2016). Therefore, *D. citri* is likely to be able to establish in warmer areas of northern New Zealand. It is likely that *T. erytrae* will be able to establish more widely in New Zealand than *D. citri*.

Potential hosts are available, especially in warmer northern regions where most commercial citrus is grown:

- *Citrus* fruit is commercially produced in both the North and South Island, with most production taking place in the North Island (see section 2.4.2). The main citrus-growing areas in New Zealand are Northland, Auckland, Bay of Plenty, Hawke's Bay and Gisborne (Plant & Food Research 2019). Citrus is also commonly grown in domestic gardens in warmer regions. Lemon (*C. limon*), a preferred host for *T. erytrae*, is grown in domestic gardens through much of the country.
- Other hosts, such as *Murraya paniculata* (a preferred host), *Casimoa edulis* and *Choisya ternata* (Cocuzza et al. 2017), are cultivated in gardens.

T. erytrae has a high reproductive rate.

- *Trioza erytrae* reproduces sexually. It is not clear if males find females using pheromones, but evidence suggests that *D. citri* adults locate each other through pheromones (Wenninger et al. 2008) and vibrational communication (Wenninger et al. 2009). If *T. erytrae* use similar mechanisms, this would increase the ability for males and females to locate each other if several individuals were to be disturbed off fruit in the same environment, either outdoors or near outdoors
- *Trioza erytrae* females lay eggs almost exclusively on soft young tissues, often along the margins of young leaves, and the timing of reproduction is related to emergence of new growth on host plants.
- *Trioza erytrae* is a highly fecund species, with females laying an average of 827 eggs during their lifetime (van den Berg 1990). *Trioza erytrae* is capable of rapid population expansion when hosts with new shoot growth are available (Gottwald et al. 2007). And under ideal conditions up to eight generations may occur in a year (van den Berg 1990).
- *Trioza erytrae* does not undergo diapause. During winter, when conditions are not suitable for reproduction, the psyllid will continue to feed and survive until conditions become favourable for breeding (van den Berg 1990; Gottwald et al. 2007; Biosecurity Australia 2011). Adults may live for 2–3 months (van den Berg 1990).

Trioza erytrae can disperse locally to enable initial establishment.

- Adults can readily locate and invade isolated areas of flush over several hundred metres (van den Berg 1990).
- *Trioza erytrae* is able to disperse via wind currents up to 1.5 km (van den Berg and Deacon 1988).

Trioza erytrae can spread over longer distances.

- An important means of long-distance dispersal to new areas is through the movement of infested host plant material (Bove 2006). Adults can hitchhike on unprocessed fruit consignments and, in the absence of fruit, have the potential to hitchhike with various forms of transport to new locations.
- *Trioza erytrae* has been demonstrated to be invasive, having recently been detected in mainland Portugal and Spain, where it is spreading in the northwest (Cocuzza et al. 2017).

The level of uncertainty for suitability of the New Zealand environment is rated as moderate, because a comparison has been made with predictions from models for *D. citri*, although evidence indicates *T. erytrae* does better than *D. citri* in climates that are more similar to New Zealand.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *T. erytrae* is likely to be low to moderate (with low uncertainty) for New Zealand overall, but moderate to high (with low uncertainty) for the citrus industry, depending on the presence of HLB in New Zealand.

The potential economic consequences of *T. erythrae* considered to be low to moderate for New Zealand, but moderate to high for the citrus industry, depending on the presence of HLB.

- *T. erythrae* feeding can severely distort leaves, which become stunted and galled. Leaves may become yellowed (CABI 2020). However, little direct economic loss has been reported as a result of *T. erythrae* alone, and it is considered a minor pest by itself (van den Berg 1990; Biosecurity Australia 2011).
- The main economic impact of *T. erythrae* is as a vector of huanglongbing (HLB) disease, also referred to as citrus greening. HLB is regarded as one of the most devastating diseases of citrus in the world. Premature fruit drop on infected trees results in decreased production. Infected fruit that remains on the tree can be small, hard, discoloured and misshapen, with a bitter unpleasant taste that makes it commercially useless. Trees become stunted and have a much shorter life. Nearly all commercial citrus species and cultivars are susceptible to the disease regardless of rootstock (Bove 2006). HLB is associated with three liberibacter species, '*Candidatus Liberibacter africanus*', '*Ca. L. americanus*' and '*Ca. L. asiaticus*'. The liberibacter are found in the phloem of the plant host. They are transmitted naturally by two psyllid vectors: *Diaphorina citri* and *Trioza erythrae* (Bove 2006). *Trioza erythrae* vectors '*Ca. L. africanus*' naturally and is capable of transmitting '*Ca. L. asiaticus*', experimentally at least (Gottwald 2010, Bove 2006).
 - '*Candidatus Liberibacter africanus*' is not known to be present in any of the countries in the IRA (EPPO 2020). It has been recorded as absent, confirmed by survey in Spain (EPPO 2020);
 - '*Candidatus Liberibacter americanus*' is known to be present in one of the IRA countries: Brazil (EPPO 2020);
 - '*Candidatus liberibacter asiaticus*' is known to be present in several of the IRA countries: Brazil, China, Japan, Mexico, USA, Viet Nam (EPPO 2020). It has been recorded as absent, confirmed by survey, in Fiji, Cook Islands, Samoa and Spain, and absent (invalid record) in Egypt (EPPO 2020).
- The introduction of *T. erythrae* to New Zealand is likely to mean the introduction of HLB if infected psyllids come from a location where the disease is present. On the other hand, if *T. erythrae* arrives in New Zealand in the absence of the disease, then establishment of psyllid populations that are capable of vectoring HLB would be of concern should the disease be introduced at a later date.
- In areas where both the vector and HLB are present, the damage to citrus production can be very high (Biosecurity Australia 2011). For example, HLB destroys 10–15% of tangerine trees in Thailand annually (Bove 2006) and in Réunion, an eight year survey conducted in the 1980s and 1990s found that 65% of trees were infected and became unproductive within seven years of planting (Biosecurity Australia 2011).
- Both *T. erythrae* and HLB affect many *Citrus* species and commercial citrus varieties including those in the New Zealand citrus industry (see section 2.5.2).
- The discovery of the presence of *T. erythrae* in New Zealand as an incursion or an established population is likely to have an immediate impact on exports of citrus to countries free from huanglongbing and *T. erythrae* where these organisms are quarantine pests. Countries and areas that have these organisms as quarantine pests are listed in the EPPO Global Database (EPPO 2020).
- If *T. erythrae* were detected in New Zealand, the cost incurred by a response would be high. It is likely that a response would be undertaken, given the ability of *T. erythrae* to vector HLB, regardless of the presence of HLB. The typical cost of a response is millions of dollars. For example, the Queensland fruit fly response in 2019 cost approximately NZ\$18 million (MPI 2020b).
- Establishment of *T. erythrae* is likely to increase phytosanitary measures required for export of citrus fresh produce to countries where *T. erythrae* and HLB are not present and where these organisms are quarantine pests.
- New Zealand's climate is likely to be more suitable for *T. erythrae* than *D. citri*, which is more heat tolerant (Bove 2006). Models predict that the climate in the northern North Island (both models) and southern North Island (one model) are climatically suitable for the establishment

of *D. citri* (Narouei-Khandan et al. 2016). Therefore, *D. citri* is likely to be able to establish in warmer areas of northern New Zealand where much of the country's commercial *Citrus* production takes place; especially in areas such as Northland, where it could have a large impact on the local economy. It is likely that *T. erytraeae* will be able to establish more widely in New Zealand than *D. citri*, potentially affecting directly more of the country's commercial citrus production.

It is likely that *T. erytraeae* will cause a low to moderate level of sociocultural impacts in New Zealand, depending on the presence of HLB.

- *Citrus* spp. and *Murraya paniculata* are common in domestic gardens in New Zealand, especially in the northern regions, although *C. limon* is grown more widely through the country. If *T. erytraeae* became established in New Zealand, it could impact home gardeners directly through feeding damage to host plants that can result in leaf distortion and yellowing (CABI 2000).
- Greater impacts could occur if the liberibacter species that cause HLB were present in New Zealand, given the role of *T. erytraeae* as a vector for HLB. Symptomatic infected citrus trees would have blotchy mottled and yellowing leaves, small, lopsided and bitter-tasting fruit with aborted seeds, with branches and eventually whole plants dying after a few years (Grafton Cardwell et al. 2018; CABI 2000).

It is likely that *T. erytraeae* will have a very low level of impact on the environment.

- *Citrus* species are members of the Rutaceae family. There are two endemic genera within Rutaceae in New Zealand, *Melicope* and *Leionema* (NZPCN 2020). Neither genus is considered threatened (NZPCN 2020), and they are usually restricted to native forest environments. Although neither of these genera are known to be hosts for *T. erytraeae*, heavy psyllid infestations can cause leaf distortions and yellowing; however, the main risk associated with *T. erytraeae* is from transmission of the disease HLB, which only affects Rutaceae, primarily *Citrus* spp.

It is likely that *Trioza erytraeae* will have negligible impacts on human health.

- No evidence was found that *T. erytraeae* has an impact on human health.

Risk assessment summary:

Given the arguments and evidence below *Trioza erytraeae* may be considered for additional measures.

- *Trioza erytraeae* has a strong association with citrus, but a weak association with citrus fruit.
- Basic measures are likely to reduce the of entry of *T. erytraeae* on citrus fruit, by a high degree (with low uncertainty). Consequently, the likelihood of entry is considered to be low (with moderate uncertainty).
- The ability of *T. erytraeae* to transfer from imported fruit to suitable host plants is high (with low uncertainty).
- The suitability of the New Zealand environment for *T. erytraeae* to establish is considered high (with moderate uncertainty).
- The level of impact caused by *T. erytraeae* is likely to be low to moderate (with low uncertainty) for New Zealand overall, but moderate to high for the citrus industry (with low uncertainty), depending on the presence of HLB in New Zealand.
- *T. erytraeae* is present in the one citrus-exporting country considered in this import risk assessment, Spain.

10.2.4 References

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11. Insects: Lepidoptera (moths, butterflies)

11.1 *Gymnandrosoma aurantianum* (citrus fruit borer)

Gymnandrosoma aurantianum, the citrus fruit borer, is a polyphagous moth native to tropical South America, which has spread to Central America and the Caribbean islands. Formerly a minor pest, it became a major pest of citrus due to the indiscriminate use of chemical pesticides (Parra et al. 2004). Internal feeding by larvae causes fruit to rot and drop prematurely and, thus, become unmarketable. Other affected crops include macadamia, avocado, peach, banana and lychee (CABI 2020).

Scientific name: *Gymnandrosoma aurantianum* Lima, 1927

Order/Family: Lepidoptera/Tortricidae

Other names: *Ecdytophpha aurantiana*, *E. aurantianum*, *E. torticornis*, *Tortrix citriana*, *macadamia nut borer* (CABI 2020)

Notes on taxonomy: *Gymnandrosoma aurantianum* was first identified and reported in 1915 by Gregorio Bondar as *Tortrix citriana* Fernald. In 1927, the species was redescribed and relocated taxonomically as *Gymnandrosoma aurantianum* (Lima), but was transferred again, in 1995, to the genus *Ecdytophpha* as *Ecdytophpha aurantiana* Adamski & Brown (2001). Following a taxonomic revision of the genera *Ecdytophpha* (Zeller), *Gymnandrosoma* (Dyar) and *Pseudogalleria* (Ragonot) of America, it was concluded that the species *aurantianum* (Lima 1927) belonged to the genus *Gymnandrosoma*, not to the genus *Ecdytophpha* (see Noboa et al. 2018 for all taxonomic references used in this section).

Summary of conclusions

Given the arguments and evidence presented:

- *Gymnandrosoma aurantianum* meets the criteria to be a quarantine pest for New Zealand.
- *G. aurantianum* has a strong association with citrus fruits with low uncertainty.
- The pest is present in a range of countries, including Brazil, Peru (and Mexico, where its current status is uncertain). These are among the countries being considered in the current citrus fresh produce import risk analysis.
- Basic measures will reduce the likelihood of entry of *G. aurantianum* on citrus fruit by a high degree (with moderate uncertainty). Consequently, the likelihood of entry is low with low uncertainty.
- The ability of *G. aurantianum* to transfer from imported fruit onto a suitable host plant to enable establishment is low (with moderate uncertainty).
- The suitability of the New Zealand environment (especially the citrus-growing areas) for the establishment of *G. aurantianum* is rated moderate to high (with moderate uncertainty).
- *Gymnandrosoma aurantianum* is likely to cause moderate impacts in New Zealand (with moderate uncertainty).
- *Gymnandrosoma aurantianum* may be considered for additional measures on citrus fruit.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	Moderate-high	Moderate
Impacts on the New Zealand economy, environment, health and society	Moderate	Moderate

11.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Gymnandrosoma aurantianum* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

There are no records of *G. aurantianum* from New Zealand.

- The pest is not recorded in PPIN (2020), NZOR (2020) or NZInverts (2020).
- It is a regulated pest for New Zealand; 'regulated' as *Ecdytolopha aurantiana* in ONZPR (2020).

Gymnandrosoma aurantianum has the potential to establish in New Zealand.

- The geographical distribution of the pest is mostly within the New World tropics, but it occurs in some areas with a subtropical climate, e.g. São Paulo in Brazil and Tucuman in Argentina (CABI 2020).
- Currently, it is widely distributed in South America: Argentina, Brazil (Minas Gerais, São Paulo, Santa Catarina, Rio Grande do Sul), Colombia, Ecuador, Peru and Venezuela; Central America: Costa Rica and Nicaragua; and in some Caribbean islands: Dominican Republic, Haiti, Puerto Rico, and Trinidad and Tobago (CABI 2020; EPPO 2020).
- When compared with New Zealand, sub-tropical/temperate areas in Brazil where the pest occurs (São Paulo, Santa Catarina and Rio Grande do Sul) have climate match index (CMI) values of 0.7, 0.8–0.9 and 0.8–0.9 respectively. These values indicate a 70–90% climate match, which suggests that the New Zealand climate would be suitable for establishment of the pest (Phillips et al. 2018), even though CMI values for the Caribbean and Central American countries where the pest occurs, which range from 0.4–0.6, suggest otherwise.

Gymnandrosoma aurantianum has the potential to cause impacts in New Zealand.

- In Brazil, *G. aurantianum* is considered to be one of the most important pests of citrus, as infesting larvae render the fruit unsuitable for both fresh consumption and industrial processing (Parra et al. 2004).
- It emerged as one of the main citrus pests in Brazil in the 1990s, and depending on the degree of infestation, yield losses ranged from 5–50% (Parra et al. 2004; Fundecitrus 2007).
- The pest causes economic damage to citrus in regions of Brazil (São Paulo, Santa Catarina and Rio Grande do Sul) that have a similar climate (CMI values of 0.7–0.9) to New Zealand, especially warmer northern areas (Phillips et al. 2018), where most commercial citrus production takes place.
- *Gymnandrosoma aurantianum* damage to citrus in the State of São Paulo, which produces most of Brazil's export citrus (Passos et al. 2018), was estimated at US\$50 million per year during the 1990s (CABI 2020; Garcia 1998 in Parra et al. 2004).
- The pest is known to attack other economically important hosts, such as avocado (*Persea americana*), peach (*Prunus persica*) and macadamia (*Macadamia* spp.) (CABI 2020), which are grown in the warmer northern regions of New Zealand (Plant & Food Research 2019).

11.1.2 Hazard identification: commodity association

Given the arguments and evidence below, *Gymnandrosoma aurantianum* is associated with citrus fruit and is recorded in countries under consideration for export of citrus fresh produce to New Zealand.

- *Gymnandrosoma aurantianum* was first described in 1915 causing damage to citrus trees in the state of São Paulo, Brazil (CABI 2020; EPPO 2017).
- The pest has been found infesting mandarin (*Citrus reticulata*) (Noboa et al. 2018).
- *Citrus* species on the EPPO (2020) host list for *G. aurantianum* include mandarin (*C. reticulata*), orange (*Citrus sinensis*) and grapefruit (*Citrus paradisi*).
- The NPPO of Spain has intercepted the pest on several occasions, in consignments of oranges (*C. sinensis*) imported from Brazil (EPPO 2017).

- The pest is recorded in a number of countries, including three being considered in the citrus fresh produce import risk analysis for New Zealand (Brazil, Peru and Mexico) (Adamski and Brown 2011, in CABI 2020; GBIF 2020).
- Note that although the presence of the pest in Mexico is validated by identifications of specimens collected from Colima state in 1923–1924 (Adamski and Brown 2011, in CABI 2020), its current status in Mexico is uncertain, due to the absence of recent records.

11.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Gymnandrosoma aurantianum* has a strong association with citrus fruit, with low uncertainty.

There are reliable records of *G. aurantianum* on citrus fruit:

- The earliest record of *G. aurantianum* is when it was first identified in 1915, as a pest of citrus trees in the state of São Paulo, Brazil (EPPO 2020).
- Each adult female *G. aurantianum* lays a single egg on the surface of citrus fruit, and first-instar larvae burrow into the fruit within two to seven hours of emerging from the egg (Parra et al. 2001).
- The pest has been found infesting mandarin (*C. reticulata*) fruit in Ecuador (Noboa et al. 2018).
- The named citrus hosts of the pest include orange (*C. sinensis*), tangerines/mandarins (*C. reticulata*), lemon (*C. limon*), lime (*C. aurantiifolia*) and pomelo (*C. paradisi*), but all types of citrus are considered likely to be susceptible hosts (EPPO 2020; CABI 2020).
- The pest has been intercepted on several occasions at the border of Spain on oranges (*C. sinensis*) imported from Brazil (EPPO 2017).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *G. aurantianum* on citrus fruit by a high degree (with moderate uncertainty). Consequently, the likelihood of entry is low, with low uncertainty.

Internally feeding larvae of *G. aurantianum* cause externally visible signs of infestation, although early infestations may not be detected:

- On mature fruit, the larval penetration hole is evident, and as the larva feeds within the fruit, it throws out frass (excrement and food scraps) that hardens on the skin of the fruit around the entry hole (Fundecitrus 2007; Parra et al. 2004).
- In addition, infested fruits often turn bright yellow prematurely (distinct from healthy fruit) and fall off the tree before they can be picked (Parra et al. 2004); such fruit would not meet basic measures and are likely to be culled and excluded from consignments meant for export.
- Signs of infestation may, however, not be as obvious on mature fruit picked shortly after becoming infested, and interception of the pest (not stated if alive or dead) on fresh oranges from Brazil at the border of Spain (EPPO 2018) may be an indication that some infestations escape detection during post-harvest processes and pre-export inspections.
- In green/immature fruit, which are attacked almost at the same rate as mature fruit when pest population levels are high, larval development takes longer (Parra et al. 2001), and as such, visible signs of infestation may also take longer to develop on such fruit.
- The length of time it takes for external signs of infestation to become obvious on fruit is uncertain, but this will depend on larval feeding and development rates.
- Note that eggs, which are 1–1.3 mm long and laid singly on the surface of fruit (Blanco-Metzler 1994), may be difficult to detect, but they could be dislodged from fruit or damaged by post-harvest measures such as washing, cleaning and waxing. Therefore, it is unlikely (but possible) that viable eggs would remain associated with exported fruit.

Larvae may not survive transit conditions and duration on fruit shipped from South America:

- Cold storage of fruit has been shown to effectively reduce the viability of pupae or larvae in fruit that is in transit (CABI 2020), and recommended storage and shipping temperature

ranges for orange (*C. sinensis*), which is a major host of *G. aurantianum*, are within the range 0 to 8°C depending on the variety/cultivar/origin (BMT 2020).

- Given that transit times are 58 and 65 days respectively from the Santos and Rio Grande ports in Brazil to the Tauranga port, 61 days from the Paita port in Peru to the Auckland port and 42 days from the Mazatlán port in Mexico to the Tauranga port in New Zealand (MSC Cargo 2020), larvae of *G. aurantianum* may not be alive/viable when infested oranges arrive in New Zealand.
- However, lack of data on how long the larvae of *G. aurantianum* can survive at low temperatures, and what those exact low temperatures are, creates some uncertainty as to whether or not larvae would be viable on arrival. There is also some uncertainty around transit times, which may be shorter if the ships are chartered and if routes are direct, with no trans-shipment.
- Some citrus commodities, e.g. grapefruit, lime and lemon, which are also hosts of *G. aurantianum*, are normally shipped at between 10°C and 14°C because they are damaged by lower temperatures (BMT 2020). Hence, larvae of *G. aurantianum*, which have an estimated lower development threshold of 9.8°C (Garcia 1998 in Parra et al. 2004), could survive transit on such commodities; these three commodities are among those for which Brazil and Peru are requesting market access to New Zealand.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *G. aurantianum* to transfer from imported fruit onto a host plant to allow establishment (exposure), is rated as low (with moderate uncertainty).

The pest needs to complete development to the adult stage for transfer to occur:

- Immature stages of *G. aurantianum* are non-dispersing and only adults can transfer to host plants (Blanco-Metzler 1994; CABI 2020).

Infested fruits that arrive in New Zealand are likely to contain mostly young larvae:

- Fruit containing older larvae usually have detectable signs of infestation (Fundecitrus 2007; Parra et al. 2004), and thus, are likely to have been detected and culled prior to export.
- Young larvae are unlikely to develop during transit in fruits (especially oranges) stored and shipped at temperatures below the estimated lower development threshold of *G. aurantianum* larvae, which is 9.8°C (Garcia 1998 in Parra et al. 2004).
- However, it is uncertain whether low in-transit temperatures would kill the larvae or simply prevent them from developing.
- Some development may occur in larvae infesting grapefruit, lemons and limes, which are usually shipped at temperatures between 10°C and 14°C (BMT 2020).

Young larvae may be able to complete development in infested fruit disposed of in open environments in warmer parts of New Zealand:

- In a laboratory study conducted at 27°C, *G. aurantianum* completed its four stages of larval development on two varieties (Natal and Pera) of orange (*C. sinensis*) in 18 and 22 days respectively, while the pupal stage took about 10 days (Garcia 1998 in Parra et al. 2004).
- At constant temperatures of 18°C, 20°C and 22°C respectively, mean duration of larval development on an artificial diet was 30.6, 30.3 and 25.9 days, while mean duration of the entire life cycle at those temperatures was 61.8, 56.5 and 50.2 days respectively (Garcia 1998 in Parra et al. 2004).
- In most of the upper North Island (where hosts are also more available), average summer temperatures are between 18°C and 21°C (NIWA 2020). In these areas, larval development of *G. aurantianum* in discarded imported fruit could be completed in 26–30 days (or slightly less, since larvae may have undergone some development in the fruit before it was exported and since the temperature in the field will not be constant).
- It is likely that fruit may decay before completion of larval development, since the postharvest life of citrus fruit, especially if it has been stored for several months or shipped for long distances at low temperatures, is severely reduced by saprophytic and pathogenic fungi (Strano et al. 2017).

- Another estimated 18–20 days may be required for pupal development and adult emergence, as mean duration of pupal development took 17.2, 18 and 20 days respectively, at 18°C, 20°C and 22°C (Garcia 1998 in Parra et al. 2004).
- Larvae in fruit arriving New Zealand at cooler times of the year are unlikely to complete development.

Adults of both sexes may need to emerge close to fruiting host plants for transfer to be completed:

- *Gymnandrosoma aurantianum* has separate male and female sexes (Blanco-Metzler 1994), and in Brazil, adults of the pest mostly mate on the third and fourth nights after emergence, between 6:00 p.m. and 9:00 p.m., in the upper crown of citrus trees (Bento et al. 2001).
- As females usually lay a single egg per fruit, several infested fruit may need to be discarded close to each other for both sexes to co-occur, leading to mating. However, females produce a sex pheromone, which facilitates the long-distance attraction of males (Bento et al. 2001), although the exact distance or radius of attraction is not stated.
- After mating, most adult movement has been observed to occur within the same host tree, although some moths flew to adjacent trees (Bento et al. 2001).
- Therefore, transfer is more likely if several infested fruits are discarded near orchards of citrus and other host plants, or within home gardens with fruiting citrus trees, so that mating can occur and newly emerged mated adult females can find suitable oviposition sites.
- Although the pest is often cited as having poor flight ability (Blanco-Metzler 1994; CABI 2020; EPPO 2020), its exact flight range or dispersal rate is not reported, which creates uncertainty around the argument about successful transfer of adults to suitable hosts.

Uncertainty:

There is moderate uncertainty around the conclusion on the ability of the pest to transfer:

- The time required to complete larval development on discarded fruit and pupal development in the soil in New Zealand are estimates, based on data from laboratory experiments at constant temperatures and using an artificial diet.
- Infested fruit may or may not be discarded near suitable hosts, and there are no up-to-date data on composting of food waste in New Zealand. In particular, the proportion of fruit waste that is composted in home gardens or in open areas where suitable hosts may be available is unknown.

Given the arguments and evidence below, the suitability of the environment of the North Island and upper South Island of New Zealand for the establishment of *G. aurantianum* is moderate to high (with moderate uncertainty), but most of the colder South Island is unlikely to be suitable.

The current geographical distribution of *G. aurantianum* is mainly tropical, but some locations where it occurs have a subtropical climate similar to parts of northern New Zealand:

- *Gymnandrosoma aurantianum* is widely distributed in South America: Argentina (Tucumán and Entre Ríos), Brazil (Minas Gerais, São Paulo, Santa Catarina), Colombia, Ecuador, Peru, and Venezuela; Central America: Costa Rica and Nicaragua; and in some Caribbean islands: Dominican Republic, Haiti, Puerto Rico, and Trinidad and Tobago.
- The climate match index (CMI) for the climate of the state of São Paulo (Brazil), where *G. aurantianum* is a major citrus pest, is 0.8 when compared to the Northland and Auckland regions (Phillips et al. 2018).
- Analysis of 50 location records for the pest in the Global Biodiversity Information Facility (GBIF 2020) shows that there is considerable temperature overlap between New Zealand's citrus-growing areas and equatorial mid-altitude and subtropical locations, particularly coastal subtropical areas (Halloy 2020).
- The pest is capable of surviving and reproducing at temperatures ranging from 18–32°C, with optimum survival and development occurring between 25–29°C.
- The lower development threshold estimated, by linear regression, is 9.81°C, with an estimated 579.05 degree days required for the completion of the life cycle from egg to adult (Garcia 1998 in Parra et al. 2004).

- Based on the above, the pest is likely to be able to establish and could potentially complete 2–4 generations each year in the main citrus-growing areas of New Zealand’s North Island (see Table 12.1.1 below, which compares climatic variables for locations where the pest occurs in Brazil and Argentina, with citrus-producing areas of New Zealand).
- Compared to the Brazil sites, temperatures in the Argentina locations are more similar to those in New Zealand’s citrus-growing areas (Table 12.1.1) and if data on the number of generations completed by the pest in the Argentina sites were available, they would provide more reliable estimates for New Zealand.
- More uncertainty is created by the absence of data on the lowest temperatures that the pest can tolerate, and since it is not known to diapause, there is some uncertainty as to whether or not the pest would survive winter temperatures, which occasionally drop to 0°C in some parts of the main citrus-growing areas of New Zealand (NIWA 2020).

Table 12.1.1. Locations in São Paulo, Brazil, with climate and number of annual generations completed by *G. aurantianum* on citrus, and two locations in Argentina where the pest has been recorded, compared with the main citrus production regions in New Zealand.

Location	Köppen-Geiger climate classification*	Mean annual temperature (°C)	Mean temperature of coldest month (°C)	Annual rainfall (mm)	<i>G. aurantianum</i> generations/year
São Paulo, Brazil					
Barretos	Aw (tropical savanna)	22.8	19	1,309	8.3
Sao Jose do Rio Preto	Aw (tropical savanna)	22.8	19.4	1,268	8.2
Bebedouro	Aw (tropical savanna)	22.3	19	1,337	7.3
Limeria	Cwa (temperate, hot summer)	20.5	16	1,284	7.2
Araraquara	Cwa (temperate, hot summer)	20.4	16	1,352	7.1
Argentina					
Entre Ríos	Cfa (humid subtropical)	17.7	11.4	989	No data
Tucumán	Cfa (humid subtropical)	19.4	12.7	997	No data
Main citrus-growing regions of New Zealand					
Northland	Cfb (temperate, warm summer)	15.6	11.7	1,658	3.0–3.6
Auckland	Cfb (temperate, warm summer)	15.2	10.6	1,284	2.9–3.8
Bay of Plenty	Cfb (temperate, warm summer)	14.4	9.6	1,426	2.1–3.2
Gisborne	Cfb (temperate, warm summer)	14.2	9.4	1,071	2.7–3.1

* For further detail, see, e.g. Beck et al. (2018) (<https://www.nature.com/articles/sdata2018214>). The Köppen-Geiger climate classification is based on five major climate types: A, C, D & E are defined by temperature (A the warmest, E the coldest), B by dryness. The major climate types are divided into subtypes with an additional one or two letters: w = dry winter, a = hot summer, f = without dry season, b = warm summer.

Climate information from Climate-Data.org (<https://en.climate-data.org/>), accessed 23 September 2020.

Data on number of annual generations of *G. aurantianum* in Brazil locations obtained from Garcia (1998) in Parra et al. (2004).

Degree-day (10°C) data for New Zealand citrus-growing regions obtained from NIWA <https://niwa.co.nz/our-science/climate/publications/regional-climatologies>, accessed 23 September 2020.

The number of *G. aurantianum* generations in New Zealand regions are estimates based on estimated lower development threshold (9.8°C) and thermal requirement of 579.05 degree days for completion of one generation from Garcia (1998), cited in Parra et al. (2004).

The locations in Argentina where occurrence of the pest is reported have a more similar temperature to New Zealand’s major citrus-growing area than the Brazil sites. However, no data was found on the number of annual generations completed by the pest in the Argentina locations.

Citrus and other host species of *G. aurantianum* are widely available in the northern regions of New Zealand’s North Island.

- All citrus species are likely to be hosts of *G. aurantianum*. The main citrus-producing areas of New Zealand, in terms of area planted and weight of produce, are in the North Island: Gisborne (56% of production), Northland (34%), Auckland (9%) and Bay of Plenty (1%) (Citrus NZ 2020).
- Other hosts of the pest (peach (*Prunus persica*), avocado (*Persea americana*), macadamia (*Macadamia integrifolia*) and banana (*Musa spp.*) are also grown in the warmer parts of the North Island (Plant & Food Research 2019) and in the case of peach, down to Otago and Southland, where the colder climate may, however, be a limitation to establishment.
- Citrus plants, especially lemons, are also commonly grown in home gardens throughout New Zealand.

Therefore, host availability is unlikely to be a barrier to establishment of *G. aurantianum*, especially in the North Island.

Impacts in New Zealand

Given the arguments and evidence below, *Gymnandrosoma aurantianum* is likely to cause moderate impacts in New Zealand, with moderate uncertainty.

Gymnandrosoma aurantianum causes economic impacts in citrus hosts.

- *Citrus* species, especially oranges (*C. sinensis*), are the main hosts of *G. aurantianum*, and once infested, fruit is rendered unsuitable for consumption as fresh produce or for processing (Fundecitrus 2007; Parra et al. 2004).
- The pest prefers to attack mature fruit, but at high populations, immature (green) fruit is also attacked, even though larval development is slower and mortality is high (29–50%) due to the high acidity of such fruit (Parra et al. 2001).
- In citrus orchards in São Paulo, Brazil, the moth can complete seven to eight annual generations, and with each female laying approximately 200 eggs, fruit losses can range from 5–50% depending on citrus varieties (Fundecitrus 2007; Garcia 1998 in Parra et al. 2004).
- However, the development and application of synthetic pheromone trapping (1 trap/10 hectares) have significantly reduced fruit losses caused by *G. aurantianum* in São Paulo and south Minas Gerais (Brazil) to an average of 0.6–1 fruit/plant (Bento et al. 2001; Carvalho 2003 in Parra et al. 2004), compared with 1 to 2 boxes (around 350 fruits/plant) without this strategy (references cited in Parra et al. 2004).
- According to Parra et al., in 2004, the pheromone trap, including a tablet containing synthetic pheromone, cost about US\$7. Therefore, the cost per hectare was 70 cents, considering that a trap covers a citrus area of 10 ha. Trapping also led to about 50% reduction in the use of chemical pesticides against the pest (Parra et al. 2004).
- Temperatures in New Zealand's main citrus production areas are lower than in Brazil, and hence, the pest is likely to complete fewer annual generations (see the section on establishment above and Table 12.1.1) and cause lower impacts in New Zealand, compared to areas of Brazil with a similar but warmer climate.
- No data were found on the number of generations and damage caused by *G. aurantianum* to citrus in areas of Argentina that have even more similar climate to citrus-growing areas of New Zealand. The reason(s) for the absence of such data is unclear, but it could be that impacts caused in Argentina are much lower than in Brazil, and as such, impacts in New Zealand may be even lower, although this is uncertain.

Gymnandrosoma aurantium may cause low economic impacts in non-citrus hosts.

- Although *G. aurantianum* is polyphagous and attacks plant species in multiple families (CABI 2020), most of its non-citrus hosts are tropical species that are either not present in New Zealand, or limited to very small areas, and therefore of little importance to New Zealand's economy.
- Of the non-citrus hosts of the pest grown in the North Island, avocados, with an export value of NZ\$104.3 million, have the highest economic value to New Zealand (Plant & Food Research 2019). Other less-valued minor hosts are peach and macadamia.
- However, the pest prefers *Citrus* species, especially oranges (*C. sinensis*) and, to a lesser extent, mandarins and other citrus varieties (CABI 2020; Parra et al. 2004). Thus, non-citrus hosts in New Zealand are less likely to be attacked if citrus hosts are available.

The pest is likely to spread, but its distribution is likely to be limited to the upper North Island.

- The pest can spread within and between nearby orchards, but the rate of spread is likely to be slow, because the pest is known to undertake only short flights (Bento et al. 2001; Blanco-Metzler 1994). However, there is some uncertainty, as its actual flight range is not known.
- If long-distance spread is to occur (to citrus orchards and other hosts), it is likely to be via the distribution of infested fruit, as the pest is not known to be migratory (Blanco-Metzler 1994; CABI 2020; Parra et al. 2004).

- Spread may also be limited to orcharding areas and home gardens in New Zealand's North Island (and possibly Nelson in the upper South Island), as cooler temperatures in most of the South Island are unlikely to support long-term establishment of the pest.

The pest is likely to have a low impact on access to export markets for host commodities.

- The main New Zealand exports likely to be affected are avocado and citrus fruit exports, which are mainly to Australia and countries in Asia (Japan and Korea) (Plant & Food Research 2019), where the pest is not present (CABI 2020; EPPO 2017).
- In 2019, the export value for New Zealand of fresh avocado and citrus (orange, mandarin and tangelo) were NZ\$104.3 million and \$2.2 million respectively (Plant & Food Research 2019).
- However, *G. aurantianum* is not listed as a quarantine pest for Australia or any of the countries that are export destinations for host commodities from New Zealand. It is on the EPPO alert list, and it is a quarantine pest for Morocco and Chile (EPPO 2020).
- Also, as natural dispersal of the pest is likely to occur slowly and since an effective and relatively cheap (US\$0.70/ha) pheromone lure is available (Parra et al. 2004), eradication may be possible, but would incur added costs.
- The cost of eradication is highly uncertain, as the pest has not established, and therefore has not needed to be eradicated outside the neotropics.

Gymnandrosoma aurantianum may cause environmental impacts, but these are likely to be negligible, with low uncertainty.

- In its native range and most of South America, *G. aurantianum* occurs in native forests, orchards and urban landscapes, usually below 500-m elevation, with primary hosts being in the Rutaceae and Sapindaceae plant families (CABI 2020).
- New Zealand has three endemic species in the Rutaceae: *Leionema nudum* (in the northern half of North Island), *Melicope simplex* and *Melicope ternata* (in lowland areas of both the North and South Island) (NZPCN 2020).
- Indigenous Sapindaceae include *Dodonaea viscosa* (lowland forest in the North, South and Chatham Islands), *Alectryon excelsus* subsp. *grandis* (endemic; Three Kings Islands) and *Alectryon excelsus* subsp. *excelsus* (endemic; North and South Islands from Te Pahi to Banks Peninsula) (NZPCN 2020).
- None of the above native species is considered threatened (de Lange et al. 2018; NZPCN 2020).

Gymnandrosoma aurantianum may cause some social impacts, but it is unlikely to cause any health impacts.

- The pest may establish on citrus plants in private gardens.
- Surveillance and eradication activities may have social impacts, due to the likely restrictions placed on the movement of host commodities, and the potential need to access and spray chemical pesticides on private properties.
- *Gymnandrosoma aurantianum* is a plant pest and has not been reported to affect human or animal health.

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11.2 *Marmara gulosa* (citrus peelminer)

The citrus peelminer is a 4-mm-long, dark-grey moth with mottled white and brown markings (Guillén et al. 2001). Females lay eggs on citrus fruit, and larvae cause cosmetic damage by mining just under the peel, forming serpentine mines that render fruit unacceptable for the fresh market (Gibson et al. 1997). The pest causes economic damage to commercial citrus fruit in California, Arizona, Northern Mexico and Cuba (Jones 2001).

Scientific name: *Marmara gulosa* Guillén and Davis 2001

Order/Family: Lepidoptera/Gracillariidae

Other names: none

Note on taxonomy: In California and Arizona, this pest was originally thought to be *Marmara salictella*, but was later described as *Marmara gulosa*. Earlier publications in which *M. salictella* was recorded as a pest of citrus probably refer to *Marmara gulosa* (Gracilliridae.net 2016).

Summary of conclusions

Given the arguments and evidence presented:

- *Marmara gulosa* meets the criteria to be a quarantine pest for New Zealand.
- *Marmara gulosa* has a strong association with citrus fruit, with low uncertainty.
- Basic measures reduce the likelihood of introduction of *M. gulosa* on citrus fruit by a high degree, with low uncertainty; therefore, the likelihood of entry is rated low.
- The ability of *M. gulosa* to transfer from imported fruit to suitable host plants is low, with moderate uncertainty.
- The suitability of the New Zealand environment for the establishment of *M. gulosa* is moderate, with moderate uncertainty.
- *Marmara gulosa* is likely to cause moderate impacts in New Zealand, with moderate uncertainty; there may be sporadic high impacts (with moderate uncertainty) in years when average summer temperatures in the main citrus-growing areas exceed 26°C, allowing the pest to complete more generations and rapidly build up populations.
- *Marmara gulosa* may be considered for additional measures on citrus fruit.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	Moderate	Moderate
Impacts on the New Zealand economy, environment, health and society	Moderate	Moderate

11.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Marmara gulosa* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

There are no records of *M. gulosa* from New Zealand.

- The pest is not recorded in PPIN (2020), NZOR (2020) or NZInverts (2020).
- It is not a regulated pest for New Zealand; it is not recorded in ONZPR (2020) or BRAD (2020).

Marmara gulosa has the potential to establish in New Zealand.

- The pest is native to the southwestern USA (California, Arizona and Texas) and has been reported in the southeastern US state of Florida, northern Mexico and Cuba (Guillén et al. 2001).
- Climate match index (CMI) values for most areas of California, Arizona and Texas are between 0.7 and 0.8, which indicates sufficient similarity to the New Zealand climate (Phillips et al. 2018) to allow establishment of *M. gulosa*.

Marmara gulosa has the potential to cause impacts in New Zealand.

- Larvae of *M. gulosa* mine and damage only the peel of grapefruit (*Citrus paradisi*), pomelo (*Citrus maxima*) and susceptible varieties of navel oranges (*Citrus sinensis*). Although damage is cosmetic, fruit with as few as two to three mines is not acceptable for the fresh fruit market (Gibson et al. 1997; Jones 2001; Stelinski 2013).
- In 1995, an outbreak of *M. gulosa* in the Coachella Valley, California, caused 80% to 90% fruit loss (due to severe mining of the peel) in some grapefruit groves (Jones 2001).

11.2.2 Hazard identification: commodity association

Marmara gulosa is associated with citrus fruit.

- Reports of *M. gulosa* from the peel of citrus fruits in southwestern USA date back to early in the 20th century; the earliest known record is of a mined orange peel collected 23 July 1915 from Pasadena, California (Vinal 1917, in Semet 2010).
- Larvae of *M. gulosa* mine and damage the peel of grapefruit (*C. x paradisi*), pomelo (*C. maxima*) and susceptible thin-skinned varieties (Fukumoto, Thompson Improved and Atwood) of navel oranges (*C. sinensis*) (Gibson et al. 1997; Jones 2001; Stelinski 2013).
- There are laboratory and field studies (e.g. Guillén et al. 2001; Guillén et al. 2003; Guillén et al. 2004; O'Neal et al. 2011) of *M. gulosa* developing on grapefruit.
- All citrus and their hybrids are considered hosts of *M. gulosa*, but grapefruit (*C. x paradisi*), orange (*C. sinensis*), pomelo (*C. maxima*), lemon (*C. limon*) and lime (*C. aurantiifolia*) have been specifically reported in the scientific literature (Gibson 1997; Guillén et al. 2001; Guillén et al. 2003, University of California 2008; Semet 2010; Stelinski 2013).

11.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Marmara gulosa* has a strong association with citrus, but a weak association with commercially traded (export) citrus fruit, with low uncertainty:

There are reliable records of *M. gulosa* from citrus fruit.

- *M. gulosa* occurs on citrus throughout the southern United States, mostly attacking grapefruit (*C. paradisi*), navel oranges (*C. sinensis*) and pomelo (*C. maxima*), but lemons (*Citrus limon*) and limes (*Citrus x aurantiifolia*) are also affected (Gibson et al. 1997; Guillén et al. 2001; Guillén et al. 2003, Guillén et al. 2004; O'Neal et al. 2011).
- Adult female *M. gulosa* lay their eggs on the surface of citrus fruit, or on the stems of new flush growth (Gibson et al. 1997; Guillén et al. 2001; Guillén et al. 2003).
- Across its current geographical distribution (southwestern USA: California, Arizona and Texas, southeastern USA (Florida), northern Mexico** and Cuba), *M. gulosa* has been reported on citrus (Guillén et al. 2001; Jones 2001; Semet 2010).
- Between 1988 and 2014, dead larvae of *Marmara* spp. were intercepted at the New Zealand border on citrus fruit from the USA: *M. salictella* (dead larvae) twice on grapefruit (*C. paradisi*); *M. gulosa* (two dead larvae) once on grapefruit and pomelo (*C. paradisi* / *C. maxima*); and *Marmara* sp. (dead larva) twice on grapefruit (LIMS 2019).

****Note:** There is some uncertainty regarding the presence of *M. gulosa* in Mexico; references to the pest's presence in Mexico were likely based on the assumption that the species of peelminer in Mexico is *M. gulosa*. However, from morphological examination of specimens collected from citrus in Sonora, northwest Mexico, Semet (2010) confirmed that citrus fruit in Mexico is attacked by a distinctly different and undescribed species of *Marmara* that was also present in Riverside and, possibly, Coachella in California, USA. In 2018, the NPPO of Mexico added *M. gulosa* to its quarantine pest list (EPPO 2020) and had earlier (October 2007) rejected a shipment of peelminer-scarred fruit from California, with the claim that *M. gulosa* was not a documented species in Mexico (Semet 2010). More precise molecular genetic studies are needed to resolve the taxonomy of the citrus peelminer species in Mexico and California (Semet 2010).

Basic measures reduce the likelihood of entry of *M. gulosa* on citrus fruit by a high degree, with low uncertainty. Therefore, the likelihood of entry is rated low (with low uncertainty).

Larvae of *M. gulosa* and the mining damage they cause are visually detectable on fruit.

- Live larvae of *M. gulosa* are active and visible within their mines on citrus fruit, and they cause highly visible damage (serpentine mines) on the peel (Guillén et al. 2001; O'Neal et al. 2011, Stelinski 2013; University of California 2008). As such, signs of infestation can be detected in the field, at harvest and during post-harvest practices in packing houses.
- Packing houses usually reject peelminer-damaged fruit; especially fresh fruit for export markets (Gibson et al. 1997; Stelinski 2013).
- Eggs of *M. gulosa* are laid externally on the surface of fruit (Guillén et al. 2001; Guillén et al. 2003; O'Neal et al. 2011; University of California 2008), and they are likely to be removed or damaged during post-harvest processes such as washing, brushing, cleaning and waxing of fruit.
- Any remaining undamaged eggs may not be detected due to their small size (0.41 mm long and 0.28 mm wide) (Kerns et al. 2004) and could remain associated with fruit after post-harvest and packhouse processes.

Larvae of *M. gulosa* may not survive pre-shipment cooling and transit conditions on citrus fruit.

- In a laboratory study, O'Neal et al. (2011) reported that at 17°C, cumulative mortality of *M. gulosa* reached 70% after 27 days, with mortality of eggs, first-instar larvae and second-instar larvae being 13%, 16% and 18% respectively. Based on these results, O'Neal et al. inferred that there would be high mortality of *M. gulosa* eggs and early-instar larvae at temperatures below the lower development threshold, which was determined to be 12.2°C.
- Given that citrus fruits are usually shipped at low temperatures (0°C to 14°C depending on citrus variety) and the minimum duration of shipping from North America to New Zealand is 18–20 days (BMT 2020), eggs and early-instar larvae of *M. gulosa* on citrus consignments can be expected to suffer high rates of mortality.
- The recommended storage and shipping temperatures for orange (*C. sinensis*), which is a major host of *M. gulosa*, range from 0°C to 8°C, while grapefruit (the most preferred host), limes and lemons (minor hosts), are normally shipped at between 10°C and 14°C because they are damaged by lower temperatures (BMT 2020). Hence, larvae of *M. gulosa* will have a slightly better chance of surviving transit on the latter commodities.
- However, between 1999 and 2019, only dead larvae of *Marmara gulosa*, *M. salictella* and *Marmara* sp. were intercepted at the New Zealand border – five times on grapefruit (*C. paradisi*) and once on pomelo (*C. maxima*) from the USA (LIMS 2019).
- Taken together, the above evidence suggests that if undetected *M. gulosa* eggs hatch after post-harvest handling and packing of fruit, early-instar larvae are not likely to survive transit conditions.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *M. gulosa* to transfer from imported fruit onto a host plant to allow establishment is rated low, with moderate uncertainty.

Eggs and larvae of *M. gulosa* are non-dispersing and, thus, cannot transfer from fruit to host plants.

- The stages (eggs and larvae) of *M. gulosa* that are likely to be present on imported citrus fruit are non-dispersing (Guillén et al 2001) and need to complete development into adults to transfer.
- Eggs of *M. gulosa* hatch and pass through four or five sap-feeding larval instars and one or two non-feeding larval instars on the fruit, after which the non-feeding larvae leave the fruit to pupate, before the emergence of adults, which can fly to find suitable host plants (Guillén et al. 2001; Guillén and Heraty 2004).

It is possible (but unlikely) that early-instar larvae of *M. gulosa* can complete development to mobile adults on peel or whole fruit discarded as waste in New Zealand:

- Optimum development of *M. gulosa* occurs between 26°C and 29°C (Guillén et al. 2003; Guillén and Heraty 2004; O'Neal et al. 2011), while its lower and upper development thresholds were determined to be 12.2°C and 33°C respectively (O'Neal et al. 2011).
- In laboratory studies, average development time from egg to adult was 29 days at 26°C, on grapefruit that is a preferred host (Guillén et al. 2001; Guillén & Heraty 2004), while on *Cucurbita pepo* (squash), which is an alternate host, it took 40.71 days at 21°C and 23.7 days at 25°C (O'Neal et al. 2011).
- Development of the feeding and non-feeding larval instars, which must be completed on fruit, required a minimum of 14.1 days on grapefruit at 26°C (Guillén et al. 2001) and 18.6 days at 21°C and about 17.6 days at 25°C on squash (O'Neal et al. 2011). Maurer et al. (1998), discussing the moth's life cycle under field temperatures during late summer in Arizona, stated that larvae complete their development cycle in 20–28 days.
- During the southern hemisphere summer when citrus fruits from the USA and Mexico are likely to begin arriving in New Zealand, mean daily maximum temperatures across most of New Zealand are between 20°C and 25°C (NIWA 2020). At these lower temperatures, based on the studies cited above, it is estimated that *M. gulosa* early instars on discarded fruit would require 17–18 days (at the least) to complete larval development, after which pupation and subsequent adult emergence could occur in another 10–15 days.
- It is uncertain if infested fruit and/or peel will contain enough sap and remain fresh to support development of the larvae for 18 days; in the laboratory study of the pest's development on squash (O'Neal et al. 2011), the fruit was kept fresh with moist vermiculite, misting and a covering of paper towels. Temperatures were also held constant in the laboratory studies, but will fluctuate in the open environments, e.g. open fields and compost heaps in home gardens where citrus waste may be discarded.
- However, the possibility of larvae completing development before the fruit decays cannot be ruled out, and adults could emerge following successful larval development and pupation.

If development is completed, adult female *M. gulosa* must mate to produce offspring:

- *Marmara gulosa* has separate male and female sexes (Guillén et al. 2001), and no evidence was found in the literature to show that unmated females can lay eggs that lead to the establishment of a viable population.
- However, exported fruit that is infested with *M. gulosa* is likely to bear both sexes, as female *M. gulosa* usually lay more than one egg on each fruit (Guillén et al. 2001; O'Neal et al. 2011) and sex ratios are approximately 1:1 or slightly biased toward males between 17°C and 29°C (O'Neal et al. 2011).
- Female *M. gulosa* produce sex pheromones that attract males (McElfresh et al. 2009), although there is no information on the distance over which the pheromones are effective.

Uncertainty:

There is moderate uncertainty regarding the ability of *M. gulosa* to transfer from imported fruit to host plants. The uncertainty is mainly due to insufficient information to determine if early-instar larvae can complete development on discarded peel or whole fruit, which may require at least 18 days at average summer temperatures in New Zealand. It is also uncertain if the discarded fruit will be fresh enough to allow completion of the larval stages. The possibility of transfer is also highly dependent on the disposal of unprocessed infested fruit waste in the vicinity of suitable hosts (see details in the section on waste disposal in section 2.4.1).

Given the arguments and evidence below, the suitability of the New Zealand environment (especially in the warmer parts of the North Island where citrus is grown commercially) for the establishment of *M. gulosa* is rated moderate, with moderate uncertainty.

The current geographical distribution of *M. gulosa* includes some locations with a similar climate to New Zealand.

- The known distribution of *M. gulosa* includes southwestern USA (California, Arizona and Texas), southeastern USA (Florida), northern Mexico and Cuba (Guillén et al. 2001; Jones 2001; Semet 2010).
- Climate match index (CMI) values for most areas of northern Mexico, California, Arizona and Texas are between 0.7 and 0.8, which indicates enough similarity to the New Zealand climate (Phillips et al. 2018) to allow establishment of *M. gulosa*. As they are more tropical, Florida (CMI: 0.5-0.7) and Cuba (CMI 0.5) have less similar climates to New Zealand.
- The optimum temperature range for the development of *M. gulosa* is 26–29°C (Guillén and Heraty 2004). Its lower and upper development thresholds were estimated, by linear regression of experimental data, to be 12.2°C and 33°C respectively (O’Neal et al. 2011). As such, the pest is more likely to establish in the warmer parts of the North Island of New Zealand, which are also the main citrus-growing areas.

Host plants of *M. gulosa* are widely available in New Zealand, especially in northern areas where the climate is more suitable for the pest.

- *Citrus* species, especially grapefruit, navel oranges and pomelo, are major hosts of *M. gulosa*, and the main citrus-producing areas of New Zealand (ranked in terms of area planted and weight of produce): Gisborne (56% of production), Northland (34%), Auckland (9%) and Bay of Plenty (1%) (Citrus NZ 2020), are in the North Island, which has a warmer climate than the South Island (NIWA 2020).
- Oranges cover the largest area (783 hectares), whereas there are only 15 hectares of grapefruit, which is the most preferred host (Citrus NZ 2020).
- Nevertheless, the pest is polyphagous, with hosts in more than 31 different plant families (Guillén et al., 2001; Semet, 2010). Some of the non-citrus hosts of *M. gulosa* include avocado (*Persea americana*), grapevine (*Vitis vinifera*), plum (*Prunus domestica*) and pepper (*Capsicum* spp.) (Gibson et al. 1997; Guillén et al. 2001), which are cultivated in New Zealand, and willow (*Salix* spp.), which is planted on riverbanks for erosion control in New Zealand (Bay of Plenty Regional Council).

Marmara gulosa is likely to spread within the main citrus production areas of New Zealand.

- Adult *M. gulosa* can disperse by flying and are likely to spread within and between citrus groves.
- In 1999, a field biologist working with the Tulare County (California) Agricultural Commissioner’s office observed citrus fruit with peelminer damage discarded outside packing houses, and peelminer damage soon appeared in orchards around the packing houses (Haines 2002, in Semet 2010).
- Subsequently, infestations were noted in orchards at a greater distance (not specified) from the initial sightings, and a wave of infestation moved northward, so that by summer 2001, peelminer infestation had increased dramatically, with some orchards sustaining as much as 80% damage (Grafton-Cardwell 2003).
- Spread beyond citrus-growing areas is likely to occur as infested fruit are distributed to other parts of New Zealand. However, outside of the upper North Island, the cooler climate may limit the pest’s establishment.

Impacts in New Zealand

Given the arguments and evidence below, *Marmara gulosa* is likely to cause moderate impacts in New Zealand, with moderate uncertainty around the magnitude of impacts.

Marmara gulosa is a cyclical pest in its native range and mainly causes high economic impact in citrus hosts during periodic outbreaks.

- In southern California where it is endemic, *M. gulosa* is a cyclical pest, and only periodically damages >5% of citrus fruit due to larvae mining just beneath the surface of fruit, with 2–3 mines per fruit rendering fruit unacceptable for the fresh market (Jones 2001; Stelinski 2013).
- In the central San Joaquin Valley (California), *M. gulosa* had been a minor pest of grapefruit (*C. paradisi*) for many years, but since 1999, it expanded its host range to include pomelo (*C. maxima*) and smooth-skinned navel orange (*C. sinensis*) varieties such as Fukumoto, Atwood, Thompson Improved, and Barnfield, which were especially susceptible. These and other crops, such as walnuts, grapes, cotton and beans, have been attacked to a greater extent than observed previously, with losses in grapefruit ranging from 10–80% (University of California 2008).
- In the Coachella Valley, California, an outbreak of *M. gulosa* in 1995 caused 80 to 90% fruit loss (due to the appearance of the mined rind) in some grapefruit groves (Jones 2001). Such huge losses have not been reported in the area since then, and this may be due to improved pest management practices.
- In other types of citrus, e.g. *C. sinensis* (orange), *C. limon* (lemon) and *C. aurantiifolia* (Mexican lime), fruit damage is reported to be usually less than 5% (University of California 2008).
- Outbreaks of *M. gulosa* in Arizona in 1994 and 1995, which resulted in economic damage in grapefruit, were most likely caused by excessive use of insecticides for whitefly control in adjacent fields of cotton; an alternate host from which *M. gulosa* dispersed to infest citrus crops (Maurer et al. 1998). It is believed that the pesticides reduced the populations of larval parasitoids of *M. gulosa* in the cotton fields, allowing it to quickly build up populations in the adjacent citrus crops. No reports were found of further outbreaks in Arizona.
- *Marmara gulosa* is likely to cause economic impacts in the main citrus-producing areas of New Zealand (ranked according to production area and weight): Gisborne (56% of production), followed by Northland (34%), Auckland (9%) and Bay of Plenty (1%) (Citrus NZ 2020).
- Impacts may be high in grapefruit, which is a preferred host of *M. gulosa* in the USA (Guillén et al. 2003; O’Neal et al. 2011). However, as of 2019, only 15 hectares in New Zealand were planted with grapefruit (Plant & Food Research 2019).
- In non-citrus hosts such as avocado, peppers, grapes and plums, *M. gulosa* mainly mines twigs, rather than fruit, and causes little to no economic impact in these crops (Gibson et al. 1997; University of California 2008).

Marmara gulosa is unlikely to cause environmental impacts.

- The pest mines twigs of *Salix* species, which are considered its native hosts in the USA (Guillén et al. 2001; University of California 2008), and several cultivars of *Salix* are used for erosion control, shelterbelts and, sometimes, as a fodder source for bees or livestock in New Zealand (Bay of Plenty Regional Council).
- However, no evidence was found indicating that mining of twigs of *Salix* species by *M. gulosa* causes any economic damage, and the pest is not known to attack any plants that are native to New Zealand.

Marmara gulosa is unlikely to cause any health impacts, but may cause some social impacts:

- *M. gulosa* is a plant pest and has not been reported to affect human or animal health
- The production of home-made marmalade from citrus fruits may be affected if people consider the peel of mined fruit to be unsuitable. However, such impacts have not been reported in the literature.
- Damage to fruit from home gardens may make such fruit unattractive; although the damage is limited to the peel and is not known to affect the quality or taste of the fruit itself.

Climate is likely to limit the overall impacts of *M. gulosa* in New Zealand (with moderate uncertainty).

- In the San Joaquin Valley, California, *M. gulosa* survives throughout the year on *Salix* species, and infests pomelo (*Citrus maxima*) from June to October (summer to autumn), during which it completes six to seven generations. The pest then attacks oranges, on which it completes three generations, from August to October (late summer to mid-autumn).

- The citrus-growing areas of New Zealand have lower average summer temperatures (18–20°C) (NIWA 2020) compared to (23–27°C) in the San Joaquin Valley (NOAA 2020) and as such, *M. gulosa* is unlikely to be able to complete as many generations in New Zealand like it does in the USA, which would limit its impacts.
- However, impacts may be high (with moderate uncertainty) in years when average summer temperatures in the main citrus growing areas exceed 26°C, allowing the pest to complete more generations and rapidly build up populations.

There is moderate uncertainty in the conclusion regarding impacts, as there is not enough evidence to accurately predict the extent to which climate will limit the pest's distribution and impacts in New Zealand. Presumably, impacts will likely increase with rising temperatures as a consequence of climate change.

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11.3 *Spodoptera littoralis* (African cotton leafworm)

Spodoptera littoralis is a grey-brown moth, 15–20 mm long, with grey-reddish brown wings. It is one of the most destructive agricultural moths within its subtropical and tropical range. The larvae feed extensively on leaves, fruit and seeds of many economically important crops, often completely stripping the plants (CABI 2020; EPPO 2020).

Scientific name: *Spodoptera littoralis* (Boisduval 1833)

Order/Family: Lepidoptera/Noctuidae

Other names: African cotton leafworm, Egyptian cotton leafworm, Mediterranean brocade moth (EPPO 2020)

Note on taxonomy: Prior to 1962, *Spodoptera littoralis* and *S. litura* were treated as a single species under the scientific name *Prodenia litura*. However, Viette (1962) demonstrated that *S. littoralis* is a species separate from *S. litura*. It is generally accepted that *S. littoralis* is found in Africa, Madagascar, Europe and the Middle East, whereas *S. litura* is found in Asia, Australia and the Pacific Islands (CABI 2020; EPPO 2020).

Summary of conclusions

Given the arguments and evidence presented:

- *Spodoptera littoralis* meets the criteria for being a quarantine pest.
- *Spodoptera littoralis* has a weak association with citrus and is not reported to be associated with the fruit of any *Citrus* species (with low uncertainty).
- Basic measures are likely to reduce the likelihood of entry of *S. littoralis* on citrus fruit by a high degree. Consequently, the likelihood of entry is considered very low, with low uncertainty.
- The ability of *S. littoralis* to transfer from imported fruit to suitable host plants, leading to establishment, is moderate (with moderate uncertainty).
- The suitability of the New Zealand climate for establishment of the pest is moderate (with moderate uncertainty). The pest may be able to establish outdoor populations in parts of the North Island and South Island, with transient populations in glasshouses.
- The pest is likely to cause moderate or sporadically high impacts in glasshouse and field crops, and it may cause environmental and social impacts by attacking native species.
- It is recommended that *Spodoptera littoralis* does not require consideration for additional measures, due to the lack of evidence of association with citrus fruit and the degree by which minimum measures reduce the likelihood of entry on the commodity.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Weak	Low
Likelihood of entry on the commodity, given the application of basic measures	Very low	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Moderate
Suitability of the New Zealand environment	Moderate	Moderate
Impacts on the New Zealand economy, environment, health and society	Moderate	Moderate

11.3.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Spodoptera littoralis* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

There are no records of *S. littoralis* from New Zealand, and the pest is regulated.

- *Spodoptera littoralis* is not recorded in PPIN (2020), NZOR (2020) or NZInverts (2020).
- The regulatory status of *S. littoralis* in New Zealand is “regulated” (ONZPR 2020).

Spodoptera littoralis has the potential to establish in New Zealand.

- The pest is mostly restricted to tropical and subtropical Africa, but occurs in southern France, Spain, Italy and parts of Portugal (EPPO 2020) in areas that have similar climates to parts of both the North and South Islands of New Zealand: climate match index (CMI) values of 0.7–0.9 (Phillips et al. 2018).
- The pest also has the potential to establish in glasshouses (CABI 2020; EPPO 2020).

Spodoptera littoralis has the potential to cause impacts in many field and glasshouse crops.

- The pest is highly polyphagous, with host species in 44 plant families, and is capable of completely defoliating crops (CABI 2020; EPPO 2020).
- Hosts of *S. littoralis* include tomato (*Solanum lycopersicum*), eggplant (*S. melongena*), potato (*S. tuberosum*), kumara (*Ipomoea batatas*), peppers (*Capsicum* spp.), grapevine (*Vitis vinifera*), apple (*Malus domestica*), corn (*Zea mays*), clover (*Trifolium* spp.), Cucurbitaceae and Brassicaceae (CABI 2020; EPPO 2020), which are economically important crops cultivated either in fields or glasshouses across New Zealand (Horticulture NZ 2017; Plant & Food Research 2019).

11.3.2 Hazard identification: commodity association

Given the arguments and evidence below, *Spodoptera littoralis* has a weak association with citrus (with low uncertainty) and has not been reported from citrus fruit.

There are few and somewhat conflicting records of *S. littoralis* from citrus species, and none from citrus fruit.

- *Citrus aurantium* (sour orange) is listed as a host in the *Crop Protection Compendium* datasheet on *S. littoralis* (CABI 2020), but details of the plant parts affected are not provided.
- Guerrero et al. (2012) list *Citrus* spp. and their hybrids as hosts of *S. littoralis*, but no supporting primary literature was found in which *S. littoralis* is associated with citrus fruit.
- *Citrus* is not included on the host list for *S. littoralis* on the UK Plant Health and EPPO databases (DEFRA 2020; EPPO 2020).
- *Spodoptera littoralis* is not recorded as a pest of citrus in Egypt (Biosecurity Australia 2002), which is within the native geographic range of the pest.

11.3.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Spodoptera littoralis* has a weak association with citrus plants and no known association with citrus fruit:

Records of *S. littoralis* on citrus are few and somewhat in conflict with each other.

- CABI (2020) lists *Citrus aurantium* (sour orange) as a host of *S. littoralis*, and *Citrus* spp. and their hybrids are named as hosts of *S. littoralis* in Guerrero et al. (2012). However, citrus is not included on the host list for *S. littoralis* in the UK Plant Health and EPPO databases (DEFRA 2020; EPPO 2020).
- No supporting primary literature in which *S. littoralis* is associated with citrus plants or fruit could be found, and it is not recorded as a pest of citrus in Egypt (Biosecurity Australia 2002), where it is a native species, nor in the south of Spain, the only other country being considered in this risk assessment, where it is known to occur.

- Nearly 80% of interceptions of *S. littoralis* at EU borders have been on shipments of cut flowers of *Rosa* spp., with other interceptions on *Aster*, *Begonia*, *Chrysanthemum*, *Dianthus*, *Eryngium*, *Eustoma*, *Lisianthus*, *Pelargonium*, *Petunia*, *Ranunculus*, *Mentha* and *Ocimum*, and a few on *Solanum melongena* and *Solidago* spp. (EFSA 2015).
- Interception records show that *S. littoralis* has not been intercepted on *Citrus* fruit or nursery stock at the New Zealand border (LIMS 2020). This could be because the pest is not present in countries from which New Zealand has previously imported citrus commodities. However, neither has the pest been intercepted on any host commodities imported into New Zealand. There is one record for *S. litura* intercepted on nursery stock of *Gypsophila* sp. from Israel (LIMS 2020). This may or may not have been *S. littoralis*, as *S. litura* is not known to be present in Israel, whereas *S. littoralis* is (CABI 2020; EPPO 2020).

Feeding and egg-laying behaviour of *S. littoralis* make it highly unlikely that the pest would be associated with citrus fruit:

- Larvae of the pest are defoliators, and adult females lay egg masses (20–1,000 eggs) on the lower surface of younger leaves on upper parts of host plants (Khalifa et al. 1982, in CABI 2020; Sadek 2011). Sadek (2011) states that: “of 1,082 egg batches found in 2 years (2007–2008) in cotton fields in Egypt, 1,035 batches (96.5%) were found on the underside of leaves, 28 (2.6%) on the upper side of leaves and 10 batches (0.9%) on petioles and leaf axillae”.
- No literature was found, in which *S. littoralis* is reported to feed or lay eggs on citrus fruit.
- Plants for planting and cut flowers and branches, but not fruits, are listed as the main risk commodities for the international spread of *S. littoralis* (CABI 2020; EPPO 2020).
- Incursions of *S. littoralis* in UK glasshouses in the 1960s, were found to have occurred via entry of the pest’s eggs on imported cuttings, especially chrysanthemums and carnations (CABI 2020). There are no records of introduction on citrus fruit.

Despite the conflicting information regarding the association of *S. littoralis* with citrus, there is low uncertainty around the conclusion that the pest has a weak association with citrus and that it is unlikely to be present on citrus fruit. This is because the conclusion is supported by reliable data on the pest’s biology and the fact that no primary sources in support of a contrary conclusion were found.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of introduction of *S. littoralis* on citrus fruit by a high degree. Consequently, the likelihood of entry is considered very low.

The life stages of *S. littoralis* that may incidentally be on citrus fruit (eggs and larvae) can be visually detected.

- Eggs are laid on leaves, and larvae feed mainly on leaves and occasionally fruit (capsicums and tomatoes), whereas pupation usually takes place in soil, and adult moths are very mobile and unlikely to remain associated with fruit (Ellis 2004; EPPO 2020).
- Eggs, though tiny (0.6 mm in diameter), are laid in batches of 20–1,000 and covered with hairy scales from the adult female’s body (CABI 2020; EPPO 2020), which makes them likely to be detected, if present on fruit.
- Egg masses are also likely to be damaged or dislodged during fruit handling and packing house processes such as washing, brushing, cleaning and waxing.
- Larvae measure 1–45 mm long (increasing in size as they develop from young instars to older instars) and feed externally, with young instars often in aggregations (EPPO 2015; CABI 2020; EPPO 2020), and are therefore likely to be detected and removed during harvest, post-harvest handling and packing house processes such as washing, brushing, waxing and culling.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *S. littoralis* to transfer from imported citrus fruit onto a suitable host plant to allow establishment (transfer/exposure) is rated moderate (with moderate uncertainty).

Climatic conditions during summer in northern parts of New Zealand may be suitable for eggs and early instar larvae to complete development:

- Eggs of *S. littoralis* need to develop (at least to second- or third-instar larvae) for transfer to occur. Eggs are not mobile and first-instar larvae are not known to disperse, but second- and third-instar larvae are able to move to different parts of a host plant, and older larvae can disperse to nearby plants (Sadek 2011).
- Eggs of *S. littoralis* reared on leaves of preferred host plants (cotton, clover, cowpea, cabbage and maize) at $25 \pm 2^\circ\text{C}$, $70 \pm 2\%$ RH and 16:8 h (L:D) photoperiod took an average of 35 days to become adults (Thoming et al. 2013). At a constant temperature of 18°C , the life cycle from egg to adult took about 70 days on lucerne (*Medicago sativa*) (Ocete Rubio 1984 cited by CABI 2020).
- Given the above temperature requirements and the fact that the citrus export season in Egypt (late November – February) coincides with New Zealand's summer, when average temperatures, especially in the northern parts of the country (Auckland, Northland, Gisborne, Hawkes' Bay) are between $18\text{--}21^\circ\text{C}$ (NIWA 2020), eggs of *S. littoralis* on citrus fruit discarded in open environments may be able to complete development into adults, but this would take considerably longer than 35 days.
- The fruit material is likely to rot before the pest completes development, as saprophytic and pathogenic fungi severely reduce the post-harvest life of citrus fruit, especially if it has been stored for several months or shipped for long distances at low temperatures (Strano et al. 2017). However, older larvae are likely to disperse away from rotting fruit in search of alternative hosts, based on the observation that older larvae can disperse to nearby plants (Sadek 2011).

If development is completed, *S. littoralis* adults could transfer to a suitable host and produce offspring:

- Adults are mobile and can disperse to find hosts. The flight range during a 4-hour period can be up to 1.5 km (Salama and Shoukry 1972).
- It is also possible that the pest undertakes long-distance migrations, as adults, which may be genuine migrants rather than those emerging from imported eggs/larvae, have been occasionally trapped in the UK (CABI 2020; Clancy 2020).
- Although the moth has separate sexes and mating is required for females to lay viable eggs, females produce a sex pheromone that effectively attracts males (Tamaki and Yushima 1974).
- Females can attract males from about 90 m downwind, and the attractive radius is about 10 m (El-Sayes 1977 and Ellis 1980, both in Ellis 2004).
- Most females mate on the first night of emergence, and approximately 50% of mated females lay their eggs on the same night of mating, before sunrise (Hassan et al. 1960, in CABI 2020).
- However, the likelihood of finding a mate may be low, given the low numbers of adults that would arise from one incursion incident, and this may further reduce likelihood of transfer leading to establishment.

There is uncertainty around the conclusion on the pest's ability to transfer from imported citrus, mainly due to lack of information on whether the pest feeds on and can complete development on citrus fruit or if the larvae can disperse from decaying citrus fruit in search of other sources of food.

Given the arguments and evidence below, the suitability of the New Zealand environment for the establishment of *S. littoralis* is rated moderate (with moderate uncertainty).

Spodoptera littoralis is a tropical and subtropical species, and a warm climate is critical to its development and persistence.

- *Spodoptera littoralis* is native to Africa and Israel, and its current geographic distribution is limited to tropical countries in Africa, the Middle East and Mediterranean Europe: Africa: Algeria, Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Congo Democratic Republic, Côte d'Ivoire, Egypt, Equatorial Guinea, Ethiopia, Eritrea, Gambia, Ghana, Guinea, Kenya, Libya, Madagascar, Malawi, Mali, Mauritania, Mauritius, Morocco, Mozambique, Namibia, Niger, Nigeria, Réunion, Rwanda, St Helena, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania, Togo, Tunisia, Uganda; Middle East/Asia: Bahrain, Iran, Iraq, Israel, Jordan, Lebanon, Oman, Pakistan, Saudi Arabia, Syria, Turkey, United Arab Emirates,

Yemen; Europe: Cyprus, Greece (Crete), Italy (Sicily), Malta, Portugal, France and Spain (CABI 2020; EPPO 2020).

- The northern distribution limit of *S. littoralis* in Europe (eastwards into Turkey and north into eastern Spain, southern France and northern Italy) corresponds to the climatic zone in which winter frosts are infrequent, and is probably the extent of migrant activity, because the pest overwinters in southern parts of Greece and Spain, but not in northern Italy or France (CABI 2020; Miller 1977).
- Miller (1977) demonstrated that exposure of *S. littoralis* pupae to $13 \pm 0.5^\circ\text{C}$ for 70 days resulted in the emergence of only a few adults, all of which were deformed and none of which mated or laid fertile eggs. Eggs and early- and late-instar larvae were also shown to be susceptible to low temperatures (1°C , 4°C , 7°C , 10°C and 13°C), and 30-day-old larvae, which were the most cold-resistant, suffered 100% mortality after 65 days at 13°C .
- The findings of Miller (1977) explained why, without being able to enter a state of diapause, the pest does not overwinter in northern Spain, Italy and France.
- Ocete Rubio (1984), cited in CABI (2020), reported that the minimum constant temperature required for normal development of all stages was between $13\text{--}14^\circ\text{C}$ and showed that egg, larval and pupal stages took 2, 10 and 8 days respectively at 36°C , whereas at 18°C , development of these stages took 9, 34 and 27 days respectively.
- In a laboratory study in Egypt, El Malki (2000) reported that eggs of *S. littoralis* kept at 10°C failed to hatch; the lower temperature threshold for the completion of development of egg, larva, pupa and adult maturation (pre-oviposition and oviposition) was estimated to be 11.8°C , 12.5°C , 11.3°C , 10.7°C , 10.8°C respectively and 12.6°C for the completion of a generation.
- Yones et al. (2012), on the other hand, considered the lower developmental threshold to be 9.9°C and based on this, determined that, on average, the thermal requirements for completing a generation (egg to adult) were about 524 degree days in the laboratory and 545 in the field (calculated from air temperatures) in Egypt.

Spodoptera littoralis may be able to establish outdoors in most of the North Island and in northern parts of the South Island with transient seasonal populations in glasshouses.

- The pest overwinters outdoors in parts of southern Greece (Crete) and southern Spain up to Barcelona (CABI 2020; EPPO 2020), which have similar enough climate (CMI: 0.7–0.8) to the Auckland and Northland regions in the North Island of New Zealand.
- The predicted distribution of *S. littoralis* in the USA (based on modelling) includes parts of Tennessee, North and South Carolina, northern Florida, northern parts of Georgia, Missouri and Oklahoma (Venette and Davis 2003 in Ellis 2004), which also have CMI values of 0.7–0.8, when compared to the Auckland and Northland regions of New Zealand.
- In Kaitia, which is in the Northland region, the monthly average maxima never drop below 15°C . Auckland drops below 15°C for only one month and never below 13°C monthly average maxima (NIWA 2020).
- On the above criterion, *Spodoptera littoralis* could breed in much of the North Island, from Kaitia to Taranaki, Gisborne and Napier, and possibly Blenheim, which covers most of the principal citrus growing areas of New Zealand.
- Degree days required to complete a life cycle were estimated, from laboratory physiological thresholds, at between 366 and 490 by El-Malki (2000), and between 544 to 641 degree days above 9.89°C by Yones et al. (2012); although recognising that laboratory data suggest fewer degree days, Yones et al. (2012) based their estimates on remote sensing information.
- Assuming mid-point estimates of 428 and 593 degree days, *Spodoptera littoralis* could complete 3–5 generations per year in Whangarei, 2–3 in Nelson and, potentially, 1 in Invercargill (Halloy 2020).
- The pest can establish in glasshouses and has been detected and eradicated from glasshouses in the UK, following its introduction as eggs on cuttings, especially chrysanthemum and carnation cuttings, imported into glasshouses (CABI 2020).
- Occasional outbreaks in glasshouses, which were also successfully eradicated, have also been reported from Sweden, Switzerland, Finland and Germany (Bartlett and Macdonald 1993, in EFSA 2015).
- The pest is highly polyphagous (CABI 2020), and many of its host plants, e.g. cabbage, broccoli, cauliflower, lettuce, tomato, potato, kumara, onion, clover and maize, are cultivated

in parts of the South Island and especially in the North Island (Horticulture New Zealand 2017), where the climate is likely to be more suitable for the pest to establish.

There is uncertainty in the conclusion about the suitability of the New Zealand environment for establishment of *S. littoralis*, because although the pest is mostly tropical, requires high temperatures for survival and development and does not overwinter in parts of Europe with similar climate to New Zealand, degree-day models suggest that the New Zealand climate is likely to be suitable for the pest's establishment.

Likelihood of impact:

Given the arguments and evidence below, *Spodoptera littoralis* is likely to cause moderate impact (with moderate uncertainty).

Spodoptera littoralis can cause economic impacts in outdoor and glasshouse crops:

- Spread of the pest in outdoor areas is likely to occur mainly via the dispersal of adults, which can fly up to 1.5 km during a 4-hour period (Salama and Shoukry 1972), and the pest could be introduced into glasshouses on infested plants for planting.
- The Auckland and Northland regions of New Zealand where the pest is more likely to be able to establish have similar climate (CMI: 0.7–0.8) to the southern areas of the European countries where the pest occurs (Phillips et al. 2018), and as such, the pattern of damage likely to be caused by the pest in these regions of New Zealand, may be similar to what occurs in southern Europe.
- Many of the field crops affected in southern Europe are grown outdoors in the North Island of New Zealand: lettuce, onions, cabbage, broccoli and cauliflower are grown in New Zealand's northern and mid-regions, with warmer climate conditions allowing year-round production (Horticulture New Zealand 2017). Tomato, eggplant and peppers are important hosts mainly grown in glasshouses in New Zealand (Vegetables New Zealand 2020).
- The size of production area, domestic value in 2018 and export value in 2019 for New Zealand tomatoes and capsicums were 120 ha (NZ\$176 million domestic, \$11.2 million export) and 95 ha (NZ\$25 million domestic, \$20.6 million export) respectively (Plant & Food Research 2019), and chrysanthemums, which are important ornamental hosts of the pest, are also grown in New Zealand glasshouses for domestic and export trade as cut flowers (Markham 2017).
- In Europe, damage caused by *S. littoralis* was minimal until about 1937, but in 1949, a population explosion of the pest in southern Spain severely affected lucerne, potatoes and other vegetable crops (EPPO 2020). At present, *S. littoralis* is considered an economically important pest in Cyprus, Malta and parts of southern Greece, Italy, France and Spain, with damage in these areas being mostly sporadic, but occasionally severe, in a wide variety of outdoor vegetable, salad and ornamental crops (CABI 2020; EFSA 2015).
- In 2009, in France (Corsica), crops of vegetables (chard, lettuce) and ornamentals (calla lilies and buttercups) were seriously damaged by *S. littoralis* (Fredon Corse 2014), and pheromone traps had to be deployed in 2013 and 2014 because of serious damage to lettuce and chard (Jean-Marie Ramel, personal communication cited in EFSA 2015).
- In Sicily and Liguria (southern Italy), *S. littoralis* is an important pest of horticultural crops (and floriculture); having spread gradually since the 1980s to coastal areas characterised by intensive cultivation of protected crops (Sannino 2003).
- In Greece, specifically Crete, *S. littoralis* causes slight damage on lucerne (*Medicago sativum*) and clover (*Trifolium* spp.) only (CABI 2020; EPPO 2020), which are important legumes used in New Zealand dairy pastures.
- The number of generations completed by the pest each year would determine the level of impact, and Halloy (2020) estimates that *Spodoptera littoralis* could complete 3–5 generations per year in Whangarei, 2–3 in Nelson and, potentially, 1 in Invercargill; based on degree days required for the completion of a generation calculated by El-Malki (2000) and Yones et al. (2012).
- Studies in Egypt show that *S. littoralis* has seven overlapping generations per annum when feeding on cotton (El-Shafei et al. 1981 and Khalifa et al. 1982, both cited in CABI 2020).

- *Spodoptera litura*, a related species that is established in parts of the North Island of New Zealand, only causes sporadic economic impacts in pasture crops following occasional outbreaks (Gerard et al. 2011).
- Based on the foregoing, overall, economic impacts may be expected to be very low to low in most years, but they could be high in glasshouses, and moderate to high outdoors in years when temperatures are higher than normal, allowing the pest to complete more generations.

Spodoptera littoralis may cause low environmental and social impacts, but is unlikely to cause health impacts:

- There are New Zealand native species in the plant families to which known hosts of the pest belong. Few examples of native plants that could be affected include *Hibiscus richardsonii* and *Hoheria* spp.: family Malvaceae, found in parts of the north Island; *Streblus banksia*: Moraceae, an endemic species of coastal forest on the North Island (University of Auckland 2020); two species of *Clianthus* (kakabeak or kōwhai ngutukākā in Māori): Fabaceae, one of which is endangered and the other of which is critically endangered (Heenan 2000).
- Kumara (*Ipomoea batatas*), which is a culturally significant food plant for Māori, is a known host of the pest that is grown exclusively in the North Island (90% in Northland) (Vegetables New Zealand 2019). The bark of *Hoheria populnea* (houhere, lacebark), found in lowland forest in the upper half of the North Island, contains a lace-like sheet that is highly prized for weaving decorative items (University of Auckland 2020).
- Many vegetable hosts of the pest, e.g. tomato, capsicum and cabbage, are grown in private gardens.
- No reports of human or animal health impacts from *S. littoralis* were found.

Effective pest management measures are available, but will lead to added costs:

- Incursions in glasshouses are likely to be detected early, due to the pest's voracity, allowing for eradication; sporadic outbreaks of the pest in northern European glasshouses have been successfully eradicated (Bartlett and Macdonald 1993 in EFSA 2015). Outdoor populations may be more difficult to eradicate, especially if the infestation is spread out over a wide area.
- Long-term insecticidal control is possible and effective, although there have been many cases of resistance, and biological control methods are not always effective (EPPO 2020), which means that introduction of *S. littoralis* into glasshouses could necessitate insecticide treatments that may interfere with existing biological control of other pests.
- The synthetic sex pheromone cis 9-trans-11-tetradecadien-1-y1 acetate is highly effective at trapping male moths of *S. littoralis* (Kehat and Dunkelblum 1993).
- Successful control of the pest and resistance management can be obtained with mass trapping, mating disruption and attract-and-kill methods, but these methods are expensive to implement (Guerrero et al. 2014).
- In Spain, *S. littoralis* is controlled effectively using entomopathogenic nematodes, such as *Steinernema feltiae* and *Heterorhabditis bacteriophora*, in IPM systems (Galeano et al. 2009). *Steinernema feltiae* is recorded as present and indigenous in New Zealand, while the latter is not known to be present (NZOR 2020).
- The pest has many other known natural enemies; pathogens (*Beauveria bassiana*, *Bacillus thuringiensis*), parasitic wasps (*Apanteles* spp., *Brachymeria* spp., *Cotesia* spp.) and predatory beetles (*Coccinella undecimpunctata*, *Euborellia annulipes*) (CABI 2020), which are present in New Zealand (NZOR 2020) and could contribute to mitigating impacts.

Uncertainty:

Uncertainty regarding the level of impact stems from the fact that damage caused by the pest in areas of Europe with similar climate to some parts of New Zealand has been described using terms such as slight, severe or serious, but is not quantified in terms of production or yield losses. Additionally, cropping practices are not the same across all locations and between those places and New Zealand, which creates uncertainty around the estimate of the potential level of economic damage. Also, with climate change resulting in higher average temperatures, more areas of New Zealand could become more suitable for the pest to establish, which could lead to increased impacts.

11.3.4 References

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12. Insects: Thripidae (thrips)

12.1 *Caliothrips fasciatus* (bean thrips)

Caliothrips fasciatus was once a significant pest of many commercial crops (lucerne, beans, cantaloupes, cotton, lettuce, pears, peas and walnuts) in California, but its status as a crop pest has waned, due to improved pest and crop management systems. However, this thrips remains a major quarantine issue for the export of fresh navel oranges (*Citrus sinensis*) and mandarins/tangerines (*C. reticulata*) from California, because adults overwinter in the navels of the oranges, posing an incursion threat to importing countries (Hoddle et al. 2006).

Scientific name: *Caliothrips fasciatus* (Pergande 1895)

Order/Family: Thysanoptera/Thripidae

Other names: *Heliiothrips fasciatus*, *Herciothrips fasciatus*, *Caliothrips woodworthi*, North American bean thrips, California bean thrips (Bailey 1933)

Summary of conclusions

Given the arguments and evidence presented:

- *Caliothrips fasciatus* meets the criteria to be a quarantine pest for New Zealand.
- *Caliothrips fasciatus* has a strong association with fruits of *Citrus sinensis* (navel orange); particularly, navel oranges from California, USA.
- Basic measures are likely to reduce the likelihood of entry of *C. fasciatus* by a low to moderate degree (with moderate uncertainty); consequently, likelihood of entry is moderate to high.
- The ability of *C. fasciatus* to transfer from imported fruit to suitable host plants is low, with moderate uncertainty.
- The suitability of the New Zealand climate for establishment of *C. fasciatus* is rated as high.
- *Caliothrips fasciatus* is likely to cause moderate impacts, overall; impacts on crop hosts is likely to be low, but establishment in citrus-growing areas could lead to long-term costs for phytosanitary measures to ensure access to foreign markets, for citrus exports.
- *Caliothrips fasciatus* may be considered for additional measures on citrus fruit.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Moderate–high	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Low	Low

12.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Caliothrips fasciatus* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

There are no records of *Caliothrips fasciatus* from New Zealand⁸⁷.

- The pest is not recorded in PPIN (2020), NZOR (2020) or NZInverts (2020).
- *Caliothrips fasciatus* is a regulated pest for New Zealand, recorded as “regulated” in ONZPR (2020).

Caliothrips fasciatus has the potential to establish in New Zealand.

- *Caliothrips fasciatus* is native to the United States of America (USA) and is found in Alabama, Arizona, California, Florida, Idaho, Louisiana, Nevada, Texas, South Carolina and Wyoming.
- Compared with New Zealand, some of the locations in the USA where *C. fasciatus* occurs have a climate match index (CMI) value ≥ 0.7 , which indicates enough climate similarity to allow establishment of the pest in New Zealand (Phillips et al. 2018).

Caliothrips fasciatus has the potential to cause impacts in New Zealand.

- The pest is of major quarantine concern as a contaminant of navel oranges from California (Hoddle et al. 2006), and its establishment in New Zealand (especially in citrus-growing areas of the North Island) is likely to affect access to export of citrus fruits, especially navel oranges to Australia.
- The pest has also been reported on more than 60 genera of plants in the state of California, including more than forty cultivated crops (Bailey 1933; Hoddle 2020). Some host plants of *C. fasciatus* that are economically important to New Zealand include pear (*Pyrus* spp.), lettuce (*Lactuca sativa*), watermelon (*Citrullus lanatus*), onion (*Allium cepa*) and brassicas (Plant & Food Research 2019; Vegetables New Zealand 2020).

12.1.2 Hazard identification: commodity association

Caliothrips fasciatus is associated with citrus fruit.

- Although *C. fasciatus* does not feed on citrus, adults of the thrips overwinter in the navel of navel oranges in California from November to March, which coincides with the harvest season for citrus fruits in California.
- The pest is frequently intercepted on citrus fruit from the USA at the borders of Australia and New Zealand (EPPO 2020; Hoddle et al. 2006; LIMS 2020).
- The pest is reported as present in USA and Mexico, two of the exporting countries being considered in the citrus fresh produce import risk analysis.

12.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Caliothrips fasciatus* has a strong association with citrus commodities, especially fresh fruit of navel oranges (*Citrus sinensis*) from the USA (California).

There are reliable records of *Caliothrips fasciatus* on citrus plants and traded citrus fruit from California:

- The first published record of this thrips, in 1895, was of two specimens collected from an orange leaf in Yuba County, California, in November 1894 (Bailey 1933).
- Bailey (1933) cites Russell (1925) as having recovered hibernating adult bean thrips from the navel end of oranges sent from California to Lincoln, Nebraska and Urbana, Illinois.
- Whitney (1930) reported that in Hawaii in December 1929, hibernating adults of *Hercotothrips fasciatus* (syn. *Caliothrips fasciatus*) were found on shipments of persimmons, tangerines and oranges from California.
- Between 1988 and 2020, there were 157 interceptions of *C. fasciatus* at the New Zealand border, 99% of the them on fresh oranges, with the remaining 1% shared between lemons,

⁸⁷ The CABI *Invasive Species Compendium* datasheet on *C. fasciatus* <https://www.cabi.org/isc/datasheet/112877> includes New Zealand in distribution table, but there is no supporting evidence from any other sources (database or primary literature).

tangerines, mandarins, tangelos, pears and apples. All commodities on which the pest was intercepted were from the USA (LIMS 2019).

- Hibernating adult bean thrips were collected from leaves of orange (*Citrus sinensis*) infested with soft brown scale (*Coccus hesperidum*) at Davis, California. The thrips were huddled among the scales, with some hiding in the emergence holes of the parasitised scales (Bailey 1933).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *C. fasciatus* on citrus fruit by a low-moderate degree. Consequently, the likelihood of entry is moderate to high.

Caliothrips fasciatus may be visually detectable in the field and in packing houses, leading to its removal from produce, but some individuals are likely to be undetected:

- Only adults of *C. fasciatus* are known to overwinter (usually in aggregations) in the navels of navel oranges (Bailey 1933; Hoddle et al. 2006), and such aggregations are likely to be detected and removed during harvest and post-harvest processes.
- Due to the high level of awareness in California of the phytosanitary risk posed by *C. fasciatus* in association with citrus exports, a rigorous systems approach for pre-export management of the pest has been developed and includes in-field monitoring using sticky traps, post-harvest inspections and packhouse processes (Harman et al. 2007a, 2007b).
- However, Harman et al. (2007b) suggest that despite the systems approach, the usually low infestation levels (less than 0.5%) of *C. fasciatus* on citrus fruit in California, coupled with the pest's small size, would be likely to make detection of all infested fruit difficult.
- Laboratory experiments by Harman et al. (2007b) showed that washing navel oranges using either of five spray rinses, including distilled water, resulted in close to 90% recovery of thrips, leaving about 10% of the pest population in the fruit.
- Thus, post-harvest processes such as washing, brushing, cleaning and waxing are likely to dislodge some of the hibernating *C. fasciatus* adults from fruit, but individuals deep inside the fruit navel may remain associated with the fruit.
- Frequent interceptions of live, adults of *C. fasciatus* on navel oranges from the USA at the New Zealand border (LIMS 2019) indicates that basic measures do not prevent entry of the pest into New Zealand.
- Therefore, additional measures may be required to adequately reduce the likelihood of entry of the pest.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *C. fasciatus* to transfer from imported fruit onto a host plant (exposure) to allow establishment, is rated low (with moderate uncertainty).

Overwintering adults of the pest on imported fruit that arrive in summer can come out of hibernation.

- Only adults of the pest, which can fly, are likely to be associated with imported citrus fruit, since only adults overwinter in citrus fruits (Bailey 1933; Hoddle 2020; Hoddle et al 2016).
- Bailey (1933) observed that entrance into and emergence from hibernation was gradual and that in the field during winter, hibernating adults became active on very warm days when temperatures rose to between 23.9°C and 26°C.
- The citrus harvest season in California is November – May, and as such, the pest is likely to arrive New Zealand on citrus shipments in the summer.
- Average summer temperatures across New Zealand are usually between 18–21°C (NIWA 2020), but daily maxima can be as high as 27°C, which may allow the pest to come out of hibernation and become active. Bailey (1933) reported that adults of *C. fasciatus* were usually active at temperatures between 10–47°C, with optimum activity between 23–32°C, and adults can be made to become inactive and to resume activity by respectively, lowering and raising temperature.

Adult *C. fasciatus* may be able to fly from fruit onto host plants, but this is highly uncertain and dependent on where the fruit is disposed of or displayed and their proximity to host plants.

- Thrips on fruit discarded along with other food waste are often stimulated (by the deteriorating materials) to search for a suitable host on which to feed (Lewis 1997).
- Individuals of most thrips species can launch themselves into the air from flat plant surfaces such as petals or leaf blades, but they often choose a protruding narrow edge from which to jump (Lewis 1997).
- However, the absence of information on adult *C. fasciatus* or other thrips launching into flight from discarded waste, creates some uncertainty. Presumably, the pest would need to crawl or climb to a sufficiently high level above ground to enable it to launch into flight, and this is not likely to be possible from waste discarded in landfills, but could be possible from open compost heaps in gardens and even more likely from a roadside fruit stall or market.
- If a launch site is found, the takeoff of thrips' flight is strongly influenced by weather factors, especially temperature, light and wind; most thrips from temperate climates are able to take off at a minimum temperature of 17°C to 21°C, with most takeoffs occurring during the warmest part of the day (Lewis 1997).
- Although thrips are regarded as weak flyers, their finely fringed wings enable them to remain airborne long enough for the wind to blow them to great heights and for long distances (Lewis 1991).
- There is abundant circumstantial evidence that, at least when they are near the level of vegetation during a long distance wind-assisted flight, thrips exercise a sufficient degree of control that allows them to choose to alight on host crops; even on individual plants (Lewis 1991). There is also experimental evidence that thrips in flight can respond to the scent of host plants and flowers, using them as visual and olfactory cues to recognise and land on suitable hosts (Kirk 1985).
- Many known hosts of the pest are present in New Zealand and include outdoor crops (e.g. clover, lucerne, lettuce, onion, corn, pear, peach, apple, grapes) and common weeds: field bindweed (*Convolvulus arvensis*), sow thistle (*Sonchus oleraceus*) and prickly lettuce (*Lactuca serriola*) (Bailey 1933), which increases the likelihood of the pest landing on a suitable host plant.

Unmated female *C. fasciatus* are not likely to establish a breeding population.

- Rugman-Jones et al. (2012) showed that virgin females (n=90) from three distinct populations, kept individually and allowed to oviposit on a bean leaf for 11 days, failed to produce any offspring, and virgin females isolated in groups of five only produced males.
- Bailey (1933) showed that after 10 days, female *C. fasciatus* mated once and lived naturally for 20 days, only laid eggs that hatched into male offspring, with repeated mating required to produce females.
- In California, adults coming out of hibernation began to feed, mate and lay eggs in March (early spring) when average daily temperatures were about 13–15°C (Bailey 1933).
- It is uncertain if previously mated females coming out of hibernation in New Zealand will be able to lay viable eggs without mating or if they can find males with which to mate.
- There is no evidence that the species produces a sex pheromone, although its ability to form overwintering aggregations inside the navels of oranges is thought to be mediated by a male-produced aggregation pheromone, which is yet to be identified (Hoddle 2020).

Cumulative cold stress, from cooling before and during transit, may render hibernating female *C. fasciatus* incapable of producing viable offspring, but this is highly uncertain.

- Hoddle et al. (2006) report that navel oranges are shipped from California at a temperature of 2.78°C to Australia (the same probably applies to New Zealand) and hypothesize that exposure to this low temperature for the duration of transit (18–24 days to Australia) could be rendering female *C. fasciatus* incapable of laying viable eggs.
- Hoddle (2020) suggests that bean thrips surviving harvest, washing/waxing, cool storage and refrigerated shipping are not “fit” when they arrive in a new locale and that this may partly explain the pest's failure to establish outside its native range despite being exported from California inside the navels of oranges since at least 1899 – a view shared by Mound et al. (2011).

- Hoddle (2020) concludes that compounding cold stress resulting from winterization, storage, and shipping may have a significant negative impact on fitness, i.e. the longevity and fecundity, of surviving thrips.
- Simply put, cold-debilitated thrips that make it to Australia and New Zealand alive and escape into the wild are unable to found viable populations of sufficient size to overcome additional establishment barriers posed by natural enemies, competition from other thrips species and unpredictable environmental effects (e.g. a heat wave).
- However, Bailey (1933) observed that hibernating *C. fasciatus* in the field did not appear to be affected by temperatures as low as -8°C, without stating the duration of exposure to this low temperature.
- It is likely that duration of exposure to cold temperature is important for the negative effect on fitness of *C. fasciatus* females that has been suggested by Hoddle et al. (2006) and Mound et al. (2011).
- The cold-stress hypothesis about *C. fasciatus* is plausible but uncertain, because it has not yet been tested and proven experimentally.

Given the arguments and evidence below, the suitability of New Zealand's environment for the establishment of *C. fasciatus* is high.

The native geographic range of *C. fasciatus* includes some locations with similar climates to New Zealand.

- *Caliothrips fasciatus* is native to western North America; United States of America (USA): Alabama, Arizona, California, Florida, Idaho, Louisiana, Nevada, Texas, South Carolina and Wyoming; and Mexico (Bailey 1933; Hoddle 2020; Hoddle et al. 2006).
- Outside of North America, *C. fasciatus* has been reported on strawberry plants in Rio Grande do Sul, Brazil (Pinent et al. 2011), Argentina (Bailey 1933) and China (Steinweden and Moulton 1930). However, these records are considered to be unreliable; the records from Brazil (and Argentina) are thought to be "a likely misidentification of *Caliothrips phaseoli* by non-specialists" (Hoddle 2020), while the record of a single female on citrus in Foochow, China, is also considered a likely misidentification of a novel species, which was later described as *Caliothrips tongi* (Mound et al. (2011). No other records of *C. fasciatus* from Brazil or China were found.
- A comparison of the climate of all of New Zealand with the US states where the pest occurs using the climate match index (CMI) of Phillips et al. (2018) shows a range of climate similarity from low to high (Arizona: 0.5–0.8; Florida and Texas: 0.6–0.7; California: 0.6–0.8; Idaho, South Carolina, Louisiana, Wyoming: 0.7–0.8).
- CMI \geq 0.7 indicates that the climate of at least some parts of New Zealand would be suitable for the pest to establish (Phillips et al. 2018).
- Hibernation is a strategy used by the pest to survive cold temperatures, and in California, this begins from the start of November (late autumn) and is terminated at the end of March (early spring) after about 5 months; temperatures as low as -8°C appeared to have little effect on hibernating adults in the field in California, although the duration of exposure to this temperature is not stated (Bailey 1933).
- The above observation suggests that climate (even in the colder southern regions of the South Island) is not likely to be a barrier to establishment of the pest in New Zealand.

Host availability is unlikely to be a barrier to the pest's establishment:

- Many known hosts of the pest are present in both the North and South Islands of New Zealand; they include outdoor crops (clover, lucerne, lettuce, onion, corn, pear, peach, apple, grape) and weeds: field bindweed (*Convolvulus arvensis*) and prickly lettuce (*Lactuca serriola*), which increases the likelihood of the pest finding suitable host plants on which to establish (Hoddle 2020).

Impacts in New Zealand:

Given the arguments and evidence below, *Caliothrips fasciatus* is likely to cause low impacts. The impacts in crop hosts are likely to be very low to low, but the pest could lead to added costs for eradication or long-term phytosanitary measures to prevent contamination of citrus fruit for export.

Caliothrips fasciatus could lead to long-term costs for phytosanitary measures to ensure continued access to export markets for navel oranges.

- The pest is not reported to cause loss of yield or quality in citrus, but it has been a perennial problem for California citrus exports, due to its habit of hibernating in the navels of citrus fruit such as navel oranges and pomelos, necessitating the development of a systems approach of phytosanitary measures to maintain access to export markets (Hoddle et al. 2006; Harman et al. 2007a; Hoddle 2020).
- Given that the pest is likely to be able to establish in New Zealand, especially in the warmer citrus-growing areas, eradication may be necessary, and if not possible, long-term management and application of phytosanitary measures would be required to maintain access to foreign markets for fresh citrus fruit (especially navel oranges), even if the value of citrus exports to New Zealand is currently low (2019 export sales (free-on-board value) of New Zealand oranges were worth NZ\$1.7 million (Plant & Food Research 2019).
- Sticky traps and many other monitoring and management tools have been developed for use in California (Harman et al. 2007a, 2007b; Hoddle 2020) and could be used in New Zealand to reduce infestation of citrus fruits.
- Hoddle (2020) states that the severity of bean thrips infestations of citrus in California may be driven, in part, by weed abundance and suggests that good weed management within and around orchards may reduce the risk of infestation.
- Therefore, the most likely economic consequences for New Zealand could come from attempting to eradicate the pest or establish control systems to ensure continued market access for oranges to Australia, where *C. fasciatus* is a regulated pest.

Caliothrips fasciatus may cause minor feeding damage on hosts other than citrus.

- Like most thrips that attack plants, the injury done by the bean thrips is the direct result of the feeding of the larvae and adults on plant tissue, with larvae causing more damage by feeding gregariously (Bailey 1933). The pest is, however, unlikely to cause feeding damage to citrus, as it has not been reported to feed on citrus (Hoddle et al. 2006).
- Bailey (1933) reported that in California, the thrips caused damage on pear, mainly by early and excessive defoliation, which weakened the tree for the ensuing season and exposed both the new growth and the fruit to “sun scalding” in the hottest part of the summer.
- The thrips only attacked pears when leaves of infested pear trees became unsuitable for food. The attacked pears were left with ugly scars and minute oily drops of excrement that lowered the grade and marketability (Bailey 1933). It was noted that such injury only occurred at high average temperatures (25–32°C) in very heavily infested local areas where early defoliation was present, with about 15% of fruit affected.
- Although the pest has been reported on a wide range of hosts (in California), some of which are economically important to New Zealand, it has not been reported as causing production losses in California or elsewhere since the 1930s (Hoddle et al. 2006; Harman et al. 2007a; Mound et al. 2011; Hoddle 2020).
- The pest feeds on many hosts in the legume family (Fabaceae), e.g. *Vicia faba* (broad beans), *Phaseolus* spp. (beans), *Pisum sativum* (peas), *Medicago sativa* (lucerne) and *Trifolium repens* (clover). Lucerne is a minor crop in New Zealand, but along with clover, it is important because of its use as fodder for livestock.
- Other host plants of *C. fasciatus* that are economically important to New Zealand include avocado (*Persea americana*), lettuce (*Lactuca sativa*) watermelon (*Citrullus lanatus*), onion (*Allium cepa*) and brassicas (Plant & Food Research 2019; Vegetables New Zealand 2020), but the damage to these crops has not been quantified.
- Bailey (1933) stated that in nearly every case of crop injury in California, the source of infestation was local weed growth, particularly the prickly lettuce and the annual sow thistle,

which suggests that good weed management practice is likely to significantly limit damage in crops.

- The pest is likely to spread naturally, through short hops and flights aided by wind, but the rate of natural spread is likely to be slow. The pest may also be spread via the distribution of infested fruit.
- Therefore, although the thrips may spread and feed on commercially grown plants in New Zealand, the damage is likely to be minor and have few impacts for the relevant industries or for the New Zealand economy.

Caliothrips fasciatus may cause low sociocultural impacts, but is unlikely to cause environmental and health impacts.

- The pest may cause social impacts, as some of its vegetable hosts, e.g. broad beans, peas and lettuce, are grown in private gardens.
- Efforts to eradicate the pest may require access to private gardens for surveillance, removal of host plants, or the application of pesticides to kill the pest, which would cause social impacts.
- None of the recorded hosts are native New Zealand species or species of particular cultural significance.
- There is no evidence that *C. fasciatus* causes human or animal health impacts.

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12.2 Chaetanaphothrips orchidii (orchid thrips)

Chaetanaphothrips orchidii adult females are about 0.8–1.0 mm long, pale yellow with two dark bands on the wings. This thrips is polyphagous and damaging to some economic crops/ornamentals.

Scientific name: *Chaetanaphothrips orchidii* (Moulton, 1907)

Order/Family: Thysanoptera/Thripidae

Other names include: *Euthrips orchidii* Moulton, 1907; *Euthrips marginemtorquens* Karny, 1914 (Mound et al. 2017); Anthurium thrips (Hara et al. 2002), orchid thrips, citrus rust thrips (http://www.ces.csiro.au/aicn/system/c_4149.htm)

Summary of conclusions

Given the arguments and evidence presented:

- *Chaetanaphothrips orchidii* meets the criteria to be a quarantine pest for New Zealand.
- *Chaetanaphothrips orchidii* has a strong association with citrus fruit.
- Basic measures are likely to reduce the likelihood of entry of *C. orchidii* to a moderate to high degree. Consequently, the likelihood of entry is considered low to moderate (with low uncertainty).
- *Chaetanaphothrips orchidii* has a moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (with low uncertainty).
- The suitability of the New Zealand environment for *C. orchidii* to establish is considered moderate (with low uncertainty).
- The level of impact caused by *C. orchidii* is considered low to moderate (with low uncertainty).
- *Chaetanaphothrips orchidii* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	Low–moderate	Low

12.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Chaetanaphothrips orchidii* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Chaetanaphothrips orchidii is not known to be present in New Zealand.

- It is recorded as not present in New Zealand in PPIN (2020).
- It is not listed in NZOR (2020).
- It is listed as 'regulated' in ONZPR (2020).

Chaetanaphothrips orchidii has the potential to establish and spread in New Zealand.

- *C. orchidii* is present in countries with regions that have a climate match index (CMI) of at least 0.7 or greater with New Zealand (Phillips et al. 2018), e.g. Australia, Spain, Japan, USA.

- *C. orchidii* is polyphagous and is reported to feed on a wide range of plants, including fruit, vegetables, ornamentals, herbs, grasses and weed species in at least 32 genera across 20 or more families (Childers and Stansly 2005). Some hosts are commonly grown in New Zealand such as citrus, sweet potato and corn/maize (see impacts below).
- *C. orchidii* is mobile and able to walk short distances, and adults are capable of flight. Dispersal and spread can be active and/or human assisted through movement of infested plant material.

Chaetanaphothrips orchidii has the potential to cause impacts on the economy and environment of New Zealand:

- *C. orchidii* is recognised as a pest of plants of economic concern to New Zealand, including fruit crops of oranges, grapefruit (Childers and Stansly 2005), lemons (Goane et al 2013), avocado (Izhar 1997; Argov 2003) and ornamentals such as anthuriums and orchids (Hara et al. 2002), *Acer* (maples), *Adiantum* (maidenhair fern), *Croton*, *Dracaena*, *Monstera* and *Rhododendron* (Childers and Stansly 2005).
- *C. orchidii* has hosts overseas in genera that have species native to New Zealand, such as *Ipomoea*, *Sonchus*, *Alternanthera* (Childers and Stansly 2005; Breitwieser et al. 2010), and has the potential to damage them.

12.2.2 Hazard identification: commodity association

Chaetanaphothrips orchidii is associated with citrus fruit.

Chaetanaphothrips orchidii is reported from citrus fruit.

- Childers and Stansly (2005) report feeding damage to citrus fruit by *C. orchidii*.

12.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Chaetanaphothrips orchidii* has a strong association with citrus fruit.

There are several published reports of *C. orchidii* on citrus fruit.

- *C. orchidii* has the specific habit of feeding where fruit in clusters are touching each other or where some other part of the plant (leaves, branches) are in contact with fruit (Childers and Stansly 2005).
- *C. orchidii* was identified as the primary cause of rind blemish damage to clustered citrus fruits in Florida. *C. orchidii* is found on citrus fruit throughout the whole year in Florida's citrus-growing areas. It is found mostly on grapefruit, more so on the red grapefruit, and has been found on oranges (Childers and Stansly 2005).
- *C. orchidii* was detected in lemon orchards in northwest Argentina causing high levels of damage to fruit (Goane et al. 2013)
- *C. orchidii* is reported from orange fruit in Spain (Campos Rivela et al. 2017) and from citrus fruit in Israel (Argov 2015).
- *C. orchidii* inserts its eggs in the epidermis of leaves and fruit. Adults and larvae are associated with fruit but there are no reports of pre-pupae or pupae remaining on the fruit or tree. (Catalán et al. 2019).

Chaetanaphothrips orchidii has been intercepted at the New Zealand border, but not on citrus fruit.

- Between 2001 and 2013 there have been six separate occasions where *C. orchidii* has been detected live on cut flowers, (e.g. *Anthurium* from Mauritius C2013/217900), and also on an unrecorded commodity from Fiji [2003/27494] (MAFBNZ Interception database 1988–2014)

- EPP0 interception data (1 September 1999 to 2 July 2020) has no records of detections for *C. orchidii* on citrus fruit.
- It is uncertain why there do not appear to be records of *C. orchidii* on imported citrus, though it is possible it may not survive in-field treatments or pre-export treatments, especially if coming from fruit fly inhabited areas. Dead-on-arrival invertebrates are seldom recorded if detected. Alternatively, New Zealand is not currently importing citrus fruit from some areas or countries where *C. orchidii* is most commonly infesting citrus fruit, e.g. Israel, Spain, Florida (Quancargo 2020).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Chaetanaphothrips orchidii* to a moderate to high degree. Consequently, the likelihood of entry is low to moderate (with low uncertainty).

Usually, visual inspection should detect *C. orchidii* on citrus fruit.

- Often, damage by *C. orchidii* to fruit begins at the onset of the fruit coming into contact with other fruit or some part of the citrus tree. High levels of infestation would be readily detectable as *C. orchidii* causes very obvious damage to citrus fruit which should be a cue to its presence. Feeding damage signs are almost circular, tan-coloured areas at the points of contact with other fruit or parts of the tree. The thrips is present on citrus throughout the fruiting season to harvest (Catalán et al. 2019), indicating it can be found on fruit ready for harvest.
- The thrips are small and pale yellow with cryptic behaviour, but their movement may make them more likely to be detected.
- However, low levels of infestation are less detectable, and very early feeding damage may be mistaken for branch rub. Individuals are harder to detect, especially as the hiding behaviour appears characteristic of this species (Childers and Stansly 2005; Goane et al. 2013).

General post-harvest handling may not dislodge some *C. orchidii*.

- In most cases, harvesting and grading is expected to reveal damaged fruit, which is likely to be excluded from export.
- However, if damage is minor or mistaken for branch rub then those fruits may still be sent for export. Although it is not reported if this species of thrips will hide under the calyx of citrus fruit, there is the opportunity for occasional individuals to remain and eggs are likely to remain embedded in fruit. Calyces are not taken off fruit, as this hastens fruit decay (Cronje et al. 2005).

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Chaetanaphothrips orchidii* to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant is considered moderate (exposure).

Most waste in New Zealand is disposed of by low-risk methods.

- Collection of bagged waste for landfill or putting food waste into a kitchen disposal unit are common methods of disposing of food waste. Thrips on imported fruit are very unlikely to survive either method (waste analysis, section 2.4.1).

Some waste from citrus fruit is likely to be disposed of in proximity to host plants.

- A proportion of unavoidable waste generated from imported citrus fruit will end up exposed to the environment, e.g. in open composts in home gardens.
- Some hosts of *C. orchidii* are commonly grown in home gardens, such as lemons, begonias, chrysanthemums, maples, parsley and sow thistle (puha).
- A proportion of the thrips that survive to this point are likely to seek a new host plant.

C. orchidii is moderately mobile.

- Immature thrips have not yet developed their wings but are capable of walking short distances between leaves, flowers and fruits and between close plants.

- Adults are winged and can fly short distances between different plants, or walk between plant parts and very close plants.
- Wind is known to assist in dispersal of adult thrips and carry them long distances (Lewis 1997; Lo et al. 2000). As *C. orchidii* is highly polyphagous, it is likely to find suitable hosts.

Given the arguments and evidence below, the suitability of the New Zealand environment for establishment of *Chaetanaphothrips orchidii* is considered moderate (with low uncertainty).

The geographic distribution of *C. orchidii* is largely tropical and subtropical, but also includes some areas of temperate climates.

- It is thought that *C. orchidii* may have its origins in South East Asia, as many other species of the genus do (Hoddle et al. 2012).
- Table 13.2.1 provides the current geographical distribution. Countries or areas that are underlined have a climate match index (CMI) with New Zealand of at least 0.7 or greater (Phillips et al. 2018).
- Climate matches of 0.7 or greater indicate there are parts of New Zealand where our climate is similar enough to be suitable for *C. orchidii* establishment.
- *C. orchidii* has spread throughout the citrus-growing region of Spain, and those areas show a 70% to 80% climatic similarity with New Zealand (CMI 0.7 – 0.8), in particular, with the northern half of the North Island (i.e.: Hawke’s Bay, Gisborne, Bay of Plenty, Auckland, Northland), where most of the citrus production is. This is the more likely area for outdoor establishment.
- In Israel, *C. orchidii* is reported from areas on the Northern Coastal Plain (e.g. Ga’ton, Bet HaEmek) and the Central Coastal Plain (e.g. Herzliyya) (Izhar 1997), which have a climate match of 0.7 with New Zealand.
- Sakimura (1975) notes that *C. orchidii* is well established in the wet, native forest areas in Hawaii and has been collected from plants (*Cyrtandra* sp., *Hedyotis* sp., *Pisonia* sp., *Spathoglottis plicata*, *Zingiber zerumbet*) found at below 1,000-m elevation.
- In northwest Argentina⁸⁸, the thrips is found in the northern region of Tucumán province (e.g. La Ramada, CMI 0.6; El Sunchal, CMI 0.7) and in the centre-south region of Tucumán province (e.g. Monte Grande and Caspinchango, CMI 0.7; Aguilares, CMI 0.8). These two regions in Tucumán have different climatic and ecological conditions, and the citrus trees perform differently. Both regions have a warm, humid climate, but the rainfall and water deficit vary. The north has an average rainfall of 700–900 mm with a water deficit of 0–200 mm between winter and spring, and the risk of frost extends from June to August. In the centre-south, the citrus-growing areas are on the mountainside with creeks, streams and rivers crossing it. The average rainfall is 900–1,700 mm with little rainfall in winter and spring, but no soil water deficit. The risk of frosts is rare. The lemon trees of the centre-south have higher vegetative growth, a larger canopy and a higher density of leaves than those of the north, and also produce larger fruits earlier (Goane et al. 2013). *C. orchidii* is found in higher numbers and causing greater damage in the centre-south of Tucumán, suggesting the conditions are more suitable there than in the north. In New Zealand, the main citrus-producing areas have a relative humidity between about 73% and 87% over the year, and a comparable rainfall with centre-south Tucumán, but, it occurs mainly during the winter months, as do the highest number of ground frost days; this information is based on data giving mean monthly values from 1981–2010 (NIWA 2020), but doesn’t reflect the change in climate trends.
- Climate trends for New Zealand were reported in October 2020 (Ministry for the Environment and StatsNZ 2020). The current trends for 30 sites throughout New Zealand during 1972 to 2019 show an overall increase in minimum and maximum daily temperatures in many of the major horticultural growing areas. There is also an increasing trend in growing degree days. Frosts are less common, e.g. Nelson and Tara Hills averaged a loss of 5 days per decade, one of the fastest decreases in frost days. Whangarei never recorded more than 2 frost days per year, but since 1994, there has not been a temperature below zero recorded at this site. Rainfall is also changing, with one third of the sites getting less, many of these are in the northern half of the North Island. Annual rainfall decreased by 4.3% per decade in Whangarei

⁸⁸ *C. orchidii* may be elsewhere in Argentina, but Goane et al. (2013) only reported on the thrips in relation to the lemon trees of specific areas in Tucumán.

and by 3.2% per decade in Tauranga, relative to the average rainfall over the entire period. Winter and spring rainfall is decreasing in a number of sites in northern North Island. Conversely, the southern South Island and West Coast sites showed increased annual rainfall (Ministry for the Environment and StatsNZ 2020).

- This high-level comparison of climate suggests there are areas in New Zealand, particularly within the northern North Island, that are likely to be suitable for *C. orchidii* establishment.

Table 13.2.1 Known geographic distribution of *Chaetanaphothrips orchidii* as at July 2020. Countries in **bold** are those considered as current or potential exporters of citrus fruit to New Zealand, and those underlined have regions with a CMI of 0.7 or greater with New Zealand.

Continent /region	Country /area
Africa	Mauritius, São Tomé and Príncipe (CPC 2019).
Asia	India, Indonesia, Japan (Honshu, Kyushu), Malaysia, Nepal, Sri Lanka, <u>Taiwan</u> (CPC 2019), Israel (Izhar 1997); China (Guizhou Province) (Yan et al. 2018), Philippines (Mituda-Sabado and Calilung 2000), Israel (Argov 2003)
North America	Mexico , USA (<u>California</u> , <u>Florida</u> , <u>Hawaii</u> , <u>Illinois</u> , <u>Louisiana</u> , <u>Massachusetts</u> (CPC 2019) and <u>Kentucky</u> , <u>Washington DC</u> and <u>New York</u> (Hara et al. 2002))
Central and South America	Costa Rica, Cuba, Dominica, Dominican Republic, Grenada, Guadeloupe, Honduras, Jamaica, Puerto Rico, Saint Lucia, Trinidad and Tobago, Argentina (Tucumán), Brazil (Minas Gerais, <u>Rio Grande do Sul</u>), <u>Ecuador</u> , Suriname (CPC 2019)
Europe	<u>Italy</u> *, <u>Poland</u> * (CPC 2019), Spain (<u>Alcanar-Tarragona</u> , <u>El Baix Maestrat</u> , <u>La Safor</u> , <u>La Costera</u> , La Ribera and the <u>Marina Alta</u>) (Catalán et al. 2019) (* are Greenhouse records)
Oceania	Australia (<u>New South Wales</u> , <u>Queensland</u>), Tonga (CPC 2019), Fiji (interception data C2003/27494, MPI internal database).

Host availability is not a barrier to the establishment of *C. orchidii*.

- *C. orchidii* is polyphagous, feeding on at least 32 genera across 20 or more families, including ornamentals, herbs, fruits, vegetables, grasses and several weed species. The following are plants that *C. orchidii* is reported from overseas and are found growing in New Zealand: *Acer* (maple), *Adiantum* (maiden hair ferns), *Alternanthera*, *Amaranthus*, *Begonia*, *Bidens pilosa*, *Cattleya labiata* (orchid), *Cyclamen*, *Citrus* spp., *Dracaena*, *Ficaria*, *Hypoxis*, *Monstera*, *Musa*, *Paspalum paniculatum*, *Philodendron*, *Portulaca oleracea*, *Rhododendron simsii*, *Saintpaulia ionantha*, *Sonchus oleraceus* (sow thistle/puha), *Spathoglottis* and *Tradescantia* (Childers and Stansly 2005). Other plants listed by CPC (2019) that are found in New Zealand include *Allium*, *Anthurium andraeanum*, *Bougainvillea*, *Chrysanthemum*, *Euphorbia* (spurges), *Ipomoea batatas* (sweet potato), *Lycopersicon*, *Passiflora*, *Petroselinum crispum* (parsley), *Piper*, *Pisonia* and *Zea mays* (corn).

Greenhouses are suitable environments for *C. orchidii* to live in.

- There are records of *C. orchidii* infesting greenhouses throughout the USA and parts of Europe (Hara et al. 2002). In Poland, this thrips was found in flowers and leaf buds of *Anthurium andraeanum* plants in glasshouses and was eliminated after several spray treatments (Labanowski 1999). In Italy, the first record for *C. orchidii* was on *Piper* in a glasshouse of a tropical plant collection in Florence (Bene and del Gargani 2001). Establishment in greenhouses would enable *C. orchidii* to increase its range within New Zealand.

Chaetanaphothrips orchidii has biological traits that can assist its establishment in new environments.

- Males of *C. orchidii* have not been reported (Sakimura 1975; Hara et al. 2002; Childers and Stansly 2005; Goane et al. 2013; Catalán et al. 2019). Hara et al. (2002) comment that “reproduction occurs without mating and is continuous throughout the year” in Hawaii. This infers reproduction is thelytokous parthenogenesis, which means the offspring are females. This provides an advantage to establishment as a single adult female does not need to find a

mate in order to be fertilised and lay eggs. This increases the likelihood that a single female could initiate a new population.

- No information was found (that was available and in English) to give lower developmental thresholds for this species, which is one factor that can contribute to assessing how likely establishment in New Zealand is. However, developmental duration is reported. At 25°C on anthurium leaves eggs take about 11 days to hatch, the time from egg to adult is about 34 days, the time from egg to egg is about 37 days, adult longevity is about 28 days, and the total eggs per female is about 75 (Argov 2003, in Childers and Stansly 2005). It is likely this species would have several overlapping generations per year. No mention of diapause or overwintering was found in the literature.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Chaetanaphothrips orchidii* is likely to be low to moderate (with low uncertainty).

Chaetanaphothrips orchidii is likely to cause economic impacts within New Zealand.

Citrus

- Citrus that *C. orchidii* is reported from overseas include lemons, oranges, red grapefruit and grapefruit.
- Adults and larvae feed directly on citrus fruit causing rind blemish on maturing fruit. Damage occurs at the point of contact between fruit and presents as brown rings or smooth russetting. (Childers and Stansly 2005). In Spain, *C. orchidii* is a key pest of oranges and is “active on fruits throughout the cycle of cultivation” (Catalán et al. 2019).
- In the Tucumán region of Argentina high levels of damage were reported on lemon fruit resulting in rejection of fruit for export. When fruit was sampled as part of a 4 year in-field study the population levels varied from 0.6 ± 0.29 individuals per fruit in the northern part of the region to 8.2 ± 1.52 individuals per fruit in the centre-south of Tucumán. About 70% of the population comprised larvae and about 30% were adults. Winter fruit had higher levels of thrips than summer fruit. In the north, less than 12% of winter fruit had feeding and oviposition damage from *C. orchidii*. In the centre-south, damage was seen in at least 62% of fruit, with more than half this amount (27% to 47% depending on orchard) considered unacceptable for the fresh fruit market. Damage distribution was not uniform through the lemon tree canopy, and this was noticed in each orchard sampled. There was a higher proportion of damaged fruit in the lower section of the tree (Goane et al. 2013). This is obviously a characteristic of the thrips, as it was also seen in grapefruit crops in Florida. It was suggested that *C. orchidii* prefers humid and shaded microhabitats, given the greater damage was reported from fruit clusters within the canopy as opposed to fruit clusters that were more exposed (Childers and Frantz 1994, in Goane et al. 2013).
- The majority of New Zealand citrus crops are grown in the northern half of the North Island, which is also the area more likely for outdoor establishment of *C. orchidii*. This thrips species appears to favour grapefruit, lemon and orange fruits. Domestic sales for New Zealand in 2019 for these three fruit crops were NZ\$30.3 million, and export sales were \$11.5 million (Plant & Food Research 2019).

Other crops

- In Bet HaEmek and subsequently 11 other sites on the Northern Coastal Plain in Israel, damage to avocado reached 74.7% in extreme cases (Izhar 1997). Immatures and adults will settle under the sepals or at points of contact between clustered avocado fruit, fruit and leaves or branches. Star-shaped feeding blemishes occur around the sepals; at points where fruit touch each other, circular or oval patches or rings of russetting are found. Similarly to citrus in Israel and other countries, only females and larvae were found on avocado (Izhar 1997). Avocado crops are common in Northland and Bay of Plenty. Avocado exports earned New Zealand about NZ\$104.3 million in 2019 and \$56.5 million domestically (Plant & Food Research 2019).
- Banana is a new crop being established in Gisborne and Northland, which could be affected by *C. orchidii* establishment. As yet, there are no costings available for this fledgling industry.
- Sweet potato and *Allium* are noted as ‘other’ hosts, indicating they are not main hosts of this thrips (CPC 2019). Onions earned NZ\$170 million in exports during 2019. Sweet potato is

grown mainly in the northern regions and in 2019 earned \$55.0 million on the domestic market (Plant & Food Research 2019).

- Overall, a proportion of these horticultural industries may experience a low to moderate level of impact from *C. orchidii* should it establish. Damage to outdoor crops may be less severe in New Zealand than experienced overseas due to inhibiting factors from our climate, such as higher rainfall and a shorter duration of high temperatures. Population growth of *C. orchidii* may be slower, not reaching levels that cause severe damage.

Greenhouse plants

- Greenhouse crops that could be affected by *C. orchidii* are largely cut flowers (orchids, chrysanthemums, anthuriums) and/or ornamentals as in nursery plants and potted indoor plants (e.g. bidens, chrysanthemums, orchids, anthuriums, begonias, monstera, maidenhair ferns, maples, cyclamen). Damage to anthuriums initially occurs from *C. orchidii* feeding within the unopened spathe ('flower') soon after the bud emerges from the leaf axil. White streaks and scarring can be found on both sides of the spathe, and with age, injured tissue becomes bronzed looking. Spathes can become deformed and in severe cases fail to open. Feeding damage to foliage causes scarring, streaking, bronzing and deformation. Plant growth can be reduced (Hara et al. 2002).
- Feeding damage would certainly cause economic losses, as cut flowers and potted ornamentals rely on an unblemished appearance in order to obtain the highest available prices. Depending on the level of infestation plants are likely to be too sickly for sale or may be sufficiently damaged as to warrant price reduction in order to sell them. The cut flower/foliage sector earned NZ\$20 million in exports in 2019 (Plant & Food Research 2019); however, that amount included several different species, some of which are not known to be hosts of this thrips. The cut flower/foliage sector earned NZ\$20 million in exports in 2019 (Plant & Food Research 2019); however, that amount included several different species, some of which are not known to be hosts of this thrips.
- Generally protected crops are well monitored, and so once a thrips is detected, most growers are likely to spot-spray for control. Labanowski (1999) noted that a few chemical spray treatments managed to eradicate *C. orchidii* from a greenhouse in Poland. However, each spray treatment can be costly to a grower, and sometimes reinfestation can occur from outside, causing another cycle of damage and treatments.

Establishment of *C. orchidii* may result in increased phytosanitary measures on exports from New Zealand to countries where it is absent.

- *C. orchidii* is on the EPPO A1 quarantine pest list. Currently, host plants of *C. orchidii* do not appear to be exported to Chile.

Chaetanaphothrips orchidii may cause impacts to sociocultural values of New Zealand, and potentially to the natural environment, but is unlikely to have impacts upon human health.

- *Ipomoea batatas* (kumara) and *Sonchus olearaceus* (puha) are reported as hosts of *C. orchidii*. Kumara and puha are treasured plants (taonga) to Māori, and so damage to these plants would be considered significant.
- A number of plants that are *C. orchidii* hosts are grown in domestic gardens and amenity plantings, such as citrus, cyclamen, maples, rhododendrons, chrysanthemums and are likely to suffer feeding and oviposition damage from *C. orchidii* establishment.
- There are genera native to New Zealand that are reported hosts of *C. orchidii* overseas, such as *Adiantum* (maidenhair ferns), *Alternanthera*, *Dracaena*, *Passiflora* and *Sonchus* species. Beever et al. (2007) stated that most exotic pests that attack native plants are polyphagous, but highly damaging polyphagous species appear to be exceptional, and it has been postulated that the impact of relatively specialised organisms is likely to be greater than highly polyphagous species. However, there are three introduced thrips species that can reach large populations on native plants in native ecosystems (pers. comm. N. Martin, 12 September 2013). For instance, the introduced thrips *Heliethrips haemorrhoidalis*, which is found outdoors in central and southern Florida and southern California but in greenhouses elsewhere in the USA (Denmark and Fasulo 2010), is known to cause damage to the seedlings of native trees in New Zealand (pers. comm. N. Martin, 12 September 2013). The northern areas of the North Island have a number of locally endemic plant species that may be at risk from young-growth herbivory, though whether they are likely hosts of *C. orchidii* is unknown.

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12.3 *Scirtothrips dorsalis* (yellow tea thrips)

Scirtothrips dorsalis is a small (0.7 mm–1.2 mm long) polyphagous thrips that causes economic damage to many crops by feeding and vectoring viruses.

Scientific name: *Scirtothrips dorsalis* Hood, 1919

Order/Family: Thysanoptera/Thripidae

Other names include: *Heliothrips minutissimus* Bagnall, 1919; *Anaphothrips andreae* Girault, 1925; *Neophysopus fragariae* Girault, 1927; *Scirtothrips dorsalis* var. *padmae* Ramakrishna, 1942 (Mound et al. 2017); chilli thrips, yellow tea thrips, Assam thrips, strawberry thrips (EPPO 2020)

Taxonomy

Scirtothrips dorsalis is now recognised as a species complex, comprising at least 9 cryptic species and 2 morphologically distinguishable species (*S. oligochaetus* and *S. aff. dorsalis*), most of which are regionally endemic (Dickey et al. 2015). This has some influence on host plants associated with a species in the complex, on its vector potential, on its climate tolerance based on its native range and its level of invasiveness (Dickey et al. 2015). For the purposes of this pest risk assessment the complex is considered as a whole, i.e. *S. dorsalis sensu lato*.

Summary of conclusions

Given the arguments and evidence presented:

- *Scirtothrips dorsalis* meets the criteria to be a quarantine pest for New Zealand;
- *Scirtothrips dorsalis* has a moderate association with citrus fruit (with moderate uncertainty);
- Basic measures are likely to reduce the likelihood of entry of *S. dorsalis* to a moderate to high degree; consequently, the likelihood of entry is considered low to moderate (with low uncertainty);
- *Scirtothrips dorsalis* has a moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (with low uncertainty);
- The suitability of the New Zealand environment for *S. dorsalis* to establish is considered moderate (with low uncertainty);
- The level of impact caused by *S. dorsalis* is considered low to moderate (with low uncertainty); and
- *Scirtothrips dorsalis* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Moderate	Moderate
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	Low–moderate	Low

12.3.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Scirtothrips dorsalis* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in the PRA area (New Zealand), and of potential importance (able to establish and cause harm).

Scirtothrips dorsalis is not known to be present in New Zealand.

- It is recorded as 'not in New Zealand' in PPIN (2020).
- It is not listed in Gordon (2010) or NZOR (2020).
- It is listed as 'regulated' in ONZPR (2020).

Scirtothrips dorsalis has the potential to establish and spread in New Zealand.

- *S. dorsalis* is established in countries with regions that have a climate match index (CMI) of 0.7 or higher with New Zealand (Phillips et al. 2018), e.g. Australia, Japan and USA.
- *S. dorsalis* is very polyphagous and is reported to feed on 225 plant taxa across 72 families and 32 orders (Kumar et al. 2013). Hosts of *S. dorsalis*, such as citrus and roses, are commonly grown in New Zealand (see Impacts in New Zealand, section 13.3.3).
- *S. dorsalis* is mobile, as it can walk small distances and adults are able to fly. Spread can be active or human-assisted through distribution of infested plant material.

Scirtothrips dorsalis has the potential to cause impacts on the economy and environment of New Zealand.

- *S. dorsalis* can feed on and damage crops of economic concern to New Zealand which include grapevine (Tatara 1994), bean, tomato and onion (in Meissner et al. 2005).
- *S. dorsalis* has the potential to vector three tospoviruses that are not reported from New Zealand (Veerekone et al. 2015; PPIN 2020) and potentially are able to damage plants of value to New Zealand.
- *S. dorsalis* has hosts overseas in genera that have species native to New Zealand, such as *Schefflera* and *Pittosporum*, to which the thrips is reported as causing severe damage (Ludwig and Bográn 2007).

12.3.2 Hazard identification: commodity association

Scirtothrips dorsalis is associated with citrus fruit.

Scirtothrips dorsalis is reported from citrus fruit.

- Tatara (1994) reports that *S. dorsalis* oviposits into the epicarps of mandarins and oranges in Shizuoka, Honshu, Japan.

12.3.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Scirtothrips dorsalis* has a moderate association with citrus fruit (with moderate uncertainty).

There are published reports documenting damage by *S. dorsalis* to citrus fruit.

- In Japan, *S. dorsalis* is reported to lay its eggs into the epicarp of mandarins and oranges (Tatara 1994), often under the calyx (Collins et al. 2006). The larvae feed upon the fruit (Tatara 1994).
- Minaei et al. (2016) report that in southern Iran, *S. dorsalis* feeds on citrus fruit, piercing and sucking out the contents of the epidermal cells causing scarring and scabbing to the rind.
- *S. dorsalis* pupates in sheltered places including under the calyces of flowers and fruits (Collins et al. 2006).

But:

- *S. dorsalis* is usually (but not always) associated with young fruit.
- In Japan, overwintering females oviposit in young leaves of viburnum and tea in the spring, and later generations oviposit into the outer layer of citrus rinds. The author noted that satsuma mandarin might not be a suitable host for *S. dorsalis*, as adult female longevity and fecundity was reduced compared to tea and viburnum plants (Tatara 1994).

- Ookubo (2001) noted that *S. dorsalis* preferred the young shoots of podocarp and viburnum trees that enclosed citrus orchards, and would only move to citrus at two periods in the year (July and late August to early September) when there were few or no suitable host plants.
- On Jeju Island, South Korea, *S. dorsalis* was observed to migrate from kiwifruit and mango orchards to citrus (Hwang et al. 2016).

However:

- The above authors and Kang et al. (2015) note that *S. dorsalis* is a serious pest on citrus in Japan, Taiwan and Korea.

Scirtothrips dorsalis has been intercepted frequently at the New Zealand border, but has not been detected on citrus fruit.

- *S. dorsalis* has been detected in cut flowers often, particularly roses from India and Colombia, e.g. C2019/256691 (LIMS 2020 MPI internal database).
- It has also been identified on basil leaves from Fiji [C2016/343900] (MAFBNZ Interception database 1988–2014).

Overseas, all life stages of *S. dorsalis* have been intercepted on mature *Momordica* fruit and vegetable consignments at the UK and USA borders from Africa and Asia (McLeod and Collins 2006; Meissner et al. 2005). Information on the transit conditions was not provided; however, there is a record of live *S. dorsalis* on live plant material intercepted in airmail from Viet Nam to the USA prior to 2005 (Meissner et al. 2005), indicating this thrips species will survive the duration of transit and obviously some handling on that pathway.

There is moderate uncertainty regarding how likely the thrips would be associated with harvested citrus fruit. It has not been intercepted on fresh citrus fruit in New Zealand or the United Kingdom but Meisner et al. (2005) report it has been found on citrus fruit carried by passengers at the USA border. Given the level of damage it can cause, it is most likely those fruits would be prevented from being exported. However, individuals of *S. dorsalis* may escape the grading process if they have newly arrived on fruit and are sheltering under the calyx.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Scirtothrips dorsalis* by a moderate to high degree. Consequently, the likelihood of entry is considered low to moderate (with low uncertainty).

Generally, visual inspection should detect *S. dorsalis* on citrus fruit.

- If thrips have been feeding on the fruit, there is likely to be visible damage, particularly around the calyx (Minaei et al. 2015).

But:

- If the feeding damage from the thrips is minor, it can sometimes be mistaken for branch-rub or wind damage, in which case the thrips may miss detection.
- *S. dorsalis* immatures, adults or pupae can shelter under the calyx of citrus fruit and thus be undetectable.
- Eggs are laid into the rind, often under the calyx and will not be visible.

Low numbers of thrips in a consignment are more difficult to detect.

- Individual thrips are less likely to be found in a consignment and therefore remain undetected.

Common post-harvest activities may not remove all thrips.

- Most thrips are expected to be removed during the usual post-harvest activities. However, as eggs are embedded into the rind, often under the calyx, they are less likely to be removed. Other life stages that can shelter under the calyx are also less likely to be removed. Calyxes are not taken off fruit, as this hastens fruit decay (Cronje et al. 2005).

Likelihood of establishment:

Given the arguments and evidence below, *Scirtothrips dorsalis* has moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure/transfer).

Most waste in New Zealand is disposed of using low-risk methods.

- Sending bagged food waste to the landfill or running waste through kitchen disposal units are common methods of food waste disposal (see section 2.4.1). Thrips on imported fruit are very unlikely to survive either method.

Some waste from citrus fruit is likely to be disposed of in proximity to host plants.

- A proportion of unavoidable waste generated from imported citrus fruit will end up exposed to the environment, e.g. in open composts in home gardens.
- Some hosts of *S. dorsalis* are commonly grown in home gardens, such as begonias, roses, chrysanthemums, alstroemerias, cucurbits, beans, tomatoes and strawberries.
- A proportion of the thrips that survive to this point are likely to seek a viable host plant.

Scirtothrips dorsalis is moderately mobile.

- Immature (larvae, prepupae, pupae) thrips have not yet developed their wings but are capable of walking short distances between leaves, flowers and fruits and between close plants. Adults are winged and can fly short distances between different plants or walk between plant parts and close plants. Dev (1964) observed that the adults are fast moving and will jump at a slight disturbance, then fly a short distance.
- Masui (2007) states females have been recorded 50 m from their source and can be wind-assisted to further distances. Lewis (1997) and Lo et al. (2000) also note that wind can assist in adult dispersal and carry adults long distances. As *S. dorsalis* is highly polyphagous, it is likely to find suitable hosts.

Given the arguments and evidence below, the suitability of the New Zealand environment for establishment of *Scirtothrips dorsalis* is considered moderate (with low uncertainty).

Scirtothrips dorsalis has a mostly tropical to subtropical geographic distribution with some temperate areas.

- The Indian subcontinent was originally thought to be the native range of *S. dorsalis*. However, the work by Dickey et al. (2015) infers the native range is wider, including South Asia, East Asia, South Africa and Australia. This covers a wide range of altitudes and climatic conditions.
- *S. dorsalis* has subsequently invaded the Caribbean, parts of South America, North America, and the Middle East, causing severe problems throughout (Seal et al. 2010; Venette and Davis 2004; Minaei et al. 2015).
- Table 13.3.1 shows the current distribution of *S. dorsalis*. The countries and areas that are underlined have a 70% or greater climate match (CMI 0.7 or higher) with New Zealand (Phillips et al. 2018).
- A CMI of 0.7 or higher indicates there are parts of New Zealand that are suitable for the establishment of *S. dorsalis*.
- *S. dorsalis* was identified on hydrangea from a nursery near Aquebogue on Long Island, New York, early in 2012. The plants were growing in containers that had overwintered in an unheated hoop house protected with a thin layer of plastic. Winter temperatures can reach -12.2°C to -17.8°C for a few days to a week or so in this region. *S. dorsalis* was found in subsequent years, and damage on plants in the landscape was attributed to *S. dorsalis* (pers. comm. D. Gilrein, 2016), which indicates there was an established population in the area.
- Climate modelling showed that most of the North Island is suitable for *S. dorsalis* establishment, and potentially the thrips could have 8 generations/yr in the Northland region. There is a low degree of uncertainty about the 'presence data' that can affect the model. For two records, it was uncertain if the thrips was reported from greenhouses or was found outdoors.
- Beever et al. (2007) state, "Although some ... introduced thrips are pest species overseas, they are rarely pests in New Zealand because the prolonged dry weather they require to produce large populations occurs infrequently (Mound and Walker 1982)." However, this is unlikely to be the case today with the current global and local warming.
- Climate trends for New Zealand were reported in October 2020 (Ministry for the Environment and StatsNZ 2020). The current trends for 30 sites throughout New Zealand during 1972 to 2019 show an overall increase in minimum and maximum daily temperatures in many of the major horticultural growing areas. There is also an increasing trend in growing degree days.

Frosts are less common, e.g. Nelson and Tara Hills averaged a loss of 5 days per decade, one of the fastest decreases in frost days. Whangarei never recorded more than 2 frost days per year, but since 1994, there has not been a temperature below zero recorded at this site. Rainfall is also changing, with one third of the sites getting less, many of these are in the northern half of the North Island. Annual rainfall decreased by 4.3% per decade in Whangarei and by 3.2% per decade in Tauranga, relative to the average rainfall over the entire period. Conversely, the southern South Island and West Coast sites had increased rainfall (Ministry for the Environment and StatsNZ 2020).

- This brief overview of the increase of warmer, drier areas indicates there is the potential for thrips pest species to produce larger populations in those areas.

Table 13.3.1 Known geographic distribution of *Scirtothrips dorsalis* as at July 2020. Countries in **bold** are those considered as current or potential exporters of citrus fruit to New Zealand, and those underlined have regions with a CMI of 0.7 or greater with New Zealand (Phillips et al. 2018).

Continent /region	Country /area
Africa	Ivory Coast, Kenya, Uganda (EPPO 2020), West Coast (Ghana, suggested from interception data, McLeod and Collins 2006), South Africa (Dickey et al. 2015)
Asia	Bangladesh, Brunei, Cambodia, China , Hong Kong, India, Indonesia (EPPO 2020), <u>Iran</u> (Minaei et al. 2015), Israel, Japan , Malaysia, Myanmar, Pakistan, Philippines, South Korea , Sri Lanka, <u>Taiwan</u> , Thailand, Viet Nam (EPPO 2020), Singapore (Dickey et al. 2015).
North America	USA (<u>Florida</u> , Georgia, <u>Hawaii</u> , Texas (EPPO 2020), Long Island, New York (pers. comm D. Gilrein 2016))
Central and South America	Barbados, Guadeloupe, Jamaica, Puerto Rico, Saint Lucia, Saint Vincent and The Grenadines, Trinidad and Tobago (EPPO 2020), Brazil (Dias-Pini et al. 2018), Colombia (Ravelo et al. 2018), Suriname, Venezuela (EPPO 2020)
Europe	<u>Netherlands</u> * (few occurrences), Spain , <u>England</u> * (few occurrences) (EPPO 2020)
Oceania	Australia (<u>New South Wales</u> , Northern Territory, <u>Queensland</u>), Papua New Guinea, Solomon Islands (EPPO 2020), Fiji (intercepted at NZ border, LIMS 2020)

* These were possibly reports from greenhouses.

Availability of host plants is unlikely to be a barrier to the establishment of *Scirtothrips dorsalis*.

- *S. dorsalis* is highly polyphagous. Using information from the Global Pest and Diseases Database, Kumar et al. (2013) report that *S. dorsalis* is recorded feeding on (not necessarily reproducing on) 225 plant taxa worldwide in 72 different families and 32 orders of plants.
- As well as citrus, *S. dorsalis* has been reported from: kiwifruit (*Actinidia chinensis*) (Sakakibara and Nishigaki 1988, in McLeod and Collins 2006); onion (*Allium cepa*), *Asparagus officinalis*, cucumber and melon (*Cucumis* spp.), pumpkin (*Cucurbita moschata*), beans (*Phaseolus vulgaris*), tomato (*Solanum lycopersicon*) (In: Meissner et al. 2005); sweet peppers (*Capsicum annuum*), avocado (*Persea americana*) (Kumar et al. 2013); pear (*Pyrus* spp.) (Masui 2007); common fig (*Ficus carica*) (Ludwig & Bogran 2007); strawberry (*Fragaria x ananassa*) (Mound and Palmer 1981); sweet potato (*Ipomoea batatas*) (Venette and Davis 2004); cherry (*Prunus* spp.) (Collins et al. 2006); eggplant (*Solanum melongena*) (Raizada 1965); grapevine (*Vitis vinifera*) (Tatara 1994), which are all economically important crops grown in New Zealand.
- Also, there are numerous economically important ornamentals and cut flowers that are hosts for *S. dorsalis* that are grown in New Zealand and are common as landscape, amenity and home garden plants, for instance, poinsettia, gerbera, alstroemeria, rose, begonia, snapdragon, crape myrtle, azalea, viburnum, *Schefflera* and *Pittosporum* (Kumar et al. 2013).

Greenhouses are likely to be suitable environments for *Scirtothrips dorsalis*, based on overseas occurrences.

- *S. dorsalis* has been reported from greenhouses overseas, e.g. on tomatoes in a plastic greenhouse in Ibaraki, Honshu, Japan (Nakagaki et al. 1984, in Vierbergen and van der Gaag 2009); as overwintering life stages from a greenhouse growing grapes in Okayama (Shibao et al. 1991) and on potted *Hydrangea* in Saitama and Chiba (Kuriyama et al. 1991).
- Small numbers of *S. dorsalis* found in a Dutch greenhouse in Hoek van Holland were eradicated by chemical treatment (Vierbergen and van der Gaag 2009). A population of *S. dorsalis* established in a botanical glasshouse in southern England in May 2008 and was still ongoing in 2012 (EFSA 2012). EPPO 2020 refers to occasional recurrences of presence in both the Netherlands and England.
- *S. dorsalis* was found on hydrangea grown in an unheated tunnel house on Long Island, New York, USA.

Scirtothrips dorsalis has biological characteristics that can assist its establishment in new environments.

- *S. dorsalis* can reproduce both sexually and by arrhenotokous parthenogenesis (unfertilised eggs produce only male offspring) (Amin and Palmer 1985). This can be advantageous in a new environment, as the male is not essential to the production of offspring. One or two unfertilised females or a single mated female may be capable of founding a population.
- *S. dorsalis* overwinters in Japan as non-diapausing adults in leaf litter or soil or on branches or leaves (Okada and Kudo 1982). The lifespan for overwintering adults appears to be about 5 months. Larvae, prepupae and pupae also hibernate over the winter if young leaves are available in a mild winter (Okada and Kudo 1982). Similarly, the population on Long Island appears to successfully overwinter and is thought to have originated from Japan (Dickey et al. 2015).
- The lower developmental threshold of *S. dorsalis* has been calculated at 8.5°C on grape (Shibao 1996) and 9.7°C on sweet viburnum (Tatara 1994), which would enable it to establish in parts of New Zealand.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Scirtothrips dorsalis* is likely to range from low to moderate (with low uncertainty).

Scirtothrips dorsalis can cause damage that reduces the yield and quality of the affected crops (see Figure 13.3.1 for examples).

- Citrus
 - Feeding by *S. dorsalis* causes significant leaf and flower deformities, scarring of fruit and yield reduction (Chiu et al. 1991). Although there are several different authors who report serious damage to citrus from this thrips in Asia, there is no quantitative information regarding percent yield loss/damage or economic cost.
 - The image in Figure 13.3.1 of oranges from the Fars region of Iran shows *S. dorsalis* feeding damage (Minaei et al. 2016).
 - The citrus industry in New Zealand earned \$58.5 million in domestic sales and \$12 million in exports during 2019. Damaged citrus fruit might be able to go for processing, but this would still result in reduced income for growers. Most citrus production occurs in areas of the North Island which are suitable for *S. dorsalis* establishment.
- Other crops
 - On grapes heavy feeding damage to flower clusters and developing fruit caused reduced fruit set and reduced saleability of the fruit (Ananthakrishnan 1971). Shibao (1997) observed that plots of grapes that were sprayed with insecticide had 60% of the fruit clusters damaged compared to unsprayed plots that had 90% of the fruit clusters damaged in Japan. The New Zealand wine industry export earnings for 2019 were more than NZ\$1.8 billion (Plant & Food Research 2019). A reduction in fruit set would result in a reduction in grape yield and therefore reduced income. Only a proportion of the wine grape production is in areas suitable for *S. dorsalis* establishment.
 - Feeding damage to onion, chilli, castor and cotton can wilt, stunt and distort young shoots and leaves, and cause premature leaf, bud or flower drop. Yield losses in chilli attributed to *S. dorsalis* have ranged from 20% to almost 50% (in Venette and Davis

2004). The New Zealand onion industry had export earnings of NZ\$170 million in 2019. The bulk of the crop is grown in areas of the North Island where *S. dorsalis* could establish (Plant & Food Research 2019).

- In India, *S. dorsalis* is a major pest of rose production, distorting or destroying leaves buds and flowers, reducing the marketability (Gahukar 1999). The cut flower and foliage export earnings for New Zealand in 2019 were NZ\$20.0 million (Plant & Food Research 2019). Some of this production is outdoors and some is under protection. Both situations have been shown to be adequate for *S. dorsalis* survival, which could result in damage to the crop.
- Economic damage to economically important crops does not always occur. For instance, multiple generations of *S. dorsalis* were observed between May and October on kiwifruit in Japan, but no economic damage resulted (Sakakibara and Nishigaki 1988, in McLeod and Collins 2006). However, presence within a crop may have an adverse effect regarding *S. dorsalis*-free export markets.

Establishment in glasshouses is likely to have a considerable but short-term impact.

- There would be costs associated with any eradication attempts. Chemical control for *S. dorsalis* on crops in glasshouses is likely to result in disruption of IPM programmes, disruption to the growing season and costs associated with crop or yield loss and control.



Fig 13.3.1 Images of feeding damage by *Scirtothrips dorsalis*: top left on capsicum fruit and leaves; top right on oranges; bottom left, rosebud and bottom right shows stunted, damaged (left) and normal rose leaves.

Scirtothrips dorsalis has the potential to vector viruses that are not present in New Zealand.

- Viruses most commonly vectored by thrips are in the genus Orthospovirus, family Tospoviridae and order Bunyvirales. Orthospoviruses are transmitted in a persistent, propagative manner and are trans-stadially passed in their insect vector (Whitfield et al. 2005). Tospoviruses are not known to be transmitted congenitally to the offspring of the vector (ICTVdB 2013). Early-instar larvae acquire a virus and retain it for their lifetime. Sometimes adults can acquire but not transmit a virus for reasons not entirely clear (Wijkamp 1996).
- *S. dorsalis* is reported to vector *Groundnut bud necrosis virus* (GBNV), *Groundnut chlorotic fan-spot virus* (GCFSV) and *Groundnut yellow spot virus* (GYSV) (Riley et al. 2011), which are not known to be in New Zealand (Veerekone et al. 2015; PPIN 2020). No evidence of these viruses affecting citrus fruits was found during the literature review, but some weed

species are natural hosts, e.g. *Solanum nigrum* is a natural host of GBNV (Bhat et al. 2020) and is quite common in or on the edge of cultivated crops.

Establishment of *S. dorsalis* may result in increased phytosanitary measures on exports from New Zealand to countries where it is absent.

- Most of Europe does not have populations of *S. dorsalis*, and it is considered an A1 quarantine pest in Europe (EPPO 2019). New Zealand exports hosts of *S. dorsalis* to continental Europe, e.g. onions, kiwifruit.
- *S. dorsalis* is on the A1 list for Brazil and Chile, and Mexico considers it a quarantine pest.

Scirtothrips dorsalis may cause impacts to New Zealand sociocultural values and potentially to the natural environment, but is unlikely to have impacts upon human health.

- *Ipomoea* sp. is a reported host of *S. dorsalis*. It is assumed that *Ipomoea batatas* (kumara) could be affected by *S. dorsalis*. Kumara is a taonga or treasured plant to Māori, and so damage to this plant would be considered significant.
- Roses, alstroemeria, begonia, azaleas, viburnum and various pittosporums are among the many hosts of *S. dorsalis* that are common in home gardens and amenity plantings. These are likely to suffer from feeding and oviposition damage should *S. dorsalis* establish.
- There are genera native to New Zealand that are hosts of *S. dorsalis* overseas. Dwarf *Schefflera* and *Pittosporum* species are frequently attacked by *S. dorsalis* in Florida and Texas (Ludwig and Bogran 2007). New Zealand species in these genera may also be vulnerable to *S. dorsalis*. Beever et al. (2007) state that most exotic pests that attack native plants are polyphagous, but highly damaging polyphagous species appear to be exceptional, and it has been postulated that the impact of relatively specialised organisms is likely to be greater than highly polyphagous species. However, there are three introduced thrips species that can reach large populations on native plants in native ecosystems (pers. comm. N. Martin, 12 September 2013). For instance, the introduced thrips *Heliothrips haemorrhoidalis*, which is found outdoors in central and southern Florida and southern California but in greenhouses elsewhere in the USA (Denmark and Fasulo 2010), is known to cause damage to the seedlings of native trees in New Zealand (pers. comm. N. Martin, 12 September 2013). The northern areas of the North Island have a number of locally endemic plant species, which may be at risk from young-growth herbivory.

12.3.4 References

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12.4 *Thrips palmi* (melon thrips)

Thrips palmi is a sap-feeding polyphagous insect pest of many horticultural and ornamental plants, especially in the Cucurbitaceae, Solanaceae and Orchidaceae families. This insect is a known vector of some plant viruses that are not known to be present in New Zealand. Adults and larvae feed mainly on the leaves, flowers and stems of host plants, and occasionally, on the surface of fruits, causing numerous feeding scars and deformities.

Scientific name: *Thrips palmi* Karny, 1925

Order/Family: Thysanoptera/Thripidae

Other names: *Thrips leucadophilus*, *Thrips gossypicola*, *Chloethrips aureus*, *Thrips gracilis*

Notes on taxonomy: Despite being previously misidentified as *Thrips flavus* in Taiwan, *T. nigropilosus* in Hawaii and *Frankliniella schultzei* in India, *T. palmi* is easily distinguished from other thrips (Palmer, 1992). Sakimura et al. (1986) provided a list of major diagnostic characters to distinguish *T. palmi* from the other known species of the same genus. The IPPC has produced a diagnostic protocol for *Thrips palmi* (DP1 in ISPM 27) that includes morphological and molecular identification techniques (FAO 2016a).

Summary of conclusions

Given the arguments and evidence presented:

- *Thrips palmi* meets the criteria to be a quarantine pest for New Zealand.
- *Thrips palmi* has a weak association with citrus plants and no known association with citrus fruit (with low uncertainty).
- Basic measures reduce the likelihood of entry of *T. palmi*, if this pest were to be present on citrus fruit, by a high degree (with moderate uncertainty); therefore, the likelihood of entry is considered low to moderate.
- The ability of *T. palmi* to transfer from imported fruit to suitable host plants is moderate, with high uncertainty.
- The suitability of the New Zealand climate for establishment of *Thrips palmi* outdoors is rated low to moderate, but it could be moderate to high in some parts of the North Island, especially due to climate warming, and the pest can establish in glasshouses.
- The establishment of *Thrips palmi* in glasshouses could result in transient high impacts, but impacts in outdoor areas are likely to be low (with moderate uncertainty).
- It is recommended that *Thrips palmi* does not require consideration for additional measures, due to the lack of evidence of association with citrus fruit and the degree by which minimum measures reduce the likelihood of entry on the commodity.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Weak	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	High
Suitability of the New Zealand environment	Low–moderate	Moderate
Impacts on the New Zealand economy, environment, health and society	Low**	Moderate

** Rating applies to impact outdoors; impacts may be high in individual glasshouses if the pest invades glasshouses.

12.4.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Thrips palmi* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in PRA area (New Zealand), and of potential importance (able to establish and cause harm).

There are no records of *Thrips palmi* from New Zealand.

- The pest is not recorded in PPIN (2020), NZOR (2020) or NZInverts (2020).

Thrips palmi is a regulated pest for New Zealand.

- It is recorded as “regulated” in ONZPR (2020).

Thrips palmi has the potential to establish outdoors in warmer parts of the upper North Island of New Zealand and in glasshouses across the country.

- *Thrips palmi* is primarily a subtropical and tropical species, but survives outdoors throughout the winter on Kyushu Island in Japan, where the mean minimum winter (December–February) temperature is 5.3°C (Yoshihara 1982). Mean minimum winter (June–August) temperatures in Gisborne and Kaitaia are 5.5°C and 8.6°C respectively (NIWA 2020).
- Also, about 25% of the location records for *T. palmi* available on the EPPO global database (EPPO 2020) (mostly in parts of China and India) have a climate match index (CMI) value of ≥ 0.7 . This indicates enough similarity between the climate of these locations and the New Zealand climate to allow establishment of the pest (Phillips et al. 2018).
- McDonald et al. (1999) calculated the lower development threshold of *T. palmi* to be 10.1°C and developed a degree-day model showing that the pest could, in principle, complete 4–5 generations outdoors during summer in parts of the UK, which have a similar climate to New Zealand (CMI of 0.8–0.9).

Thrips palmi has the potential to cause impacts in New Zealand.

- *Thrips palmi* is a highly polyphagous pest and has been recorded on over 200 host species from over 20 plant families (EFSA 2019; EPPO 2020).
- Adults and larvae of *T. palmi* feed by bursting the cells of host plants and sucking the cell sap (Kirk 1997, in Seal et al. 2013), leading to stunting, distortion and scarring of plants and produce, with significant reductions in yield and marketability (Kawai 1990).
- First recognised as a major threat to vegetable growers in Japan in 1978, by 1990 *T. palmi* had become the most serious pest of *Cucumis sativus* (cucumber), *Solanum melongena* (eggplant) and *Capsicum annuum* (sweet peppers) in greenhouses and open fields in the western part of Japan (Kawai 1990).
- *Thrips palmi* is also a known vector of some plant tospoviruses (Ullman et al. 1997; EFSA 2019) that are either regulated or not known to be present in New Zealand (ONZPR 2020; BRAD 2020; NZOR 2020; PPIN 2020).
- *T. palmi* host plants that are economically important to New Zealand include *Capsicum* spp. (peppers), *Solanum melongena* (egg plant), *S. lycopersicum* (tomato), *Cucurbita pepo* (squash) and *Cucumis sativus* (cucumber) (Plant & Food Research 2019; Vegetables New Zealand 2020).

12.4.2 Hazard identification: commodity association

Thrips palmi is associated with citrus plants, but is not reported from citrus fruit.

- A single adult female *T. palmi* was detected in a sample of flowers of *Citrus x latifolia* (Tahitian lime) in Florida (Childers and Beshear 1992).
- Adult *T. palmi* lay their eggs in incisions made with the ovipositor in the green tissue of host plants (EPPO 2020), but no evidence was found to indicate that the pest lays eggs in/on citrus fruit.
- There are no records of interceptions of *T. palmi* on citrus fruit at EU and New Zealand borders (EPPO 2020; LIMS 2019).

12.4.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Thrips palmi* has a weak association with citrus plants and no known association with citrus fruit (with low uncertainty).

There are very few published records of *Thrips palmi* from citrus.

- Citrus is listed in EPPO (2020) as an incidental host of *T. palmi*, likely based on the record of a single adult female collected from a 'Tahiti' 'Tahiti' lime (*Citrus × latifolia*) flower sample in Dade County, Florida (Childers and Beshear 1992), although CABI (2020) includes citrus among the 'main' hosts of the pest without specific reference to primary sources.
- *Thrips palmi* was not among 36 species of thrips detected in surveys of seven unsprayed citrus orchards in south and central Florida conducted between 1995 and 1996 (Childers and Nakahara 2006).

There are no records of interception of *T. palmi* on citrus fruit.

- In the EU, the pest is frequently intercepted on plants for planting, fruits of eggplant (*Solanum melongena*), bitter melon (*Momordica charantia*) and mango (*Mangifera indica*), and on cut flowers of species in the Orchidaceae, but there are no records of interceptions on any citrus commodity (EPPO 2020).
- Between 1999 and 2019, there were 103 interceptions of *T. palmi* at the New Zealand border, none of which was from citrus. Commodities on which the pest was intercepted were mainly cut flowers of Rosaceae, Orchidaceae and Asteraceae, cut foliage of Amaranthaceae and fresh produce of Cucurbitaceae, Malvaceae and Rosaceae (LIMS 2019).
- The absence of interception records for *T. palmi* on citrus commodities at the EU and New Zealand borders indicates a weak association between the pest and citrus; however, it could be that additional phytosanitary measures that eliminated *T. palmi* were applied to the citrus commodities, but not to the commodities (cut flowers and foliage) on which the pest has been intercepted.

Therefore, given the very limited records of *T. palmi* on citrus, combined with the fact that the pest has not been intercepted on citrus at the borders of both the EU and New Zealand, *T. palmi* is not likely to be present on the citrus fresh produce pathway.

Given the arguments and evidence below, basic measures reduce the likelihood of entry of *T. palmi* on citrus fruit by a high degree (with moderate uncertainty), and the likelihood of entry is considered low to moderate.

If *T. palmi* were to be present in citrus crops, it is likely to be detected and eliminated in the field and in packing houses, but some factors may make detection difficult:

- Heavy infestations of *T. palmi* are easily detected, because the pest feeds externally and heavily infested plants are characterised by a silvered or bronzed appearance of the leaves, stunted leaves and terminal shoots and scarred and deformed fruits (Smith et al. 1997, in Seal and Sabines 2012).
- However, at low levels of infestation, the pest may produce little or no detectable symptoms. Also, given that citrus is an incidental host, detection of the pest may be more difficult in the field.
- There is no evidence to suggest that *T. palmi* feeds on or lays eggs in citrus fruit, but on fruit such as eggplant, scarring damage caused by larval feeding is often visible beyond the cover of the calyx, even though larvae of *T. palmi* usually hide under the calyx (CABI 2020). Eggs laid in any fruit are unlikely to be detected (FAO 2016a).
- If *T. palmi* was present on citrus fruit, post-harvest processes such as washing, brushing, cleaning and waxing are likely to dislodge adults and larvae. However, there is moderate uncertainty because adults and larvae of *T. palmi* are about 1 mm long and pale in colour, which means they may not be easily detected and dislodged, especially if they were to hide under calyces or in the navel of navel oranges.

Note: In a review on the pathways and possibilities of spread of *T. palmi*, Vierbergen (2001) concluded that there was no indication that products for consumption were an entry pathway for the pest and that plants for planting was the most likely entry pathway. These conclusions were based on analysis of interception data from the USA and Europe, and the pathways through which *T. palmi* had spread within Asia out to the Pacific, and its incursions into glasshouses in the Netherlands. Furthermore, EPPO (2020) lists plants for planting as a commodity group for the likely spread of *T. palmi* via trade but does not include fresh fruit for consumption.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *T. palmi* to transfer from imported fruit onto a host plant to allow establishment is rated moderate (with moderate uncertainty).

Some aspects of the biology of the pest limit its ability to transfer to suitable hosts.

- Larvae, and, to a lesser extent, adults, are the stages of *T. palmi* likely to be associated with citrus fruit; adults mostly feed on fresh leaves and flowers and occasionally fruit, whereas larvae are found on older leaves and fruit of some hosts (capsicum and eggplant), and pupation occurs in the soil (Capinera 2015; EPPO 2020; Kawai 1990).
- There is no information on the ability of *T. palmi* larvae to complete development on citrus fruit; for example, *T. palmi* larvae reared on tomato and strawberry were unable to pupate (Kawai 1986). Thus, if larvae are unable to complete development on discarded citrus fruit, they would need to disperse to a suitable host to complete development.
- However, *T. palmi* larvae are wingless and, therefore, less mobile (Capinera 2015; CABI 2020; EPPO 2020), which will limit their ability to disperse from discarded fruit to a suitable host plant/substrate to complete larval development.
- Unmated adult female *T. palmi* can lay viable eggs (Yoshihara and Kawai 1982), with a preoviposition period of 1–3 days and 3–164 eggs (1.0–7.9 eggs per day) laid during their lifespan (Wang et al. 1989). However, all eggs produced by unmated females hatch into male offspring (Yoshihara and Kawai 1982).
- Hence, even if larvae were to complete development to adults and adult females dispersed to a suitable host, such females would not be able to establish a breeding population without mating.
- However, Yadav and Chang (2014) found that unmated adult females lived for an average of 56.7, 46.7 and 38.8 days at 16°C, 19°C and 22°C respectively, and at these temperatures, the mean durations of development (egg to adult) of eggs laid by the females, were 35.7, 26.8 and 19.3 days respectively. These results raise the possibility that under conditions similar to the experimental conditions, female *T. palmi* may live long enough to mate with their male offspring.
- Considering that mean monthly temperatures during summer (December to January) in New Zealand's upper North Island are between 17.8°C and 24°C (NIWA 2020), newly emerged adult female *T. palmi* could potentially live to mate with their male offspring. This is, however, highly uncertain because, while the studies by Yadav and Chang (2014) were conducted at constant temperatures under laboratory conditions, *T. palmi* on fruit discarded in outdoor areas in New Zealand will encounter temperatures that vary over the course of each day.

Other traits and factors may increase the ability of *T. palmi* to transfer to suitable hosts:

- Although adult thrips are weak fliers, they can be blown long distances by wind (Lewis 1997), which may increase the chances of adults moving from discarded fruit landing on suitable hosts; especially for a polyphagous species like *T. palmi*.
- Also, some *T. palmi* populations in India were found to harbour the bacterial endosymbiont, *Wolbachia* (Saurav et al. 2016). Some strains of this symbiont are known to induce thelytokous parthenogenesis — the production of female offspring by unmated females in species that are otherwise incapable of doing so (Stouthamer et al. 1999; Werren and Windsor 2000; Correa and Ballard 2016).
- However, other plant-feeding thrips species such as *Echinothrips americanus* (Thripidae), *Suocerathrips linguis* (Phlaeothripidae) and *Gynaikothrips ficorum* (Phlaeothripidae), in which

Wolbachia has been detected, are incapable of thelytoky (Kumm and Moritz 2008) and there is no data on whether the strain found in *T. palmi* is capable of inducing thelytoky.

- A thelytoky-inducing strain of *Wolbachia* has been detected in the predatory thrips *Franklinothrips vespiformis* (family: Aeolothripidae) (Arakaki et al. 2001).
- Transfer of larvae and adults to a suitable host is also more likely if infested fruit waste is discarded near a glasshouse or in a field with suitable host plants. Arrival of infested commodity and its disposal as waste during summer would also increase the chances of *T. palmi* completing development and transferring to suitable hosts.

Uncertainty:

The lack of information on whether *T. palmi* can complete development on citrus fruit and how far adults can disperse to find to hosts raises some uncertainty around the likelihood of transfer, especially if fruit infested with larvae is discarded far from glasshouses and host plants.

Given the arguments and evidence below, the suitability of New Zealand's climate for the establishment of *T. palmi* outdoors is moderate (with high uncertainty); the pest could establish outdoors in some northern locations and in glasshouses.

Thrips palmi is mainly a tropical and subtropical species, with high temperature requirements for development.

- The pest is native to south east Asia, and its current geographical distribution includes Asia: Bangladesh, Brunei, **China** (numerous provinces, including Hong Kong), India (numerous states), Indonesia (Java, Sumatra), **Japan**, North Korea, **South Korea**, Malaysia, Myanmar, Pakistan, Philippines, Singapore, Sri Lanka, Thailand, **Taiwan**, **Viet Nam**; Africa: Mauritius, Nigeria, Réunion, Sudan; Caribbean: throughout; North America: **United States** (Florida and Hawaii); South America: **Brazil**, Columbia, French Guiana, Venezuela; Oceania: American Samoa, **Australia** (Queensland, Northern Territory, Western Australia), Federated States of Micronesia, French Polynesia, Guam, **New Caledonia**, Palau, Papua New Guinea and **Samoa** (CABI 2020; EPPO 2020). (Countries in **bold** are included in the scope of this risk assessment.)
- The optimum temperature range for development of *T. palmi* is 25–30°C, and estimates of its lower development threshold range from 7.4°C to 11.6°C (Kawai 1985; McDonald et al. 1999; Park et al. 2010; Yadav and Chang 2014). At 25°C, the life cycle lasts 17.5 days (Kawai 1990), compared to 42 days when the insects were cultured at 15°C (Capinera 2015).
- When compared with the Auckland and Northland regions of New Zealand, 83% of georeferenced point locations (data from EPPO 2020) in countries where *T. palmi* is currently established, have a climate match index (CMI) value <0.7. This indicates insufficient climate similarity and suggests that the pest would be unable to establish outdoors in most of New Zealand, including the northern regions (Phillips et al. 2018). In Florida, for example, field populations of *T. palmi* have only been reported south of Orlando (Capinera 2015; Seal and Stansly 2000), which, with a CMI range of 0.5–0.6, has a climate that is insufficiently matched to that of New Zealand.
- Tsumuki et al. (1987) analysed the cold hardiness of *T. palmi* in Japan and concluded that it could not survive outdoor winter conditions in southern Honshu. In the southern Honshu cities of Hiroshima, Takamatsu and Osaka, the mean minimum winter (December–February) temperatures are 2.5°C, 3.2°C and 3.3°C.

However, some locations in the upper North Island of New Zealand may be marginally suitable for outdoor establishment of *T. palmi*.

- Climate models (Dentener et al 2002; Stephen and Dentener 2005) indicate that parts of the upper North Island (including Kaitaia, Kerikeri, Gisborne and Auckland) may be suitable for the establishment of *T. palmi* outdoors. Locations identified as potentially suitable, matched the known New Zealand distribution of *Hercinothrips bicinctus* (banana thrips), a species found worldwide in locations similar to that of melon thrips (Dentener et al. 2002).
- *Thrips palmi* survives outdoors throughout the winter on Kyushu Island in Japan, where the mean minimum winter (December–February) temperature is 5.3°C (Yoshihara 1982). Mean minimum winter temperatures are higher than 5.3°C (5.5°C and 8.6°C respectively) in Gisborne and Kaitaia in New Zealand's North Island (NIWA 2020).

- About 13% of the georeferenced locations (mostly in parts of China and India) where *T. palmi* occurs (data from EPPO 2020) have a climate match index (CMI) value of 0.7, when compared with Auckland and Northland regions of New Zealand. This indicates enough climate similarity to allow establishment of the pest (Phillips et al. 2018) in some sites in these regions of New Zealand.
- McDonald et al. (1999) calculated the lower development threshold of *T. palmi* to be 10.1°C and developed a degree-day model from which they estimated that the pest could potentially complete 3–5 generations outdoors during summer in the Midlands area of the UK. The west Midlands have a CMI of 0.7 when compared with Auckland and Northland areas of New Zealand, whereas most of the east Midlands have a CMI of 0.6.
- However, McDonald et al. (2000) measured cold tolerance of *T. palmi* and concluded that if introduced to the UK, overwintering of *T. palmi* would be largely restricted to protected environments, as its cold tolerance is insufficient to permit outdoor survival for a complete winter, supported by data that showed that on release, caged populations of *T. palmi* died out after as little as 25 days in outdoor winter conditions in Yorkshire, UK (CMI: 0.6–0.7).

Thrips palmi could establish transient populations in glasshouses in New Zealand:

- *Thrips palmi* has the potential to infest hosts grown in glasshouses (Capinera 2015), and outbreaks have occurred in and been eradicated from glasshouses in the Netherlands, Germany and the UK (EFSA 2019; MacLeod et al. 2004; Cannon et al. 2007).
- Nagai and Tsumuki (1990) reported no reduction of adult populations of *T. palmi* at temperatures as low as -3°C to -7°C on weeds in an unheated glasshouse between mid-January and mid-February in Japan, which suggests that glasshouses provide microclimates that mitigate some of the negative effects of low temperature on the pest.
- In New Zealand, several host plants of *T. palmi*, e.g. eggplant, cucumber, sweet pepper and tomatoes, are cultivated in glasshouses, many of which are located around Auckland and other northern regions (Vegetables New Zealand 2020).
- The movement of infested material (plants for planting, packing material and soil) could facilitate the spread of *T. palmi* between nurseries and glasshouses.

There is uncertainty around the likelihood and extent of establishment of *T. palmi* in New Zealand, due to conflicting data in the literature about the cold tolerance and lower development threshold of the species.

Impacts in New Zealand:

Given the arguments and evidence below, *Thrips palmi* is likely to cause low impacts in outdoor crops, but may cause high impacts in glasshouses.

Thrips palmi can cause economic impacts in New Zealand, especially in host plants grown in glasshouses.

- Adults and larvae of *T. palmi* feed mainly on foliage, causing bronzing and premature leaf and fruit drop, with heavy infestations resulting in scarred and/or deformed fruit with no marketable value (Seal and Sabines 2012).
- Since 1978, *T. palmi* has become the most serious pest of cucumber, eggplant and sweet pepper in glasshouses and open fields in south and western Japan, regularly causing crop losses (Kawai 1990). Continuous cultivation of its favoured hosts (cucumber, melon and eggplant) in glasshouses enables the survival and quick buildup of *T. palmi* populations, which results in very severe impacts (Murai 2002).
- At the optimum temperature for population growth (25–30°C), the number of generations was estimated at 25–26/year (Huang and Chen 2004).
- Several *T. palmi* host crops of economic importance, e.g. cucumbers, capsicums, melons, squash, eggplant and tomato, are mainly grown in glasshouses in New Zealand (Tomatoes NZ 2020; Vegetables New Zealand 2020).
- The size of production area and domestic value in 2018 and the export value in 2019 of some major hosts of *T. palmi* grown in glasshouses in New Zealand were: Cucumber – 71 ha, NZ\$20 million domestic; eggplant – \$8.5 M domestic; tomato – 120 ha, \$176 M domestic, \$11.2 M export; squash – 6642 ha, \$3 M domestic, \$59.7 M export; capsicum – 95 ha, \$25 M

domestic, \$20.6 M export; melons – 211 ha, \$28 M domestic; lettuce – 50 ha, \$25 M domestic (Plant & Food Research 2018, 2019).

- Cut flowers of orchids and chrysanthemums, which are important ornamental hosts of *T. palmi* are grown in New Zealand glasshouses for domestic and export trade. Cut flower and foliage exports were worth NZ\$27 million in 2016, with orchids making up the bulk of the sales at \$14.6 million (Markham 2017).

Thrips palmi is a known vector of viruses in the genus *Tospovirus* of the family *Bunyaviridae*.

- The pest is reported to be able to transmit the following tospoviruses: *Groundnut bud necrosis virus* (GBNV), *Capsicum chlorosis virus* (CaCV) and *Watermelon bud necrosis virus* (WBNV) (Seepiban et al. 2011; EFSA 2019), which are regulated pests for New Zealand (ONZPR 2020).
- In transmission experiments in Thailand, *T. palmi* transmitted *Tomato necrotic ringspot virus* (TNRV) isolated from tomato to leaf discs of *Physalis minima* (gooseberry), with an efficiency of 83 per cent (Seepiban et al. 2011). It is also a vector of *Watermelon silver mottle virus* (WSMoV), *Melon yellow spot virus* (MYSV) (Okuda et al. 2002) and *Calla lily chlorotic spot virus* (CCSV) (Chen et al. 2005)
- Although the four viruses above (TNRV, WSMoV, MYSV, CCSV) do not have a regulatory status in New Zealand, i.e. they are not currently regulated in ONZPR (2020), they have not been reported from New Zealand (NZOR 2020; PPIN 2020).

Thrips palmi could lead to high costs for phytosanitary measures and eradication and could impact overseas trade.

- Eradication or a long-term pest management strategy would be necessary to limit economic impacts of the pest in affected glasshouse crops. The estimated cost of eradicating *T. palmi* from an infested chrysanthemum glasshouse in Sussex (south of England) between April 2000 and July 2001 exceeded £56,000 (MacLeod et al. 2004).
- Impact on overseas trade is likely to be limited, as most host commodities of the pest produced in New Zealand are exported to countries where the pest is already present (Vegetables New Zealand 2020). However, small volumes of *T. palmi* host commodities (e.g. tomatoes and capsicums) are exported to Pacific countries where the pest is absent, and access to markets where the pest is absent could be affected.

T. palmi may cause low environmental impact, but is unlikely to cause social and health impacts.

- The pest infests plant species in the Orchidaceae, Malvaceae and Rosaceae families (CABI 2020; EPPO 2020). New Zealand has over 120 species of native wild orchids, which occur across the country (Carlos et al. 2016), including northern coastal areas, which may be suitable for establishment of *T. palmi*. There are also native Malvaceae, e.g. *Hoheria* species, some of which also occur in parts of the North Island where *T. palmi* could potentially establish.
- There is no evidence that *T. palmi* causes any negative human or animal health impacts.

Uncertainty:

There is uncertainty regarding the magnitude of impacts; impacts would be less, if *T. palmi* incursion into a glasshouse was quickly detected and transient, but higher, if the pest established year-round outdoor populations that then invade multiple glasshouses.

12.4.4 References

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13. Mites

13.1 *Aculops pelekassi* (pink citrus rust mite)

Aculops pelekassi is a monophagous mite species that feeds on citrus fruit. It is an economically significant pest in citrus orchards in Korea, Japan and Florida.

Scientific name: *Aculops pelekassi* (Keifer, 1944)

Order/Family: Acarida/Eriophyidae

Other names include: None

Taxonomic notes: *Aculops pelekassi* is similar in appearance to *Phyllocoptruta oleivora* (citrus rust mite) but can be differentiated based on its concave back and dorsal tubercles that arise at the rear shield margins. The dorsal setae extend beyond the distal margin of the prodorsal shield (Childers and Achor 1999).

Summary of conclusions

Given the arguments and evidence presented:

- *Aculops pelekassi* meets the criteria to be a quarantine pest for New Zealand.
- *Aculops pelekassi* has a low to moderate association with citrus fruit, with low uncertainty.
- Basic measures are likely to reduce the likelihood of entry of *A. pelekassi* by a moderate degree. Consequently, the likelihood of entry is considered low. The uncertainty associated with this conclusion is considered low.
- *Aculops pelekassi* is considered to have a low to moderate ability (with moderate uncertainty) to move from imported fruit and into a suitable environment to allow establishment.
- The suitability of the New Zealand environment for the establishment of *A. pelekassi* is considered high, with low uncertainty.
- The level of impact caused by *A. pelekassi* is likely to be low, with low uncertainty.
- *Aculops pelekassi* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rate	Uncertainty
Strength or frequency of association with the commodity	Low–moderate	Low
Likelihood of entry on the commodity, given the application of basic measures	Low	Low
The ability to move from the imported commodity onto a suitable host	Low–moderate	Moderate
Suitability of the New Zealand environment	High	Low
Impacts on the New Zealand economy, environment, health and society	Low	Low

13.1.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Aculops pelekassi* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and is of potential importance (able to establish and cause harm).

Aculops pelekassi is not known to be present in New Zealand.

- *Aculops pelekassi* is a regulated pest (ONZPR 2020).
- There is no record of *A. pelekassi* in NZOR (2020) or PPIN (2020).

Aculops pelekassi has the potential to establish and spread within New Zealand.

- It is a subtropical species reported from subtropical host species in palearctic, oriental and neotropical regions (Vacante 2010).
- The mite has been reported from countries with a similar climate to New Zealand, including Croatia (climate match index (CMI) value 0.8), Italy (CMI 0.8–0.9) and Greece (CMI 0.8) (Phillips et al. 2018).

The establishment of *A. pelekassi* in New Zealand has the potential to cause unwanted impacts.

- *Aculops pelekassi* feeds on leaves, shoots and fruits of citrus (Tsuchida and Masui 2018). Damage is mainly caused to fruit and can be observed as either skin calluses or bronzing (Ashihara et al. 2004), reducing the marketability of affected fruit. Damaged fruit is also smaller (Ashihara et al. 2004).
- There are not likely to be any environmental or human health impacts caused by its establishment.

13.1.2 Hazard identification: commodity association

Aculops pelekassi is associated with citrus fruit.

- Adults of *A. pelekassi* feed and lay eggs on the outside of the fruit of *Citrus* spp. (Childers and Achor 1999; Ashihara et al. 2004).
- The only hosts of the mite are *Citrus* spp. (Vacante 2016).
- It has been reported associated with *C. sinensis* (sweet orange), *C. reticulata* (mandarin) (Childers 1994, in Childers et al. 2017) and *C. limon* (lemon) (Mineo and Ragusa 1970).

13.1.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Aculops pelekassi* has a low to moderate association with citrus commodities, with low uncertainty.

Citrus species are the only hosts of *A. pelekassi*.

- Adults of *A. pelekassi* feed and lay eggs on the outside of citrus fruit (Childers and Achor 1999; Ashihara et al. 2004).
- Mites overwintering in buds from late September to early October have been reported in Florida (Childers and Achor 1999), Croatia (Mijuskovic and Kosac 1972) and Japan (Seki 1979). However, in Japan, if autumn temperatures are unusually warm, populations may be high through to early November (Ashihara et al. 2004). Following overwintering, mites are not active on fruit again until mid-June, with populations on fruit reaching a peak in July and August in Korea and Japan (Seo and Kim 2014; Ashihara et al. 2004).
- As citrus is a commodity that comes into season during winter (from October to June) (Florida Citrus Mutual 2017; Japan-Guide.com 2020) when the mite populations on fruits are lowest, the likelihood of the mites being associated with the harvested commodities is reduced to low to moderate.
- In Florida, all citrus varieties are hosts of *A. pelekassi* (Qureshi et al. 2020).

Aculops pelekassi is present on *Citrus* spp. in countries that are included in the Citrus IHS project.

- *Aculops pelekassi* is present in Japan, USA (Florida) (Childers and Achor 1999), Korea (Seo and Kim 2014), Brazil and China (see Table 14.1.1).

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *A. pelekassi* by a moderate degree. Consequently, the

likelihood of entry is considered low. The uncertainty associated with this conclusion is considered low.

Chemical in-field controls are available for *A. pelekassi* and may reduce populations to a low level:

- Until the 1990s, the mite was successfully controlled in Japan using the fungicide dithiocarbamate, which was sprayed to prevent melacose disease caused by *Diaporthe citri* (Ashihara et al. 2004; Tsuchida and Masui 2020). However, since the development of dithiocarbamate-resistant *A. pelekassi* populations, the mite has sometimes reached outbreak levels that cause severe damage (Ashihara et al. 2004).
- In Florida, there is a recommended in-field control strategy, including sampling method and schedule, as well as chemical treatments for citrus growers to prevent damage by *A. pelekassi* (Qureshi et al. 2020).
- There are control methods available for the mite, and there is ongoing research into its control. Surveying and chemical treatments are likely to reduce the prevalence of the mite in commercial citrus orchards to a low level but are unlikely to eliminate it.

Aculops pelekassi feeding may be visually detectable in the field and/or packhouses, leading to the removal of infested produce, but individuals are likely to be undetected.

- Feeding of the mites on citrus fruits causes obvious symptoms on the surface of the affected fruit (Childers and Achor 1999; Ashihara et al. 2004). In Florida, early-season feeding of *A. pelekassi* caused extensive rind blemishing in many groves during 1999 (Childers and Achor 1999). In Japan, early mite feeding has been associated with callus formation on the skin of *Citrus unshiu* (satsuma mandarin) (Ashihara et al. 2004). Feeding late in the season (September to October) causes skin bronzing, and both symptoms have been observed when mites feed mid-season (Ashihara et al. 2004). Such symptoms are likely to be detected during in field inspections or during harvesting and packhouse activities, with the infested fruit removed.
- However, the mites are very small (females 140–150 µm) and are golden yellow/pink in colour (Childers and Achor 1999). Therefore, mites on healthy-looking fruit would not be detected by visual inspection.
- The mite feeds and lays eggs on the outside of fruit (Childers and Achor 1999) and is likely to be removed by post-harvest processes such as washing and brushing. However, it is possible that within a consignment of fruit a small proportion of mites could be sheltered under fruit calyces. Calyces are usually not removed from citrus as removal hastens decay (Cronje et al. 2005).
- The navel of some orange cultivars can be a complex structure with tight spaces suitable for mites to hide in.
- No detections of *A. pelekassi* at the New Zealand border have been recorded (LIMS database). EPPO has not reported any detections of *A. pelekassi* at EU borders 1999–2016 (EPPO interceptions).

Aculops pelekassi is likely to survive transit on citrus commodities.

- Transit of citrus fruit usually includes cold storage, though temperatures may not be very low (for example, grapefruit and mandarins exhibit chilling injury at 7°C and 8°C respectively and unconditioned lemons below 14.5°C; McGregor 1987). Recommended storage and shipping temperature ranges for oranges (*C. sinensis*) are within the range 0°C to 8°C depending on the variety/cultivar/origin (BMT 2020).
- Regions in Japan where citrus is produced can have average daily winter temperatures similar to those that would be encountered during cold storage, for example, Takamatsu has average low temperatures between December and March of 3.7°C, 1.6°C, 1.8°C and 4.4°C and Kyoto 3.2°C, 1.2°C, 1.4°C and 4°C (Statistics Bureau, Japan 2020). As the mite successfully overwinters in Japan, it is assumed that *A. pelekassi* would survive cold transit to New Zealand. However, this may depend on whether the mites are physiologically prepared to overwinter.

The overall likelihood of entry for *A. pelekassi* on commercially produced citrus is considered low, with low uncertainty. There are in-field control programs including sampling and chemical treatments available for the mite, which can prevent and reduce *A. pelekassi* infestations. Furthermore, citrus varieties are in season when the mite populations on fruits are at their lowest. Inspection of fruit is

likely to detect fruit damaged by mite feeding, but not the mites themselves. Therefore, the likelihood of entry of the mite is rate low, with low uncertainty.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Aculops pelekassi* to transfer from imported citrus fruit into a suitable environment to allow establishment (exposure) is considered to be low to moderate, with moderate uncertainty.

Most organic waste in New Zealand is disposed of by low-risk methods, meaning mites would be unable to reach suitable hosts.

- The majority of waste in New Zealand is bagged and disposed of in landfills or run through kitchen disposal units. These methods would mean that the mite is unlikely to survive or to find a suitable host. See section 2.4.1 for discussion on waste disposal.

However, some waste is likely to be disposed of using high-risk methods, including composting in gardens, discarding into the environment (e.g. roadsides, parks) and using as animal feed, potentially allowing mites to come into contact with suitable hosts.

- Citrus trees are not naturalised in the New Zealand environment (Breitwieser et al. 2010). Therefore, any mites on fruit discarded into the environment are unlikely to find a suitable host.
- However, citrus trees are commonly grown by home gardeners across the country. Therefore, any mites on fruits discarded into home compost bins or used to feed animals may be able to find a host for establishment.

Adult *A. pelekassi* can be spread between plants via wind.

- Mite species in the Tetranychidae and Eriophyidae have adaptive behaviours, such as moving to plant tips, raising their front legs and leaping into the air, which enable them to disperse better on wind currents. However, while aerial dispersal is considered the most important means of dispersal for eriophyid mites, it has been regarded as the most risky mode of dispersal for specialised feeders, as the probability of landing on a suitable host is very low (Michalska et al. 2010).
- Individuals of *A. pelekassi* have been captured even up to 80 m from infested trees. This suggests that the mites can be moved on the wind between and among orchards. It is recommended that windbreaks are used to prevent spread between orchards (Tsuchida and Masui 2018).
- Therefore, the mite may be spread by wind from an open home compost bin to a suitable citrus host, particularly as citrus trees are commonly grown by home gardeners.

There is moderate uncertainty associated with this conclusion (that the likelihood of exposure is low to moderate). There is no information available on the movement of mites from discarded fruit, and furthermore, the assumptions regarding disposal methods may not be correct.

Given the arguments and evidence below, the suitability of New Zealand's environment for the establishment of *Aculops pelekassi* is considered high, with low uncertainty.

Aculops pelekassi is described as a subtropical species and is reported from Mediterranean countries with high climate similarity to New Zealand:

- It is a subtropical species recorded from palearctic, oriental and neotropical regions (Vacante 2010).
- The mite has been reported from countries with a similar climate to New Zealand, including Croatia (CMI 0.8), Italy (CMI 0.8–0.9), mainland Japan (CMI 0.7–0.8) and Greece (CMI 0.8) (Phillips et al. 2018). This species has also been reported from Florida (CMI 0.5–0.7), Korea (CMI 0.6–0.7) and Thailand (0.3–0.5) (Phillips et al. 2018).

- It is highly likely that the New Zealand climate would be suitable to support establishment of the mite. However, the warmer, northern regions (where the majority of citrus crops are grown) are likely to be most suitable for the mite.

However, the New Zealand climate may increase the developmental time and reduce the oviposition rate, compared to those countries where the mite is economically significant.

- In Croatia, there are 18–22 generations of the mite per year (Mijuskovic and Kosac 1972). No evidence was found of the mite being an economically significant pest in this country. The New Zealand climate is very similar to that of Croatia, and it is assumed the number of generations of the mite per year in New Zealand would be similar.
- The development of the mites is influenced by temperature (Vacante and Bonsignore 2009). At 20°C, the developmental time (from egg to adult) was 14.9 days compared to 6.3 days at 30°C (Seki 1979).
- Maximal oviposition occurs at 25°C with 21.8 eggs per female and stopped at 15°C (Seki 1979). Increased relative humidity was also found to improve the life span and fecundity of the mites. The life span was 7.5, 14.5 and 14.6 days and the fecundity 5.4, 21.5 and 27.1 eggs at 33%, 75% and 84% relative humidity respectively (the temperature used is unknown) (Seo and Kim 2014).
- In New Zealand, citrus is mainly grown in areas with high humidity and warm summers; however, temperatures are rarely over 30°C (Chappell 2013a, b; Chappell 2016). Therefore, although the conditions are likely to be suitable for establishment, developmental times would be increased and oviposition may be reduced compared to countries where the mite is a serious pest.
- Until Huang (1971) observed spermatophores on citrus leaves and the genital organs of some specimens indicated the presence of male mites, it was thought that *A. pelekassi* populations consisted of only females (Ashihara et al. 2004). The sex ratios within populations in Japan are biased towards females and vary between seasons. During overwintering, the population is 100% females (Ashihara et al. 2004). Therefore, the ability to reproduce and establish a population of *A. pelekassi* is unlikely to be limited by the ability to find a mate.

Table 14.1.1 Geographic distribution of *Aculops pelekassi* on *Citrus* spp. Areas in **bold** are included in the Citrus IHS project.

Region	Country	Reference
Europe	Croatia	Mijuskovic and Kosac (1972)
	Greece	Keifer (1959), cited in Vacante (2016)
	Italy	Costantino (1962), cited in Vacante (2016)
North America	USA (Florida)	Denmark (1962)
South America	Brazil	Keifer (1944), cited in Ashihara et al. (2013)
	Paraguay	Flechtmann et al. (1970)
Asia	China	Kuang et al. (2005), cited in Vacante (2016)
	Iran	Hajizadeh and Hosseini (2004), cited in Vacante (2016)
	Japan	Ehara (1964), cited in Vacante (2016)
	Korea	Seo and Kim (2014); Vacante (2010)
	Taiwan	Huang and Wang (1997)
	Thailand	Keifer and Korr (1978), cited in Vacante (2016)

Host availability may be a limiting factor.

- Citrus is the only host of *A. pelekassi* (Ellis 2019). Citrus species are commercially grown in New Zealand and by home gardeners around the country. However, commercial orchards are concentrated in specific regions in the north of the country (see section 2.4.2).
- There are no *Citrus* species naturalised in the New Zealand environment (Breitwieser et al. 2010).

- Therefore, the limited availability of suitable host plants may act as a barrier to establishment of *A. pelekassi*.
- However, individuals of *A. pelekassi* have been captured up to 80 m from infested trees (Tsuchida and Masui 2018). Therefore, the mites are likely to be able to spread within and between citrus orchards.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Aculops pelekassi* is likely to be low, with low uncertainty.

Damage caused by *A. pelekassi* reduces the quality and marketability of citrus fruits.

- The mite is found, along with *Phyllocoptruta oleivora* (citrus rust mite), on all citrus varieties throughout Florida (Childers and Achor 1999; Qureshi et al. 2020). No evidence was found of the mite affecting any host other than citrus.
- Adult *A. pelekassi* feed on citrus fruit (Ashihara et al. 2004). On *Citrus sinensis*, the feeding caused punctures in the skin, and on *C. unshiu*, calluses were formed if the mites fed as the fruit was growing (Ashihara et al. 2004). In Florida, early feeding by *A. pelekassi* caused extensive rind damage during the 1999 season (Childers and Achor 1999). Infestations in autumn cause skin bronzing. Sometimes both symptoms were seen on fruit (Ashihara et al. 2004). Such symptoms would reduce the marketability and grade of the affected fruits (Qureshi et al. 2020).
- The quality of fruit may also be reduced, as the size and weight of fruit following mite feeding were less than the size and weight of fruit not damaged by the mites (Ashihara et al. 2004).
- The mite is an economically significant pest on citrus in Korea (Seo and Kim 2014), Japan (Ashihara et al. 2004) and Florida (Childers and Achor 1999).
- In Japan, outbreaks leading to severe damage occur when spring temperatures are above average and there is unusually low rainfall in early spring (Childers and Achor 1999). Therefore, economically significant outbreaks may not occur every year, only when the climate is suitable.
- *Aculops pelekassi* has a quarantine status in the EPPO database (EPPO 2020). Therefore, establishment of the mite in New Zealand has the potential to cause trade impacts.
- No information on the mite causing yield losses of citrus crops was found.

As the impacts associated with *A. pelekassi* are limited to reducing the marketability of citrus fruits and are only expected to be severe during years with unusually high spring temperatures, the impacts to the New Zealand economy are rated as low. However, during outbreak years, the mite has the potential to cause economically significant impacts for the citrus industry.

Aculops pelekassi may cause low sociocultural impacts in home gardens.

- Citrus trees are commonly grown in home gardens. However, the symptoms caused by the mite (skin calluses and discolouration) do not affect the yield or taste of the fruit and are unlikely to cause severe affects for home gardeners.
- However, during times of severe outbreaks, gardeners may have to invest in chemical control treatments.

Environmental impacts caused by the establishment of *A. pelekassi* are likely to be negligible.

- *Aculops pelekassi* is a monophagous pest and only attacks citrus trees (Ellis 2019).
- There are no native *Citrus* species in New Zealand, and the commercial species are not fully naturalised in the environment (Breitwieser et al. 2010). Therefore, establishment of *A. pelekassi* would not cause environmental impacts.

Aculops pelekassi is unlikely to cause unwanted impacts on human health.

- No evidence of such impacts has been found.

Risk assessment summary:

Given the arguments and evidence below, *Aculops pelekassi* may be considered for additional measures.

- Mite feeding causes visible symptoms on citrus fruit skins, which are visibly detectable.
- Adult mites feed and lay eggs on the surface of fruit and are likely to be removed by general handling and post-harvest processes. However, low levels of mites on healthy-looking fruit, or mites in areas such as navels, may not be detected.
- *Aculops pelekassi* may be capable of moving, due to adaptive behaviours, from imported fruit into a suitable environment to allow establishment.
- The mite does not require a mate in order to reproduce and establish a population.
- Although the New Zealand climate is likely to be suitable for establishment, as the mite only affects citrus, availability of suitable hosts is likely to be limited.
- The establishment of *A. pelekassi* is likely to cause low economic impacts to New Zealand. The mite is not known to cause environmental or human health impacts.

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13.2 *Eotetranychus lewisi* (Lewis spider mite)

The female body is ovoid, about 360 µm long, a pale greenish-amber colour with blackish spots laterally. The male is smaller and of a mustard yellow colour (Vacante 2016).

Scientific name: *Eotetranychus lewisi* (McGregor, 1943)

Order/Family: Acari/Tetranychidae

Other names include: *Tetranychus lewisi* McGregor, 1943; Lewis mite

Summary of conclusions

Given the arguments and evidence presented:

- *Eotetranychus lewisi* meets the criteria to be a quarantine pest for New Zealand.
- *Eotetranychus lewisi* has a moderate association with citrus fruit.
- Basic measures are likely to reduce the likelihood of introduction of *E. lewisi* to a moderate degree; consequently, the likelihood of entry is low-moderate (with low uncertainty).
- *Eotetranychus lewisi* has moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (with low uncertainty).
- The suitability of the New Zealand environment for *E. lewisi* to establish is considered moderate (with low uncertainty).
- The level of impact caused by *E. lewisi* is likely to be low to moderate (with moderate uncertainty).
- *Eotetranychus lewisi* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Moderate	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	Low–moderate	Moderate

13.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Eotetranychus lewisi* meets the criteria to be a quarantine pest for New Zealand

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm).

Eotetranychus lewisi is not known to be present in New Zealand:

- It is not recorded in NZInverts (2020); NZOR (2020) or PPIN (2020).
- It is listed as 'regulated' in ONZPR (2020).

Eotetranychus lewisi has the potential to establish and spread in New Zealand.

- The current geographical distribution of *Eo. lewisi* includes countries with a climate match index (CMI) of 0.7 to 0.9 (Phillips et al. 2018), e.g. parts of Chile, USA, South Africa and Japan, indicating potential to establish in New Zealand.
- *Eo. lewisi* is polyphagous. It has been reported on 75 plant species ascribed to 28 families. The highest number of species are within the Euphorbiaceae (15), and the second highest are in the Leguminosae (Fabaceae) (10) (Migeon et al. 2006–2020).
- A number of *Eo. lewisi* hosts are widely grown in New Zealand, such as citrus, roses, *Euphorbia* spp. and *Acacia* spp.

Eotetranychus lewisi has the potential to cause impacts on the economy and environment of New Zealand.

- Host plants of *Eo. lewisi* include crops that are economically important to New Zealand, such as citrus, strawberries, poinsettia and grapevine.

Eotetranychus lewisi has the potential to harm the New Zealand environment.

- The Lewis mite has been reported on plant species under genera that are present in New Zealand, e.g. *Euphorbia*, *Rubus* and *Solanum*.

13.2.2 Hazard identification: commodity association

Eotetranychus lewisi is associated with citrus fruit.

Eotetranychus lewisi is reported from citrus fruit.

- *Eotetranychus lewisi* occurs on the fruit of citrus and the underside of leaves of other hosts (Vacante 2016).

Eotetranychus lewisi has previously been intercepted at the New Zealand border on citrus fruit.

- There are 6 historic records of live adults detected on oranges from California. These are likely to have been prior to the 1990s, given that the dates and consignment numbers were not recorded (MPI interception database 1988–2014).
- However, there do not appear to be any recent interceptions of *Eo. lewisi* on citrus recorded (LIMS database up to 2019). This could be for any of several reasons. Mite populations may be well managed and killed or removed prior to export, or they may be so few they are not detected, or they may be too damaged for full identification. There have been detections of live tetranychid eggs on citrus fruit (e.g. consignments C2015/360546 and C2016/414962, LIMS).

13.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Eotetranychus lewisi* has a moderate association with citrus fruit (with low uncertainty).

Eotetranychus lewisi is reported from citrus and specifically from the fruit.

- *Eotetranychus lewisi* lives and reproduces on the fruit of citrus, laying eggs in the depressions of the rind (Jeppson et al. 1975). The egg has a short stalk, but no attachment threads extend from the stalk to the host (Vacante 2016).
- It attacks lemon and sweet orange in the southern citrus areas of California (Jeppson et al. 1975).

But:

- *Eotetranychus lewisi* is considered a minor pest of citrus by Vacante (2010), occurring only occasionally on citrus in southern California, except for the desert areas (Jeppson et al. 1975). Although it is reported from other countries, it seems to be on other host plants, and specific association with citrus is not elaborated upon.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of introduction of *Eotetranychus lewisi* to a moderate degree; consequently, the likelihood of entry is considered low to moderate (with low uncertainty):

Visual inspection should usually detect *Eo. lewisi* on citrus fruit.

- *Eotetranychus lewisi* produces profuse webbing on leaves which collects dust and makes infestations highly visible. The presence of webbing is an indication that mites may be present (Jeppson et al. 1975).
- Heavy infestations of the mite cause obvious feeding damage to the rind of citrus fruit (Jeppson et al. 1975).

But:

- The mites are very small (0.36 mm or less) and cryptically coloured (Vacante 2016) so may not be readily detected on all lemons and oranges.

A low level of infestation of mites in a consignment makes detection more difficult.

- Webbing is less likely to be present, and mites are less likely to be encountered during an inspection.

Common post-harvest activities may not remove all mites.

- It is expected that most mites and eggs would leave or be removed from fruit during the usual post-harvest activities. However, it is possible that within a consignment of fruit, a small proportion of mites could be sheltered under fruit calyces. Calyces are usually not removed from citrus, as removal hastens decay (Cronje et al 2005).
- The navel of some orange cultivars can be a complex structure with tight spaces suitable for mites to hide in.

Likelihood of establishment:

Given the arguments and evidence below, *Eotetranychus lewisi* has moderate ability (with low uncertainty) to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (exposure/transfer).

Most waste in New Zealand is disposed of using low-risk methods.

- Using landfills or kitchen disposal units are common waste disposal methods. In these situations, it is very unlikely mites on imported fruit would survive.

Some citrus waste is likely to be disposed of in proximity to host plants.

- A proportion of the unavoidable waste generated by citrus fruit will find its way into the environment, such as open composts in home gardens.
- Hosts of *Eo. lewisi* include lemons, roses, strawberry and cucurbit species, which are commonly grown in New Zealand home gardens.
- A proportion of mites on discarded citrus waste may move to a nearby host plant.

Tetranychid mites can disperse by both active and passive means.

- “Dispersal of tetranychid mites occurs by locomotion [walking] between different parts of the same plant and/or between plants and by passive dispersal. Air currents, rain, irrigation water, agricultural operators, harvesting tools and various animals may be involved in passive dispersal.” (Vacante 2016)

Tetranychid nymphs (active phase) and adults are mobile.

- *Eotetranychus lewisi* nymphs in their active phase and adults can walk between fruits/leaves and between plants, either on the webbing they produce or on the plant's surface. Deterioration of a host plant has been shown as a trigger for dispersal in some tetranychid species (Ghazy et al. 2016). *Eo. lewisi* produces silk and may be able to balloon on air currents like some other tetranychids (e.g. *T. kanzawai*). Passive movement is also possible on animals such as insects, birds, rodents or household pets, on garden equipment or on clothing (EFSA 2017). Some hosts of *Eo. lewisi* are common in domestic gardens, residential areas and community spaces, such as lemons, roses, strawberry plants, oaks, acacia and species of *Euphorbia*.

Given the arguments and evidence below, the suitability of the New Zealand environment for establishment of *Eotetranychus lewisi* is considered moderate (with low uncertainty).

The geographic distribution of *Eotetranychus lewisi* ranges across subtropical, tropical and temperate regions.

- The current geographic distribution is presented in Table 14.2.1. The countries and areas that are underlined have a climate match (see section 2.4.2) with New Zealand of at least 0.7 or greater (Phillips et al. 2018).
- A climate match of 0.7 or greater indicates there are parts of New Zealand that are suitable for the establishment of *E. lewisi*.
- In California it was found primarily along the coast (EFSA 2017). Northwards of Los Angeles, the Californian coastal regions mostly have a climate match of 0.7 to 0.8 with New Zealand, whereas southwards of Los Angeles has largely climate match index (CMI) values between 0.6 and 0.7 with New Zealand (Phillips et al. 2018).

Table 14.2.1 Known geographic distribution of *Eotetranychus lewisi* as at June 2020. Countries in **bold** are those considered as current or potential exporters of citrus fruit to New Zealand, and those underlined have regions with a CMI of 0.7 or greater with New Zealand.

Continent /region	Country /area
Africa	<u>South Africa</u> ; Libya (Migeon et al. 2006–2020)
Asia	<u>Iran</u> (Beyzavi et al. 2013); Japan ; Philippines; <u>Taiwan</u> (Migeon et al. 2006–2020);
North America	Mexico ; <u>Canada</u> ; (Migeon et al. 2006-2020); USA - <u>California</u> , <u>Florida</u> , Hawaii, <u>Maryland</u> , <u>Michigan</u> , <u>Arizona</u> , <u>Illinois</u> , <u>Massachusetts</u> , <u>Oregon</u> , <u>Washington</u> (EFSA 2017)
Central and South America	<u>Bolivia</u> ; <u>Chile</u> ; Colombia; Costa Rica; <u>Ecuador</u> ; El Salvador; Guadeloupe; Guatemala; Honduras; Nicaragua; Panama; <u>Peru</u> (Migeon et al. 2006–2020)
Europe	Portugal (Madeira) (Migeon et al. 2006–2020); <u>Poland</u> (greenhouses) (EFSA 2017)

Availability of host plants is unlikely to be a barrier to *Eotetranychus lewisi* establishment (with moderate uncertainty).

- *Eotetranychus lewisi* is polyphagous, with a known host range of at least 75 species across 28 families of which species in the Euphorbiaceae and Leguminosae are favoured (Migeon and Dorkeld 2006–2020).
- *Eotetranychus lewisi* has been reported from lemons (*Citrus limon*), oranges (*Citrus sinensis*), roses (*Rosa* sp.), *Acacia* sp., oak (*Quercus* sp.), olive trees (*Olea europaea*), strawberry (*Fragaria x ananassa*), raspberry (*Rubus* sp.), peaches (*Prunus persica*), pear (*Pyrus communis*), *Ipomoea* sp., *Cucurbita* sp., cottonwood, aspen (*Populus deltoides* and *P. tremuloides*), castor bean (*Ricinus communis*), ponderosa pine (*Pinus ponderosa*), *Solanum* sp. and grapevine (*Vitis* sp.) (Migeon and Dorkeld 2006–2020) which are all grown in New

Zealand (Breitwieser et al. 2010; NZCPN 2020). It is also a recognised major pest of the popular ornamental, poinsettia (*Euphorbia pulcherima*) (Kaur and Zalom 2017).

Greenhouses are likely to be suitable environments for *E. lewisi* to live in.

- *Eotetranychus lewisi* has been reported as a significant pest of greenhouse poinsettia (Zhang 2003), and is also known from greenhouses in Poland where it has occurred a few times (EFSA 2017). It is reported as a pest on poinsettia in Taiwan (Ho and Shih 2004).
- Strawberry is a host for *E. lewisi* and in New Zealand some of the commercial strawberry production is in greenhouses (<http://www.grower2grower.co.nz/news/post/year-round-strawberry-production/>).

Eotetranychus lewisi has biological characteristics that can assist its establishment in new environments

- *E. lewisi* can reproduce both sexually and parthenogenetically. The latter is arrhenotokous, producing only male offspring, and does not require the female to be mated. In this way, small founding populations may be initiated by an unmated female, as inbreeding between mothers and sons, sisters and brothers is common in tetranychid populations (in Vacante 2016).
- Heavy infestations of *E. lewisi* produce loose webbing under which the colony will live and feed (Zhang 2003). The webbing gives protection against weather and predators.
- Lai and Lin (2005) used a linear model and a Lactin model to calculate the lower threshold temperature [sic] for *E. lewisi* (egg to adult) at 8.3°C and 9.0°C respectively. Deutonymphs are the most cold-tolerant life stage with their lower threshold calculated at 2.5°C (Lactin) and 3.4°C (linear). The upper threshold temperature was calculated to be 28.2°C. No eggs hatched at 30°C. The highest net reproductive rate occurred at 24°C with 17.7 offspring per female; the egg-adult survival rate varied between 65 and 85% from 16 to 26°C, but dropped considerably to about 30% at 28°C. These estimates indicate *E. lewisi* could establish in many parts of New Zealand where suitable hosts can be found. Ho (2007) noted that *E. lewisi* was commonly found in Taiwan at higher altitudes where the temperatures were cooler.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Eotetranychus lewisi* is likely to be low to moderate (with moderate uncertainty).

Eotetranychus lewisi has been reported as a minor pest of citrus by Vacante (2010).

- Citrus:
 - The reports of damage to citrus tend to be from California. On lemons, heavy infestations of the mite cause silvering, and on oranges silvering or russetting. There is no notable damage to leaves other than the presence of webbing (Jeppson et al 1975). On Madeira (Portugal) the mite is reported from 'citrus' (Vacante 2010). No information was found detailing economic impacts upon citrus in either California or Madeira. *Eotetranychus lewisi* is reported from other countries, but typically on other host plants or the hosts are not mentioned.

However,

- Other crops:
 - There have been reports of outbreaks of *E. lewisi* in vineyards in some regions of Chile (EFSA 2017). However, no further information was provided regarding injury or economic losses. The mite is also noted from grapevine on the island of Madeira (EFSA 2014).
 - In north-central Mexico it is mostly found in peach and sometimes apple trees. It is of major economic importance in peaches as densities can be high on leaves and limit peach production. Yield was reduced by 62% and fruit weight was reduced by 54% with *E. lewisi* infestations. It would take several years for heavily defoliated trees to recover from mite infestations (EFSA 2017). In New Zealand peaches (and a proportion of the apple crop) are grown in the Hawkes Bay. Fresh fruit peach sales earned \$9m domestically and processed peaches earned close to \$13 m in 2019 (Plant & Food Research 2019).
 - *Eotetranychus lewisi* is considered an emerging pest in California on organic strawberries and its presence on raspberry has been increasing. Feeding damage on

strawberry causes chlorosis and bronzing of the leaves and in high densities of the mite fruit production is reduced (Kaur and Zalom 2017a; Kaur and Zalom 2017b). The berryfruit industry in New Zealand earned \$47.2m domestically for 2018-2019 and in 2019 exported \$47.7m worth of berryfruit to overseas markets.

Resistance to miticides potentially reduces options for managing outbreaks of mites.

- Some mites become resistant to certain chemical treatments. Generally, the same chemical shouldn't be applied more than once in a season (<https://citrusindustry.net/2018/04/18/managing-mites-florida-citrus/>).

Eotetranychus lewisi may cause impacts to New Zealand sociocultural values and potentially to the natural environment, but it is unlikely to have impacts on human health.

- *Ipomoea* sp. is a reported host of *E. lewisi*. It is assumed that *Ipomoea batatas* (kumara) could be affected by *E. lewisi*. Kumara is a taonga or treasured plant to Māori, and so damage to this plant would be considered significant.
- A number of *E. lewisi* hosts, such as roses, lemons, hydrangeas and oaks, are grown in domestic gardens and/or amenity plantings and would suffer the impacts of *Eo. lewisi* establishment.
- *Eotetranychus lewisi* has hosts in several families, in particular, Euphorbiaceae, Fabaceae and Rosaceae; there are genera in these families that are represented in the New Zealand native flora. In the Euphorbiaceae, there is *Euphorbia glauca*. The Fabaceae includes *Carmichaelia* spp. (native brooms), *Clianthus puniceus* (kakabeak) and, most commonly, *Sophora* spp. (kowhai). The Rosaceae includes 4 species and 2 varieties of a species of *Rubus* (e.g. *R. australis*, *R. cissoides*) and several species of *Acaena* (e.g. *A. anserinifolia*, bidibids), as well as the less commonly encountered species of *Geum*. While both the latter two families have lots of native representatives, *Sophora*, *Rubus* and *Acaena* are the most likely to be regularly encountered. Most exotic pests that attack native plants are polyphagous, but highly damaging polyphagous species appear to be exceptional, and it has been postulated that the impact of relatively specialised organisms is likely to be greater than highly polyphagous species (Beever et al. 2007). Therefore, although *E. lewisi* may cause some damage to native plants, it seems to be unlikely that it will have severe impacts.

There is a moderate degree of uncertainty associated with this conclusion, as there is very limited quantitative information found on the economic and environmental impacts of *Eo. lewisi* overseas.

13.2.4 References

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13.3 *Tetranychus kanzawai* (kanzawa spider mite)

Description: *Tetranychus kanzawai* is a small (about 0.4–0.5 mm long), carmine-coloured, polyphagous spider mite that can cause feeding and webbing damage to stems, leaves and fruits of economically important plants.

Scientific name: *Tetranychus kanzawai* Kishida, 1927

Order/Family: Prostigmata/Tetranychidae

Other names include: *Tetranychus hydrangeae* Pritchard & Baker, synonymy by Navajas et al. 2001; Kanzawa spider mite, tea red spider mite (Vacante 2016)

Summary of conclusions

Given the arguments and evidence presented:

- *Tetranychus kanzawai* meets the criteria to be a quarantine pest for New Zealand.
- *Tetranychus kanzawai* has a weak association with citrus fruit (with low uncertainty).
- Basic measures are likely to reduce the likelihood of introduction of *T. kanzawai* to a moderate degree. Consequently, the likelihood of entry is low to moderate (with low uncertainty).
- *Tetranychus kanzawai* has a moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (with low uncertainty).
- The suitability of the New Zealand environment for establishment of *T. kanzawai* is considered to be moderate (with low uncertainty).
- The level of impact caused by *T. kanzawai* is considered moderate (with low uncertainty).
- *Tetranychus kanzawai* may be considered for additional measures.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Weak	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–moderate	Low
The ability to move from the imported commodity onto a suitable host	Moderate	Low
Suitability of the New Zealand environment	Moderate	Low
Impacts on the New Zealand economy, environment, health and society	Moderate	Low

13.3.1 Hazard identification: quarantine status

Given the arguments and evidence below, *Tetranychus kanzawai* meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a quarantine pest relevant to this assessment are: not present in New Zealand, and of potential importance (able to establish and cause harm⁸⁹).

Tetranychus kanzawai is not known to be present in New Zealand.

- *T. kanzawai* is not listed in Zhang et al. (2002), Gordon (2010), PPIN (2020) or NZOR (2020).
- *T. kanzawai* is listed as 'regulated' in ONZPR (2020).

⁸⁹ Refer to [ISPM 5](#) for the definition of a quarantine pest under the IPPC, and the [Biosecurity Act 1993](#), for factors to consider when defining "harm".

Tetranychus kanzawai has the potential to establish and spread in New Zealand.

- The current geographical distribution of *T. kanzawai* includes countries with a climate match index (CMI) of 0.7 to 0.9, e.g. parts of USA, South Africa, Japan and Eastern Australia (Phillips et al. 2018), indicating potential to establish in New Zealand.
- *T. kanzawai* is highly polyphagous with a broad host range. It is reported from 193 wild and cultivated plants across 63 families, among which Fabaceae and Rosaceae have the highest number of species (24 and 19 respectively) (Migeon and Dorkeld 2006–2020).
- Many of these hosts are widespread and readily accessible in New Zealand, for instance, clover, citrus, and weed species such as *Solanum nigrum*.

Tetranychus kanzawai has the potential to cause impacts to the economy and environment of New Zealand.

- Host plants of *T. kanzawai* include crops that are economically important to New Zealand, such as citrus, grapevine, strawberry, kumara, apple, pear, stonefruit, beans, eggplant, clover, maize; and ornamentals, such as hydrangea, roses, camellias and poinsettia (Migeon and Dorkeld 2006–2020).
- *T. kanzawai* is reported to cause damage to some citrus in California (Grafton-Cardwell et al. 2017), strawberries, grapes, eggplant, hydrangeas, tea and other crops in parts of Asia (Vacante 2016) and has the potential to do so in New Zealand.

13.3.2 Hazard identification: commodity association

Tetranychus kanzawai is associated with citrus fruit.

Tetranychus kanzawai is reported from citrus fruit.

- Pest management guidelines for citrus in California note that *T. kanzawai* produces more webbing than *Tetranychus urticae* on citrus, which is “more prominent on the fruit than the leaves” (Grafton-Cardwell et al. 2017).
- Kanzawa mite can be found on late-harvested Valencia oranges or red grapefruit, and extensive feeding causes rind blemishing and associated webbing (Grafton-Cardwell et al. 2017).

13.3.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Tetranychus kanzawai* has a weak association with citrus fruit (with low uncertainty).

Tetranychus kanzawai is considered a minor pest of citrus and seems uncommon on citrus fruit.

- “Minor pests are those that are present and damage citrus only locally” (Gerson 2003). There do not appear to be global reports of serious damage to citrus fruit by *T. kanzawai*. Despite its large list of hosts, “the mite is a major pest of only a restricted number of plants in Japan, southern China and Korea” (Vacante 2016)⁹⁰.

Tetranychus kanzawai primarily feeds on leaves.

- Generally, *T. kanzawai* is more likely to be found on the underside of the host plant leaves and stems, where it will oviposit, feed and build its webbing (Osakabe 1967; Zhang et al. 2002, Vacante 2016). *T. kanzawai* adults of both sexes and eggs have been intercepted at

⁹⁰ Vacante (2016) goes on to say, “The mite infests cherry in China (Wang 1981a), aubergine (Ho and Chen 1992b) and papaya in Taiwan (Cheng et al. 2009), and grapevines in Taiwan (Ho and Chen 1994) and Japan (Ehara 1964a; Ashihara 1996). The mite was also recorded on strawberry in Taiwan (Chang and Huang 1995) and cassava in the Congo (Gutierrez and Bonato 1994) and the Philippines (Villacarlos and Vasquez 1988).”

the NZ border on cordyline leaves from Malaysia (e.g. consignments C2014/80437 and C2014/115374, MPI Interception database 1988–2014).

However, *T. kanzawai* can also be found on fruit at times.

- It is reported on the fruits of oranges and red grapefruit in California, usually in late summer to early autumn (Grafton-Cardwell et al. 2017). As citrus fruit and leaves are in close proximity, it is likely that in other states and countries, there will be occasions when the mite may be found on fruit.
- Tetranychid⁹¹ mites are often intercepted at the New Zealand border on fruit, for example: oranges (*Tetranychus* sp. from USA, C2014/54913 and C2014/101297 MPI Interception database 1988-2014); strawberries (*Tetranychus* sp. from Australia, C2017/264467LIMS); grapes (*Tetranychus* sp. from Australia C2018/126264 LIMS). Potentially, some of the unidentified intercepted *Tetranychus* species may have been *T. kanzawai*.

Given the arguments and evidence below, basic measures are likely to reduce likelihood of entry of *T. kanzawai* to a moderate degree. Consequently, the likelihood of entry is considered to be low to moderate (with low uncertainty).

Usually, visual inspection should detect adult females and males of *T. kanzawai* on citrus fruit.

- Presence of webbing is often an indication of mite presence.
- Adults are up to 0.5 mm long and red or yellowish red (Zhang 2002; Vacante 2016). They can be visible to the naked eye, though a '10x' hand lens increases the likelihood of seeing them.
- Generally, eggs and active life stages are aggregated on their hosts in the field, increasing the likelihood of detection.

Life stage may influence detectability.

- Eggs and nymphs are smaller and a lighter colour (Zhang 2002; Vacante 2016), so can be more difficult to see.
- There is a quiescent period between each instar before moulting, from hatching through to adulthood (Vacante 2016). During this time, the mite is firmly anchored to its substrate (Crooker 1985, in Ikegami et al. 2000) and their colour usually begins to fade towards white prior to moult (Ikegami et al. 2000). Detectability may be reduced by their lack of movement and paleness.

A low infestation of mites in a consignment makes detection more difficult.

- Webbing is less likely to be apparent, and mites are less likely to be encountered during inspection.

Common post-harvest activities may not remove all mites.

- *Tetranychus* species usually prefer the underside of leaves. In the absence of leaves, *T. kanzawai* may shelter under the fruit calyx, where it would not be visible and would be well protected, for instance, from handling and surface washing. Calyces are not usually removed from fruit as to do so hastens decay (Cronje et al. 2005).
- The navel of some citrus, i.e. navel oranges, is also a potential shelter for mites.

Likelihood of establishment:

Given the arguments and evidence below, *Tetranychus kanzawai* has a moderate ability to move from imported fruit and into a suitable environment to allow establishment, that is, onto a host plant (with low uncertainty) (exposure).

Some citrus waste will be disposed of in proximity to host plants.

- A proportion of the unavoidable waste generated from citrus fruit will find its way into the environment, e.g. open composts in home gardens (see section 2.4.1, waste disposal).

⁹¹ A tetranychid is a mite of the family Tetranychidae, and *Tetranychus* is a genus within the family Tetranychidae.

- Many host plants of *T. kanzawai* such as clover, citrus, beans, roses, impatiens, chrysanthemums, carnations, hydrangeas, camellias and weed species are commonly found in home gardens and amenity plantings.
- A proportion of mites on discarded citrus fruit or peel may move to a nearby host to ensure their survival.

Tetranychid mites can disperse by both active and passive means.

- “Dispersal of tetranychid mites occurs by locomotion [walking] between different parts of the same plant and/or between plants and by passive dispersal. Air currents, rain, irrigation water, agricultural operators, harvesting tools and various animals may be involved in passive dispersal.” (Vacante 2016)

Tetranychus kanzawai adults and nymphs (active phase) are mobile.

- Host plant deterioration is one of several stimuli that can initiate dispersal in *Tetranychus* species (in Ghazy et al. 2016). Kondo and Takafuji (1985) showed in a laboratory experiment that *T. kanzawai* responded more sensitively to food deterioration and dispersed more quickly than did *T. urticae*. Dispersal can occur via walking to a new plant or ‘ballooning’ on air currents by producing silken threads. The mite either moves up a plant to the apices for aerial dispersal or drops down in still air to the ground, from where it will crawl to another plant (in Ghazy et al. 2016).

Given the arguments and evidence below, the suitability of the New Zealand environment for establishment of *Tetranychus kanzawai* is considered moderate (with low uncertainty).

The geographic distribution of *T. kanzawai* is largely tropical and subtropical, but also includes temperate areas.

- Table 14.3.1 provides the current geographical distribution. Countries or areas that are underlined have a climate match index (CMI) with New Zealand of at least 0.7 or greater (Phillips et al. 2018).
- Climate matches of 0.7 or greater indicate there are parts of New Zealand where the climate is similar enough to be suitable for *T. kanzawai* establishment.
- Climate niche modelling showed that similarity of some origin climates with New Zealand climate regions (destination x season) could be above 70% and even 80% for most New Zealand sites, with the main exception (lower similarity due to high rainfall) being the western South Island (Halloy et al. 2019)
- Additionally, *T. kanzawai* shares a very similar geographical distribution and biology with two congeners, *T. lambi* and *T. ludeni*, that have established in New Zealand (Zhang et al. 2002).

Table 14.3.1 Known geographic distribution of *Tetranychus kanzawai* as at June 2020. Countries in **bold** are current or potential exporters of citrus fruit to New Zealand, and those underlined have regions with a CMI of 0.7 or greater with New Zealand.

Continent/region	Country/area
Africa	Congo, <u>South Africa</u> (EPPO 2019), Ivory Coast (Migeon 2015)
Asia	China (<u>Anhui</u> , <u>Fujian</u> , Guangxi, <u>Jiangsu</u> , Jilin, <u>Liaoning</u> , <u>Shaanxi</u> , <u>Shandong</u> , Xianggang (Hong Kong), <u>Zhejiang</u> (EPPO 2019), Xinjiang (Zhang et al. 2009); <u>Shanghai</u> (Takafuji and Hinemoto 2008)), <u>Iran</u> (Beyzavi et al. 2013), India, Indonesia, Japan (<u>Hokkaido</u> , <u>Honshu</u> , Kyushu, <u>Shikoku</u> , Okinawa) South Korea , Malaysia, Philippines, Taiwan, Thailand, Viet Nam (EPPO 2019), Singapore (Migeon and Dorkeld 2006–2019)
North America	Mexico (EPPO 2019), USA (<u>California</u> , Wisconsin (greenhouse)) (Navajas et al. 2001)
Europe	<u>Netherlands</u> (Migeon 2015), <u>Greece</u> (Migeon and Dorkeld 2006–2019)

Continent/region	Country/area
Oceania	<u>Australia</u> (New South Wales, Queensland) (Gutierrez and Schicha 1983), <u>Papua New Guinea</u> (EPPO 2019)

Host plant availability is not a barrier to *T. kanzawai* establishment.

- *T. kanzawai* is highly polyphagous, with a broad host range of at least 193 species in 63 families, of which species in Fabaceae and Rosaceae seem to be more prominent (Migeon and Dorkeld 2006–2020).
- Host plants include commercially and domestically grown fruit/vegetable crops such as *Citrus* spp., sweet potato/kumara (*Ipomoea batatas*), cucumber (*Cucumis sativa*), melon (*Cucumis melo*), watermelon (*Citrullis lanatus*), tea⁹² (*Camellia sinensis*), bean (*Phaseolus vulgaris*), pea (*Pisum sativum*), corn/maize (*Zea mays*), strawberry (*Fragaria × ananassa*), hop (*Humulus lupulus*), stonefruit (*Prunus* sp.), apple (*Malus domestica*), pear (*Pyrus communis*), persimmon (*Diospyros kaki*), sweet pepper (*Capsicum annuum*), eggplant (*Solanum melongena*) and grapevine (*Vitis vinifera*); ornamental plants (commercial, amenity and domestic) such as roses, *Cordyline* sp., *Dianthus caryophyllus*, *Ageratum* sp., *Gladiolus* sp., *Bidens* sp., *Chrysanthemum* sp., *Camellia japonica*, *Hydrangea* sp., *Alcea rosea*, *Bambusa* sp. and *Cyathea* sp.; and weed species such as *Chenopodium* sp., *Sonchus oleraceus* and *Solanum nigrum*.
- The above-listed host plants grow in New Zealand, with many of them in places of likely first point of arrival, such as the Auckland and Bay of Plenty regions. There are host plants for *T. kanzawai* growing throughout New Zealand (Breitwieser et al. 2010).

Greenhouses are suitable environments for *Tetranychus kanzawai*, and some hosts are grown in them.

- *T. kanzawai* is reported from greenhouses in Japan on grapes (Kondo 2004) and in Wisconsin, USA (as *T. hydrangeae*, Navajas et al. 2001).
- Greenhouse crops in New Zealand include beans, cucumber, capsicums, eggplant and some ornamentals like *Euphorbia pulcherrima*.

Tetranychus kanzawai has biological characteristics that facilitate establishment in new environments.

- *Tetranychus kanzawai* has two reproductive strategies: arrhenotoky, where an unmated adult female can lay eggs that will produce only male offspring, and sexual reproduction, which requires males to fertilise females resulting in offspring of both sexes. The sex ratio is female-biased, ranging from 2:1 to 3:1 (female:male) (Oku 2014). Inbreeding between mothers and sons and between sisters and brothers is common in tetranychid populations (Vacante 2016), and so it seems likely that an unmated female could establish a small population. “There is mostly no expression of deleterious mutations and/or population death, as there is sufficient genetic variability to adapt to changes of conditions” (Vacante 2016).
- *Tetranychus kanzawai* females attract males to them, for mate guarding and initiating copulation, by emitting pheromones, which enhances the likelihood of meeting, mating and founding a population (Oku and Shimoda 2013).
- *Tetranychus kanzawai* populations from the four main islands of Japan are known to have a strong capacity for diapause (Takafuji and Morishita 2001). Diapause enables survival of adult females in unfavourable conditions. The common stimulus for entry into diapause is a reduction in daylength and temperature. Also, Boudreaux (1963) states that, “exhaustion of healthy food plants usually can induce diapause when otherwise the photoperiod would not.”
- Hasanvand et al. (2019) demonstrated that *T. kanzawai* can develop under a wide range of temperatures (from 15°C to 37.5°C) in Iran on soy bean. Osakabe (1967) estimated the lower developmental thresholds were 8.7°C for eggs, 14.6°C for larvae, 13.4°C for protonymphs and 13.2°C for deutonymphs on tea plants in Japan, which would allow development in parts of New Zealand.
- *Tetranychus kanzawai* produces a complex and irregular webbing, usually on leaf surfaces (Saito 1985). The webbing is protection for all lifestages against some predators and adverse weather and, as the fecal pellets, cast skins and eggs collect upon it, the inhabited leaf surface remains relatively clean (Saito 1985; Oku 2003).

⁹² Tea production is a relatively recent boutique industry in New Zealand, e.g. Zealong Tea Estate in the Waikato produces organic premium tea.

Impacts in New Zealand:

Given the arguments and evidence below, the level of impact caused by *Tetranychus kanzawai* is likely to be moderate (with low uncertainty).

Tetranychus kanzawai feeding damage can reduce vigour, quality and yield of host plants.

- Tetranychids mainly feed on leaves but can also feed on cotyledons, flowers, fruit and shoots, etc. They feed by piercing the cells of the palisade tissue, which is the primary area of photosynthesis. They remove chloroplasts and other cellular contents, creating necrotic areas (Vacante 2016). A reduction of photosynthetic ability can lead to reduced vigour in the host plant and a decrease of crop yields.
- In a comparison of resource use between *T. urticae*⁹³ and *T. kanzawai*, Kondo and Takafuji (1985) observed that damage by *T. kanzawai* “more heavily hindered the growth of mottled kidney bean (*Phaseolus vulgaris*).” Injured leaves turned brown, withered and dropped. In summarising their work, Kondo and Takafuji (1985) stated that *T. kanzawai* was more sensitive to food deterioration and dispersed more quickly than *T. urticae*, and it damaged its host plants more severely, causing earlier and more extensive defoliation.

Tetranychus kanzawai damages crops of economic importance overseas.

- Zhang et al. (1996) note that strawberries grown in Fuzhou (Fujian, China) may have infestation rates of *T. kanzawai* as high as 90–100%, with between 2,000 to 3,000 mites per leaf.
- In Japan, it is a serious pest of greenhouse grapevine (Kondo 2004) and damages vegetable and fruit crops (Vacante 2016).
- In various Asian countries, it is damaging to tea, feeding on the new shoots, thus inducing direct crop loss (Vacante 2016). Hasanvand et al. (2019) report that damage by *T. kanzawai* has significantly increased in recent years, with the increasing temperatures in parts of western Iran and is considered a disastrous mite on soybean.
- In several countries, it is reported as a minor pest of citrus on which the symptoms and damage are unclear (Vacante 2016). However, in California, Grafton-Cardwell et al. (2017) state that the numbers of *T. kanzawai* can become problematic towards the end of the year (September to October) on late-harvested Valencia oranges or red grapefruit. Extensive feeding can lead to rind bleaching and associated webbing of fruit.

But:

- Most of the damage has been reported from the warmer areas of these countries, where *T. kanzawai* is more likely to reach its full pest potential.

New Zealand has horticultural industries that could be economically impacted by *T. kanzawai* establishment.

- The largest export earnings for 2019 in horticulture came from the wine industry, which sold NZ\$1.8 billion of wine to more than 100 overseas markets (Plant & Food Research 2019).
- Apple exports earned NZ\$828.8 million, and berryfruits earned \$47.7 million in exports and \$47.1 million in domestic sales.
- There are several other horticultural crops that might be affected, which include, but are not limited to, citrus, beans, peas, cucumbers, capsicum, kumara, eggplant, tea, sweet corn and hop.
- The ornamental industry and cut flowers/foilage industry grow several host plants of *T. kanzawai*, such as roses, camellias, chrysanthemums, orchids and hydrangea. In 2018, exports of chrysanthemums earned NZ\$0.1 million, hydrangea \$1.3 million and orchids \$10.9 million plus \$11.6 million in domestic sales (Plant & Food Research 2019).
- Clover was estimated to contribute over NZ\$2 billion to the New Zealand economy (NZIER report 2012).

Resistance to miticides potentially reduces options for managing outbreaks of mites.

⁹³ *Tetranychus urticae* is present in New Zealand (NZOR 2020)

- Chemical resistance is a well documented problem with mites under chemical control. Vacante (2016) reports several acaricides that have become ineffective in treating *T. kanzawai*.

But:

- Some horticultural industries are spread over New Zealand. For instance, grapes are grown around Auckland, Gisborne, Hawke's Bay, Wairarapa, Nelson, Marlborough, Canterbury and Otago. It is likely that only a proportion of a national industry would be affected and therefore only a proportion of the export/domestic value of that industry.

Tetranychus kanzawai may cause impacts to sociocultural values of New Zealand and potentially to the natural environment, but is unlikely to have impacts upon human health.

- Kumara (*Ipomoea batatas*) is reported as a host of *T. kanzawai*. It is a treasured plant to Māori, and so damage to this plant would be considered significant.
- Home gardens and amenity plantings use many of the hosts described and therefore would suffer damage from the establishment of *T. kanzawai*.
- No evidence has been found that human health could be affected by *T. kanzawai* establishment.
- “*T. kanzawai* has hosts in Rosaceae and Fabaceae (Migeon and Dorkeld 2006); both these families have many native representatives in New Zealand. For Rosaceae, this includes *Rubus* (for example, bush lawyer, *R. cissoides*, which is in the same genus as blackberry), and *Acaena* (for example *A. anserinifolia*, bidibids), as well as *Geum*, which is less commonly encountered. For Fabaceae, this includes *Carmichaelia* spp. (native brooms), *Clianthus puniceus* (kakabeak), *Monitigena novaezealandiae* and, most commonly, *Sophora* spp. (kowhai). While both families have lots of native representatives, *Sophora*, *Rubus* and *Acaena* are the most likely to be regularly encountered. Most exotic pests that attack native plants are polyphagous, but highly damaging polyphagous species appear exceptional, and it has been postulated that the impact of relatively specialised organisms is likely to be greater than highly polyphagous species (Beever et al. 2007).” (excerpt from BNZ-MAF 2009) Therefore, although *T. kanzawai* may cause some damage to native plants, it seems to be considered unlikely that it will have severe impacts.

13.3.4 References

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14. Vector analysis

14.1 Insect vector analysis: aphids, mealybugs, thrips

[See 15.2 for an analysis of mite vectors]

An insect vector analysis was carried out for 17 insect species (Table 15.1.1) that are present in one or more citrus-exporting countries and are associated with citrus fruit. All 17 species are recorded from New Zealand, but they are considered in this analysis because they are known to vector various pathogens, some of which are not reported from New Zealand.

Table 15.1.1 The 17 vector species considered in this analysis

Scientific name	Common name	Pest group	Order: Family
<i>Aphis gossypii</i>	cotton aphid / melon aphid	aphid	Hemiptera: Aphididae
<i>Aphis spiraecola</i>	green citrus aphid	aphid	Hemiptera: Aphididae
<i>Aphis craccivora</i>	cowpea aphid	aphid	Hemiptera: Aphididae
<i>Brachycaudus persicae</i>	black peach aphid	aphid	Hemiptera: Aphididae
<i>Macrosiphum euphorbiae</i>	potato aphid/ tomato aphid	aphid	Hemiptera: Aphididae
<i>Macrosiphum rosae</i>	green rose aphid	aphid	Hemiptera: Aphididae
<i>Myzaphis rosarum</i>		aphid	Hemiptera: Aphididae
<i>Myzus persicae</i>	green peach aphid	aphid	Hemiptera: Aphididae
<i>Toxoptera aurantii</i>	black citrus aphid	aphid	Hemiptera: Aphididae
<i>Toxoptera citricida</i>	oriental black citrus aphid	aphid	Hemiptera: Aphididae
<i>Pseudococcus calceolariae</i>	citrophilus mealybug	mealybug	Hemiptera: Pseudococcidae
<i>Pseudococcus longispinus</i>	long-tailed mealybug	mealybug	Hemiptera: Pseudococcidae
<i>Planococcus citri</i>	citrus mealybug	mealybug	Hemiptera: Pseudococcidae
<i>Pseudococcus viburni</i>	obscure mealybug	mealybug	Hemiptera: Pseudococcidae
<i>Frankliniella intonsa</i>	eastern flower thrips	thrips	Thysanoptera: Thripidae
<i>Frankliniella occidentalis</i>	western flower thrips / alfalfa thrips	thrips	Thysanoptera: Thripidae
<i>Thrips tabaci</i>	common cotton thrips	thrips	Thysanoptera: Thripidae

Generally, the risk posed by vectors is considered to be low. This is because successful introduction of the pathogen requires the vector to: i) acquire the pathogen from its host (either citrus or another plant host); ii) remain infectious during transit and after arrival in New Zealand and then iii) successfully find and transmit the pathogen to another suitable plant host in which the pathogen is able to establish (and cause unwanted impacts).

Pathogens that are associated with citrus are considered to be higher risk than those that are not associated with citrus. It is assumed that entry of citrus-associated pathogens transmitted by insect vectors is possible, no matter if the pathogen is transmitted in a non-persistent, semi-persistent or persistent manner. Non-citrus pathogens that are transmitted in a non-persistent manner are unlikely to be retained by the vector long enough to be exposed to suitable hosts in New Zealand. Non-citrus pathogens that are transmitted in a semi-persistent or persistent manner by the insect vector may be able to enter New Zealand. This is because non-persistent transmission has a retention time⁹⁴ of several minutes to hours, but semi-persistent and persistent transmission have a retention time of

⁹⁴ Retention time: the length of time after virus acquisition that the vector carries the virus.

several hours to a few days and a few days to a lifetime of the insect respectively (Ng and Falk 2006). If the commodities are transported by air, it is possible that they can arrive in New Zealand from the exporting country within a few days. However, this risk is much lower than that associated with citrus-associated pathogens. This is because successful entry requires an extra step, i.e. the vector must successfully acquire the pathogen from a non-citrus host, move to citrus and remain associated with the citrus commodity before successfully locating a suitable host in New Zealand. In most cases, the host range of the pathogen is more restricted than that of the insect vector.

When assessing the risk of vectors associated with fresh produce, it is usually assumed that commercial citrus orchards are grown as monocultures and that vectors are unlikely to be in contact with plant species other than the commodity being assessed. Therefore, vector analysis is usually limited to considering vectored pathogens that are associated with the commodity. However, a large number of citrus-exporting countries are involved in the citrus IHS, and agricultural practices may be different among these countries (e.g. companion planting, close distancing between citrus and other plant crops and multi-cropping), although monoculture is likely to be the most common practice. Different agricultural practices like companion planting and close distancing between citrus and other plant crops increase the risk of vectors being in contact with other plants that are potentially infected with pathogens not associated with citrus. To allow for this possibility, high-priority viruses and viroids (Table 15.1.2) are also considered in this analysis to determine whether any of the insect vectors have the potential to transmit these pathogens. This list of pathogens⁹⁵ is compiled from the MPI high-priority organism (HPO) list and the list of sector risk organisms (SRO) as listed/described by each government industry agreement (GIA).

Table 15.1.2 Pathogens initially considered in this section. This list is compiled from the MPI high-priority organism (HPO) list and the list of sector risk organisms (SRO) as listed/described by each government industry agreement (GIA) partner in either their draft operational agreement, biosecurity plan or website.

Scientific name	Family: Genus
<i>Avocado sunblotch viroid</i>	<i>Avsunviroidae: Avsunviroid</i>
<i>Blueberry scorch virus</i>	<i>Quinvirinae: Carlavirus</i>
<i>Broad bean wilt virus</i>	<i>Comovirinae: Fabavirus</i>
<i>Clover yellow mosaic virus</i>	<i>Alphaflexiviridae: Potexvirus</i>
<i>Cucumber green mottle mosaic virus</i>	<i>Virgoviridae: Tobamovirus</i>
<i>Cucurbit yellow stunting disorder virus</i>	<i>Closteroviridae: Crinivirus</i>
<i>High Plains wheat mosaic emaravirus</i> = High Plains virus	<i>Fimoviridae: Emaravirus</i>
<i>Hop stunt viroid</i>	<i>Pospiviroidae: Hostuviroid</i>
<i>Pea early-browning virus</i>	<i>Virgaviridae: Tobravirus</i>
<i>Plum pox virus</i>	<i>Potyviridae: Potyvirus</i>
<i>Potato mop-top virus</i>	<i>Virgaviridae: Pomovirus</i>
<i>Potato spindle tuber viroid</i>	<i>Pospiviroidae: Pospiviroid</i>
<i>Pepino mosaic virus</i>	<i>Alphaflexiviridae: Potexvirus</i>
<i>Squash leaf curl virus</i>	<i>Geminiviridae: Begomovirus</i>
<i>Tomato apical stunt viroid</i>	<i>Pospiviroidae: Pospiviroid</i>
<i>Tomato torrado virus</i>	<i>Secoviridae: Torradovirus</i>
<i>Maize dwarf mosaic virus</i>	<i>Potyviridae: Potyvirus</i>
<i>Capsicum chlorosis orthospovirus</i>	<i>Tospoviridae: Orthospovirus</i>
<i>Potato virus Y</i>	<i>Potyviridae: Potyvirus</i>
<i>Grapevine pinot gris virus</i>	<i>Betaflexiviridae: Trichovirus</i>
<i>Grapevine red blotch virus</i> = Grapevine red blotch-associated virus	<i>Geminiviridae: Grablovirus</i>
<i>Little cherry virus 2</i>	<i>Closteroviridae: Ampelovirus</i>

⁹⁵ Only viruses and viroids from the MPI priority pest and disease list and the list of sector risk organisms are considered.

Scientific name	Family: Genus
Pea enation mosaic virus*	See information below table *
<i>Peach rosette mosaic virus</i>	Comovirinae: Nepovirus
<i>Tomato ringspot virus</i> = Peach yellow bud mosaic disease, yellow bud mosaic	Comovirinae: Nepovirus
<i>Pelargonium zonate spot virus</i>	Bromoviridae: Anulavirus
<i>Potato virus H</i>	Quinvirinae: Carlavirus
<i>Tomato brown rugose fruit virus</i>	Virgoviridae: Tobamovirus
<i>Tomato chlorosis virus</i>	Closteroviridae: Crinivirus
<i>Tomato infectious chlorosis virus</i>	Closteroviridae: Crinivirus
<i>Tomato leaf curl New Delhi virus</i>	Geminiviridae: Begomovirus
<i>Tomato leaf curl purple vein virus</i>	Geminiviridae: Begomovirus
<i>Tomato mottle virus</i>	Geminiviridae: Begomovirus
<i>Tomato yellow leaf curl virus</i>	Geminiviridae: Begomovirus

* Pea enation mosaic virus is regulated in ONZPR (2020). Neither *Pea enation mosaic virus 1* (Luteoviridae: Enamovirus) nor *Pea enation mosaic virus 2* (Calusvirinae: Umbravirus) is known to be present in New Zealand (PPIN; Veerakone et al. 2015).

Therefore, the criteria for an insect vector to be considered a hazard on any country pathway in the analysis are:

- The insect transmits at least one citrus pathogen or one pathogen in the HPO or SRO list that is regulated⁹⁶ or not present in New Zealand;
- For pathogens not associated with citrus, the insect transmits the risk pathogen in a persistent or semi-persistent manner; and
- Both the insect vector and the pathogen are present in the same citrus-exporting country.

Summary of the analysis

Six vector species are considered to be hazards in this analysis. These vectors are considered to be risks on at least one of the following citrus fresh produce pathways: Australia, Brazil, China, Egypt, Spain and the USA. Table 15.1.3 summarises the vector species considered to be hazards, the pathways on which the vectors are considered to be risks and the risk pathogens that are transmitted by these vectors.

Table 15.1.3 The six vector species considered to be hazards in this analysis and their associated risk pathogen/pathway combinations.

Hazard spp.	Suggested regulated pathway	Virus infecting (or affecting) citrus	Viruses in the priority pest and disease list that are transmitted in a persistent manner (all hosts)
<i>Aphis gossypii</i>	Australia		Pea enation mosaic virus
	China		Pea enation mosaic virus
	Egypt		Pea enation mosaic virus
	Spain		Pea enation mosaic virus
	USA		Pea enation mosaic virus
<i>Aphis spiraecola</i>	China	<i>Citrus yellow vein clearing virus</i>	
<i>Aphis craccivora</i>	China	<i>Citrus yellow vein clearing virus</i>	
<i>Macrosiphum euphorbiae</i>	Australia		Pea enation mosaic virus
	China		Pea enation mosaic virus
	Egypt		Pea enation mosaic virus

⁹⁶ Strains of pathogens that are not recorded in New Zealand and have no defined entity (a named subspecies, pathovar, haplotype, etc.) are not considered hazards in this analysis. The criteria for regulating taxa below species level require that:

- There is a defined entity (a named subspecies, pathovar, haplotype, etc.) that is not known to be present in New Zealand.
- The entity is biologically distinct (for example host range, pathogenicity or vector relationships). Genetic differences alone are not sufficient.
- There is an increased risk to New Zealand posed by the entity.

Hazard spp.	Suggested regulated pathway	Virus infecting (or affecting) citrus	Viruses in the priority pest and disease list that are transmitted in a persistent manner (all hosts)
	Spain		Pea enation mosaic virus
	USA		Pea enation mosaic virus
<i>Myzus persicae</i>	Australia		Pea enation mosaic virus
	China		Pea enation mosaic virus
	Egypt		Pea enation mosaic virus
	Spain		Pea enation mosaic virus
	USA		Pea enation mosaic virus
<i>Toxoptera citricida</i>	Brazil	<i>Citrus sudden death-associated virus</i>	

Aphis craccivora, *My. persicae*, *A. spiraecola* and are considered to have a weak to moderate association with citrus fruit, while *A. gossypii*, *Ma. euphorbiae* and *T. citricida* are considered to have a weak association with citrus fruit. Basic measures are likely to reduce the likelihood of entry of *Aphis gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida* by a high degree. Consequently, the likelihood of entry is considered to be very low. In addition, generally, the risk posed by vectors that are present in New Zealand is considered to be low. Therefore, it is recommended that *Aphis gossypii*, *A. spiraecola*, *A. craccivora*, *Ma. euphorbiae*, *My. persicae* and *T. citricida* do not require consideration for additional measures.

Insect vector analyses – vector species considered to be hazards

14.1.1 *Aphis gossypii* (Hemiptera: Aphididae)

Citrus-exporting country status:

Aphis gossypii is present in all of the potential citrus-exporting countries considered in this analysis, i.e. Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Korea, Mexico, New Caledonia, Peru, Samoa, Solomon Islands, Spain, the USA, Vanuatu and Viet Nam (CPC 2020).

New Zealand status:

- *Aphis gossypii* is present in New Zealand (NZOR 2020).
- *Aphis gossypii* is listed as a 'potential vector' in ONZPR (2020).

Plant hosts:

Aphis gossypii is polyphagous and has been recorded on over 92 plant families (CPC 2020). It has been recorded on crop, fibre and ornamental species, including but not limited to: soursop (*Annona muricata*), avocado (*Persea americana*), betel (*Piper betle*), kava (*Piper methysticum*), carnation (*Dianthus caryophyllus*), cocoa (*Theobroma cacao*), kenaf (*Hibiscus cannabinus*), okra (*H. esculentus*), Chinese hibiscus (*H. rosa-sinensis*), cotton (*Gossypium hirsutum*; *G. arboreum*), passionfruit (*Passiflora edulis*), papaya/pawpaw (*Carica papaya*), cucumber (*Cucumis sativus*), melon (*Cucumis melo*), pumpkin (*Cucurbita* spp.), zucchini (*Cucurbita pepo*), tomato (*Solanum lycopersicum*), turnip (*Brassica campestris*), persimmon (*Diospyros virginiana*), apple (*Malus pumila*), strawberry (*Fragaria* spp.), pear (*Pyrus communis*), loquat (*Eriobotrya japonica*), cowpea (*Vigna unguiculata*), green gram / mung bean (*Vigna radiata*), black gram (*Vigna mungo*), bean (*Phaseolus vulgaris*), soybean (*Glycine max*), Egyptian clover (*Trifolium alexandrinum*), macadamia (*Macadamia* sp.), guava (*Psidium guava*), pomegranate (*Punica granatum*), grape (*Vitis vinifera*), lychee (*Litchi chinensis*), cashew nut (*Anacardium occidentale*), orange (*Citrus sinensis*), lime (*C. aurantiifolia*), sour orange (*C. aurantium*), lemon (*C. limon*), mandarin (*C. reticulata*), grapefruit (*Citrus x paradisi*), celery (*Apium graveolens*), carrot (*Daucus carota*), eggplant (*Solanum melongena*), chilli (*Capsicum annum*), potato (*Solanum tuberosum*), tobacco (*Nicotiana tabacum*), sweet potato (*Ipomoea batatas*), blond psyllium / isabgol (*Plantago ovata*), breadfruit (*Artocarpus altilis*; *A. communis*), sesame (*Sesamum indicum*), gardenia (*Gardenia augusta*), chrysanthemum (*Dendrathera grandiflorum*), sunflower (*Helianthus annuus*), zinnia (*Zinnia elegans*), lettuce (*Lactuca sativa*), coconut (*Cocos nucifera*), taro (*Colocasia esculenta*), sugarcane (*Saccharum officinarum*), corn (*Zea mays*), wheat (*Triticum aestivum*), banana (*Musa acuminata*), abaca (*Musa textilis*), Easter lily (*Lilium longiflorum*), garlic (*Allium sativum*), Japanese plum (*Prunus salicina*), peanut/groundnut (*Arachis hypogaea*), sugarbeet (*Beta vulgaris*) and Chinese yam (*Dioscorea batatas*) (CPC 2020; Ebert and Cartwright 1997). Pawpaw, melon, cucumber, pumpkin, cotton, Japanese plum and tomato are categorised as 'main' hosts by CPC (2020).

Plant parts affected:

Aphis gossypii attacks most plant parts if the population density is high enough, with the exception of direct feeding on mature fruits, berries, nuts and roots (CPC 2020). However, CPC (2020) also states that fruits can carry adults and nymphs externally in plant trade, but it did not specify the host plants for which the pest may be found on fruit. In addition, *Aphis gossypii* has been identified on orange fruit once at the New Zealand border (LIMS 2019).

Vectored organisms:

Aphis gossypii is known to transmit a number of non-persistent and persistent viruses, which includes, but is not limited to: *Alfalfa mosaic virus*, *Bean common mosaic necrosis virus*, *Bean common mosaic virus*, *Bean leafroll virus*, *Bean yellow mosaic virus*, *Beet yellows virus*, *Commelina mosaic virus*, *Carnation mottle virus*, *Cauliflower mosaic virus*, *Citrus tristeza virus*, *Citrus woody gall virus* (= *Citrus vein enation virus*), cotton blue disease, *Cowpea aphid-borne mosaic virus*, *Cucumber mosaic virus*, *Lettuce mosaic virus*, *Lily symptomless virus*, *Maize dwarf mosaic virus*, *Onion yellow dwarf virus*, *Papaya ringspot virus*, pea enation mosaic virus, *Peanut mottle virus*, *Peanut stripe virus*, *Pepper vein mottle virus*, *Plum pox virus*, *Potato leafroll virus*, *Potato virus Y*, *Sugarcane mosaic virus*, *Sweet potato feathery mottle virus*, *Tobacco etch virus*, *Tulip breaking virus*, *Turnip mosaic virus*,

Watermelon mosaic virus, *Watermelon mosaic virus 1*, *Yam mosaic virus* and *Zucchini yellow mosaic virus* (CPC 2020).

Of the reported viruses, only two pathogens are known to affect citrus – *Citrus tristeza virus* (CTV) and *Citrus vein enation virus* (CVEV). Both CTC and CVEV are present in New Zealand (Veerakone et al. 2015).

Of the reported viruses, *Plum pox virus* (PPV), *Maize dwarf mosaic virus* (MDMV) and pea enation mosaic virus (PEMV) are in the HPO or SRO list in New Zealand and are known to be transmitted by *A. gossypii*. PPV and MDMV are transmitted by *A. gossypii* in a non-persistent manner (CPC 2020). PEMV is regulated in ONZPR (2020) and is transmitted by *A. gossypii* in a persistent manner (CPC 2020). Both PEMV and *A. gossypii* are present in Australia (Department of Agriculture, New South Wales 1943), the USA (CPC 2020), China (Larsen and Porter 2010), Egypt (Makkouk et al. 1988) and Spain (Tornos et al. 2008).

Hazard identification conclusion:

Aphis gossypii is considered to be a hazard in this analysis. *Aphis gossypii* is considered to be a risk on the citrus fresh produce pathway from Australia, China, Egypt, Spain and the USA, given that:

- *Aphis gossypii* is known to transmit PEMV, which is in the priority pest and disease list, in a persistent manner; and
- Both PEMV and *A. gossypii* are present in Australia, China, Egypt, Spain and the USA.

14.1.2 *Aphis spiraecola* (Hemiptera: Aphididae)

Citrus-exporting country status:

Aphis spiraecola is present in Egypt, Japan, Mexico, Spain, the USA, Vanuatu, Australia, Korea, Brazil, China, Peru, Viet Nam and Fiji (CPC 2020).

New Zealand status:

- *Aphis spiraecola* is present in New Zealand (NZOR 2020).
- *Aphis spiraecola* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Aphis spiraecola is moderately polyphagous, with hosts from over 20 families. The primary hosts are citrus and meadowsweet (*Spiraea* spp.). Other crop plant hosts include, but are not limited to, celery, capsicum, pawpaw, cucumber, carrot, soybean, walnut, lettuce, apple, avocado, common bean, stone fruits (*Prunus* spp.), pear, potato, grapevine and maize (*Zea mays*).

Plant parts affected:

Feeding damage can be found on leaves, flowers and fruits. Eggs or colonies can be spread in trade on planting material or fruit (especially citrus and apple) (CPC 2020).

Vectored organisms:

Aphis spiraecola transmits the viburnum strain of *Alfalfa mosaic virus*, *Citrus psorosis virus B*, *Citrus tristeza virus*, *Cowpea aphid-borne mosaic virus*, *Cucumber mosaic virus*, *Maize dwarf mosaic virus*, *Papaya ringspot virus* (= *Watermelon mosaic virus 1*), *Peanut stunt virus*, *Plum pox virus*, *Potato virus Y*, *Watermelon mosaic virus 2* and *Zucchini yellow mosaic virus* (CPC 2020). It has also been reported to transmit *Asystasia mottle virus* (Thouvenel et al. 1988), *Araujia mosaic virus* (Charudattan et al. 1980), *Chilli veinal mottle virus* (Ong et al. 1978), cowpea severe mottle virus (Santos et al. 1984), Groundnut chlorotic spot virus (Dollet et al. 1987), *Moroccan watermelon mosaic virus* (Chatzivassiliou et al. 2016), *Papaya mosaic virus* (Adsuar 1946), Sri Lankan passionfruit mottle virus (Dassanayake et al. 2003), Tobacco etch virus (Laird and Dickson 1963), *Tobacco vein banding mosaic virus* (Chin 1983), *Citrus yellow vein clearing virus* (Zhang et al. 2018), *Groundnut rosette virus* (Dollet et al. 1987), *Soybean mosaic virus* (Quimio and Calilung 1993), *Blueberry scorch virus*, *Bean common mosaic virus*, *Beet mosaic virus*, *Bidens mottle virus*, *Carrot virus Y*, *Passiflora ringspot virus*, *Pepper veinal mottle virus* and *Telfairia mosaic virus* (Smith and Eyre 2014).

Of the reported viruses, only three pathogens are known to affect citrus – *Citrus tristeza virus* (CTV), *Citrus psorosis virus B*⁹⁷ (CPsV B) and *Citrus yellow vein clearing virus* (CYVCV). CTV and CPsV are present in New Zealand (Veerakone et al. 2015), so they are not considered to be risk pathogens in this analysis. CYVCV is regulated in ONZPR (2020) (as “yellow vein clearing of lemon”) and is present in China (CPC 2020).

Of the reported viruses, *Maize dwarf mosaic virus* (MDMV), *Plum pox virus* (PPV) and *Blueberry scorch virus* (BIScV) are in the high-priority pest and disease list and are known to be vectored by *A. spiraecola*. MDMV, PPV and BIScV are transmitted by aphids in a non-persistent manner (CPC 2020; Lowery et al. 2008), and therefore, they are not considered to be risk pathogens in this analysis.

Hazard identification conclusion:

Aphis spiraecola is considered a hazard in this analysis. *Aphis spiraecola* is considered to be a risk on the citrus fresh produce pathway from China, given that:

- CYVCV is regulated in ONZPR (2020) (as “yellow vein clearing of lemon”);
- CYVCV is present in China (CPC 2020);
- *Aphis spiraecola* is a vector of CYVCV; and
- Both *Aphis spiraecola* and CYVCV are present in China.

⁹⁷ CPsV B is regulated in BORIC (2020). However, according to BRAD, there are records of CPsV in New Zealand, but these records do not state whether the virus present in New Zealand is CPsV A or CPsV B. As CPsV is present in New Zealand, it does not meet the criteria to be considered a hazard in this analysis.

14.1.3 *Aphis craccivora* (Hemiptera: Aphididae)

Citrus-exporting country status:

Aphis craccivora is present in Egypt, Japan, Mexico, Samoa, Spain, the USA, Australia, Korea, Brazil, China, Solomon Islands, Viet Nam and Fiji (CPC 2020).

New Zealand status:

- *Aphis craccivora* is present in New Zealand (NZOR 2020).
- *Aphis craccivora* is listed as a 'potential vector' in ONZPR (2020).

Plant hosts:

Aphis craccivora is polyphagous. It has a marked preference for Leguminosae, such as *Caragana*, *Lupinus*, *Medicago*, *Melilotus*, *Robinia*, *Trifolium* and *Vicia*. Groundnut (peanut), pigeon pea (*Cajanus cajan*), honey locust (*Gleditsia triacanthos*), lentil (*Lens culinaris* subsp. *culinaris*), lucerne (*Medicago sativa*), mung bean (*Vigna radiata*) and cowpea (*V. unguiculata*) are listed as "main" hosts of *A. craccivora* in CPC (2020).

Plant parts affected:

Direct feeding damage of *A. craccivora* can be found on young leaves, shoots, flowers and immature seedpods. The aphid has been identified (alive) on citrus fruit three times (orange and mandarin from Australia) at the New Zealand border from 1929 to 2019 (LIMS 2019).

Vectored organisms:

Alfalfa mosaic virus, *Bean common mosaic virus*, *Bean leafroll virus*, *Bean yellow mosaic virus*, *Blackeye cowpea mosaic virus*, *Broad bean wilt virus (1 & 2)*, *Chickpea chlorotic stunt virus*, *Chilli veinal mottle virus*, *Cowpea aphid-borne mosaic virus*, *Cucumber mosaic virus*, *Faba bean necrotic stunt virus*, *Faba bean necrotic yellows virus*, *Groundnut rosette assistor virus*, *Groundnut rosette virus*, *Maize dwarf mosaic virus*, *Onion yellow dwarf virus*, *Papaya ringspot virus*, *Pea seed-borne mosaic virus*, *Bean leafroll virus (= Pea leafroll virus)*, *Peanut mottle virus*, *Peanut stripe virus*, *Peanut stunt virus*, *Pepper veinal mottle virus*, *Plum pox virus*, *Senna mosaic virus*, *Soybean mosaic virus*, *Subterranean clover stunt virus*, *Sudanese broad bean mosaic virus*, *Sunflower mosaic virus*, *Watermelon mosaic virus*, *Zucchini yellow mosaic virus* (CPC 2020). *Alfalfa leaf curl virus* (Ryckebusch et al. 2020), *Asparagus virus 1* (Nothnagel et al. 2013), *Beet western yellows virus* (Schwinghamer et al. 2009), *bitter gourd mosaic virus* (Tomar and Jitendra 2001), *Canavalia maritima mosaic virus* (Edwardson and Christie 1991), *celery mosaic virus* (Karl and Wolf 1974), *Chickpea distortion mosaic virus* (Mali et al. 1988), *Chickpea stunt disease associated virus* (Reddy and Kumar 2004), *Citrus tristeza virus* (Chavan and Singh 2005), *Citrus yellow vein clearing virus* (Onelge et al. 2011), *Clover yellows virus* (Ohki et al. 1976), *Cowpea stunt virus* (Tsuchizaki et al. 1986), *Desmodium mosaic virus* (Sreenivasulu et al. 1992), *Garlic mosaic virus* (Marrou et al. 1972), *Peanut chlorotic ring mottle* (Fukumoto et al. 1987), *Groundnut eyespot virus* (Dubern and Dollet 1980), *Groundnut mosaic virus* (Badak et al. 2009), *Johnsongrass mosaic virus* (Karina et al. 2016), *Lucerne enation virus* (Leclant et al. 1973), *Milk vetch dwarf virus* (Inouye et al. 1968), *Pepper severe mosaic virus* (Roy et al. 2003), *periwinkle chlorotic stunt virus* (Zaidi et al. 1984), *Pigweed mosaic virus* (Singh et al. 1972), *pole sitao mosaic virus* (Dolores and Valdez 1988), *pumpkin mosaic virus* (Singh 1982), *Ranunculus mottle virus* (Laird and Dickson 1967), *Sweet potato feathery mottle virus* (Moyer and Kennedy 1978), *Tobacco vein banding mosaic virus* (Fang et al. 1985), *Solanum torvum mosaic virus* (Singh et al. 1975), *Tobacco etch virus* (Herold 1970), *Tomato aspermy virus* (Haack et al. 1986), *Turnip mosaic virus* (Sako et al. 1984), *Wisteria vein mosaic virus* (Conti and Lovisollo 1969) and *Yam mosaic virus* (Thouvenel and Fauquet 1979).

Of these viruses, only *Citrus yellow vein clearing virus* (CYVCV) and *Citrus tristeza virus* (CTV) are known to affect citrus. CTV is present in New Zealand (Veerakone et al. 2015). CYVCV is regulated in ONZPR (2020) (as "yellow vein clearing of lemon") and is present in China (CPC 2020).

Of the reported viruses, *Maize dwarf mosaic virus* (MDMV), *Plum pox virus* (PPV) and *Broad bean wilt virus* (BBWV) are in the high-priority pest and disease list and are known to be vectored by *A. craccivora*. MDMV, PPV and BBWV are transmitted by aphids in a non-persistent manner (CPC 2020).

Hazard identification conclusion:

Aphis craccivora is considered to be a hazard in this analysis. *Aphis craccivora* is considered to be a risk on the citrus fresh produce pathway from China, given that:

- *Aphis craccivora* is known to vector CYVCV, which affects citrus; and
- Both *A. craccivora* and CYVCV are present in China.

14.1.4 *Macrosiphum euphorbiae* (Hemiptera: Aphididae)

Citrus-exporting country status:

Macrosiphum euphorbiae is present in Egypt, China, Japan, Korea, Spain, Mexico, the USA, Australia, New Caledonia, Brazil and Peru (CPC 2020).

New Zealand status:

- *Macrosiphum euphorbiae* is present in New Zealand (NZOR 2020).
- *Macrosiphum euphorbiae* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Macrosiphum euphorbiae is polyphagous, with hosts in more than 20 plant families. The primary host is roses. Sugarbeet, sweet potato lettuce, tomato, eggplant, potato and maize are "main" hosts in CPC (2020). *Citrus* spp. are also hosts of *M. euphorbiae* (e.g. Sellami et al. 2013; Abo Kaf 2005).

Plant parts affected:

It is recorded that nymphs and adults of *M. euphorbiae* can be found on flowers, fruits, leaves and stems in plant trade (CPC 2020).

Vectored organisms:

Macrosiphum euphorbiae can transmit more than 40 plant viruses, such as *Bean common mosaic necrosis virus*, *Bean common mosaic virus*, *Bean leafroll virus*, *Bean yellow mosaic virus*, *Beet chlorosis virus*, *Beet yellows virus*, *Beet yellow net virus*, *Cowpea aphid-borne mosaic virus*, *Cucumber mosaic virus*, *Cucurbit aphid-borne yellows virus*, *Hop mosaic virus*, *Lettuce mosaic virus*, *Maize dwarf mosaic virus*, *Papaya ringspot virus*, *Pea enation mosaic virus*, *Potato leafroll virus*, *Potato virus Y*, *Sugarcane mosaic virus*, *Sweet potato leaf speckling virus*, *Tobacco etch virus*, *Tulip breaking virus*, *Watermelon mosaic virus* and *Zucchini yellow mosaic virus* (CPC 2020).

There is no pathogen vectored by *M. euphorbiae* that is known to affect citrus.

Among the reported viruses, *Maize dwarf mosaic virus* (MDMV) and pea enation mosaic virus (PEMV) are in the HPO or SRO list. MDMV is transmitted by *M. euphorbiae* in a non-persistent manner (CPC 2020). PEMV is regulated in ONZPR (2020), and it is transmitted by *M. euphorbiae* in a persistent manner (Hinz 1966). Both PEMV and *M. euphorbiae* are present in Australia (Guy et al. 2020; Department of Agriculture, New South Wales 1943), the USA (CPC 2020), China (Larsen and Porter 2010), Egypt (Makkouk et al. 1988) and Spain (Tornos et al. 2008).

Hazard identification conclusion:

Macrosiphum euphorbiae is considered to be a hazard in this analysis. *Macrosiphum euphorbiae* is considered to be a risk on the citrus fresh produce pathway from Australia, China, Egypt, Spain and the USA, given that:

- *Macrosiphum euphorbiae* is known to transmit PEMV, which is in the priority pest and disease list, in a persistent manner; and
- Both PEMV and *M. euphorbiae* are present in Australia, China, Egypt, Spain and the USA.

14.1.5 *Myzus persicae* (Hemiptera: Aphididae)

Citrus-exporting country status:

Myzus persicae is present in Egypt, China, Japan, Korea, Viet Nam, Spain, Mexico, the USA, Australia, Fiji, New Caledonia, Brazil and Peru (CPC 2020).

New Zealand status:

- *Myzus persicae* is present in New Zealand (NZOR 2020).
- *Myzus persicae* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Myzus persicae is highly polyphagous on summer hosts with host species in over 40 plant families, while primary winter hosts are *Prunus* spp. Many plant crops are recorded as "main" hosts of *M. persicae* in CPC (2020), such as celery, citrus, groundnut (peanut), horseradish (*Armoracia rusticana*), asparagus (*Asparagus officinalis*), sugarbeet, Chinese cabbage (*Brassica rapa* subsp. *chinensis*), pigeon pea, capsicum and pawpaw.

Plant parts affected:

Myzus persicae can be found on leaves, stems, inflorescence and growing points of the host (CPC 2020). It has been identified five times (one alive) on citrus fruits (from the USA and Australia) at the New Zealand border between 1929 to 2019 (LIMS 2019).

Vectored organisms:

Myzus persicae has been shown to transmit over 100 plant viruses (CPC 2020), such as *Alfalfa mosaic virus*, *Bean common mosaic necrosis virus*, *Bean common mosaic virus*, *Bean leafroll virus*, *Bean yellow mosaic virus*, *Beet mild yellowing virus*, *Beet mosaic virus*, *Beet western yellows virus*, *Beet yellows virus*, *Carnation latent virus*, *Cauliflower mosaic virus*, *Clover yellow vein virus*, *Cowpea aphid-borne mosaic virus*, *Cucumber mosaic virus*, *Hop mosaic virus*, *Lettuce mosaic virus*, *Maize dwarf mosaic virus*, *Onion yellow dwarf virus*, *Papaya ringspot virus*, *Pea enation mosaic virus 1*, *Peanut mottle virus*, *Peanut stripe virus*, *Peanut stunt virus*, *Pepper vein mottle virus*, *Plum pox virus*, *Potato leafroll virus*, *Potato virus S*, *Potato virus Y*, *Red clover vein mosaic virus*, *Soybean mosaic virus*, *Sugarcane mosaic virus*, *Tobacco etch virus*, *Tobacco vein distorting virus*, *Tobacco vein mottling virus*, *Tobacco yellow net virus*, *Tuberose mild mottle virus*, *Tulip breaking virus*, *Turnip mosaic virus*, *Watermelon mosaic virus*, *Zucchini yellow mosaic virus* (CPC 2020), *Citrus vein enation virus* (Hermoso de Mendoza et al. 1994), *Citrus tristeza virus* (El-Sharkawy 2002), *Cowpea mosaic virus* (Nagaraju et al. 1997), *Subterranean clover stunt virus* (Grylls and Butler 1959) and *Tobacco necrotic dwarf virus*.

Of these viruses, only *Citrus vein enation virus* (CVEV) and *Citrus tristeza virus* (CTV) are known to affect citrus. Both CVEV and CTV is present in New Zealand (Veerakone et al. 2015).

Among the reported viruses, *Maize dwarf mosaic virus* (MDMV), *Plum pox virus* (PPV) and *Pea enation mosaic virus* (PEMV) are in the HPO or SRO list. MDMV and PPV are transmitted by *M. persicae* in a non-persistent manner (CPC 2020). PEMV is regulated in ONZPR (2020), and it is transmitted by *M. persicae* in a persistent manner (CPC 2020). Both PEMV and *M. persicae* are present in Australia (Department of Agriculture, New South Wales 1943), the USA (CPC 2020), China (Larsen and Porter 2010), Egypt (Makkouk et al. 1988) and Spain (Tornos et al. 2008).

Hazard identification conclusion:

Myzus persicae is considered to be a hazard in this analysis. *Myzus persicae* is considered to be a risk on the citrus fresh produce pathway from Australia, China, Egypt, Spain and the USA, given that:

- *Myzus persicae* is known to transmit PEMV, which is in the priority pest and disease list, in a persistent manner; and
- Both PEMV and *M. persicae* are present in Australia, China, Egypt, Spain and the USA.

14.1.6 *Toxoptera citricida* (Hemiptera: Aphididae)

Citrus-exporting country status:

Toxoptera citricida is present in China, Japan, Korea, Viet Nam, Spain, Mexico, the USA, Australia, Fiji, Cook Islands, Samoa, Solomon Islands, Vanuatu, Brazil and Peru (CPC 2020).

New Zealand status:

- *Toxoptera citricida* is present in New Zealand (NZOR 2020).
- *Toxoptera citricida* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Primary hosts of *T. citricida* are citrus, and they occasionally feed on other Rutaceae (CPC 2020).

Plant parts affected:

Direct feeding damage of *T. citricida* can be found on shoots, flower buds and sometimes young fruits (OEEP/EPPO 2006). However, CPC (2020) states that flowers are not a preferred host tissue, and mature leaves, stems and fruit cannot sustain *T. citricida* populations.

Vectored organisms:

Toxoptera citricida can transmit *Citrus tristeza virus*, *Papaya ringspot virus*, *Watermelon mosaic virus* (CPC 2020), *Citrus psorosis virus* (Portillo and Benatena 1986), *Citrus vein enation virus* (Maharaj and Graca 1989), *Chilli veinal mottle virus* (Ong et al. 1978), *Cucurbita mosaic virus* (Owolabi et al. 2011), *Cowpea aphid-borne mosaic virus* (Pio-Ribeiro et al. 2000), *Soybean mosaic virus* (Halbert et al. 1986), *Pepper veinal mottle virus* (Wijs 1973), *Plum pox virus* (Gildow et al 2004) and *Yam mosaic virus* (Thouvenel and Fauquet 1979). *Toxoptera citricida* is a putative aphid vector for *Citrus sudden death-associated virus* (Loeza-Kuk et al. 2008).

Vectored organisms:

Of the reported viruses, *Citrus tristeza virus* (CTV), *Citrus psorosis virus* (CPsV), *Citrus vein enation virus* (CEVE) and *Citrus sudden death-associated virus* (CSDaV) are known to affect citrus. CTV, CPsV and CEVE are present in New Zealand (Veerakone et al. 2015). CSDaV is not recorded in ONZPR (2020) and BRAD and is not known to be present in New Zealand (PPIN; Veerakone et al. 2015). It has been detected in adult *T. citricida* in Brazil (Loeza-Kuk et al. 2008). Both CSDaV and *T. citricida* are present in Brazil (CPC 2020; Loeza-Kuk et al. 2008). CSDaV was suggested to be associated with citrus sudden death disease in Brazil (Fadel et al. 2018; Matsumura et al. 2016). This disease is highly destructive and has caused the eradication of millions of citrus trees in southern Brazil (Fadel et al. 2018).

Of the reported viruses, *Plum pox virus* (PPV) is in the priority pest and disease list in New Zealand and is known to be transmitted by *T. citricida*. PPV is transmitted by *T. citricida* in a non-persistent manner (CPC 2020).

Hazard identification conclusion:

Toxoptera citricida is considered to be a hazard in this analysis. *Toxoptera citricida* is considered to be a risk on the citrus fresh produce pathway from Brazil, given that:

- CSDaV affects citrus and is not present in New Zealand;
- CSDaV was suggested to be associated with the highly destructive citrus sudden death disease in Brazil;
- CSDaV was detected in adult *T. citricida*; and
- Both CSDaV and *T. citricida* are present in Brazil.

14.1.7 Entry assessment for *Aphis gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida*

Likelihood of entry:

Given the arguments and evidence below, *Aphis gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida* have a weak to moderate association with citrus fruit depending on individual species.

Aphis spiraecola, *A. craccivora*, *Ma. euphorbiae*, *My. persicae* and *Toxoptera citricida* are likely to be associated with citrus, but the strength of association with the fruit of citrus varies.

- *Citrus* spp. has been reported as hosts of these aphid species in CPC (2020).
- Interception of these aphid species is not common at the New Zealand border. Adults of *A. gossypii*, *A. craccivora* and *My. persicae* have been identified at the New Zealand border on citrus fruits for one, three and five times respectively between 1929 to 2019 (LIMS 2019).
- For *A. spiraecola*, CPC (2020) reported that citrus is one of the primary hosts. Feeding damage can be found on leaves, flowers and fruits, and eggs or colonies can be spread in trade on planting material or fruits (especially citrus and apple) (CPC 2020). There were no identifications of *A. spiraecola* at the New Zealand border from 1929 to 2019 (LIMS 2019).
- The primary hosts of *T. citricida* are *Citrus* spp., and they occasionally feed on other Rutaceae (CPC 2020). Direct feeding damage caused by *T. citricida* can be found on shoots, flower buds and sometimes young fruits (OEEP/EPPO 2006). However, CPC (2020) states that flowers are not a preferred host tissue, and mature leaves, stems and fruit cannot sustain *T. citricida* populations.
- For *A. gossypii* and *Ma. euphorbiae*, CPC (2020) reported that fruit can carry adults and nymphs externally in plant trade, but it did not specify which plant species the fruit is from. No record was found mentioning *Ma. euphorbiae* on citrus fruit specifically.
- *Aphis gossypii* has been identified once (alive) on orange fresh produce at the New Zealand border from 1929 to 2019 (LIMS 2019). However, CPC (2020) reported that *A. gossypii* attacks most parts of the plant, apart from directly feeding on mature reproductive structures and roots.

Aphis gossypii, *A. spiraecola*, *A. craccivora*, *Ma. euphorbiae*, *My. persicae* and *Toxoptera citricida* are present in at least one of the citrus-exporting countries in the citrus fresh produce IHS.

Therefore, the strength of association of *A. gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida* with citrus fruit varies:

- *Aphis craccivora*, *My. persicae*, *A. spiraecola* and are considered to have a weak to moderate association with citrus fruit.
- *Aphis gossypii*, *Ma. euphorbiae* and *T. citricida* are considered to have a weak association with citrus fruit.

Given the arguments and evidence below, basic measures are likely to reduce the likelihood of entry of *Aphis gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida* by a high degree. Consequently, the likelihood of entry is considered to be very low.

Aphis gossypii, *A. craccivora* and *My. persicae* may survive transit on some citrus commodities.

- Living *A. gossypii*, *A. craccivora* and *My. persicae* have been identified on citrus fruit at the New Zealand border, suggesting some of them were able to survive transit on some citrus commodities.
- However, interception is not common. There are only five, three and one identification records for *My. persicae*, *A. craccivora* and *A. gossypii* respectively from 1929 to 2019 (LIMS 2019).

Visual inspection can usually detect infestations of aphids.

- Aphid species excrete honeydew, which leads to the growth of sooty moulds that will be visible during inspection (Richards and Davies 1977).
- Except for the egg stage, life stages of aphids are mobile, so they are likely to be visible when moving.
- However, aphids are small insects. The size of adults of *A. gossypii*, *A. spiraecola*, *A. craccivora*, *Macrosiphum euphorbiae*, *Myzus persicae* and *Toxoptera citricida* ranges from 1–3.6 mm (CPC 2020). If aphids hide in sheltered places on citrus commodities, such as in the navel of navel oranges, visual inspection can be difficult. Navel orange has been reported as a host of *Ma. euphorbiae*, but no reports found mention that the aphid is associated with fruits of navel orange. *Myzus persicae*, *A. craccivora* and *A. gossypii* have been intercepted on fresh oranges at the New Zealand border, but interception events are not common (five, three and one times for *My. persicae*, *A. craccivora* and *A. gossypii* respectively from 1929 to 2019 (LIMS 2019)).

General handling after harvesting is likely to remove most aphids on the commodity.

- All life stages (except eggs) of aphids have legs and are mobile (Richards and Davies 1977).
- Aphids are likely to move away from commodities or be killed during general handling (e.g. washing, brushing and grading).
- If eggs are laid in protected places (e.g. the navel of navel oranges), they can be difficult to detect. However, the association of the eggs of these aphids is likely to be weak, as no report was found mentioning that eggs from these aphids were laid on citrus fruit.

Insect vector analyses – vector species not considered to be hazards

14.1.8 *Brachycaudus persicae* (Hemiptera: Aphididae)

Citrus-exporting country status:

Brachycaudus persicae is present in Australia (CPC 2019).

New Zealand status:

- *Brachycaudus persicae* is present in New Zealand (NZOR 2020).
- *Brachycaudus persicae* is listed as 'non-regulated' in New Zealand (ONZPR 2020).

Plant hosts:

Brachycaudus persicae feeds on *Prunus* spp. (CPC 2019). Citrus is not recorded as a host in CPC (2019), but *B. persicae* was identified once on citrus fresh produce (mandarin) from Australia at the New Zealand border in 2015 (LIMS interception data).

Plant parts affected:

Injury caused by *B. persicae* consists of leaf curling, yellowing, and premature leaf drop (UC IPM 2017). Apart from the border interception on mandarin, other evidence of *B. persicae* on citrus cannot be found.

Vectored organisms:

Brachycaudus persicae can transmit *Plum pox virus* (PPV). PPV is not known to affect citrus and is not vectored by *B. persicae* in a persistent manner.

Hazard identification conclusion:

Brachycaudus persicae is not considered to be a hazard in this analysis, given that:

- *Brachycaudus persicae* is not known to transmit any pathogen that is known to affect citrus; and
- *Brachycaudus persicae* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.9 *Macrosiphum rosae* (Hemiptera: Aphididae)

Citrus-exporting country status:

Macrosiphum rosae is present in Egypt, China, Korea, Spain, the USA, Australia and Brazil (CPC 2019).

New Zealand status:

- *Macrosiphum rosae* is present in New Zealand (NZOR 2020).
- *Macrosiphum rosae* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Macrosiphum rosae is commonly found on Rosaceae, especially on species in the genus *Rosa*. It is also commonly found on *Fragaria*, *Geum*, *Pyrus*, *Malus* and *Rubus* (CPC 2019). Host records for citrus cannot be found in CPC (2019) or CAB Abstracts, but *M. rosae* has been identified once on orange from Australia (in 2005) at the New Zealand border (LIMS 2019).

Plant parts affected:

Nymphs and adults of *M. rosae* can be found on flowers, leaves and stems of plant hosts. It has been identified on orange fruit at the New Zealand border (LIMS 2019).

Vectored organisms:

Macrosiphum rosae can transmit *Bean yellow mosaic virus* (CPC 2019), *Strawberry vein banding caulimovirus*, *Teasel mosaic potyvirus*, *Strawberry mild yellow edge luteovirus* (BRAD).

There is no pathogen vectored by *M. rosae* that is known to affect citrus.

There is no virus that is in the HPO or SRO list which is known to be transmitted by *M. rosae* in a persistent manner.

Hazard identification conclusion:

Macrosiphum rosae is not considered to be a hazard in this analysis, given that:

- *Macrosiphum rosae* is not known to transmit pathogens that are known to affect citrus; and
- *Macrosiphum rosae* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.10 *Myzaphis rosarum* (Hemiptera: Aphididae)

Citrus-exporting country status:

Myzaphis rosarum is present in the USA (Frazier 1951).

New Zealand status:

- *Myzaphis rosarum* is present in New Zealand (NZOR 2020).
- *Myzaphis rosarum* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Hosts of *Myzaphis rosarum* are *Rosa* spp. *Myzaphis rosarum* has been trapped downwind of a plot of *Potato virus Y* (PVY)-infected potatoes and is reported as able to transmit PVY (Lewis 1985). It is not recorded as a pest on citrus in literature in search results from CPC (2019), CAB Abstracts and Google Scholar, but there is an identification record (in 2008) of *M. rosarum* on orange fresh produce from Australia (LIMS interception database). However, according to CPC (2019), CAB Abstract and Google Scholar, *M. rosarum* is not known to be present in Australia.

Plant parts affected:

Myzaphis spp. live on the undersides of leaves (Kanturski et al. 2018).

Vectored organisms:

Myzaphis rosarum can transmit PVY (Lewis 1985). It was recorded to be capable of transmitting the strawberry virus complex experimentally in California (Frazier 1951). These viruses are not known to affect citrus and are not vectored by *M. rosarum* in a persistent manner.

Hazard identification conclusion:

Myzaphis rosarum is not considered to be a hazard in this analysis, given that:

- *Myzaphis rosarum* is not known to transmit pathogens that are known to affect citrus; and
- *Myzaphis rosarum* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.11 *Toxoptera aurantia* (Hemiptera: Aphididae)

Citrus exporting country status:

Toxoptera aurantia is found in Egypt, China, Japan, Viet Nam, Spain, Mexico, the USA, Australia, Fiji, New Caledonia, Samoa, Solomon Islands, Vanuatu, Brazil and Peru (CPC 2019).

New Zealand status:

- *Toxoptera aurantia* is present in New Zealand (NZOR 2020).
- *Toxoptera aurantia* is listed as 'non-regulated' in New Zealand (ONZPR 2020).

Plant hosts:

Toxoptera aurantia has a relatively limited range of plant hosts. *Citrus*, *Camellia*, *Coffea*, *Mangifera*, *Theobroma* are listed as "main" hosts of *T. aurantia* in CPC (2019).

Plant parts affected:

Toxoptera aurantia is often found on the undersides of young leaves and young shoots of many economically important plants (CPC 2019). It has been identified once on citrus fresh produce (orange) from Australia at the New Zealand border (LIMS 2019).

Vectored organisms:

Toxoptera aurantia is reported to be capable of transmitting *Citrus tristeza virus*, *Zucchini yellow mosaic virus* (CPC 2019), *Papaya ringspot potyvirus* (type W) (Chao and Chen 1991), *Citrus psorosis virus* (Portillo and Benatena 1986), *Citrus vein enation virus* (Manjunath 1987), *Cucumber mosaic virus* (Chin 1983) and *Tea rose yellow mosaic virus* (Ahlawat and Sardar 1973).

Of the reported viruses, *Citrus tristeza virus* (CTV), *Citrus psorosis virus* (CPsV) and *Citrus vein enation virus* (CEVE) are known to affect citrus. CTV, CPsV and CEVE are present in New Zealand (Veerakone et al. 2015).

There is no virus that is in the HPO or SRO list that is known to be transmitted by *T. aurantia* in a persistent manner.

Hazard identification conclusion:

Toxoptera aurantia is not considered to be a hazard in this analysis, given that:

- *Toxoptera aurantia* is not known to transmit any pathogen that is known to affect citrus and is not known to be present in New Zealand; and
- *Toxoptera aurantia* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.12 *Pseudococcus calceolariae* (Hemiptera: Pseudococcidae)

Citrus-exporting country status:

Pseudococcus calceolariae is present in China, Spain, Mexico, the USA, Australia and Brazil (CPC 2019).

New Zealand status:

- *Pseudococcus calceolariae* is present in New Zealand (NZOR 2020).
- *Pseudococcus calceolariae* is listed as 'non-regulated' in New Zealand (ONZPR 2020).

Plant hosts:

Pseudococcus calceolariae is highly polyphagous and has hosts from over 40 plant families. Citrus is one of the main hosts of *P. calceolariae* (CPC 2019).

Plant parts affected:

Pseudococcus calceolariae feeds on fruits, growing points, inflorescence, roots and stems (CPC 2019). It has been identified on citrus fruit at the New Zealand border over 1,800 times (LIMS 2019).

Vectored organisms:

Pseudococcus calceolariae can transmit *Grapevine leafroll-associated virus-3* (CPC 2019), which is present in New Zealand (Veerakone et al. 2015).

Hazard identification conclusion:

Pseudococcus calceolariae is not considered a hazard in this analysis, given that

- *Pseudococcus calceolariae* is not known to transmit pathogens that are known to affect citrus; and
- *Pseudococcus calceolariae* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.13 *Pseudococcus longispinus* (Hemiptera: Pseudococcidae)

Citrus exporting country status:

Pseudococcus longispinus is present in Egypt, China, Japan, Viet Nam, Spain, Mexico, the USA, Australia, Cook Islands, Fiji, New Caledonia, Solomon Islands, Vanuatu, Brazil and Peru (CPC 2019).

New Zealand status:

- *Pseudococcus longispinus* is present in New Zealand (NZOR 2020).
- *Pseudococcus longispinus* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Pseudococcus longispinus is highly polyphagous and has been recorded on over 100 host plants belonging to 78 plant families. Host plants include many plants of economic importance, such as citrus, pear and grapevine (CPC 2019).

Plant parts affected:

Signs of external feeding of *P. longispinus* can be found on fruit, growing points, inflorescences, leaves and stems (CPC 2019). It has been identified over 800 times on citrus fruit at the New Zealand border (LIMS interception database).

Vectored organisms:

Pseudococcus longispinus is known to vector *Grapevine leafroll-associated virus 1* (GLRaV) (Bertin et al. 2010), *Grapevine leafroll-associated virus 3* (CPC 2019), *Grapevine leafroll-associated virus 5* (=GLRaV 4) (Golino et al. 2002), *Grapevine leafroll-associated virus 9* (=GLRaV 4) (Tsai et al. 2010), *Grapevine virus A* (GVA) (Notte et al. 1997), *Grapevine virus B* (GVB) (Kuniyuki et al. 2006) and *Cacao swollen shoot virus* (CSSV) (CPC 2019). In Solomon Islands and other islands in the southwest Pacific region, it is a vector of the smaller of two bacilliform viruses associated with 'bobone' disease in taro and *Xanthosoma* sp. It is also associated with viruses with stem-pitting in grapevines (CPC 2019).

None of the reported viruses are known to affect citrus. GLRaV 1, 3 and 4 and GVA and GVB are 'Non-regulated' in New Zealand (ONZPR 2020). There is no virus in the HPO or SRO list that is known to be transmitted by *P. longispinus* in a persistent manner.

Hazard identification conclusion:

Pseudococcus longispinus is not considered to be a hazard in this analysis, given that:

- *Pseudococcus longispinus* is not known to transmit pathogens that are known to affect citrus; and
- *Pseudococcus longispinus* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.14 *Planococcus citri* (Hemiptera: Pseudococcidae)

Citrus-exporting country status:

Planococcus citri is present in Egypt, China, Japan, Viet Nam, Spain, Mexico, the USA, Australia, Cook Islands, Fiji, New Caledonia, Samoa, Brazil and Peru (CPC 2020).

New Zealand status:

- *Planococcus citri* is present in New Zealand (NZOR 2020).
- *Planococcus citri* is listed as a 'potential vector' in ONZPR (2020).

Plant hosts:

Planococcus citri is highly polyphagous, with hosts of over 200 plant species belonging to 82 families. Many plants of economic importance are hosts of the pest, such as citrus, banana and taro (CPC 2020).

Plant parts affected:

Nymphs and adults of *P. citri* can be found on fruits, growing points, leaves, inflorescence, roots and stems (CPC 2020). It has been identified on citrus fruits at the New Zealand border over 90 times (LIMS 2019).

Vectored organisms:

Planococcus citri is known to vector Banana streak disease (BSD), *Cacao swollen shoot virus* (CSSV), *Cucumber mosaic virus*, *Dioscorea bacilliform virus* (DBV), *Schefflera ringspot virus* (SRV) (CPC 2020), *Grapevine virus A*, *Grapevine leafroll-associated virus 1*, *Grapevine leafroll-associated virus 3* (Bertin et al. 2016), *Citrus mosaic disease* (a synonym for *Citrus yellow mosaic virus*) (Reddy et al. 2010; Ahlawat and Pant 2003) and *Piper yellow mottle virus* (PYMV) (Silva et al. 2002).

Of the reported viruses, *Citrus yellow mosaic virus* (CiYMV) is known to affect citrus. CiYMV is regulated in New Zealand (ONZPR 2020) and transmitted by *P. citri* in a persistent manner (CPC 2020; Reddy et al. 2020). According to CPC (2020) and results from literature searches in CAB Abstracts, CiYMV is only known from India (CPC 2020). India is not one of the citrus-exporting countries in the citrus fresh produce IHS.

There is no virus in the HPO or SRO list that is known to be transmitted by *P. citri* in a persistent manner.

Hazard identification conclusion:

Planococcus citri is not considered to be a hazard in this analysis, given that:

- *Planococcus citri* transmits CiYMV, which can affect citrus, but the virus is not present in any citrus-exporting country in the IHS; and
- *Pseudococcus longispinus* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.15 *Pseudococcus viburni* (Hemiptera: Pseudococcidae)

Citrus-exporting country status:

Pseudococcus viburni is present in China, Korea, Spain, Mexico, the USA, Australia, Brazil and Peru (CPC 2019).

New Zealand status:

- *Pseudococcus viburni* is present in New Zealand (NZOR 2020).
- *Pseudococcus viburni* is listed as 'non-regulated' in New Zealand (ONZPR 2020).

Plant hosts:

The "main" hosts of *P. viburni* in CPC (2019) are tea (*Camellia sinensis*), citrus, apple, orchids (Orchidaceae), *Pelargonium*, pear, potato and grapevine.

Plant parts affected:

Nymphs and adults of *P. viburni* can be found on whole plants, including leaves, inflorescences, fruit, growing points, roots and stems (CPC 2019). It has been identified on citrus fresh produce at the New Zealand border 19 times (15 alive) from 1929 to 2019 (LIMS 2019).

Vectored organisms:

Pseudococcus viburni can transmit *Cacao swollen shoot virus* (CSSV) (Obok et al. 2018), *Grapevine leafroll-associated virus 3* (CPC 2019), *Grapevine virus A*, *Grapevine virus B* (Garau et al. 1995). Apart from CSSV, these viruses are all 'non-regulated' in New Zealand (ONZPR 2020). CSSV is listed as 'regulated' (ONZPR 2020). CSSV is vectored by mealybug species in a semi-persistent manner (Obok 2016), and it is not in the HPO or SRO list.

Hazard identification conclusion:

Pseudococcus viburni is not considered to be a hazard in this analysis, given that:

- *Pseudococcus viburni* is not known to transmit pathogens that are known to affect citrus; and
- *Pseudococcus viburni* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.16 *Frankliniella intonsa* (Thysanoptera: Thripidae)

Citrus-exporting country status:

Frankliniella intonsa is present in Japan, Spain, the USA (Washington), Korea and China (CPC 2020).

New Zealand status:

- *Frankliniella intonsa* is present in New Zealand (NZOR 2020).
- *Frankliniella intonsa* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

In CPC (2020), the "main" hosts of *F. intonsa* are okra, groundnut (peanut), asparagus, capsicum, chrysanthemum, strawberry, soybean, cotton, lucerne (*Medicago sativa*), rice (*Oryza sativa*), common bean, pea, peach, tomato and adzuki bean (*Vigna angularis*). Citrus is not listed as a host of *F. intonsa* in CPC (2020). However, it is one of the common thrips found in citrus orchards in mainland China and Taiwan (Xu et al. 2012; Qin et al. 2010; Chiu et al. 1991).

Plant parts affected:

Eggs of *F. intonsa* may be laid in leaves, flowers or fruit. Larvae tend to reside in concealed places on hosts, such as within flowers or developing leaves or under the calyx of fruit. It has been found on young citrus fruit in Taiwan (Chiu et al. 1991).

Vectored organisms:

Frankliniella intonsa can transmit *Chrysanthemum stem necrosis orthospovirus* (Okuda et al. 2013), *Groundnut ringspot orthospovirus* (Wijkamp 1995), *Impatiens necrotic spot virus* (Sakurai et al. 2004), *Tomato spotted wilt virus* (CPC 2020) and *Tomato chlorotic spot orthospovirus* (Wijkamp 1995).

There is no pathogen vectored by *F. intonsa* that is known to affect citrus.

There is no virus in the HPO or SRO list that is known to be transmitted by *F. intonsa* in a persistent manner. *Capsicum chlorosis orthospovirus* (CaCV) is a species in the orthospovirus and in the SRO list. In general, viruses in this genus are transmitted by thrips in a persistent and propagative manner. However, Chiaki et al. (2020) shows that CaCV can be transmitted by *T. palmi* but not by *T. tabaci*, *Frankliniella occidentalis* or *F. intonsa*.

Hazard identification conclusion:

Frankliniella intonsa is not considered to be a hazard in this analysis, given that:

- *Frankliniella intonsa* is not known to transmit any pathogen that is known to affect citrus; and
- *Frankliniella intonsa* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.17 *Frankliniella occidentalis* (Thysanoptera: Thripidae)

Citrus exporting country status:

Frankliniella occidentalis is present in Egypt, China, Japan, Mexico, Spain, the USA, Australia, Korea, Brazil and Peru (CPC 2020).

New Zealand status:

- *Frankliniella occidentalis* is present in New Zealand (NZOR 2020).
- *Frankliniella occidentalis* is listed as a 'potential vector' in ONZPR (2020).

Plant hosts:

Frankliniella occidentalis is highly polyphagous. It has been recorded on plant species belonging to over 65 families. It attacks many plants of economic importance growing both outdoors and in glasshouses, such as onion, beetroot, capsicum, orange, grapefruit, cucumber, carrot, strawberry, peach, potato and grapevine (CPC 2020).

Plant parts affected:

Eggs of *F. occidentalis* may be laid in leaves, flowers or fruit. Larvae tend to reside in concealed places on hosts, such as within flowers or developing leaves or under the calyx of fruit (CPC 2020).

Vectored organisms:

Frankliniella occidentalis has been reported to transmit *Alstroemeria necrotic streak orthotospovirus* (Hassani-Mehraban et al. 2010), *Chrysanthemum stem necrosis orthotospovirus*, *Impatiens necrotic spot orthotospovirus*, *Tobacco streak virus*, *Tomato spotted wilt virus*, *Tomato yellow ring orthotospovirus* (Mortazavi and Aleosfoor 2015), *Tomato zonate spot orthotospovirus* (CPC 2020), *Tomato chlorotic spot orthotospovirus* (Webster et al. 2015), *Groundnut ringspot orthotospovirus* (Webster et al. 2015) and *Parietaria mottle virus* (Aramburu et al. 2010). It has also transmitted *Maize chlorotic mottle virus* (Zhao et al. 2014) experimentally.

None of the reported viruses are known to affect citrus.

There is no virus in the HPO or SRO list that is known to be transmitted by *F. occidentalis* in a persistent manner. *Capsicum chlorosis orthotospovirus* (CaCV) is a species in the orthotospovirus and in the SRO list. In general, viruses in this genus are transmitted by thrips in a persistent and propagative manner. However, Chiaki et al. (2020) shows that CaCV can be transmitted by *T. palmi* but not by *T. tabaci*, *Frankliniella occidentalis* or *F. intonsa*.

Hazard identification conclusion:

Frankliniella occidentalis is not considered to be a hazard in this analysis, given that:

- *Frankliniella occidentalis* is not known to transmit any pathogen that is known to affect citrus; and
- *Frankliniella occidentalis* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.18 *Thrips tabaci* (Thysanoptera: Thripidae)

Citrus-exporting country status:

Thrips tabaci is present in Egypt, New Caledonia, Japan, Mexico, Spain, USA, Australia, Korea, Brazil, Peru, Solomon Islands, Viet Nam, Fiji (CPC 2019)

New Zealand status:

- *Thrips tabaci* is present in New Zealand (NZOR 2020).
- *Thrips tabaci* is listed as a 'potential vector' in New Zealand (ONZPR 2020).

Plant hosts:

Thrips tabaci is polyphagous. Onion is its preferred host plant. Other "main" hosts include, but are not limited to, garlic, leek, cauliflower, daisy, cucumber and tobacco (CPC 2019).

Plant parts affected:

Nymphs and adults of *T. tabaci* can be found on flowers, fruit, leaves and stems in plant trade (CPC 2019). *Thrips tabaci* has been identified on citrus fruit (orange, mandarin and tangor) at the New Zealand border. These specimens were from the USA and Australia (LIMS interception database).

Vectored organisms:

Thrips tabaci has been reported to be able to transmit *Iris yellow spot virus*, *Maize chlorotic mottle virus*, *Prunus necrotic ringspot virus*, *Sowbane mosaic virus*, *Tobacco ringspot virus*, *Tobacco streak virus* (TSV), *Tomato spotted wilt virus*, *Tomato yellow fruit ring virus* (syn. of *Tomato yellow ring virus*) and *Alstroemeria yellow spot virus* (CPC 2019; Hassani-Mehraban et al. 2019; Mwando et al. 2018; Mortazavi and Aleosfoor 2015; Golnaraghi et al. 2007; Messieha 1969).

None of the above viruses are known to affect citrus.

There is no virus in the HPO or SRO list that is known to be transmitted by *T. tabaci* in a persistent manner. *Capsicum chlorosis orthospovirus* (CaCV) is a species in the orthospovirus and in the SRO list. In general, viruses in this genus are transmitted by thrips in a persistent and propagative manner. However, Chiaki et al. (2020) shows that CaCV can be transmitted by *T. palmi* but not by *T. tabaci*, *Frankliniella occidentalis* or *F. intonsa*.

Hazard identification conclusion:

Thrips tabaci is not considered to be a hazard in this analysis, given that:

- *Thrips tabaci* is not known to transmit pathogens that are known to affect citrus;
- *Thrips tabaci* is not known to transmit any pathogen in the priority pest and disease list in a persistent or semi-persistent manner.

14.1.19 References

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14.2 Mite vector analysis: *Brevipalpus* spp. (flat mites or false spider mites), vectors of citrus leprosis viruses

[See 15.1 for an analysis of insect vectors]

Subclass/Family: Acari/Tenuipalpidae

Scientific name: *Brevipalpus californicus* (Banks 1904)

Other names: *Brevipalpus australis*, *Tenuipalpus australis*, *T. californicus*, citrus flat mite (CABI 2020), sweet potato false spider mite (EPPO 2020).

Scientific name: *Brevipalpus obovatus* Donnadieu, 1875

Other names: *Brevipalpus inornatus*, *Tenuipalpus obovatus*, *T. inornatus*, scarlet tea mite privet mite, ornamental flat mite (CABI 2020; EPPO 2020)

Scientific name: *Brevipalpus phoenicis* (Geijskes 1939) *sensu lato* (s. l.)

Other names: *Tenuipalpis phoenicis* Geijskes, 1939, *Brevipalpus yothersi* Baker 1949, passion vine mite (CABI 2020), red and black flat mite, leprosis mite (EPPO 2020).

Brevipalpus species are very small (< 1 mm long), plant-feeding mites with wide host ranges that include many cultivated (ornamentals, fruit trees, forest trees, vegetables) and wild plants. Citrus hosts of *Brevipalpus* spp. include *C. aurantium*, *C. aurantiifolia*, *C. latifolia*, *C. limon*, *C. reticulata* and *C. sinensis* (Vacante 2016). Among the over 300 *Brevipalpus* species worldwide, *B. californicus*, *B. obovatus* and *B. phoenicis* s. l. are considered to be of particular economic importance, mainly because they are implicated in the transmission of plant viruses, especially those that cause citrus leprosis. Citrus leprosis leads to defoliation, premature fruit drop, dry branches and, in advanced stages, death of citrus trees. The disease has resulted in enormous losses in Brazilian citriculture (Roy et al. 2015; Bastianel et al. 2010; Kitajima et al. 2010; Childers and Rodrigues 2011). At high densities, these mites may also cause direct feeding damage to economic plants such as citrus. Although the *Brevipalpus* spp. of concern are present in New Zealand (NZOR 2020; PPIN 2020), they are regulated as potential vectors in ONZPR (2020) because of their association with citrus leprosis viruses, which are not present in the country.

Brief notes on taxonomy: As with many other mite groups, poor descriptions of *Brevipalpus* mites have caused substantial taxonomic challenges for several decades (Beard et al. 2013). Thus, the actual host ranges and role of these three *Brevipalpus* species in virus transmission is complicated by historical misidentifications. The recent taxonomic revision by Beard et al. (2015), which established that *B. phoenicis sensu lato* (s. l.) is a complex (a group) with eight distinct species, has provided some clarity. However, it also creates uncertainty regarding the actual geographic distribution (including the New Zealand status), host range and vector competence of these species.

Summary of conclusions

Given the arguments and evidence presented:

- The *Brevipalpus* species assessed (those implicated as vectors of citrus leprosis and other viruses) have a strong association with citrus fruit, with low uncertainty.
- Basic measures will reduce the likelihood of entry of *Brevipalpus* spp. on citrus fruit by a moderate to high degree (with moderate uncertainty); therefore, the likelihood of entry is considered low to moderate, with low uncertainty.
- The ability of *Brevipalpus* spp. to transfer from imported fruit to citrus hosts, leading to the potential transmission of citrus viruses, is low (with moderate uncertainty).
- Entry and transfer of *Brevipalpus* spp. infected with citrus leprosis viruses, to a citrus host, leading to introduction of the viruses, is likely to cause a high level of impact to New Zealand's citrus industry, but the impact to the overall New Zealand economy is likely to be low (with moderate uncertainty).

- Entry and transfer of *Brevipalpus* mites that are not infected with citrus leprosis viruses, is likely to have negligible impact, with low uncertainty; but entry of *Brevipalpus* species not currently present in New Zealand, may have phytosanitary implications.
- Some *Brevipalpus* spp. (including species in the *B. phoenicis* complex) may be considered for additional measures on citrus fruit from countries where citrus leprosis virus is confirmed to be present.

Summary of risk assessment against criteria

Criteria	Rating	Uncertainty
Strength or frequency of association with the commodity	Strong	Low
Likelihood of entry on the commodity, given the application of basic measures	Low–Moderate	Low
The ability to move from the imported commodity onto a suitable host	Low	Moderate
Suitability of the New Zealand environment	Not assessed ⁹⁸	
Impacts on the New Zealand economy, environment, health and society	Moderate ⁹⁹	High

14.2.1 Hazard identification: quarantine status

Given the arguments and evidence below, the *Brevipalpus* species assessed (*B. californicus*, *B. obovatus* and *B. phoenicis* s. l.) meet some, but not all, of the criteria to be quarantine pests for New Zealand.

- *Brevipalpus obovatus*, *B. californicus* and *B. phoenicis* s. l. are present in New Zealand; they are recorded in NZInverts (2020), NZOR (2020) and PPIN (2020).
- However, because of their association with regulated viruses, these mites are ‘regulated’ as potential vectors in ONZPR (2020).
- Of relevance to this assessment is citrus leprosis (CL), an important and well-characterised disease of citrus, especially sweet orange (*Citrus sinensis*), which is transmitted by *Brevipalpus* spp. (EFSA 2017; Bastianel et al. 2010).
- Six viruses belonging to three different genera have been identified as causing CL symptoms in various citrus varieties. They are: *Citrus leprosis virus C* (CiLV-C, genus *Cilevirus*), *Citrus leprosis virus C2* (CiLV-C2, genus *Cilevirus*), *Hibiscus green spot virus 2* (HGSV-2, genus *Higrevirus*), *Citrus leprosis virus N dichoravirus* (CiLV-N, genus *Dichoravirus*) and *Citrus chlorotic spot dichoravirus* (CiCSV, genus *Dichoravirus*) and the citrus strain of *Orchid fleck dichoravirus* (OFV, genus *Dichoravirus*) (EFSA 2017; Roy et al. 2015; Bastianel et al. 2010; Childers et al. 2003).
- The viruses that cause CL are not known to be present in New Zealand; they are not recorded in NZOR (2020), NZFungi (2020) and PPIN (2020).
- Also, species in the *Brevipalpus phoenicis* s. l. complex whose distributions, host ranges and roles as vectors are yet to be determined pose an undetermined level of risk to New Zealand.
- Dispersal of *Brevipalpus* spp. (especially *B. phoenicis* sensu lato) represents the most important means of the spread of the viruses causing citrus leprosis (EFSA 2017).
- Entry of *Brevipalpus* spp. from an area with citrus leprosis viruses, and exposure (transfer) of virus-infected mites to citrus hosts in New Zealand is sufficient to introduce these viruses; once infected, all motile stages of the mites (larvae, nymphs and adults) remain infective throughout their lifespan and only need to feed on a host plant for 2–3 hours to transmit the virus (Childers et al. 2003; Bastianel et al. 2006; Tassi et al. 2017; Ferreira et al. 2020).
- The viruses responsible for citrus leprosis and their *Brevipalpus* vectors (including *B. yothersi* a species within the *B. phoenicis* complex, which is the main vector of CiLVC) are present in

⁹⁸ Suitability of the New Zealand environment for establishment was not considered in this assessment because the *Brevipalpus* species assessed are known to be present in New Zealand. Additionally, an infected mite entering on fruit need only transfer to, and feed on, a suitable host (establishment is not necessary) to introduce citrus leprosis

⁹⁹ Level of economic impact is likely to be high for the citrus industry, if entry of the mites and transfer to host plants leads to the introduction of citrus leprosis viruses. Otherwise, impact is likely to be negligible

two of the citrus exporting countries in this IHS, i.e. Brazil and Mexico (Roy et al. 2015; SENASICA 2018; CPC 2020; EPPO 2020).

This assessment, therefore, determines the likelihood of entry into New Zealand, of *Brevipalpus* spp. on imported citrus fruits and their ability to transfer from imported commodities to citrus host plants, which could lead to the introduction of citrus leprosis viruses that are not recorded from New Zealand (NZFungi 2020; NZOR 2020; PPIN 2020).

Given that the *Brevipalpus* spp. in this PRA are already established in New Zealand, the suitability of the New Zealand environment for establishment of the mites is not assessed. The level of impact is assessed mainly as it relates to the introduction of leprosis disease. Other viruses transmitted by *Brevipalpus* mites, but for which citrus is not a known host, are not considered¹⁰⁰.

14.2.2 Hazard identification: commodity association

Given the arguments and evidence below, *Brevipalpus* spp. implicated in the transmission of citrus leprosis disease have a strong association with citrus:

There are reliable records of *Brevipalpus* spp. on citrus:

- *Brevipalpus* spp. attack the stems, leaves and fruit of many citrus species (Childers et al. 2003)
- In Brazil, *B. phoenicis* s. l. has been reported causing damage on citrus, mainly due to the transmission of citrus leprosis virus (Bastianel et al 2010; Rodrigues et al. 2003).
- *Brevipalpus yothersi* (syn. *B. phoenicis* s. l.) was associated with the first report of Citrus leprosis virus C (CiLV-C) in groves of sweet orange (*C. sinensis*) in the south Mexican states of Tabasco and Chiapas (Castillo et al. (2011), and *B. californicus* s. l. was detected in CiLV-N -infected citrus groves located at high elevation (between 1,500 and 2,200m above sea level) on the central Mexican plateau and was the only *Brevipalpus* species present at these altitudes (Roy et al. 2016).
- In the Mexican states of Yucatan, Quintana Roo and Campeche¹⁰¹, *B. phoenicis* s. l. and *B. californicus* were collected and identified from citrus orchards containing sweet orange (*C. sinensis*), grapefruit (*C. paradisi*), bitter orange (*C. aurantium*), mandarin (*C. reticulata*) and Persian/Tahiti lime (*C. latifolia*).
- Between 1994 and 2017, live *Brevipalpus* spp. (*B. phoenicis* s. l., *B. obovatus*, *B. californicus*) were intercepted 107 times at the New Zealand border on citrus fresh produce: limes (*C. aurantiifolia* and *C. latifolia*), oranges (*C. sinensis*), pomelo (*C. maxima*), grapefruit (*C. x paradisi*) and mandarins (*C. reticulata*). These interceptions were mostly from the USA, with the remaining records being from Australia, Vanuatu, Samoa and Tonga (LIMS 2020).
- The confirmed citrus hosts of the three vector species under consideration, based on the most recent taxonomic revision of *Brevipalpus* spp. (Beard et al. 2015), are shown in Table 15.2.1 below.

Table 15.2.1 *Brevipalpus* spp. that are suspected or confirmed vectors of citrus leprosis virus, with their confirmed citrus hosts

Species	Citrus hosts
<i>B. californicus</i>	<i>C. sinensis</i> (sweet orange) <i>C. aurantiifolia</i> (key lime) <i>C. limon</i> (lemon) <i>C. reticulata</i> (tangor)
<i>B. phoenicis</i> s. l.	<i>C. sinensis</i> (sweet orange) <i>C. aurantiifolia</i> (Mexican/key lime) <i>C. latifolia</i> (Persian/Tahitian lime) <i>C. medica</i> (citron), <i>C. reticulata</i> (mandarins)

¹⁰⁰ *Brevipalpus* mites entering New Zealand on fresh citrus fruit, are likely to have fed, mainly (if not solely), on citrus hosts, given that they are poor dispersers. Thus, the likelihood that a mite fed on a non-citrus host, acquired a non-citrus virus and then, transferred to a citrus fruit in an exporting country, is considered to be negligible. And while it is theoretically possible for the same mite to enter NZ on imported citrus fruit and transfer to a non-citrus host of the said virus in New Zealand, the likelihood of this sequence of events is also considered to be negligible.

¹⁰¹ In Campeche, only *B. phoenicis* was present in orchards containing sweet orange, mandarin and lime.

Species	Citrus hosts
<i>B. obovatus</i>	<i>C. limon</i> (lemon), <i>C. sinensis</i>

Due to previous taxonomic confusions, only hosts based on *Brevipalpus* spp. specimens identified by Beard et al. (2013), are listed.

14.2.3 Risk assessment

Likelihood of entry:

Given the arguments and evidence below, *Brevipalpus* spp. have a strong association with citrus plants and fruit, with low uncertainty

There are reliable records of *Brevipalpus* spp. on citrus hosts and commodities:

- In Brazil, *B. phoenicis* s. l. has been reported causing damage on citrus, mainly due to the transmission of CiLV-C (Bastianel et al 2010; Rodrigues et al. 2003, 2011).
- *Brevipalpus yothersi*, one of the species within the *B. phoenicis sensu lato* complex (Beard et al. 2015) is reported as the most common species in Mexican and Brazilian citrus orchards (Sánchez Velázquez et al. 2015; Salinas-Vargas et al. 2016).
- In Mexico, *B. californicus* s. l. was detected in CiLV-N -infected citrus groves located at high elevation (between 1,500 and 2,200m above sea level) in the central Mexican plateau and was the only *Brevipalpus* species present at these altitudes (Roy et al. 2016).
- *Brevipalpus phoenicis* is recorded as a pest of sweet oranges (*Citrus sinensis*) in Mexico (Chiapas, Oaxaca, San Luis Potosi, Sinaloa, Tabasco and Veracruz) and citrus leprosis is reported as a disease of oranges in the Mexican states of Chiapas, Queretaro, Tabasco and Veracruz (SENASICA 2018).
- Live adults and nymphs of *B. phoenicis*, *B. californicus* and *B. obovatus* have been intercepted many times at the New Zealand border, on citrus fresh produce; limes (*C. aurantiifolia* and *C. latifolia*), oranges (*C. sinensis*), pomelo (*C. maxima*), grapefruit (*C. x paradisi*) and mandarins (*C. reticulata*) from the USA, Australia and the Pacific Island countries of Samoa, Tonga and Vanuatu (LIMS 2020).

Given the arguments and evidence below, basic measures will reduce the likelihood of entry of viruliferous *Brevipalpus* spp. on citrus fruit by a moderate-high degree (with moderate uncertainty); consequently, the likelihood of entry is low-moderate

Brevipalpus mites, especially at high infestations on citrus fruits, are likely to be detected:

- On citrus hosts, the population of *Brevipalpus* mites is usually low, but high densities occur in natural cracks and crevices on the surface of fruit, as well as cracks caused by wind or hail (Vacante 2016).
- High mite densities in cracks/crevices on fruit occur because females tend to oviposit in such sites and juvenile and adult stages feed around the edges of these sites, which emphasizes the cracks (Vacante 2016) and makes the mites more likely to be detected, leading to the removal of infested fruit during field, packhouse and pre-export inspections.
- Though eggs are laid singly, they are also likely to be detected because of their bright red colour and occurrence in clusters formed by several females laying eggs close together in the same cracks on citrus fruit (Denmark and Fasulo 2018).

High infestations of *Brevipalpus* spp. cause detectable feeding injuries:

- High population densities of *Brevipalpus* spp. cause feeding injuries on citrus, such as silvery patches on lemon fruit (Jeppson et al. 1975 in Childers and Rodrigues 2011).
- In grapefruit and orange, high density populations of *B. californicus* and *B. phoenicis* s. l. have been associated with rind spotting that begins as slight yellowish circular discoloured lesions in depressions on the surface of grapefruit and orange, which later develop central brown

necrotic areas or spots that darken and become corky (Dean & Maxwell 1967; Rakha 1994 cited in Vacante 2016). The brown spots are irregular in shape and vary from 3-12 mm in diameter.

- Commercially produced fruits with some, or all, of the above signs of damage, are likely to be culled during packing house processes.
- In a risk management document for the importation of lemons from Argentina, the United States Department for Agriculture (USDA) determined that visual inspection was an adequate phytosanitary measure against *B. californicus*, *B. obovatus* and *B. phoenicis*, “as mite infestations cause bronzing of fruits that can be detected upon inspection” (USDA 2016).

Fruits infected with citrus leprosis (and infested with mite vectors) can be detected and are likely to be excluded from consignments:

- Mature orange fruit that have been infected with citrus leprosis virus (and which may harbour virus-infected mites) often have lesions (10–20mm in diameter) that appear as slightly depressed necrotic spots with a characteristic dark brown halo (Rodrigues et al. 2003; León et al. 2006).
- On green fruits, the lesions are initially yellowish, later becoming brown or blackish, sometimes depressed, and reduce the market value of the fruits (Rodrigues et al. 2003).
- Fruits infested with viruliferous mites are usually lighter (in weight) than uninfested fruits, with weight decreasing as the number of mites increases. Also, affected fruits drop 50% more frequently than fruits without mites or lesions (Rodrigues et al. 2003), making them less likely to be packed.

However, fruit with few mites may not show symptoms of infestation or disease:

- *Brevipalpus* spp. are very small mites, with the largest life stage (adult females) measuring between 200 – 300 µm long, which makes them difficult to detect without magnification, especially at low densities (Vacante 2016; Childers et al. 2003).
- Leprosis symptoms appear from 17 to 60 days after mite transmission, with most symptoms appearing between 21 and 30 days after (Chiavegato and Salibe 1984 cited in EFSA 2017).
- If leprosis lesions are not yet evident, and feeding injuries are not obvious due to low mite density, the mites may not be detected. Therefore, it is possible for asymptomatic fruit with low mite infestations to be unknowingly included in consignments.

In-field pest control and common packing house postharvest processes will greatly reduce the density of mites on harvested fruit, but are unlikely to completely eliminate the mites:

- In countries where citrus leprosis disease is present, *Brevipalpus* spp. are regularly controlled in citrus crops using a combination of cultural, biological, but mainly chemical methods (EFSA 2017; Rodrigues et al. 2011), which is likely to lead to low density of mites on fruit.
- Rodrigues et al. (2003) considered that packing house processes, which included a double wash, drying and waxing, were sufficient to eliminate the mites from citrus fruit for export.
- However, Peña et al. (2015) tested the efficacy of commonly used fruit cleaners, soaps, waxes, and mechanical brushing techniques to remove and kill all life stages of *Brevipalpus* mites on lemons (*Citrus limon*), using virus-free *B. yothersi* (one of the species in the *B. phoenicis* s. l. complex) as a model and found that:
 - no treatment provided 100% reduction of all mite stages, and reduction following single treatments (soap rinse, brushing or waxing alone) was not significantly different from reduction obtained with a water drench control.
 - several combination treatments, particularly those that included application of a food-grade wax coating, achieved ~90% reduction of mites.
- Peña et al. (2015) concluded that a combination of treatments, including a soap wash and mechanical brushing followed by a wax coating, may be the most effective method to achieve significant reduction (although not complete elimination) of all stages of *Brevipalpus* mites from infested citrus.

The *Brevipalpus* spp. considered in this assessment are likely to survive transit on citrus fruit:

- Frequent interception of live adults, nymphs and eggs of *B. phoenicis*, *B. obovatus* and *B. californicus* at the New Zealand border, especially on citrus fruits imported from the USA (LIMS 2020), suggests that *Brevipalpus* spp. can survive transit conditions for citrus shipped to New Zealand.

- There are currently no data on interceptions of *Brevipalpus* spp. on commodities from Mexico and Brazil (where citrus leprosis is present) at the New Zealand border (LIMS 2020); probably because there has been no trade in host commodities of *Brevipalpus* spp. between these countries and New Zealand (QuanCargo 2020).

Uncertainty:

- The main source of uncertainty is the fact that the mites may not be detected at low levels of infestation and post-harvest processes may not eliminate all undetected mites from fruit, which increases the likelihood of entry.

Likelihood of establishment:

Given the arguments and evidence below, the ability of *Brevipalpus* spp. to transfer from imported fruit onto a citrus host plant, leading to establishment of citrus leprosis, is rated as low (with moderate uncertainty)

Brevipalpus spp. have poor natural dispersal ability, and are likely to remain on or near discarded fruit, unless passively dispersed by wind and other agents:

- Under experimental greenhouse conditions, only about 3% of 6000 *B. phoenicis* s. l. crawled 40-50cm from the point of release in 24 hours, with the remaining 97% crawling only about 1cm/day (Alves et al. 2005).
- Alves et al. (2005) further demonstrated (under laboratory conditions) that fan-generated wind speeds below 30 km/h were unable to dislodge *B. phoenicis* from the surface of citrus fruit, while higher wind speeds (30 – 40 km/h) dispersed only about 1% of the mite population.
- In a field study using sticky traps, only three adults of *B. phoenicis* were captured on traps placed 1.5m from the hedge around two separate plots of citrus groves (Alves et al. 2005). On sticky traps placed within the two plots, 99% and 83% of the mites collected belonged to the family Tetranychidae, 0.8% and 4.8% to the family Phytoseiidae and 0.4% and 11.8% to Tenuipalpidae – the family to which *Brevipalpus* spp. belong.
- Based on their results, (Alves et al. 2005) suggested that, relative to other mite species, *Brevipalpus* mites have limited aerial dispersal ability, which was attributed to their flat anatomy, behaviour of hiding in cracks or protrusions and lesions on fruits and branches, as well as their low response to wind currents – as demonstrated in the laboratory studies. In contrast, mite species in the Tetranychidae and Eriophyidae have adaptive behaviours, which enable them to disperse better on wind currents (Alves et al. 2005).
- In another field experiment (Peña et al. 2010), *B. phoenicis*-infested lemons were placed on the ground 2m away from the lemon tree, and one mite was detected on the tree after 14 days, with wind speeds averaging about 33 km/h. Also, when the lemons were placed touching the base of the tree, two mites were able to transfer to the tree after 14 days (Peña et al. 2010).
- The mites failed to transfer, from lemon fruit placed in a trash can, to a lemon tree 2m away. And even when infested fruits were suspended 1m above ground, no mites were detected on fruit placed at different heights on the tree after 28 days (Peña et al. 2010).
- When lemons infested with *B. phoenicis* were placed in contact with fruit flies, 3/60 fruit flies had mites attached to their seta or body (Peña et al. 2010). Transfer to citrus hosts via attachment to other insects or birds is highly uncertain, as this would depend on the sites/hosts visited by the transporting agent, and there is no data indicating that mites have the ability to choose which “transport agents” they become attached to.
- Given that there are likely to be few mites on export grade fruit, and that *Brevipalpus* spp. are not known to have the ability to control where they land when carried by wind (Bassanezi and Laranjeira 2007), dispersal by wind does not guarantee that a mite will land on a citrus host.
- Mites dispersed by wind or other agents, would have a higher chance of landing on a citrus host in the main citrus producing areas of New Zealand and, possibly, in home gardens across the country, where citrus plants, especially lemons, are commonly grown.
- Taken together, the evidence presented above indicates that transfer of *Brevipalpus* spp. from imported citrus fruit to citrus host plants in New Zealand is only likely, if infested fruits are

discarded in citrus orchards, or on open compost heaps very close to citrus hosts in home gardens.

Uncertainty:

- High wind speeds are common in New Zealand and may increase the likelihood of dispersal of mites from fruit discarded in open areas close to citrus hosts.
- There are no current data on the proportion of imported citrus waste that is discarded in and around citrus orchards or composted in home gardens. Although Hogg et al. (2010) reported that New Zealanders discard around 400,000 tonnes of kitchen waste each year and about 12.5% is composted, there are no data on the proportion of composted waste that is imported citrus. Also, the distances of compost heaps to citrus hosts in home gardens is unknown.

Impacts in New Zealand:

Given the arguments and evidence below, introduction of citrus leprosis disease by *Brevipalpus* spp. is likely to cause low-moderate impacts in New Zealand (with high uncertainty)

Citrus leprosis is likely to cause high economic impacts for growers, especially, of sweet oranges:

- Citrus leprosis virus (CiLV) causes one of the most serious virus diseases of citrus, associated with premature fruit drop, defoliation, and death of the twigs or branches, with crop damage sometimes leading to 100% yield loss (Childers and Rodrigues 2011; Rodrigues et al. 2003).
- The most sensitive hosts for CiLV-C and CiLV-C2 are sweet orange (*C. sinensis*), but mandarin (*C. reticulata*) and its hybrids are also widely affected, although varieties express various degrees of resistance or tolerance to CiLV-C (EFSA 2017; Roy et al. 2015).
- In Brazil, citrus leprosis has been reported to cause losses of 35 –75% in sweet oranges, due to premature fruit drop (Rodrigues et al. 2003), while lemons (*C. limon*), Mexican lime (*C. aurantiifolia*), grapefruit (*Citrus paradisi*), sweet lemon (*C. limetta*) and Persian lime (*C. latifolia*) are not found naturally infected with CiLV-C and are considered resistant, while *C. limetta* is considered to be immune to CiLV-C (Bastianel et al. 2010).
- Introduction of any of the citrus leprosis viruses into New Zealand is likely to affect exports of citrus because the disease is not known to occur in any of the countries that are export destinations for New Zealand citrus.
- The cost of response activities, including eradication efforts that involve elimination of all infected hosts and mites from an area, may be considerable.

Costs for long-term mite and disease control may be high:

- Bastianel et al. (2010) reported that Brazilian citrus growers spent around US\$800 million (21% of production costs) every year to control the *Brevipalpus* mites that vector citrus leprosis.
- Observations made in the State of São Paulo, Brazil, indicate that when virus inoculum is present in an area and acaricides are not applied, 2–3 years are sufficient to allow for the complete spread of leprosis throughout an orchard; the large size of citrus orchards contributes to the occurrence and widespread distribution of citrus leprosis in the São Paulo industry, making control more difficult (Rodrigues et al. 2003).
- No evidence was found (Google; HortResearch and New Zealand Citrus Growers Incorporated 2001) to indicate that *Brevipalpus* spp. require control in New Zealand citrus, but introduction of citrus leprosis would necessitate mite control (likely using chemicals) and increase production costs.
- Increased use of chemicals to control *Brevipalpus* spp. may lead to increased outbreaks of citrus red mite (*Panonychus citri*), which is typically considered a 'pesticide induced' pest in New Zealand citrus (Pyle & Stevens 2004 cited in Jamieson & Stevens 2009).
- Populations of citrus red mite (CRM) have been observed to increase dramatically in orchards following application of broad-spectrum insecticides to control other major pests, particularly Kelly's citrus thrips (*Pezothrips kellyanus*) and citrus flower moth (*Prays nephelomima*). It is thought that these chemicals disrupt the activity of CRM natural enemies, especially the

coccinellid ladybird, *Stethorus* sp. and the predatory mite, *Agistemus longisetus* (Jamieson et al. 2005, 2008).

Economic impacts may be moderated by the non-systemic nature of citrus leprosis viruses and the inability of mites to transmit them to their offspring:

- In contrast to the vast majority of plant-infecting viruses, citrus leprosis viruses are unable to systemically invade their citrus host plants (Bastianel et al. 2010; Roy et al. 2015).
- These viruses are only able to move locally from an infected cell to immediately neighbouring cells, which results in the development, around inoculation points, of the localised, centimetric infection lesions on leaves, young stems or fruits that is typical of the disease (Bastianel et al. 2010; Roy et al. 2015).
- There are no known systemic hosts for these viruses (Bastianel et al. 2010; Roy et al. 2015), therefore, virus lesions are only associated with the feeding sites of *Brevipalpus* spp. vectors, and vegetative multiplication practices used to produce planting materials are highly unlikely to represent a major mechanism for virus spread (EFSA 2017).
- Bassanezi and Laranjeira (2007) reported that in citrus orchards in Brazil, leprosis-infected plants clustered together, partly because the vector *Brevipalpus* mites move slowly and depend on passive mechanisms (such as being carried on tools, machinery or clothing of farm workers) for dispersal within orchards.
- Adult *Brevipalpus* mites are not known to transmit the viruses to their eggs, so unless adults and their offspring feed on an infected site and disperse to other plants, the disease cycle can be broken (Tassi et al. 2017; Bastianel et al. 2010).

Introduction of citrus leprosis viruses by *Brevipalpus* spp. is likely to cause very low environmental impacts, with high uncertainty:

- The recorded natural hosts of the citrus leprosis viruses are mainly citrus species, and there are no *Citrus* species native to New Zealand.
- There are two genera within the Rutaceae that are endemic to New Zealand: *Leionema* and *Melicope*, but none of the species in either genera are considered threatened (NZPCN 2020).
- Outside the Rutaceae, there are very few recorded natural infections of plants by leprosis viruses: CiLV-C has been recorded from *Commelina benghalensis* (Commelinaceae); CiLV-C2 and OFV citrus strains from *Dieffenbachia* sp. (Araceae); HGSV-2 from *Hibiscus arnottiana* and CiCSV from *Hibiscus tiliaceus* (Rosaceae) (Freitas-Astúa 2018; Roy et al. 2015). There are two native (non-endemic) *Hibiscus* species in New Zealand, which are both considered “threatened, nationally critical” (*H. richardsonii* and *H. diversifolius* subsp. *diversifolius*) (NZPCN 2020).
- Uncertainty centres on the host range of the citrus leprosis viruses, which appears to not be fully elucidated; this is in part related to the uncertain host ranges of their known vectors and the possibility of unidentified vectors. Both of these uncertainties are, in turn, linked to the taxonomic difficulties within the genus *Brevipalpus*.

Introduction of citrus leprosis by *Brevipalpus* spp. is unlikely to cause health impacts, but may cause low social impacts (with high uncertainty):

- No evidence was found of any citrus leprosis viruses causing human health issues.
- The high economic impact of citrus leprosis may cause social impacts in citrus growing communities.
- A biosecurity response is likely to be mounted following an incursion, and will involve activities that disrupt cultural practices in citrus producing areas, including the trade and movement of host commodities.

Uncertainty:

- There is uncertainty around the conclusion on impacts, since the natural host ranges of the *Brevipalpus* transmitted viruses are not fully known/described; CiLV-C has a wide range of several hundreds of experimental hosts, ranging from *Arabidopsis* to *Phaseolus* (Arena et al. 2017; Garita et al. 2014).
- Although the host ranges of the viruses may be expected to fall within those of the vector mites, the host ranges of the vectors are also uncertain; given historical taxonomic difficulties and recent revisions of the genus *Brevipalpus*. For example, it is suspected, but yet to be

confirmed that HGSV-2 is transmitted by *Brevipalpus* mites, and a tentative vector species has not been identified (Freitas-Astúa 2018; Roy et al. 2015).

- There is also uncertainty around which *Brevipalpus* spp. are present in New Zealand, partly due to a recent taxonomic revision of the genus by Beard et al. (2015).

14.2.4 References

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Appendix 1: Summary of taxa excluded at hazard identification

Appendix 1, Table 1 Groups and species identified at the hazard identification stage as not requiring further assessment and not requiring measures over and above basic measures, and the rationale for exclusion

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Fungi	
Family Aspergillaceae	<i>Aspergillus flavus</i> , <i>A. niger</i> , <i>Penicillium digitatum</i> and <i>P. italicum</i> reported from citrus fruit but are present in New Zealand (NZFungi2 2020; PPIN 2020). <i>Penicillium ulaiense</i> was considered in more depth, because it is recorded as absent from New Zealand (NZFungi2 2020); however, it is not recorded as a citrus pathogen, although it can cause rot of citrus fruit in storage. <i>Penicillium ulaiense</i> was commonly associated with packing houses in the USA but could not be detected at production sites (Holmes et al. 1994). In Egypt, it has been reported in packing houses (Youseff et al. 2010), and in Japan, it has been reported only as a storage rot of stored fruit (Tashiro et al. 2012).

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Botryosphaeriaceae	<p><i>Phyllosticta citricarpa</i> (<i>Guignardia citricarpa</i>) required a full pest risk assessment. Several other <i>Phyllosticta</i> spp. were excluded at the hazard identification stage, because they are not associated with fruit or do not meet the criteria for additional measures. For example:</p> <ul style="list-style-type: none"> • <i>Phyllosticta citribraziliensis</i> and <i>P. paracapitalensis</i> have only been reported as endophytes from healthy citrus leaves and have not been reported from fruit (Glienke et al. 2011; EFSA 2014a; Guarnaccia et al. 2017a). • <i>Phyllosticta citrimaxima</i> was isolated from tan spots on the fruit surface of pomelo fruit in Thailand (Wikee et al. 2013). • <i>Phyllosticta paracitricarpa</i> was isolated from leaf litter of <i>C. limon</i> in Greece and fruit spots on <i>C. limon</i> and <i>C. sinensis</i> in China (Guarnaccia et al. 2017a, 2019). Since this species was only recently described, there is only limited evidence for its pathogenicity to citrus fruit (Guarnaccia et al. 2017a carried out preliminary pathogenicity testing on detached mature orange fruit) and insufficient information for a pest risk assessment. • <i>Phyllosticta citriasiana</i> causes citrus tan spot on <i>C. maxima</i> fruit and leaves. It is only reported from tropical areas such as Thailand and Viet Nam and several tropical provinces of China (Wulandari et al. 2009; Wang et al. 2012), which have very different climate conditions to the whole of New Zealand, indicated by a climate match index (CMI) of ≤ 0.6 (Phillips et al. 2018). Pomelo (<i>C. grandis</i>/<i>C. maxima</i>) is the only recorded host of <i>P. citriasiana</i> (Wulandari et al. 2009; Wang et al. 2012) and is not widely grown in New Zealand. Therefore, both likelihood of establishment and potential for this fungus to have impacts in New Zealand were considered extremely low. • <i>Phyllosticta citrichinaensis</i> was isolated from mandarins (<i>C. reticulata</i>), pomelos (<i>C. maxima</i>), oranges (<i>C. sinensis</i>) and lemons (<i>C. limon</i>) (Wang et al. 2012). Infected fruit and leaves show some irregular spots or freckles. However, pycnidia (reproductive structures) were not found on lesions, so there is no evidence that <i>P. citrichinaensis</i> could move from imported fruit to a new host in New Zealand. No significant losses resulted from this pathogen (Wang et al. 2012). <p>Several <i>Lasiodiplodia</i> spp. were also excluded at the hazard identification stage, because they are not associated with citrus fruit, they do not meet the criteria for additional measures, or searches¹⁰² found insufficient information to assess further on citrus fruit. For example:</p> <ul style="list-style-type: none"> • There is only a single report of <i>L. pseudotheobromae</i> from citrus fruit as a post-harvest rot of lemons in Turkey (Awan et al. 2016). <p><i>Lasiodiplodia pseudotheobromae</i> and <i>L. brasiliensis</i> were also reported from Persian lime plants in Mexico with gummosis, stem cankers and dieback symptoms (Bautista-Cruz et al. 2019). However, searches (Google Scholar; CAB Abstracts, July 2020) on the search terms 'Lasiodiplodia brasiliensis' and citrus found no evidence of citrus fruit rots caused by this fungus.</p>

¹⁰² Searches of CAB abstracts, CPC and Google Scholar using the species name and "citrus" as search terms.

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Ceratobasidiaceae	<p><i>Rhizoctonia noxia</i> (synonyms <i>Corticium koleroga</i>; <i>Ceratobasidium noxium</i>; <i>Koleroga noxia</i> <i>Pellicularia koleroga</i>) has previously been assessed on fresh citrus fruit from Samoa, as <i>C. koleroga</i> (MAF 2008) and does not currently have additional measures on citrus fruit from Samoa. <i>Rhizoctonia noxia</i> attacks twigs, fruit and leaves of <i>Citrus</i> trees (Timmer 2000). Rhizomorphs form and cover the tissue, which may die if heavily invaded. Small black sclerotia often form on the rhizomorphs and basidiospores may form on the wefts of mycelium on host tissue (Timmer 2000). Timmer (2000) states that <i>C. koleroga</i> infection on citrus fruit is seldom severe enough to require treatment. MAF (2008) concluded that recent infections (less than one week old) of <i>C. koleroga</i> are unlikely to be detected by visual inspection on arrival in New Zealand, but that fruit with sclerotia will be detected during harvesting and handling and be rejected prior to export. Infestations of thread blight are highly unlikely to go undetected on citrus plants grown in commercial production.</p>
Family Ceratocystidaceae	<p><i>Ceratocystis fimbriata</i> was considered in the hazard identification, because it is a major pathogen and has been reported as associated with citrus. However, fruit is not infected by <i>C. fimbriata</i> and is not considered to be a pathway for entry (EFSA 2008a). The CPC datasheet (CABI 2020) makes a general statement that the surface of host fruit may be contaminated with fruiting bodies; hyphae; spores. However, searches of CAB Abstracts and Google Scholar found no evidence for a routine association between <i>Ceratocystis fimbriata</i> and citrus fruit. Farr and Rossman (2020) list substrates as woody branches and stems, roots, leaves, tubers, but do not include fruit. Search results for 'Ceratocystis fimbriata' and 'citrus' and 'fruit' often related to a fruity odour or to biocontrol of fungi with citrus oils.</p> <p><i>Ceratocystis radicola</i> causes post-harvest and opportunistic rots of citrus fruit but is extremely unlikely to be associated with unblemished fruit. In pathogenicity tests, intact citrus fruit were not susceptible to infection by fungal spores of <i>C. radicola</i>; the fungus could only enter damaged fruit through wounds or cracks (Mirzaee and Mohammadi 2005).</p>
Family Dermateaceae	<p><i>Cryptosporiopsis citricarpa</i> (synonym <i>Pseudofabraea citricarpa</i>) does not meet the criteria for further assessment, because there is no evidence for an association with citrus fruit. <i>Cryptosporiopsis citricarpa</i> is a destructive leaf spot, which was first reported China in 2010 (Zhu et al, 2012). The same species or a species with the same name was recorded on older leaves of several citrus species in the Cook Islands, Fiji, Niue, Tonga, Vanuatu and Western Samoa (Johnston and Fullerton 1988). <i>Cryptosporiopsis citricarpa</i> was not reported from fruit in either case. Searches¹⁰³ found only these reports and taxonomic studies referring to Zhu et al. (2012).</p> <p><i>Paracercosporidium microsorum</i> (synonyms <i>Cercospora microsora</i>, <i>Mycosphaerella microsora</i>, <i>Mycosphaerella millegrana</i>, <i>Passalora microsora</i>) was added to the initial hazard list for further checking because it was historically listed in the citrus nursery stock pest list. However, it did not meet the criteria for further assessment, because searches (CAB Abstracts; Farr and Rossman; Google Scholar, June 2020) using 'Paracercosporidium microsorum' or the synonyms above and 'citrus' as search terms found no references suggesting that this fungus is associated with citrus.</p>

¹⁰³ Searches of CAB Abstracts, CPC and Google Scholar in June and October 2020 using the species name and "citrus" as search terms.

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Diaporthaceae	A number of recently described <i>Diaporthe</i> species are associated with citrus, either as symptomless endophytes or associated with leaf scab and cankers on twigs, branches and trunks (Huang et al. 2013, 2015). Generally, these have no association with fruit. Although Huang et al. (2015) isolated <i>D. subclavata</i> from pomelo fruit (<i>C. grandis</i>) and <i>D. unshiuensis</i> from <i>C. unshiu</i> fruit with melanose symptoms in China (Huang et al. 2015), this study appears to be the only primary record of these species associated with citrus fruit, although several later taxonomic studies refer back to this study.
Family Didymellaceae	<i>Plenodomus tracheiphilus</i> (synonym <i>Phoma tracheiphila</i>) was considered in more depth, because it causes economically important damage to citrus, particularly lemon trees, in Greece, Italy and Turkey (EFSA 2014b; Karapapa et al. 2015; Nigro 2011). Fruit of diseased citrus plants can be invaded by <i>P. tracheiphilus</i> , causing discolouration of the peel, withering and mummification or fruit drop (Nigro et al. 2011). Although <i>Plenodomus tracheiphilus</i> can be detected in citrus fruit and as mycelium on the coats of seeds, there is no evidence that the pathogen is spread by the movement of fruit (EFSA 2014). Infected fruit is of low quality and usually falls to the ground before harvest (Migheli et al. 2009).
Family Elsinoeaceae	<i>Elsinoe australis</i> required a pest risk assessment, and the regulatory status of several pathotypes of <i>E. fawcettii</i> has also been assessed, because these strains have not been reported in New Zealand. No evidence was found for other fungi in this family that would qualify as quarantine pests associated with citrus fruit.
Family Erysiphaceae	The powdery mildew fungi <i>Erysiphe quercicola</i> and <i>Fibroidium tingitaninum</i> (synonym <i>Oidium tingitaninum</i>) are unlikely to be associated with mature fruit at the time of harvest. They infect leaves and immature fruit in the first flush of growth and can cause premature fruit drop (Biosecurity Queensland 2011).

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Glomerellaceae	<p>A number of Colletotrichum species were considered in more depth at the hazard identification stage, but either there is no evidence that they would be associated with mature fruit at harvest, or they do not meet the criteria for additional measures because symptoms would be highly visible and infected fruit would not meet the commodity symptom. For example:</p> <ul style="list-style-type: none"> • The lime anthracnose strain of <i>C. acutatum</i> (synonyms: <i>C. limetticola</i>; <i>Gloeosporium limetticola</i>; <i>Gloeosporium fructigenum</i> f. <i>limetticola</i>) is highly likely to be detected during production or phytosanitary inspection, or to damage infected fruit to the extent that is not fit for export. <ul style="list-style-type: none"> ○ Young tissues, including young fruit of key lime (<i>C. aurantiifolia</i>) are susceptible to <i>C. acutatum</i> (Peres et al. 2005, 2008). ○ Spores germinate rapidly when they land on young susceptible fruit, almost immediately causing necrotic lesions. • No evidence was found for an association of <i>C. abscissum</i> with mature fruit at harvest. <ul style="list-style-type: none"> ○ <i>Colletotrichum abscissum</i> is associated with blossoms and immature fruit (Crous et al. 2015; Rodrigues Marques et al. 2020). It causes post-bloom drop of immature fruit at a very early stage of development. ○ The fruitlets detach between the calyces and young fruit, and the calyces (or buttons) remain on the plant and do not abscise as they normally would if no fruit is set (Dewdney 2015; Rodrigues Marques et al. 2020). • <i>Colletotrichum queenslandicum</i> has been reported only once on citrus (from Persian lime leaves in USA) (Kunta et al. 2018), and there is no evidence of an association with citrus fruit. <p>A number of recently described Colletotrichum species (e.g. <i>C. catinaense</i>, <i>C. helleniense</i>, <i>C. hystricis</i> and <i>C. limonicola</i>) cause lesions on citrus fruit (Guarnaccia et al. 2017b) but are not reported from any of the IHS countries. There is very little information about these pathogens beyond the initial report. These species may need to be assessed in future if their distribution changes.</p>
Family Meliolaceae (sooty blotches)	<p><i>Meliola citricola</i> has previously been assessed on citrus fruit from Samoa (MAF 2008) and is likely to be managed by basic measures. Although infections develop slowly, <i>M. citricola</i> requires young leaves to infect, and it could be assumed the same applies to fruit (MAF 2008). Therefore, it is likely <i>M. citricola</i> will have developed visible symptoms (unsightly black fungal growth) by time of harvest, and infected fruit are likely to be removed prior to export. <i>Meliola camelliae</i> is also reported from citrus (Farr and Rossman 2020).</p> <p><i>Meliola citricola</i> is not a strong parasite, and economic loss is usually related to the unsightly appearance of the black fungal growth on the fruit (MAF 2008). Like sooty moulds, severe infections may affect the photosynthesis ability of plants and reduce fruit yields. (MAF 2008). Searches using the species name and 'citrus' as search terms in CAB Abstracts and Google Scholar (November 2020) and literature records in Farr and Rossman (2020) found some records of <i>M. citricola</i> and <i>M. camelliae</i> in historic country indexes and lists of fungal species but no evidence of recent or severe economic impacts.</p>

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Mycosphaerelleaceae	<p>A number of leaf and fruit spot species in the Mycosphaerelleaceae were considered during the hazard identification process, including:</p> <ul style="list-style-type: none"> • <i>Mycosphaerella citri</i> (synonym <i>Zasmidium citri</i>) does not meet the criteria for further assessment, because there is no pathway for establishment from citrus fruit (based on MAF 2008). <i>Mycosphaerella citri</i> is extremely unlikely to establish from citrus fruit that meets the commodity description (in particular without leaves), because it overwinters in the soil and sporulates on fallen leaves (MAF 2008). • <i>Mycosphaerella horii</i> is also reported to sporulate on decomposing leaves (Ieki 1986). • There is no evidence that either <i>M. citri</i> or <i>M. horii</i> can complete their life cycles on discarded citrus peel or fruit. • Searches¹⁰⁴ found very little life cycle information about <i>M. loefgreni</i>, <i>Cercospora penzigii</i>, <i>Z. fructicola</i> or <i>Z. fructigenum</i>; they are either recently described, or there is very little information about them and no record of economic impacts. They are assumed to have a similar life cycle to the closely related species <i>M. citri</i> and <i>M. horii</i>. • <i>Mycosphaerella citrigena</i> and <i>Z. indonesianum</i> are reported from leaves but not fruit of citrus species. • <i>Pseudocercospora angolensis</i> is only found in sub-Saharan Africa and Yemen (EFSA 2017). It is not currently found in any of the countries being assessed for the citrus fresh fruit IHS. This species would require urgent assessment if it spreads to an IHS country.
Family Nectriaceae	<p>Two species in the Nectriaceae were considered in more detail because they have been reported from citrus fruit:</p> <ul style="list-style-type: none"> • <i>Cylindrocarpon lichenicola</i> (synonyms include <i>Fusarium lichenicola</i>; <i>Neocosmospora lichenicola</i>) was reported as a cause of severe post-harvest fruit rot of pomelo in Viet Nam (Amby et al. 2015). However, although other citrus species developed rot symptoms in pathogenicity tests (Amby et al. 2015) searches using the search term '<i>Cylindrocarpon lichenicola</i>' or its synonyms and 'citrus' found no other reports of <i>C. lichenicola</i> from citrus. <i>Cylindrocarpon lichenicola</i> is also reported as a cause of opportunistic infections in humans in tropical areas (e.g. Summerbell and Schroers 2002), and it is likely that it is a common environmental fungus in tropical areas that can cause opportunistic fruit rots. <p><i>Fusarium solani</i> has been reported from citrus fruit (Abd-Elsalam et al. 2015). <i>Fusarium solani</i> is now considered to be a species complex; however, <i>F. solani</i> sensu stricto (as its synonym <i>Nectria haematococca</i>) has been recorded from citrus plants in New Zealand (NZFungi2).</p>

¹⁰⁴ Searches of CAB Abstracts, CPC and Google Scholar in June–August 2020, using the species name and “citrus” as search terms

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Family Pleosporaceae	<p>A number of <i>Alternaria</i> species were considered in more depth at the hazard identification stage but do not meet the criteria for additional measures:</p> <ul style="list-style-type: none"> • <i>Alternaria limicola</i>, the cause of the citrus leaf spot disease mancha foliar de los citros, may produce small lesions on young fruitlets, but symptoms disappear as the fruit develops (Timmer et al. 2000; Timmer et al. 2003). Therefore, it is highly unlikely to be associated with mature fruit at harvest. <p>A number of other <i>Alternaria</i> species are described from <i>Citrus</i> but are now considered synonyms of species that are present in New Zealand and have been recorded from citrus here (e.g. <i>A. pellucida</i> is a synonym of <i>A. alternata</i>; <i>A. scorzonerae</i> is a synonym of <i>A. linicola</i>).</p>
Root, butt or wood rot fungi (e.g. Agaricales, Hymenochaetales, Polyporales, many Xylariales)	<p>Fungi that are primarily reported as root or wood rots were not assessed further unless there was evidence for an association with fruit. For example, <i>Armillaria</i> spp., <i>Rosellinia</i> spp. are root rots, and <i>Pyrrhoderma noxium</i> (<i>Phellinus noxius</i>) and <i>Ganoderma</i> spp. are wood rots.</p>
Sooty moulds (Families Capnodiaceae and Chaetothyriaceae)	<p><i>Capnodium citri</i> is a sooty mould fungus associated with honeydew-excreting insects such as mealybugs, aphids or soft scales (MAF 2008). It is not pathogenic to plants, although it can cause production losses by impairing photosynthesis (MAF 2008). The following sooty moulds have been reported from citrus but fungal symptoms (and the underlying insect infestations) are visually detectable in a phytosanitary inspection, and the biosecurity risks associated with these species are managed by basic measures: <i>Antennella citrina</i>, <i>Capnodium citri</i>, <i>Capnodium tanakae</i>, <i>Capnophaeum fuliginoides</i>, <i>Chaetothyrium citri</i>, <i>Chaetothyrium javanicum</i>, <i>Chaetothyrium spinigerum</i>, <i>Hypocapnodium japonicum</i>.</p>
Yeasts	<p>No yeast species were found that met the criteria for additional measures. <i>Galactomyces citri-aurantii</i> (synonyms <i>Geotrichum candidum</i>, <i>Galactomyces geotrichum</i>, <i>Geotrichum candidum</i> var. <i>citri-aurantii</i>) is very commonly reported from citrus (e.g. CABI 2020a and b; NPPO country pest lists) but is present in New Zealand (NZFungi2 2020) and non-regulated in ONZPR (2020). <i>Eremothecium coryli</i> (synonym <i>Nematospora coryli</i>) does not meet the criteria for additional measures. It is an insect-transmitted yeast associated with dry rot in native and cultivated citrus fruits (Shivas et al. 2005). However, there is no evidence that there is a pathway for <i>E. coryli</i> to establish from infected citrus fruit.</p>
Bacteria	

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Bacteria	<i>Xanthomonas citri</i> (citrus canker) required assessment. No evidence was found during hazard ID for other bacteria that may meet the criteria for further assessment; most are not a risk on fruit. Some serious vector-transmitted pathogens can be associated with citrus fruit, e.g. <i>Xylella fastidiosa</i> (Pierce's disease of grapevine), huanglongbing (citrus greening) causative agents (' <i>Candidatus Liberibacter africanum</i> ', ' <i>Ca. L. asiaticum</i> ', ' <i>Ca. L. americanum</i> ', ' <i>Ca. L. caribbeanus</i> '), <i>Spiroplasma citri</i> (citrus stubborn disease); however, there is no plausible means for them to be transferred to host plants in New Zealand (see vector-transmitted pathogens section of this table).
Oomycetes	
Oomycetes	One oomycete species was identified during scoping as requiring further assessment (<i>Phytophthora palmivora</i>). Other species did not meet requirements because they were not clearly associated with disease on citrus fruit.
Seed-transmitted pathogens	
Seed-transmitted pathogens	Seed-transmitted pathogens were not considered in scoping, as they have no plausible means of establishing from citrus fruit. Wild records of citrus in New Zealand are rare (see section 2.1), indicating that propagation from discarded seeds is highly unlikely.
Vector-transmitted pathogens	
Vector-transmitted pathogens	Vector-transmitted pathogens have no plausible means of establishment from citrus fruit. For this reason, such significant pathogens as <i>Xylella fastidiosa</i> (Pierce's disease of grapevine), citrus greening (huanglongbing) causative agents (' <i>Candidatus Liberibacter africanum</i> ', ' <i>Ca. L. asiaticum</i> ', ' <i>Ca. L. americanum</i> ', ' <i>Ca. L. caribbeanus</i> '), <i>Spiroplasma citri</i> (citrus stubborn disease) were not considered for further assessment. For example, DEFRA (2014) and EFSA (2015) consider infected fruit unlikely to represent an efficient entry pathway for <i>X. fastidiosa</i> . Note that vectors of pathogens have been considered in separate vector analysis PRAs.
Insects	
Order Coleoptera (beetles)	Scoping has not found any evidence that there are Coleoptera that can occur internally in fruit or have other traits that would mean they would remain with fruit and be undetected.

Order Diptera:
Family Tephritidae
(fruit flies)

Bactrocera occipitalis and *B. pedestris* have been ruled out as hazards in this import risk analysis, because there is insufficient evidence for them being found in the countries in the scope for this IHS. Both of these flies have been identified as being reported on citrus in China by the USDA in the pest risk analysis for “Importation of *Citrus* spp. (Rutaceae) fruit from China into the continental United States” (United States Department of Agriculture 2020). The USDA cites Li et al. (1997) as evidence for the presence of these two species in China; however, this paper is based on expert opinion and therefore only provides anecdotal evidence, not data. Because both *B. occipitalis* and *B. pedestris* are part of the *B. dorsalis* species complex, they are often confused with other taxa in the complex such as *B. carambolae*, *B. papayae*, *B. melastomatos*, *B. philippinensis* and *B. dorsalis* sensu stricto (Drew and Hancock 1994) – the last of which has a confirmed distribution in China (EPPO 2020). It is likely that any reports of *B. occipitalis* and *B. pedestris* in China are actually reports of *B. dorsalis* sensu stricto. Literature searches in both the English language and Chinese language literature support this contention. Hardy (1974) considers the distribution of *B. pedestris* to be in the Philippines, Indonesia and Malaysia, whereas White and Elson-Harris (1994) consider *B. pedestris* to be a very rare fruit fly known from only one locality in the Philippines. Although Huang et al. (1984) has been cited as evidence for the presence of *B. pedestris* on citrus in China (Liquido et al. 2016), the paper refers to *Chaetodacus ferrugineus* (a synonym for *B. dorsalis*) (EPPO 2020) and makes no reference to *C. ferrugineus* var. *pedestris* (a synonym of *B. pedestris*) (EPPO 2020). Similarly, both EPPO (2020) and Plant Health Australia (2018) consider the distribution of *B. occipitalis* to be restricted to Borneo and the Philippines. There is a single report of *Dacus (Bactrocera) occipitalis* in a mango orchard in Hainan province in China; however, based on the taxonomic issues raised above, this is likely to be a misidentification (Liang 1985). A subsequent paper states that *Dacus occipitalis* has not been reported in China (Xie et al. 1987).

Bactrocera umbrosa has been ruled out as a hazard in this import risk analysis, because there is insufficient evidence for *Citrus* being a host for the species. White and Elson-Harris (1994) consider *B. umbrosa* to be a pest of breadfruit (*Artocarpus altilis*) and jackfruit (*A. heterophyllus*) and cite old host records requiring confirmation for pummelo (*Citrus maximus*) (Perkins 1938) and sour orange (*C. aurantium*) (Froggatt 1909). Perkins (1938) gives a secondhand account of *Strumeta umbrosa* (a synonym of *B. umbrosa*) being found on “falling and rotting” pomelos in Kuala Lumpur in 1921, whereas Froggatt (1909) gives a secondhand account of *Dacus frenchi* (a synonym of *B. umbrosa*) being bred from oranges coming into Victoria from New Caledonia. There are no further references in the literature to citrus being a host for *B. umbrosa*, and subsequent field surveys have only recorded the species from a small number of *Artocarpus* species (Tan and Soo-Lam 1982; Allwood et al. 1999; Leblanc et al. 2012).

Bactrocera halfordiae (Tryon) has been ruled out as a hazard in this import risk analysis, because the information supporting citrus as a host is weak for this species. This species, however, is currently regulated on grapefruit, lemon, lime, mandarin, orange, tangelo, tangerine from Australia. White and Elson-Harris (1994) state that records from grapefruit (*Citrus paradisi*), mandarin (*C. reticulata*), and sweet orange (*C. sinensis*) were probably based on misidentifications of *B. tryoni*. They considered citrus to be a doubtful host and only included the records to indicate previously published records that should be dismissed as being in error. Vargas et al. (2015) list *B. halfordiae* as a Category C pest [relatively minor oligophagous or specialist fruit or cucurbit pests] noting that it is oligophagous. Hancock et al. (2000) listed *C. paradisi* (grapefruit) and *C. reticulata* (mandarin) as host species, citing May (1953). Royer (2015) states that *B. halfordiae* was recently considered a possible market access pest due to old host records from citrus (May 1953, in Hancock et al. 2000). The author goes on to say that since then, the only host records have been in rainforest fruit, citing Hancock et al. (2000). Royer (2015) states that the preferred host is *Planchonella australis* (Sapotaceae), which is

common in rainforests in southeast Queensland. *Bactrocera halfordiae* is considered a fruit fly of economic concern in Australia, and Sultana (2020) lists citrus as a host for the species (citing Hancock et al. 2000) and indicates that citrus is a major commercial species. Distribution: Australia (Hancock et al. 2000, White and Elson-Harris 1994).

Bactrocera musae (Tryon) has been ruled out as a hazard in this import risk analysis, because there is insufficient evidence citrus is a host for this species. Hancock et al. (2000) note that *Musa banksii* (native banana) is a major host for *B. musae*. These authors list *Citrus paradisi* (grapefruit) and *C. reticulata* (mandarin) as host species, citing the QDPI ESEQld Papaya fruit fly database. However, Hancock et al. (2000) state that there is only one record for *C. paradisi* as a host, and one record from ripe fruit for *C. reticulata* as a host. They also state that care should be taken for records from large databases, such as that for the QDPI ESEQld Papaya fruit fly database, because these contain a variety of suspected errors. They further note that many of those in unusual hosts, based on a single or few specimens (which they note in comments in the host lists), are particularly doubtful and at least some may represent contamination of samples. This implies some doubt by these authors for the records of *B. musae* from *C. paradisi* and *C. reticulata*. *Citrus* spp. are not listed as hosts for *B. musae* in White and Elson-Harris (1994). There were no records of *B. musae* from *Citrus* in the survey carried out in the Pacific by Leblanc et al. (2012). Plant Health Australia (2018) describe the host range as: "Polyphagous. Recorded on 16 hosts from nine families, although these are mostly single records or specimens that may be dubious. Confirmed families are Musaceae, Caricaceae and Myrtaceae. Primary economic host is banana, but papaya and guava are occasional hosts."

Dirioxa pornia (Walker) (Island fruit fly) has been ruled out as a hazard in this import risk analysis, because it is attracted to overripe or damaged fruit of *Citrus*, and *Citrus* can be considered a conditional host. Such fruit would not meet the commodity description for this import risk analysis. White and Elson-Harris (1994) state that *D. pornia* is frequently reared from cultivated fruits, but it is not a pest, as it usually only attacks damaged fruit, preferring fruit that has been thorn-pricked, fallen or damaged by another fruit fly or codling moth. The authors note that it has been recorded from lemon (*Citrus limon*), mandarin orange (*C. reticulata*), orange (*Citrus* sp.), citing Gurney (1912). Hancock et al. (2000) list many *Citrus* spp. as hosts for *D. pornia* and comment for each *Citrus* species that *D. pornia* is associated with ripe or damaged fruit. Plant Health Australia (2011) states that *D. pornia* attacks ripe, damaged and fallen fruit. It has been recorded on hosts from a wide range of families, including Rutaceae. Hancock (2015) states: "Larvae of *Dirioxa pornia* (Walker) attack a wide range of overripe or damaged fruit and even fallen Araucaria cones (Permkam and Hancock 1995; Hancock et al. 2000)." Plant Health Australia (2018) states that *D. pornia* is polyphagous but on overripe, damaged or fallen fruit. They describe the host range as: "Recorded on 83 hosts in 27 families including Anacardiaceae, Annonaceae, Caricaceae, Curcubitaceae, Lauraceae, Lecythidaceae, Moraceae, Musaceae, Myrtaceae, Oxalidaceae, Passifloraceae, Rosaceae, Rubiaceae, Rutaceae, Sapotaceae and Solanaceae. Commercial hosts include mango, papaya, carambola, peach, pear, citrus, capsicum and eggplant."

Zeugodacus cucumis (French) (cucumber fruit fly) (syn *Bactrocera cucumis*) has been ruled out as a hazard in this import risk assessment, because there is insufficient evidence that *Citrus* is a host, though it is possible that *Citrus* fruit that is damaged could be a conditional host. Such fruit would not meet the commodity description for this import risk analysis. White and Elson-Harris (1994) note that this species is a serious pest of cucurbits, tomato and papaya and do not list any *Citrus* (or other Rutaceae) as hosts. These authors also state that under laboratory conditions, *B. cucumis* will not readily accept fruit outside its normal host range when deprived of preferred hosts, citing Fitt (1986). Hancock et al. (2000) list *Citrus limon* (lemon), *C. paradisi* (grapefruit),

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
	<p><i>C. reticulata</i> (mandarin) and <i>C. sinensis</i> (orange) as host species, citing the QDPI ESEQId Papaya fruit fly database. However, Hancock et al. (2000) comment that there is only one record for each of these <i>Citrus</i> species as hosts for <i>B. cucumis</i> [<i>Z. cucumis</i>]. They also state that care should be taken for records from large databases, such as that for the QDPI ESEQId Papaya fruit fly database, because these contain a variety of suspected errors. They further note that many of those in unusual hosts, based on a single or few specimens (which they note in comments in the host lists), are particularly doubtful, and at least some may represent contamination of samples. This implies some doubt by these authors for the records of <i>Z. cucumis</i> from <i>C. limon</i>, <i>C. paradisi</i>, <i>C. reticulata</i> and <i>C. sinensis</i>. Plant Health Australia (2018) describe the host range as: “Polyphagous. Recorded from 40 hosts in 15 families including the families Caricaceae, Curcubitaceae, Myrtaceae, Passifloraceae, and Solanaceae, although many recorded hosts are single records and may require confirmation. Major commercial hosts include papaya, cucumber, pumpkin, squash, zucchini, guada bean, passionfruit and tomato.” CABI (2020c) states that most major hosts of <i>B. cucumis</i> [<i>Z. cucumis</i>] are cucurbits; however, tomato can suffer heavy attack, and pawpaw moderate attack, and there are isolated records from several other fruit crops. CABI (2020c) goes on to say: “Hancock et al. (2000) presented a comprehensive list and only those marked as moderate or major hosts in that list are included here. The rare or incidental hosts (usually a single rearing) include mango, avocado, guava, carambola, apricot, some species of <i>Citrus</i>, and capsicum. It is likely that most of these records could be attributed to fruit damage prior to oviposition.”</p>
<p>Order Diptera: <i>Drosophila suzukii</i> (SWD)</p>	<p>There are host records for <i>Drosophila suzukii</i> (SWD) from some <i>Citrus</i> species in the scientific literature and in extension reports. Where clearly specified, these records are in association with overripe or damaged fruit, e.g.</p> <ul style="list-style-type: none"> • Wang et al. (2016) state SWD can complete development on ‘suboptimal’ hosts such as orange when these hosts are damaged, rotted, or overripe; • Haviland et al. (2016) found that SWD was not able to reproduce on intact or rotting citrus fruit, but was able to reproduce on sound, split fruit. These authors concluded that commercially harvested citrus fruit should not be considered a host of SWD, although it is clear that damaged fruit in an orchard can serve as reproductive hosts for SWD throughout the winter. • In California, Wang et al. (2019) reported that SWD adults emerged in very low numbers from field collected mandarins and oranges, but only from damaged fruit, not from intact fruit. They showed in laboratory tests that SWD was only able to oviposit into rotting or cut navel oranges. <p>No evidence has been found to show that the fly can infest sound, undamaged citrus fruit. Therefore, fruit complying with the commodity description in this IRA (fruit must have an intact skin, free from defects such as splits and cuts) is not considered to be a host for SWD.</p>
<p>Order Hemiptera: Family Aleyrodidae (whiteflies)</p>	<p>The whitefly group, including <i>Aleurocanthus woglumi</i> (citrus blackfly), <i>Aleurodicus dispersus</i> (spiralling whitefly), <i>Aleurocanthus spiniferus</i> (citrus spiny whitefly) and <i>Dialeurodes citri</i> (citrus whitefly), does not meet the criteria for further assessment, because no evidence was found that the pests are directly associated with the fruit of citrus.</p>

Pest taxon	Rationale for excluded taxa, examples of excluded taxa
Order Hemiptera: Family Aphididae (aphids)	Aphids that are present in New Zealand but have the potential to vector viruses and are associated with citrus fruit are assessed in a separate vector analysis PRA. Other species were excluded from further assessment due to at least one of the following reasons: 1) no evidence suggests the pest is associated with citrus fruits; 2) the pest is not known to be present in any citrus-exporting countries in the citrus fresh produce IHS; 3) impact is limited to hosts that are not important to New Zealand; 4) establishment in New Zealand is unlikely.
Order Hemiptera: Family Cicadellidae (leafhoppers)	No evidence was found of a strong association between leafhoppers and fruit of citrus. Adults and nymphs feed externally, mainly on sap from either leaves, stem or twigs; they are not expected to feed on mature fruit. Adult females lay eggs in/on leaves, not fruit. Leafhoppers, as their name implies, are very mobile; quickly hopping off leaves when disturbed. This means that even if they were present on fruit, they are highly likely to jump off or be dislodged during harvesting and post-harvest processing prior to packing of the fruit. This group includes known vectors for <i>Spiroplasma citri</i> and <i>Xylella fastidiosa</i> .
Order Hemiptera: Family Pseudococcidae (mealybugs)	Three mealybug species were identified during scoping as requiring further assessment (<i>Nipaecoccus viridis</i> , <i>Planococcus kraunhiae</i> , <i>Pl. minor</i>). Other species were excluded from further assessment due to at least one of the following reasons: 1) no evidence suggests the pest is associated with citrus fruits; 2) the pest is not known to be present in any citrus-exporting countries in the citrus fresh produce IHS; 3) there is little information on the pest; 4) there is little information on the impact of the pest. Note that mealybugs that are potential vectors, e.g. <i>Pseudococcus calceolariae</i> , <i>Ps. viburni</i> , <i>Ps. longispinus</i> , will be assessed in a separate vector analysis PRA.
Order Hemiptera: Family Psyllidae (psyllids)	Psyllids, in general, do not meet the criteria for further assessment, because the pests have a weak association with citrus fruit as hitchhikers. Two psyllid species were identified during scoping as requiring further assessment (<i>Diaphorina citri</i> , <i>Trioza erythrae</i>), because of their attraction to citrus and close relatives in the Rutaceae and their status as vectors of the liberibacters that cause the significant citrus disease huanglongbing.

Order Lepidoptera (moths, butterflies)	<p>Four species that can attack healthy fruit and occur internally in the fruit were identified during scoping as requiring further assessment based on their biology (<i>Marmara gulosa</i>, <i>Spodoptera littoralis</i>, <i>Thaumatotibia leucotreta</i> and <i>Gymnandrosoma aurantianum</i>). <i>Thaumatotibia leucotreta</i> was excluded, as it is not present in any of the countries under consideration for this IRA.</p> <p><i>Amyelois transitella</i> (navel orangeworm) was excluded, as it is reported as usually infesting already damaged citrus fruit, which would not meet the commodity description that is part of basic measures.</p> <p><i>Ostrina furnacalis</i> (Asian corn borer) is unlikely to be associated with commercially produced citrus fruit:</p> <ul style="list-style-type: none"> • Larvae mainly infest maize and sweetcorn (CABI 2019a); infestation of citrus only occurs if maize grows near citrus groves. • Larvae bore into citrus fruit; infestations on young citrus fruit can lead to early drop (Cai and Peng 2008). <p><i>Cryptoblabes gnidiella</i> (lemon borer moth) is unlikely to be present on citrus fruit that meets the commodity description and to which minimum measures are applied:</p> <ul style="list-style-type: none"> • In its early stages, it feeds on honeydew excreted on the fruit surface by aphids or mealybugs, and in later stages burrows into the fruit using holes previously made by birds or other borers. • Fruit that become infested are typically smaller in size (Moore, 2003), and damage by larvae feeding internally causes the fruit to yellow prematurely and may cause them to drop (Silva and Mexia 1999). • It is a secondary pest of citrus fruit (Silva and Mexia 1999). <p><i>Carposina sasakii</i> / <i>C. niponensis</i> are unlikely to be associated with citrus fruit meeting basic measures (following information from CABI 2019b; EFSA 2018):</p> <ul style="list-style-type: none"> • The pest is not reported from citrus and is mainly a pest of Rosaceae (pears, apples, peaches). • The USA PRA decided to associate it with citrus, because <i>C. niponensis</i>, whose identity has been confused with <i>C. sasakii</i>, has been associated with citrus in China. • On the pest's identity, EFSA 2018 notes that <i>C. niponensis</i>, a valid species of no economic significance, was previously mistakenly synonymised with <i>C. sasakii</i> and was regulated in Annex IIAI of 2000/29 EC. • A taxonomic review by Diakonoff in 1989 concluded that <i>C. niponensis</i> and <i>C. sasakii</i> were distinct and valid species; <i>C. niponensis</i> is of no economic importance, whereas <i>C. sasakii</i> is known as a major pest of rosaceous fruits in eastern Asia. • International trade of rosaceous fruits is a possible cause of spread of <i>C. sasakii</i>, but it is difficult for it to enter non-native countries under quarantine inspection. <ul style="list-style-type: none"> ○ Several eggs may be laid on each fruit, usually near the calyx, and many larvae may tunnel a single fruit (up to 13 have been recorded), which would make penetration holes visible on fresh fruit. ○ Even if <i>C. sasakii</i> enters non-native countries by international trade, it is not easy to establish a population, probably because the larvae in fruits cannot find a cocooning site near rosaceous plants after escaping from the fruits.
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Pest taxon	Rationale for excluded taxa, examples of excluded taxa
	<ul style="list-style-type: none"> The distribution of <i>C. sasakii</i> is limited to the temperate Far East, centred on northeastern China and Japan. It is not known to have spread to other areas. <p><i>Prays citri</i> (citrus flower moth). External feeder on flowers, leaves, buds. Eggs are laid individually on the flowers, and sometimes on young fruit. On hatching the larvae bore flowers and small fruits, however, larvae are likely to have emerged from infested young fruit by the time fruit is mature. Cocoons may be found on fruits, flowers and leaves (CABI 2019c). From EFSA (2008b): eggs are occasionally also laid on larger fruits, but it is reported that in lemon, larval development from such eggs is not successful. Larvae very rarely infest more developed fruits. Pupal cocoons may be found externally on fruits but can easily be detected by the naked eye. Eggs or late developmental stages (like fully grown larvae or pupae) of <i>P. citri</i> that could be present on the outside of the fruit are unlikely to survive routine packinghouse procedures (washing, waxing, grading).</p> <p>Other Lepidoptera identified as potentially feeding on citrus typically feed on plant parts other than fruit and are unlikely to be associated with fruit in trade, e.g. <i>Eudocima fullonia</i> (fruit-piercing moth – adult only feeds on fruit), <i>Gymnoscelis rufifasciata</i> (double-striped pug), <i>Platynota stultana</i> (omnivorous leafroller), <i>Spodoptera eridania</i> (southern armyworm), <i>Stathmopoda auriferella</i>, <i>Trichoplusia ni</i> (cabbage looper), <i>Xestia c-nigrum</i> (spotted cutworm).</p>
Order Thysanoptera (thrips)	<p>Four thrips were identified as requiring further assessment (<i>Caliothrips fasciatus</i>, <i>Chaetanaphothrips orchidii</i>, <i>Scirtothrips dorsalis</i>, <i>Thrips palmi</i>). Of the few other thrips that were reported to be associated with fruit, such as <i>Thrips hawaiiensis</i> and <i>Scirtothrips citri</i>, the association was with very young fruit or the flower ovary and therefore did not meet the criteria for further assessment.</p> <p>Note that thrips that are potential vectors, e.g. <i>Thrips tabaci</i>, <i>Frankliniella intonsa</i> and <i>F. occidentalis</i>, were assessed in a separate vector analysis PRA.</p>
Mites	
Subclass Acari (mites): (Families Eriophyidae, Tenuipalpidae, Tetranychidae)	<p>Three mites were identified as requiring further assessment (<i>Auculops pelekassi</i>, <i>Eotetranychus lewisi</i>, <i>Tetranychus kanzawai</i>). Of the few other mites that were reported to be associated with citrus fruit, such as <i>Eotetranychus kankitus</i>, the association was either with very young fruit or caused premature fruit drop and therefore did not meet the criteria for further assessment.</p> <p>Note that mites that are potential vectors, e.g. <i>Brevipalpus phoenicis</i> and other <i>Brevipalpus</i> spp., were assessed in a separate vector analysis PRA.</p>

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Appendix 2: Glossary and Abbreviations

Term or abbreviation	Definiton
BRAD	Biosecurity Risk Analysis Database. MPI internal database that records the historic regulatory status and other information about plant pests.
CASE	C ontention A rgument S ource E vidence. Under the CASE schema, the contention or conclusion is presented first, followed by the arguments supporting this contention and the evidence and sources supporting each argument.
CMI	Climate (or composite) match index, a value that indicates the similarities between a location overseas and New Zealand (Phillips et al. 2018).
Commercial production	Definition for the purposes of risk assessment: a process/system where activities, such as in-field monitoring, in-field pest control activities, harvesting, cleaning, sorting and grading have been undertaken to produce a commodity that is free of defects such as broken skin, rot and damage. Depending on the systems in place, these activities can be undertaken at any stage from the point of planting to the point of export.
commodity description	A description of a commodity that includes all relevant aspects of its production or manufacture, storage, transport and processing or treatment that is not mandated through measures (and as such does not require a risk assessment).
conditional non-host	A commodity at a specified physical condition that cannot support the complete development of a particular pest or disease.
CPC	<i>Crop Protection Compendium</i> . A CABI database that provides information about crop pests.
disease	A finite abnormality of structure or function with an identifiable pathological or clinicopathological basis, and with a recognizable syndrome of clinical signs. Its cause may not be known or may be from infection with a known organism (Blood & Studdert 1990).
endemic	An animal, plant, pest, or disease that is native to and is not naturally found outside a defined geographical area.
establishment	Perpetuation, for the foreseeable future, of an organism or disease within an area after entry (ISPM 5 2021).
ERS	Emerging Risk System, an MPI workflow system that allows MPI to receive, process and store information about new biosecurity risks and to manage those risks in a timely fashion.
exposure	The transfer of a pest or disease from an imported commodity or inanimate object, to a host or environment suitable for the completion of development or production of offspring.
exotic	This word has different meanings in different fields, but in this document, it is defined as an animal, plant, pest or disease that is not indigenous to New Zealand.
hazard	Any pest or disease that is associated with a commodity or import pathway and has the potential to produce adverse consequences within a risk analysis area.
indigenous	Native; organism originating or occurring naturally in a specified area.
inspection	Official visual examination of plants, plant products or other regulated articles to determine if pests are present and/or to determine compliance with phytosanitary regulations (ISPM 5 2021).
introduced	Not indigenous, not native to the area in which it now occurs, having been brought into this area directly or indirectly by human activity.

Term or abbreviation	Definiton
IPPC	International Plant Protection Convention, a 1951 multilateral treaty overseen by the Food and Agriculture Organization that aims to secure coordinated, effective action to prevent and to control the introduction and spread of pests of plants and plant products.
ISPM	International Standards for Phytosanitary Measures, international standards adopted by the Conference of the Food and Agriculture Organization, the Interim Commission on phytosanitary measures or the Commission on phytosanitary measures, established under the IPPC.
IHS	Import Health Standard (See “Import Health Standard” for a definition.)
Import Health Standard	An import health standard (IHS) is a document issued under section 24A of the Biosecurity Act 1993. It states the requirements that must be met before risk goods can be imported into New Zealand.
IRA	Import Risk Analysis, an administrative process through which quarantine policy is developed or reviewed, incorporating risk assessment, risk management and risk communication.
MPI	Ministry for Primary Industries, New Zealand
non-host	A commodity that will not support the complete development of a particular pest or disease.
NPPO	National Plant Protection Organisation, official service established by a government to discharge the functions specified by the IPPC (ISPM 5 2021).
NZOR	New Zealand Organisms Register, an actively maintained compilation of all organism names relevant to New Zealand: indigenous, endemic or exotic species or species not present in New Zealand but of national interest.
ONZPR	Official New Zealand Pest Register. MPI database that records organisms that may be associated with plants or plant products that are imported into New Zealand. Plant and plant product importers can use ONZPR to find out the regulatory status of a pest or disease – regulated or non-regulated.
pest	Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (ISPM 5 2021)
pest-free area	An area in which a specific pest is absent as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained (ISPM 5 2021).
pest-free place of production	Place of production in which a specific pest is absent as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period (ISPM 5 2021).
PFA	Pest-free area (See “Pest-free area” for a definition.)
PFPP	Pest-free place of production (See “Pest-free place of production” for a definition.)
PPIN	Plant Pest Information Network database (MPI), a record of organisms collected in New Zealand and identified by MPI’s Plant Health and Environment Laboratory.
PRA	Pest Risk Assessment or Pest Risk Analysis
QuanCargo	New Zealand border transaction database, detailing commercial consignments and interceptions of pests made by quarantine inspection (MPI).
quarantine pest	A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (ISPM 5 2021).

Term or abbreviation	Definiton
risk management question/s	Specific question/s which the risk manager needs answered in order to make a decision.
systems approach	A pest risk management option that integrates different measures, at least two of which act independently, with cumulative effect (ISPM 5 2021).
vector	An organism or object that transfers a pest, parasite, pathogen or disease from one area or host to another.

Appendix 3: Risk Status of Armoured Scale Insects

To facilitate the management of pests and diseases associated with an imported commodity, an IHS can include a list of pests or diseases that are a risk on the pathway e.g., if they were associated with the pathway they have a likelihood of entry and a level of impact that when combined equate to an unacceptable level of risk.

ISPM 19 (2003) provides guidelines on creating lists of regulated pests and diseases. The standard covers generic lists of regulated pests and specific lists of regulated pests and diseases by commodity which equates to the pest list include in an IHS. The standard notes that the IPPC requires technical justification for all regulated pests through pest risk analysis.

The standard states that “*A specific list of regulated pests, which should be a subset of those lists, may be provided by the importing contracting party to the exporting contracting party as the means to make known to the exporting contracting party those pests for which inspection, testing or other specific procedures are required for particular imported commodities, including phytosanitary certification.*”

MPI (2014) assessed the risk of diaspidids on the fresh produce pathway and concluded that exotic diaspidid species are unlikely to be successfully introduced into New Zealand. The highest overall risk identified was “moderate” (for *Pseudaulacaspis pentagona*) on favoured hosts, e.g., kiwifruit. Measures may be justified if the risk estimate (as determined by the risk assessment) is very low or greater (MPI Risk Analysis Guidelines 2021).

Some factors are recognised as increasing the risk associated with this pathway (see below). Polyphagous species and species that reproduce parthenogenetically (asexually) are considered to present a higher risk, as are host commodities that are architecturally complex and/or particularly robust or have high amounts of unavoidable waste associated with them (MPI 2014).

Although Citrus fruit is relatively robust, it is also structurally simple. In general, aggregations of diaspidids or infestations by adult females, which present the highest risk, are considered likely to be visible during harvesting, processing and on inspection¹⁰⁵. In addition, while there is unavoidable waste (peel) associated with Citrus commodities, this waste is unlikely to remain suitable for the development of the scale insect once discarded (MPI 2014).

Summary of Advice

The diaspidid scale insects associated with *Citrus* species treated by Garcia Morales et al. (2016) are listed in Tables 2 –7. This list is reasonably comprehensive but not exhaustive. It is expected to cover the spectrum of risk that species in this family pose to New Zealand on this pathway.

Records of scale species present in all exporting countries are tabulated for each *Citrus* species.

The following risk factors are assessed¹⁰⁶:

- Commodity association: presence on the fresh produce pathway, in particular the *Citrus* fresh produce pathway. MPI databases, DAWE (2021), EPPO interception records and selected publications were searched.
- Mode of reproduction: diaspidids that are capable of unisexual or parthenogenetic reproduction are likely to represent a higher risk than sexually reproducing species.

¹⁰⁵ However low levels of infestation, particularly by cryptically coloured species, may not be detected (Table 8).

¹⁰⁶ Information from limited sources (see reference list) in order to meet the required timeframe.

Information on mode of reproduction was sourced from Garcia Morales et al. (2016), Watson (2002) and selected publications.

- Host range: polyphagous species are considered to represent a higher risk than oligophages or monophages (MPI 2014). Information on host range was sourced from Garcia Morales et al. (2016), Watson (2002) and selected publications.
- Economic impacts: a very brief precis of information on impacts on plant species of importance to New Zealand is summarised from Garcia Morales et al. (2016) and/or Watson (2002). No other sources have been consulted due to time constraints. This information should be interpreted in the context of the discussion of economic impacts of diaspidids in MPI (2014). Where no impacts are reported in either of these databases it could suggest that the species in question is not likely to be an important pest species, though this is an unsupported assumption.
- Environmental impacts: while some exotic diaspidids have been reported on native plants in New Zealand, there have been no reports of impacts in native systems here. Unlike pseudococcids, diaspidids do not secrete honeydew nor are they known to vector plant diseases (MPI 2014 and references within).
- As a group, diaspidids are likely to present a similar but slightly lower likelihood of establishing via the fresh produce pathway than pseudococcids (mealybugs). Diaspidids are unable to move once the crawler stage is settled, whereas all pseudococcid life stages have some ability to move. Their greater mobility is likely to result in a slightly increased likelihood of exposure for pseudococcids, especially when they are associated with host material (discarded harvested fruit or fruit waste) that is no longer in optimal condition. In addition, many mealybugs feed on roots of plants as well as above ground plant parts, whereas this is not common in diaspidids. Plant roots could be easily accessible near disposed waste.

Supporting Information

The scope of this assessment is limited to searches of the database “ScaleNet” (Garcia Morales et al. 2016) for the *Citrus* commodities assessed in MPI (2021) (Table 1). Note that there are no results for *Citrus reticulata* × *Citrus paradisi* (“Tangelo”) or *Citrus reticulata* × *Citrus sinensis* (“Tangor”). It is expected that range of diaspidids assessed for other *Citrus* species will be representative for these hosts.

Commodity associations were obtained from Watson (2002), ScaleNet (2016), Garcia Morales et al. 2016, CPC (2021), MPI interceptions databases, EPPO GPD (2021) and DAWE (2021).

Commodity/Country Table

Table 1: *Citrus aurantiifolia*

<i>Citrus aurantiifolia</i>	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Aonidiella comperei</i>	Regulated	Brazil, China, Japan, Vietnam	infests leaves, twigs, and larger branches (Garcia Morales et al. 2016), but detected on non-citrus FP (LIMS)	polyphagous; 12 host genera known (Garcia Morales et al. 2016)	male has not been identified (Garcia Morales et al. 2016); may reproduce parthenogenetically	reported as a pest of papaya in Brazil and the Pacific (Martins et al. 2004)	Very low
<i>Aspidiotus excisus</i>	Regulated	China, Fiji, Japan, Mexico, USA, Vietnam	detected on citrus FP (LIMS)	30 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	a pest of ornamental plants (Garcia Morales et al. 2016)	Very low
<i>Chrysomphalus aonidum</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, United States, Viet Nam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low
<i>Howardia biclavis</i>	Regulated	Australia, Brazil, China, Cook Islands, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, United States, Vanuatu, Western Samoa	detected on non-citrus FP (LIMS)	195 host genera known (Garcia Morales et al. 2016)	reproduces parthenogenetically (Garcia Morales et al. 2016)	a pest of citrus, ornamentals, tea and coffee (Garcia Morales et al. 2016)	Low
<i>Lepidosaphes conchiformis</i>	Regulated	China, Egypt, Japan, Spain, USA, North Korea, South Korea	infests fruit (Garcia Morales et al. 2016)	38 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a fig pest (Garcia Morales et al. 2016)	Very low

<i>Citrus aurantiifolia</i>	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Viet Nam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (Garcia Morales et al. 2016); often under effective biological control (Watson 2002)	Very low
<i>Lopholeucaspis cockerelli</i>	Regulated	Australia, Brazil, Cook Islands, Fiji, Japan, Mexico, Peru, USA, Vanuatu, Western Samoa	infests leaves (Watson 2002); not associated with citrus fruit (GG)	polyphagous (Watson 2002); 68 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor pest in the Pacific (Watson 2002)	Negligible
<i>Opuntiaspis carinata</i>	Regulated	Mexico, Peru, USA	no information	Two host genera known (Garcia Morales et al. 2016)	males known (Hamon 1978) so reproduction is probably sexual ¹	no information	Very low
<i>Parlatoria cinerea</i>	Regulated	Brazil, China, Cook Islands, Japan, Mexico, New Caledonia, Spain, United States, Vanuatu, Viet Nam, Western Samoa	detected on citrus FP (LIMS); mainly on stems and branches, but sometimes on leaves and fruit (Watson 2002)	polyphagous (Watson 2002); 14 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	citrus pest in the Pacific (Watson 2002)	Very low
<i>Parlatoria ziziphi</i>	Regulated	Australia, Brazil, China, Egypt, Japan, Peru, Spain, USA, Vietnam	detected on citrus FP (LIMS)	16 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest in some regions (Watson 2002)	Very low
<i>Pinnaspis strachani</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Viet Nam, South Korea, Western Samoa	detected on non-citrus FP (LIMS)	highly polyphagous (Watson 2002); 247 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important occasional pest of several economic crops including citrus, avocado, olive and asparagus (Watson 2002)	Very low
<i>Pseudaonidia trilobitiformis</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, New Caledonia, Peru, USA, Vanuatu, Vietnam	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 111 host genera known (Garcia Morales et al. 2016)	males unknown (Garcia Morales et al. 2016) so may reproduce parthenogenetically	important pest of cashew, citrus and cacao (Watson 2002)	Very low

<i>Citrus aurantiifolia</i>	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Pseudischchnaspis acephala</i>	Regulated	Mexico, Peru	undersides of leaves (Garcia Morales et al. 2016); "not associated with citrus fruit" (Grousset et al. 2016)	11 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	potential pest of avocado in Colombia (Kondo et al. 2016)	Negligible
<i>Selenaspis articulatus</i>	Regulated	Australia, Brazil, China, Fiji, Japan, Mexico, Peru, Solomon Islands, USA, Vietnam	detected on citrus FP (LIMS); on leaves, sometimes on fruit (Watson 2002)	highly polyphagous (Watson 2002); 105 host genera known	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus and coffee (Watson 2002)	Very low
<i>Unaspis citri</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Viet Nam, American Samoa, Western Samoa	detected on citrus FP (LIMS); usually on the trunk and main limbs, but occasionally on leaves and fruits (Watson 2002)	fairly polyphagous (Watson 2002); 18 host genera known	reproduces sexually (Watson 2002)	one of the principal pests of citrus spp. in many regions of the world (Watson 2002)	Very low

¹Does not exclude the possibility of uniparental populations

Table 2: *Citrus latifolia*

<i>Citrus latifolia</i> (1)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Pseudaonidia trilobitiformis</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, New Caledonia, Peru, USA, Vanuatu, Vietnam	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 111 host genera known (Garcia Morales et al. 2016)	males unknown (Garcia Morales et al. 2016) so may reproduce parthenogenetically	important pest of cashew, citrus and cacao (Watson 2002)	Low

Table 3: *Citrus limon*

<i>Citrus limon</i> (25)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Acutaspis scutiformis</i>	Regulated	Brazil, Mexico, USA	no evidence found of association with fruit; infests leaves (Garcia Morales et al. 2016); “not associated with citrus fruit” (Grousset et al. 2016)	10 host genera known (Garcia Morales et al. 2016)	no males have been observed (Garcia Morales et al. 2016), so may reproduce parthenogenetically	a citrus and banana pest in Central and South America (García Morales et al. 2016)	Negligible
<i>Aonidiella citrina</i>	Regulated	Australia, China, Egypt, Fiji, Japan, Mexico, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests mainly leaves and fruit (Garcia Morales et al. 2016)	polyphagous (Garcia Morales et al. 2016); 43 host genera known	reproduces sexually (Garcia Morales et al. 2016)	a pest of citrus in some regions (Watson 2002)	Very low
<i>Aonidiella orientalis</i>	Regulated	Australia, Brazil, China, Mexico, Peru, USA, Vietnam	detected on non-citrus FP (LIMS)	highly polyphagous; 163 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious pest on some tropical crops, also reported as a pest of citrus and ornamentals (Watson 2002)	Very low
<i>Aulacaspis citri</i>	No entry	China	detected on citrus at Korean border, pathway not specified (Suh 2016)	5 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important citrus pest in Sichuan (Lin et al. 1997)	Low
<i>Chrysomphalus aonidum</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low

Citrus limon (25)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Clavaspidiotus apicalis</i>	No entry	Egypt	forms dense colonies on citrus fruit (Garcia Morales et al. 2016)	3 host genera known (Garcia Morales et al. 2016)	no information	a potential citrus pest (Garcia Morales et al. 2016)	Very low
<i>Diaspidiotus degeneratus</i>	No entry	China, Japan, USA, North Korea, South Korea	infests leaves (Garcia Morales et al. 2016, DAWE 2020)	11 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	once a common nursery pest, now rare (Garcia Morales et al. 2016)	Negligible
<i>Duplaspidiotus claviger</i>	Regulated	China, Cook Islands, Fiji, Japan, USA, Western Samoa	on twigs and branches, under the epidermis (Watson 2002); "not associated with citrus fruit" (Grousset et al. 2016)	13 host genera known (Garcia Morales et al. 2016)	male is not known (Watson 2005), so may reproduce parthenogenetically	a pest of ornamentals (Watson 2002)	Negligible
<i>Fiorinia proboscidea</i>	Regulated	China, Fiji, Japan, USA	detected on citrus FP (LIMS)	13 host genera known (Garcia Morales et al. 2016)	male known (FDACS 2015) so reproduction is probably sexual ¹	a potential citrus pest (Garcia Morales et al. 2016)	Very low
<i>Hemiberlesia palmae</i>	No entry	Australia, Brazil, China, Fiji, Mexico, Peru, Solomon Islands, USA, Vietnam, Western Samoa	detected on non-citrus FP (LIMS)	97 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a pest of various crops and palms in the tropics (Garcia Morales et al. 2016)	Low
<i>Howardia biclavata</i>	Regulated	Australia, Brazil, China, Cook Islands, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vanuatu, Western Samoa	detected on non-citrus FP (LIMS)	195 host genera known (Garcia Morales et al. 2016)	reproduces parthenogenetically (Garcia Morales et al. 2016)	a pest of citrus, ornamentals, tea and coffee (Garcia Morales et al. 2016)	Low
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (Garcia Morales et al. 2016); often under effective biological control (Watson 2002)	Very low
<i>Lopholeucaspis cockerelli</i>	Regulated	Australia, Brazil, Cook Islands, Fiji, Japan, Mexico, Peru, USA, Vanuatu, Western Samoa	infests leaves (Watson 2002); "not associated with citrus fruit" (Grousset et al. 2016)	polyphagous (Watson 2002); 68 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor pest in the Pacific (Watson 2002)	Negligible

<i>Citrus limon</i> (25)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Morganella longispina</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, USA, Western Samoa	detected on citrus FP (LIMS); on branches and occasionally on fruit (Watson 2002)	polyphagous (Watson 2002); 39 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor citrus pest (Garcia Morales et al. 2016); also a pest of other tropical fruit but more often ornamentals (Watson 2002)	Very low
<i>Odonaspis morrisoni</i>	Regulated	Fiji	no information due to limited distribution	6 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	no information due to limited distribution	Very low
<i>Parlatoria cinerea</i>	Regulated	Brazil, China, Cook Islands, Japan, Mexico, New Caledonia, Spain, United States, Vanuatu, Vietnam, Western Samoa	detected on citrus FP (LIMS); mainly on stems and branches, but sometimes on leaves and fruit (Watson 2002)	polyphagous (Watson 2002); 14 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	citrus pest in the Pacific (Watson 2002)	Very low
<i>Parlatoria crypta</i>	Regulated	N/A (does not occur in any of the exporting countries)	intercepted on non-citrus FP (DAWE 2021)	39 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	pest of olive (Najafinia et al. 2002)	Very low
<i>Parlatoria oleae</i>	Regulated	Australia, Brazil, China, Egypt, Mexico, Spain, USA	infests fruit (Garcia Morales et al. 2016)	highly polyphagous (Watson 2002); 120 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	pest of olives; also stonefruit, pipfruit (particularly on fruits) and ornamentals (Watson 2002)	Very low
<i>Parlatoria pergandii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Japan, Mexico, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 57 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest, occasional pest of ornamentals (Watson 2002)	Very low
<i>Parlatoria ziziphi</i>	Regulated	Australia, Brazil, China, Egypt, Japan, Peru, Spain, USA, Vietnam	detected on citrus FP (LIMS)	16 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest in some regions (Watson 2002)	Very low

<i>Citrus limon</i> (25)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Pinnaspis strachani</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Vietnam, South Korea, Western Samoa	detected on non-citrus FP (LIMS)	highly polyphagous (Watson 2002); 247 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important occasional pest of several economic crops including citrus, avocado, olive and asparagus (Watson 2002)	Very low
<i>Pseudaonidia trilobitiformis</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, New Caledonia, Peru, USA, Vanuatu, Vietnam	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 111 host genera known (Garcia Morales et al. 2016)	males unknown (Garcia Morales et al. 2016) so may reproduce parthenogenetically	important pest of cashew, citrus and cacao (Watson 2002)	Low
<i>Selenaspidus articulatus</i>	Regulated	Australia, Brazil, China, Fiji, Japan, Mexico, Peru, Solomon Islands, USA, Vietnam	detected on citrus FP (LIMS); on leaves, sometimes on fruit (Watson 2002)	highly polyphagous (Watson 2002); 105 host genera known	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus and coffee (Watson 2002)	Very low
<i>Unaspis citri</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, American Samoa, Western Samoa	detected on citrus FP (LIMS); usually on the trunk and main limbs, but occasionally on leaves and fruits (Watson 2002)	fairly polyphagous (Watson 2002); 18 host genera known	reproduces sexually (Watson 2002)	one of the principal pests of citrus spp. in many regions of the world (Watson 2002)	Very low

¹Does not exclude the possibility of uniparental populations

Table 4: *Citrus maxima*

<i>Citrus maxima</i> (24)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Aonidiella comperei</i>	Regulated	Brazil, China, Japan, Vietnam	infests leaves, twigs, and larger branches (Garcia Morales et al. 2016), but detected on non-citrus FP (LIMS)	polyphagous; 12 host genera known (Garcia Morales et al. 2016)	male has not been identified (Garcia Morales et al. 2016); may reproduce parthenogenetically	reported as a pest of papaya in Brazil and the Pacific (Martins et al. 2004)	Very low
<i>Aonidiella orientalis</i>	Regulated	Australia, Brazil, China, Mexico, Peru, USA, Vietnam	detected on non-citrus FP (LIMS)	highly polyphagous; 163 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious pest on some tropical crops, also reported as a pest of citrus and ornamentals (Watson 2002)	Very low
<i>Aspidiotus destructor</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Vietnam, South Korea, American Samoa, Western Samoa	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 134 host genera known (Garcia Morales et al. 2016)	Reproduces sexually (Watson 2002). Taylor (1935) reported that <i>A. destructor</i> reproduces parthenogenetically, but Beardsley (1970) refutes this. See footnote 2.	mainly a pest of coconut, banana (Garcia Morales et al. 2016), also mangoes and ornamentals (Grousset et al. 2016)	Very low
<i>Aulacaspis citri</i>	No entry	China	detected on citrus at Korean border, pathway not specified (Suh 2016)	5 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important citrus pest in Sichuan (Lin et al. 1997)	Low
<i>Chrysomphalus aonidum</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low

<i>Citrus maxima</i> (24)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low
<i>Clavaspidiotus apicalis</i>	No entry	Egypt	forms dense colonies on citrus fruit (Garcia Morales et al. 2016)		no information	a potential citrus pest (Garcia Morales et al. 2016)	Very low
<i>Fiorinia proboscidea</i>	Regulated	China, Fiji, Japan, USA	detected on citrus FP (LIMS)	13 host genera known (Garcia Morales et al. 2016)	male known (FDACS 2015) so reproduction is probably sexual ¹	a potential citrus pest (Garcia Morales et al. 2016)	Very low
<i>Lepidosaphes citricola</i>	No entry	China	no information due to limited distribution	1 host genus known (Garcia Morales et al. 2016)	no information due to limited distribution	no information due to limited distribution	Very low
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (Garcia Morales et al. 2016); often under effective biological control (Watson 2002)	Very low
<i>Lepidosaphes tokionis</i>	Regulated	Australia, Fiji, Japan, Mexico, USA, Western Samoa	detected on NS/CFF but not FP (LIMS); on leaves (Watson 2002)	9 host genera known (Garcia Morales et al. 2016)	male known (Watson 2002) so reproduction is probably sexual ¹	minor pest (Watson 2002)	Negligible
<i>Lopholeucaspis cockerelli</i>	Regulated	Australia, Brazil, Cook Islands, Fiji, Japan, Mexico, Peru, USA, Vanuatu, Western Samoa	infests leaves (Watson 2002); "not associated with citrus fruit" (Grousset et al. 2016)	polyphagous (Watson 2002); 68 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor pest in the Pacific (Watson 2002)	Negligible

Citrus maxima (24)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Lopholeucaspis japonica</i>	Regulated	Australia, Brazil, China, Japan, USA, North Korea, South Korea	rarely on fruit; on bark of branches and trunk, rarely on leaves and fruits (Watson 2002)	polyphagous (Watson 2002); 60 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	major pest of citrus, other fruits, tea and ornamental plants (Garcia Morales et al. 2016)	Very low
<i>Morganella longispina</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, USA, Western Samoa	detected on citrus FP (LIMS); on branches and occasionally on fruit (Watson 2002)	polyphagous (Watson 2002); 39 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor citrus pest (Garcia Morales et al. 2016); also a pest of other tropical fruit but more often ornamentals (Watson 2002)	Very low
<i>Parlatoria cinerea</i>	Regulated	Brazil, China, Cook Islands, Japan, Mexico, New Caledonia, Spain, United States, Vanuatu, Vietnam, Western Samoa	detected on citrus FP (LIMS); mainly on stems and branches, but sometimes on leaves and fruit (Watson 2002)	polyphagous (Watson 2002); 14 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	citrus pest in the Pacific (Watson 2002)	Very low
<i>Parlatoria pergandii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Japan, Mexico, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 57 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest, occasional pest of ornamentals (Watson 2002)	Very low
<i>Parlatoria ziziphi</i>	Regulated	Australia, Brazil, China, Egypt, Japan, Peru, Spain, USA, Vietnam	detected on citrus FP (LIMS)	16 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest in some regions (Watson 2002)	Very low
<i>Pinnaspis strachani</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Vietnam, South Korea, Western Samoa	detected on non-citrus FP (LIMS)	highly polyphagous (Watson 2002); 247 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important occasional pest of several economic crops including citrus, avocado, olive and asparagus (Watson 2002)	Very low

<i>Citrus maxima</i> (24)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Pseudaonidia trilobitiformis</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, New Caledonia, Peru, USA, Vanuatu, Vietnam	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 111 host genera known (Garcia Morales et al. 2016)	males unknown (Garcia Morales et al. 2016) so may reproduce parthenogenetically	important pest of cashew, citrus and cacao (Watson 2002)	Low
<i>Pseudaulacaspis pentagona</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, South Korea, Western Samoa	detected on non-citrus FP, especially kiwifruit (LIMS)	251 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	pest of a wide range of crops grown in New Zealand, including kiwifruit and stonefruit. Unusually for a scale insect, it is known to be able to kill some of its hosts (MPI 2014 and references within)	Very low
<i>Selenaspis articulatus</i>	Regulated	Australia, Brazil, China, Fiji, Japan, Mexico, Peru, Solomon Islands, USA, Vietnam	detected on citrus FP (LIMS); on leaves, sometimes on fruit (Watson 2002)	highly polyphagous (Watson 2002); 105 host genera known	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus and coffee (Watson 2002)	Very low
<i>Unaspis citri</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, American Samoa, Western Samoa	detected on citrus FP (LIMS); usually on the trunk and main limbs, but occasionally on leaves and fruits (Watson 2002)	fairly polyphagous (Watson 2002); 18 host genera known	reproduces sexually (Watson 2002)	one of the principal pests of citrus spp. in many regions of the world (Watson 2002)	Very low
<i>Unaspis euonymi</i>	Regulated	China, Egypt, Japan, Mexico, Spain, USA, South Korea	all plant parts (Garcia Morales et al. 2016)	33 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	serious pest of some ornamentals, particularly <i>Euonymus</i> (García Morales et al. 2016)	Very low

<i>Citrus maxima</i> (24)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Unaspis yanonensis</i>	Regulated	Australia, China, Fiji, Japan, Vietnam, South Korea	detected on citrus FP (LIMS)	18 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus in some growing regions (Watson 2002)	Very low

¹Does not exclude the possibility of uniparental populations

² Taylor (1935) reported that *A. destructor* reproduced primarily by parthenogenesis in Fiji. This report has been repeated by other publications and in other databases e.g. Crop Knowledge Master ([Aspidiotus destructor \(hawaii.edu\)](http://Aspidiotus destructor (hawaii.edu))); CPHST data sheet ([2821 \(purdue.edu\)](http://2821 (purdue.edu))). However Beardsley (1970) refutes this assertion and states (of *Aspidiotus destructor*): "Taylor states that males are superfluous in this species and that crawlers of both sexes are produced by parthenogenesis. However cytological studies of *A. destructor* based on material from several localities in the West Indies, have revealed no evidence of parthenogenesis", citing Brown (1965). More recent primary sources do not mention parthenogenesis as a mode of reproduction for this species, e.g. Watson (2002), Garcia Morales et al. (2016) only mention sexual reproduction.

Table 5: *Citrus reticulata*

<i>Citrus reticulata</i> (21)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity Association	Host range	Reproduction	Impact	Risk Assessment (pre-inspection)
<i>Aonidiella citrina</i>	Regulated	Australia, China, Egypt, Fiji, Japan, Mexico, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests mainly leaves and fruit (Garcia Morales et al. 2016)	polyphagous (Garcia Morales et al. 2016); 43 host genera known	reproduces sexually (Garcia Morales et al. 2016)	a pest of citrus in some regions (Watson 2002)	Very low
<i>Aonidiella inornata</i>	Regulated	Australia, China, Fiji, Japan, USA, Vanuatu, Vietnam, Western Samoa	detected on citrus FP (LIMS)	34 host genera known (Garcia Morales et al. 2016)		a pest of papaya and mango (Garcia Morales et al. 2016)	Very low
<i>Aspidiotus excisus</i>	Regulated	China, Fiji, Japan, Mexico, USA, Vietnam	detected on citrus FP (LIMS)	30 host genera known (Garcia Morales et al. 2016)		a pest of ornamental plants (Garcia Morales et al. 2016)	Very low
<i>Aulacaspis citri</i>	No entry	China	detected on citrus at Korean border, pathway not specified (Suh 2016)	5 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important citrus pest in Sichuan (Lin et al. 1997)	Low

<i>Citrus reticulata</i> (21)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity Association	Host range	Reproduction	Impact	Risk Assessment (pre-inspection)
<i>Chrysomphalus aonidum</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low
<i>Fiorinia fioriniae</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vanuatu, Western Samoa	detected on citrus at Taiwan border, pathway not specified (DAWE 2021)	highly polyphagous (Watson 2002); 93 host genera known (Garcia Morales et al. 2016)	male known (Watson 2002) so reproduction is probably sexual ¹	a pest of palms and ornamentals, avocado and olive (Watson 2002)	Very low
<i>Fiorinia proboscidea</i>	Regulated	China, Fiji, Japan, USA	detected on citrus FP (LIMS)	13 host genera known (Garcia Morales et al. 2016)	male known (FDACS 2015) so reproduction is probably sexual ¹	a potential citrus pest (Garcia Morales et al. 2016)	Very low
<i>Hemiberlesia palmae</i>	No entry	Australia, Brazil, China, Fiji, Mexico, Peru, Solomon Islands, USA, Vietnam, Western Samoa	detected on non-citrus FP (LIMS)	97 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a pest of various crops and palms in the tropics (Garcia Morales et al. 2016)	Low
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (Garcia Morales et al. 2016); often under effective biological control (Watson 2002)	Very low

<i>Citrus reticulata</i> (21)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity Association	Host range	Reproduction	Impact	Risk Assessment (pre-inspection)
<i>Morganella longispina</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, USA, Western Samoa	detected on citrus FP (LIMS); on branches and occasionally on fruit (Watson 2002)	polyphagous (Watson 2002); 39 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor citrus pest (Garcia Morales et al. 2016); also a pest of other tropical fruit but more often ornamentals (Watson 2002)	Very low
<i>Octaspidiotus stauntoniae</i>	Regulated	China, Japan, Vietnam, South Korea	reported on citrus leaves, fruit and twigs (Dao et al. 2017)	23 host genera known (Garcia Morales et al. 2016)	no information	no information	Very low
<i>Parlatoria cinerea</i>	Regulated	Brazil, China, Cook Islands, Japan, Mexico, New Caledonia, Spain, United States, Vanuatu, Vietnam, Western Samoa	detected on citrus FP (LIMS); mainly on stems and branches, but sometimes on leaves and fruit (Watson 2002)	polyphagous (Watson 2002); 14 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	citrus pest in the Pacific (Watson 2002)	Very low
<i>Parlatoria oleae</i>	Regulated	Australia, Brazil, China, Egypt, Mexico, Spain, USA	infests fruit (Garcia Morales et al. 2016)	highly polyphagous (Watson 2002); 120 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	pest of olives; also stonefruit, pipfruit (particularly on fruits) and ornamentals (Watson 2002)	Very low
<i>Parlatoria pergandii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Japan, Mexico, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 57 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest, occasional pest of ornamentals (Watson 2002)	Very low
<i>Parlatoria ziziphi</i>	Regulated	Australia, Brazil, China, Egypt, Japan, Peru, Spain, USA, Vietnam	detected on citrus FP (LIMS)	16 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest in some regions (Watson 2002)	Very low
<i>Pinnaspis strachani</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Vietnam, South Korea, Western Samoa	detected on non-citrus FP (LIMS)	highly polyphagous (Watson 2002); 247 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important occasional pest of several economic crops including citrus, avocado, olive and asparagus (Watson 2002)	Very low

<i>Citrus reticulata</i> (21)	ONZPR status	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity Association	Host range	Reproduction	Impact	Risk Assessment (pre-inspection)
<i>Pseudaulacaspis pentagona</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, South Korea, Western Samoa	detected on non-citrus FP, especially kiwifruit (LIMS)	251 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	pest of a wide range of crops grown in New Zealand, including kiwifruit and stonefruit. Unusually for a scale insect, it is known to be able to kill some of its hosts (MPI 2014 and references within)	Very low
<i>Selenaspidus articulatus</i>	Regulated	Australia, Brazil, China, Fiji, Japan, Mexico, Peru, Solomon Islands, USA, Vietnam	detected on citrus FP (LIMS); on leaves, sometimes on fruit (Watson 2002)	highly polyphagous (Watson 2002); 105 host genera known	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus and coffee (Watson 2002)	Very low
<i>Unaspis citri</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, American Samoa, Western Samoa	detected on citrus FP (LIMS); usually on the trunk and main limbs, but occasionally on leaves and fruits (Watson 2002)	fairly polyphagous (Watson 2002); 18 host genera known	reproduces sexually (Watson 2002)	one of the principal pests of citrus spp. in many regions of the world (Watson 2002)	Very low
<i>Unaspis yanonensis</i>	Regulated	Australia, China, Fiji, Japan, Vietnam, South Korea	detected on citrus FP (LIMS)	18 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	important pest of citrus in some growing regions (Watson 2002)	Very low

¹Does not exclude the possibility of uniparental populations

Table 6: *Citrus paradisi*

<i>Citrus paradisi</i> (5)	NZ (ONZPR)	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Host range	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Aonidiella citrina</i>	Regulated	Australia, China, Egypt, Fiji, Japan, Mexico, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests mainly leaves and fruit (Garcia Morales et al. 2016)	polyphagous (Garcia Morales et al. 2016); 43 host genera known	reproduces sexually (Garcia Morales et al. 2016)	a pest of citrus in some regions (Watson 2002)	Very low
<i>Chrysomphalus aonidum</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (Garcia Morales et al. 2016); often under effective biological control (Watson 2002)	Very low
<i>Lopholeucaspis cockerelli</i>	Regulated	Australia, Brazil, Cook Islands, Fiji, Japan, Mexico, Peru, USA, Vanuatu, Western Samoa	infests leaves (Watson 2002); “not associated with citrus fruit” (Grousset et al. 2016)	polyphagous (Watson 2002); 68 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor pest in the Pacific (Watson 2002)	Negligible

¹Does not exclude the possibility of uniparental populations

Table 7: *Citrus sinensis*

<i>Citrus sinensis</i> (16)	NZ (ONZPR)	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Polyphagy	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Aonidiella citrina</i>	Regulated	Australia, China, Egypt, Fiji, Japan, Mexico, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests mainly leaves and fruit (Garcia Morales et al. 2016)	polyphagous (Garcia Morales et al. 2016); 43 host genera known	reproduces sexually (Garcia Morales et al. 2016)	a pest of citrus in some regions (Watson 2002)	Very low
<i>Aonidiella comperei</i>	Regulated	Brazil, China, Japan, Vietnam	infests leaves, twigs, and larger branches (Garcia Morales et al. 2016), but detected on non-citrus FP (LIMS)	polyphagous; 12 host genera known (Garcia Morales et al. 2016)	male has not been identified (Garcia Morales et al. 2016); may reproduce parthenogenetically	reported as a pest of papaya in Brazil and the Pacific (Martins et al. 2004)	Very low
<i>Aonidiella orientalis</i>	Regulated	Australia, Brazil, China, Mexico, Peru, USA, Vietnam	detected on non-citrus FP (LIMS)	highly polyphagous; 163 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious pest on some tropical crops, also reported as a pest of citrus and ornamentals (Watson 2002)	Very low
<i>Aspidiotus destructor</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, USA, Vanuatu, Vietnam, South Korea, American Samoa, Western Samoa	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 134 host genera known (Garcia Morales et al. 2016)	Reproduces sexually (Watson 2002). Taylor (1935) reported that <i>A. destructor</i> reproduces parthenogenetically, but Beardsley (1970) refutes this. See footnote 2.	mainly a pest of coconut, banana (Garcia Morales et al. 2016), also mangoes and ornamentals (Grousset et al. 2016)	Very low
<i>Chrysomphalus aonidium</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS); infests leaves and fruit (Garcia Morales et al. 2016)	very polyphagous; 181 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Garcia Morales et al. 2016)	a serious citrus pest in a number of countries; a minor avocado pest (Watson 2002)	Very low
<i>Chrysomphalus dictyospermi</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	very polyphagous; 196 host genera known (Garcia Morales et al. 2016)	unisexual and bisexual populations have been reported (Garcia Morales et al. 2016)	a serious pest of avocado and citrus; capable of infesting a range of commercial crops (MPI 2014)	Low

<i>Citrus sinensis</i> (16)	NZ (ONZPR)	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Polyphagy	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Fiorinia proboscidaria</i>	Regulated	China, Fiji, Japan, USA	detected on citrus FP (LIMS)	13 host genera known (Garcia Morales et al. 2016)	male known (FDACS 2015) so reproduction is probably sexual ¹	a potential citrus pest (García Morales et al. 2016)	Very low
<i>Lepidosaphes gloverii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Solomon Islands, Spain, United States, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 40 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	serious pest of Florida citrus (García Morales et al. 2016); often under effective biological control (Watson 2002)	Very low
<i>Lopholeucaspis cockerelli</i>	Regulated	Australia, Brazil, Cook Islands, Fiji, Japan, Mexico, Peru, USA, Vanuatu, Western Samoa	infests leaves (Watson 2002); “not associated with citrus fruit” (Grousset et al. 2016)	polyphagous (Watson 2002); 68 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	minor pest in the Pacific (Watson 2002)	Negligible
<i>Parlatoria cinerea</i>	Regulated	Brazil, China, Cook Islands, Japan, Mexico, New Caledonia, Spain, United States, Vanuatu, Vietnam, Western Samoa	detected on citrus FP (LIMS); mainly on stems and branches, but sometimes on leaves and fruit (Watson 2002)	polyphagous (Watson 2002); 14 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	citrus pest in the Pacific (Watson 2002)	Very low
<i>Parlatoria crotonis</i>	Regulated	Brazil, China, Cook Islands, Egypt, Fiji, Mexico, New Caledonia, Solomon Islands, USA	no evidence of association with fruit; detected on NS/CFF (LIMS)	15 host genera known (Garcia Morales et al. 2016)	males known (Garcia Morales et al. 2016) so reproduction is probably sexual ¹	Listed as a “potential or actual” pest of citrus in Egypt (FAO 1996)	Negligible
<i>Parlatoria oleae</i>	Regulated	Australia, Brazil, China, Egypt, Mexico, Spain, USA	infests fruit (Garcia Morales et al. 2016)	highly polyphagous (Watson 2002); 120 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	pest of olives; also stonefruit, pipfruit (particularly on fruits) and ornamentals (Watson 2002)	Very low
<i>Parlatoria pergandii</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Japan, Mexico, Spain, USA, Vietnam, South Korea, Western Samoa	detected on citrus FP (LIMS)	polyphagous (Watson 2002); 57 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest, occasional pest of ornamentals (Watson 2002)	Very low

<i>Citrus sinensis</i> (16)	NZ (ONZPR)	Exporting countries in which scale is reported (Garcia Morales et al. 2016)	Commodity association	Polyphagy	Reproduction	Impacts	Risk Assessment (pre-inspection)
<i>Parlatoria ziziphi</i>	Regulated	Australia, Brazil, China, Egypt, Japan, Peru, Spain, USA, Vietnam	detected on citrus FP (LIMS)	16 host genera known (Garcia Morales et al. 2016)	reproduces sexually (Watson 2002)	important citrus pest in some regions (Watson 2002)	Very low
<i>Pseudaonidia trilobitiformis</i>	Regulated	Australia, Brazil, China, Egypt, Fiji, Japan, New Caledonia, Peru, USA, Vanuatu, Vietnam	detected on citrus FP (LIMS)	highly polyphagous (Watson 2002); 111 host genera known (Garcia Morales et al. 2016)	males unknown (Garcia Morales et al. 2016) so may reproduce parthenogenetically	important pest of cashew, citrus and cacao (Watson 2002)	Low
<i>Unaspis citri</i>	Regulated	Australia, Brazil, China, Cook Islands, Egypt, Fiji, Japan, Mexico, New Caledonia, Peru, Solomon Islands, Spain, USA, Vanuatu, Vietnam, American Samoa, Western Samoa	detected on citrus FP (LIMS); usually on the trunk and main limbs, but occasionally on leaves and fruits (Watson 2002)	fairly polyphagous (Watson 2002); 18 host genera known	reproduces sexually (Watson 2002)	one of the principal pests of citrus spp. in many regions of the world (Watson 2002)	Very low

¹ Does not exclude the possibility of uniparental populations

² Taylor (1935) reported that *A. destructor* reproduced primarily by parthenogenesis in Fiji. This report has been repeated by other publications and in other databases e.g. Crop Knowledge Master ([Aspidiotus destructor \(hawaii.edu\)](http://Aspidiotus destructor (hawaii.edu))); CPHST data sheet ([2821 \(purdue.edu\)](http://2821 (purdue.edu))). However Beardsley (1970) refutes this assertion and states (of *Aspidiotus destructor*): "Taylor states that males are superfluous in this species and that crawlers of both sexes are produced by parthenogenesis. However cytological studies of *A. destructor* based on material from several localities in the West Indies, have revealed no evidence of parthenogenesis", citing Brown (1965). More recent primary sources do not mention parthenogenesis as a mode of reproduction for this species, e.g. Watson (2002), Garcia Morales et al. (2016) only mention sexual reproduction.

Table 8: Preliminary assessment of detectability of adult female diaspidids associated with *Citrus* species

Species	Detectability	Colour Contrast*	Tolerance from 600 sample	Sample to achieve 0.5% tolerance
<i>Acutaspis scutiformis</i>	scale is dark brown, with the exuviae yellowish (García Morales et al. 2016); likely to be detectable	100%	0.5%	600
<i>Aonidiella citrina</i>	scale is lemon yellow to yellow-brown (Watson 2002); may be harder to detect on citrus fruit	80%	0.5%	600
<i>Aonidiella comperei</i>	scale is yellow, turning orange at maturity (García Morales et al. 2016); may be harder to detect on citrus fruit	40%	0.63% (1 in 159)	759
<i>Aonidiella inornata</i>	scale is yellow-brown, translucent (García Morales et al. 2016); may be harder to detect on citrus fruit	60%	0.5%	600
<i>Aonidiella orientalis</i>	scale is off-white to pale brown or yellow, with yellow to dark brown exuviae (Watson 2002) and is likely to be detectable on citrus fruit	100%	0.5%	600
<i>Aspidiotus destructor</i>	scale is pale and translucent, with yellow exuviae (Watson 2002) and may be harder to detect on citrus fruit	70%	0.5%	600
<i>Aspidiotus excisus</i>	scale is semi-transparent, whitish or very pale ochreous with yellow exuviae (García Morales et al. 2016) and may be harder to detect on citrus fruit	70%	0.5%	600
<i>Aulacaspis citri</i>	scale is white or dirty white (García Morales et al. 2016) and is likely to be detectable on citrus fruit	100%	0.5%	600
<i>Chrysomphalus aonidum</i>	scale is dark brown or bluish-black with reddish brown central exuviae (Watson 2002) and is likely to be detectable on citrus fruit	100%	0.5%	600
<i>Chrysomphalus dictyospermi</i>	scale is greyish or reddish-brown, often with a coppery tinge and with yellow or white exuviae (Watson 2002) and may be harder to detect on citrus fruit	70%	0.5%	600
<i>Clavaspidotus apicalis</i>	No information found	100%	0.5%	600
<i>Diaspidiotus degeneratus</i>	scale is very light brown, becoming white sub-centrally (García Morales et al. 2016) and may be harder to detect on citrus fruit	70%	0.5%	600
<i>Duplaspidiotus claviger</i>	scale is often concealed under host's epidermis, grey with subcentral yellow-orange or bronze exuviae (Watson 2002) (unlikely to be on fruit)	20%	1.25% (1 in 80)	1,497
<i>Fiorinia fioriniae</i>	scale is transparent light or yellowish brown with a yellowish exuviae (Watson 2002) and may be harder to detect on citrus fruit	50%	0.55% (1 in 182)	655
<i>Fiorinia proboscidaria</i>	scale is light brown, glossy with white cast skin (FDACS) and may be harder to detect on citrus fruit	60%	0.5%	600
<i>Hemiberlesia palmae</i>	scale is off-white or straw-coloured to dark brown with darker exuviae (Watson 2002); some variations may be harder to detect on citrus fruit	70%	0.5%	600
<i>Howardia biclavis</i>	scale is white or yellow with light brown submarginal exuviae (Watson 2002) and is likely to be detectable on citrus fruit	100%	0.5%	600
<i>Lepidosaphes conchiformis</i>	scale is brown (García Morales et al. 2016) and may be harder to detect on citrus fruit	80%	0.5%	600
<i>Lepidosaphes gloverii</i>	scale changes from brownish-yellow to dark brown with age, with yellowish-brown exuviae (Watson 2002); some variations may be harder to detect on citrus fruit	70%	0.5%	600
<i>Lepidosaphes tokionis</i>	scale is more or less pale brown, sometimes with a paler margin, with brown terminal exuviae (Watson 2002) and may be harder to detect on citrus fruit	70%	0.5%	600

Species	Detectability	Colour Contrast*	Tolerance from 600 sample	Sample to achieve 0.5% tolerance
<i>Lopholeucaspis cockerelli</i>	scale is brown but covered in a thin secretion of white wax that sometimes gets rubbed off (Watson 2002); some variations may be harder to detect on citrus fruit	80%	0.5%	600
<i>Lopholeucaspis japonica</i>	scale is red-brown with grey-white wax cover (sometimes gets rubbed off) and a brown exuviae (Watson 2002); likely to be detectable	100%	0.5%	600
<i>Morganella longispina</i>	scale is almost black, with a dark central exuviae (Watson 2002) and is likely to be easily detectable	100%	0.5%	600
<i>Octaspidiotus stauntoniae</i>	scale is grey, semi-transparent (García Morales et al. 2016) and may be harder to detect on citrus fruit	80%	0.5%	600
<i>Odonaspis morrisoni</i>	No information found	Unknown	Unknown	Unknown
<i>Opuntiaspis carinata</i>	No information found	Unknown	Unknown	Unknown
<i>Parlatoria cinerea</i>	scale is white or grey, with yellow-brown exuviae (Watson 2002) and is likely to be detectable	100%	0.5%	600
<i>Parlatoria crotonis</i>	No information found	Unknown	Unknown	Unknown
<i>Parlatoria crypta</i>	No information found	Unknown	Unknown	Unknown
<i>Parlatoria oleae</i>	scale is white to very light grey with darker exuviae (Watson 2002) and is likely to be detectable	100%	0.5%	600
<i>Parlatoria pergandii</i>	scale is translucent light tan or grey-brown, with slightly darker yellow-brown exuviae (Watson 2002) and may be harder to detect on citrus fruit	70%	0.5%	600
<i>Parlatoria ziziphi</i>	scale is black with a lip of white wax on the posterior margin (Watson 2002) and is likely to be easily detectable	100%	0.5%	600
<i>Pinnaspis strachani</i>	scale is white to grey, with yellowish-brown exuviae (Watson 2002) and is likely to be detectable	100%	0.5%	600
<i>Pseudaonidia trilobitiformis</i>	scale is pale or yellow-brown, with dark red-brown exuviae (Watson 2002) and may be harder to detect on citrus fruit	60%	0.5%	600
<i>Pseudaulacaspis pentagona</i>	scale is white or yellow-white with yellow or reddish brown exuviae (Watson 2002) and is likely to be detectable	100%	0.5%	600
<i>Pseudischnaspis acephala</i>	No information found	Unknown	Unknown	Unknown
<i>Selenaspis articulatus</i>	scale is semitransparent, grey to light brown, with margin white or yellow; exuviae yellow or brown (Watson 2002); may be harder to detect on citrus fruit	60%	0.5%	600
<i>Unaspis citri</i>	scale is brown or brown-black with a paler margin with brown-yellow terminal exuviae (Watson 2002) and is likely to be easily detectable	100%	0.5%	600
<i>Unaspis euonymi</i>	No information found	Unknown	Unknown	Unknown
<i>Unaspis yanonensis</i>	scale is blackish-brown with a paler margin and brownish-yellow exuviae (Watson 2002) and is likely to be easily detectable	100%	0.5%	600

*note: estimates only based on description.

Additional information was requested about weedy and poaceous hosts of the following species: *Aonidiella comperei*, *Chrysomphalus dictyospermi*, *Hemiberlesia palmae*, *Howardia biclavis* and *Pseudaonidia trilobitiformis*.

1. *Aonidiella comperei*

- This species is not highly polyphagous
- no grasses (Poaceae) are reported as hosts by García Morales et al. (2016)

2. *Chrysomphalus dictyospermi*

- a wide variety of common garden plants present in New Zealand* are reported as hosts by García Morales et al. (2016), e.g. roses, camellias, box hedging, peonies
- some common New Zealand weedy species are reported as hosts by García Morales et al. (2016), e.g. wild broom (*Cytisus scoparius*), barberry (*Berberis*) and cotoneaster
- the only Poaceae (grass family) García Morales et al. (2016) record *C. dictyospermi* from is bamboo

3. *Hemiberlesia palmae*

- some common New Zealand weedy species belong to genera that are reported as hosts by García Morales et al. (2016), e.g. milkweed (*Euphorbia peplus*) and the weedy grass species *Miscanthus nepalensis*
- *Cordyline* has been reported as a host (García Morales et al. 2016), indicating that native cabbage trees may host this species

4. *Howardia biclavis*

- no grasses (Poaceae) are reported as hosts by García Morales et al. (2016)
- “*Howardia biclavis* is a tropical species, probably of African origin, but now occurs almost world-wide (under glass in cooler regions)” (Watson 2006)
- Though it has been detected at the NZ border on non-citrus FP (LIMS), it does not have a strong association with fruit. “On bark of trunk and branches, often under the epidermis” (Watson 2006)

5. *Pseudaonidia trilobitiformis*

- no grasses (Poaceae) are reported as hosts by García Morales et al. (2016)
- some New Zealand weedy species are reported as hosts by García Morales et al. (2016), e.g. loquat (*Eriobotrya japonica*) and *Passiflora edulis*
- *Cordyline* has been reported as a host (García Morales et al. 2016), indicating that native cabbage trees may host this species

References: references for plant presence in NZ are from New Zealand Plant Conservation Network [New Zealand Plant Conservation Network \(nzpcn.org.nz\)](http://nzpcn.org.nz). Weed species are listed here: [Consolidated list of environmental weeds in New Zealand \(doc.govt.nz\)](http://doc.govt.nz).

Additional information on impacts was requested for: *Hemiberlesia palmae* and *Pseudaonidia trilobitiformis*

1. *Hemiberlesia palmae*

Some plant species of economic importance to New Zealand have been reported as hosts of *Hemiberlesia palmae*, including apple, avocado, citrus species, *Eucalyptus* and *Pinus*, however it does not appear to have been reported to be economically important on these species. It has been reported as a pest (economically important) on some tropical crops, e.g. bananas, tea and oil palm in Malaysia and bananas in Fiji (DAWE 2021, Watson 2006).

Watson (2002) describes *Hemiberlesia palmae* as a tropical species and García Morales et al. (2016) report it as a “pest of crops in the tropics”. It is present in temperate countries “under glass”, i.e. in glasshouses and other sheltered environments. As such, its impact on outdoor crops in New Zealand and also its distribution is likely to be limited by climate, However it may cause damage and control costs to host crops grown under cover, such as orchids and palms in greenhouses (García Morales et al. 2016).

2. *Pseudaonidia trilobitiformis*

Some plant species of economic importance to New Zealand have been reported as hosts of *Pseudaonidia trilobitiformis*, including avocado, capsicum, citrus species, pears and grapevine. Impacts have been reported on citrus (Watson 2006) but otherwise this species is not reported to be an important pest. Leathers (2016) states: “despite its polyphagous nature and widespread distribution, *Pseudaonidia trilobitiformis* is not well-documented to be a plant pest and is therefore not expected to lower crop yields. It may increase crop production costs as growers may treat to control scale populations for quarantine purposes”.

Cordyline has been reported as a host (García Morales et al. 2016), indicating that native cabbage trees may host this species.

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