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The material contained in the import risk analysis is preliminary and will be updated based on any feedback received during consultation on any related import health standards or any further feedback that may be provided by internal or external experts.

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Import risk analysis: Citrus (*Citrus* spp.) budwood for propagation

Version 1.0

April 2021

Approved for general release

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Biosecurity New Zealand

Ministry for Primary Industries

Version information

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1.0	Peer-reviewed and current at date of release	12 April 2021

New Zealand is a member of the World Trade Organization and a signatory to the Agreement on the Application of Sanitary and Phytosanitary Measures (“the SPS Agreement”). Under the SPS 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* budwood from all countries. It assesses the introduction of pathogens associated with *Citrus* budwood (not assessed as part of the 2016 import risk analysis) imported from all parts of the world 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. 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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Executive summary

Background
This import risk analysis (IRA) has been developed in response to a request to review the import health standard (IHS) for germplasm of all *Citrus* species listed in the Plant Biosecurity Index (PBI). In 2016, a review of the IHS was initiated, and a draft IHS was prepared, along with relevant PRAs (https://www.mpi.govt.nz/dmsdocument/14338-Citrus-spp.-nursery-stock-Pest-Risk-Assessment). This current IRA identifies any new pathogens since the 2016 IRA that meet the criteria for additional measures (or anything that was missed, e.g. pathogens may not be new since 2016 but literature may not have been found or available).

Objectives

To ensure that the known biosecurity risk from regulated organisms associated with imported *Citrus* nursery stock is managed appropriately, Biosecurity New Zealand's objectives in reviewing the import health standard for germplasm of *Citrus* species are to:

a) identify any pathogens where there are changes in measures in the 2016 import risk analysis and where the risk assessment isn't documented and determine if they meet the criteria for additional measures,
b) identify any new pathogens since the 2016 import risk analysis which meet the criteria for additional measures (or anything that was missed, e.g. not new since 2016 but literature may not have been found or available),
c) identify any pathogens which are not listed as requiring additional measures in 3B but may meet the criteria for additional measures if the minimum requirements are level 3A post-entry quarantine,
d) identify pathogens which are associated with the commodity and may require additional measures, and
e) assess those pathogens using a method that provides sufficient evidence about the biosecurity risks for a robust and transparent decision on whether to apply additional measures.

Import risk analysis methodology

The import risk analysis process involves three principal stages:

- Scoping/commissioning
- Hazard identification
- Pest risk assessment

Scoping/commissioning

This involves a detailed project plan with estimated timeframes and approval of that plan. The following key questions are answered:

- What are the risk management questions?
- What is the commodity description?
- What basic measures will be applied to the commodity?

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 for that commodity.
Description specific to this *Citrus* budwood IRA	1. Does each assessed pathogen meet the criteria to be a quarantine pest?[1] 2. Does each assessed pathogen meet (or potentially meet) the criteria for requiring additional measures (i.e. over and above basic measures)?

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[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. For the purposes of this analysis, it also includes diseases.

Commodity description	
General description	The commodity description defines the form of the commodity that is covered by the import health standard, e.g. the commodity species and the countries under consideration. The commodity description may also include commercial commodity quality specifications, e.g. commercial production.
Description specific to this *Citrus* budwood IRA	*Citrus* budwood (*Citrus* bud stick with buds but no leaves). In this case, the commodity description does not include any requirements for 'commercial production' methods to be used in the production of the budwood.

Minimum requirements	
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 and are justified by existing risk assessments.
Description specific to this *Citrus* budwood IRA	Consignments of *Citrus* budwood imported into New Zealand must: 1. Comply with the commodity description (e.g. leafless budwood); 2. Undergo basic measures; and 3. Be held in level 3A post-entry quarantine for one growing season. These conditions were determined based on the 2016 PRAs.

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 or is under official control),
- Has the ability to establish and cause harm in New Zealand, and
- Is associated with imported risk goods and import pathways.

Hazard identification is the process where, depending on the scope of the import risk analysis, a list of pests and diseases potentially associated with the commodity is compiled and then assessed against specified criteria, in order to determine which pests or diseases require further assessment. The objective for hazard identification in this import risk analysis is to identify any new pathogens, nematodes or diseases since the 2016 IRA (or anything that was missed, e.g. the pest may not be new since 2016 but literature may not have been found or available) that meet the risk evaluation criteria for requiring additional measures over and above basic measures.

Because this import risk analysis will be used to develop an import health standard for *Citrus* spp., the hazard identification needs to consider pathogens, nematodes or diseases associated with any *Citrus* spp. listed on the Plant Biosecurity Index (PBI 2020). To identify pathogens that potentially meet risk evaluation criteria, the hazard identification focused on the following:

- Pathogens, nematodes or diseases that are associated with leafless *Citrus* budwood of all *Citrus* species listed on the MPI Plant Biosecurity Index;
- Pathogens, nematodes or diseases that are not present in New Zealand (or are present but still represent a biosecurity risk, e.g. they are capable of vectoring pathogens not present in New Zealand, or they are under official control);
- Pathogens, nematodes or diseases that have traits that indicate that they may not be identified or contained in Level 3A post-entry quarantine.

The hazard identification only identified pathogens (viruses and fungi) that required further assessment. These are addressed in the Pest Risk Assessment section below and listed in Summary Table 1.

As the search sources used were English language sources and data systems that may not be available in all countries, they are recognised as being deficient in information contained in non-English language publications and countries that hold pest and disease information locally (e.g. not on the internet). No effort was made to access or translate non-English language information or to research pathogen records in countries with science publication systems with less digital presence. Therefore, while all pathogens identified in the hazard identification are assessed in this import risk analysis, the sources used should not be considered an adequate representation of pathogens in non-English language countries or countries with more analogue-based publication systems.

Pest groups and pest species that did not meet the criteria to require pest risk assessments 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 pathogens (identified at the hazard identification stage as requiring further assessment) present to New Zealand. Specifically, the pest risk assessment concludes whether the pathogen meets the risk evaluation criteria for requiring additional measures over and above the minimum requirements.

For this import risk analysis, pathogens that meet, or potentially meet, the criteria for additional measures are those that cannot be contained in a Level 3A post-entry quarantine facility and/or cannot be detected during one growing season in Level 3A post-entry quarantine.

Some traits that potentially indicate additional measures may be required include:

- ability of the pathogen to be latent for long periods (more than one growing season, such as fungi that are endophytic);
- tendency of the pathogen to only show symptoms under certain growing conditions, such as when the plants are stressed;
- ability of the pathogen to produce wind-dispersed spores.

The PRA addresses the following:

- Likelihood of entry:
    - the strength or frequency of the association with *Citrus* budwood
    - the likelihood of entry given the application of minimum requirements
- Likelihood of establishment:
    - the suitability of the New Zealand environment for the pathogen (including the climate, host plants and vectors)
    - conditions necessary for the pathogen to spread
- 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 ecosystems
    - sociocultural impacts: plant losses or wider consequences that would affect socially important plants
    - human health impacts

Summary Table 1 shows pest species for which PRAs were carried out and the PRA conclusion with respect to the requirement for additional measures.

Pest group	Species considered in the pest risk assessment (PRA)	PRA conclusion: Are the criteria to be considered for additional measures met?
Fungi	*Colletotrichum abscissum*	No
	Colletotrichum acutatum	No
	Diaporthe baccae, D. hongkongensis, D. novem	Yes
	Elsinoe australis	No
	Erysiphe quercicola, Fibroidium tingitaninum	Some, but not all
	Lasiodiplodia brasiliensis, L. citricola, L. hormozganensis, L. iranensis, L. mediterranea, L. mitidjana, L. pseudotheobromae, L. subglobosa	Some, but not all
	Phyllosticta citrocarpa	Yes
	Plenodomus tracheiphilus	Some, but not all

Pest group	**Species considered in the pest risk assessment (PRA)**	**PRA conclusion: Are the criteria to be considered for additional measures met?**
Virus	Citrus leprosis viruses: *Citrus leprosis virus C* (CiLV-C), *Citrus leprosis virus C2* (CiLV-C2), *Hibiscus green spot virus 2, Orchid fleck dichorhavirus* [citrus strain], *Citrus leprosis N dichorhavirus, Citrus chlorotic spot dichorhavirus, Citrus chlorotic spot virus*	Yes

Contents

1 Risk analysis process

The World Trade Organization Agreement on the Application of Sanitary and Phytosanitary Measures (the SPS Agreement) states that phytosanitary measures must be supported by risk assessment and not maintained without sufficient evidence. That is, to require additional measures, MPI must have evidence that a pathogen would not be sufficiently managed by the application of the minimum requirements.

The Biosecurity New Zealand (BNZ) process for undertaking an import risk analysis 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)[2]. The BNZ process and methodology for undertaking an IRA is summarised in **Figure 1**.

Import risk analyses are used in the development or review of import health standards under the Biosecurity Act (1993). An import health standard specifies the requirements to be met for the effective management of risks associated with importing risk goods[3].

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"[4].*

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 import health standard for recommendation to the Director-General. A number of these are part of an import risk analysis, as described by the OIE and IPPC:

- The likelihood that the goods will import organisms[5]
- The nature of the organisms that the goods may import
- The possible effect on human health, the New Zealand environment[6], and the New Zealand economy of the organisms that the goods may import
- In relation to requirements proposed for inclusion in an import health standard, the extent to which the requirements reduce or manage the likelihood or impacts of adverse effects from organisms that may be imported on or in association with goods[7]

An import risk analysis 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. 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 justification[8]. Measures must not be maintained without sufficient scientific evidence[9]. Measures must also not be unnecessarily trade-restrictive[10]. In order to meet these obligations, the SPS Agreement requires that measures are based on a risk analysis. Under the Convention on Biological Diversity, countries must consider environmental impacts in decision-making and prevent the introduction of alien species that threaten ecosystems, habitats and species and control or eradicate them.

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[2] Biosecurity Act section 24(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 referring to paragraphs (a) to (c).

[3] Section 22, Biosecurity Act 1993

[4] Section 23(1), Biosecurity Act 1993

[5] 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"

[6] 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)"

[7] Sections 23(4)(b) and (d) Biosecurity Act 1993

[8] SPS Agreement 1995, Article 3(1) and (3)

[9] SPS Agreement 1995, Article 5(7)

[10] SPS Agreement, Article 5(6)

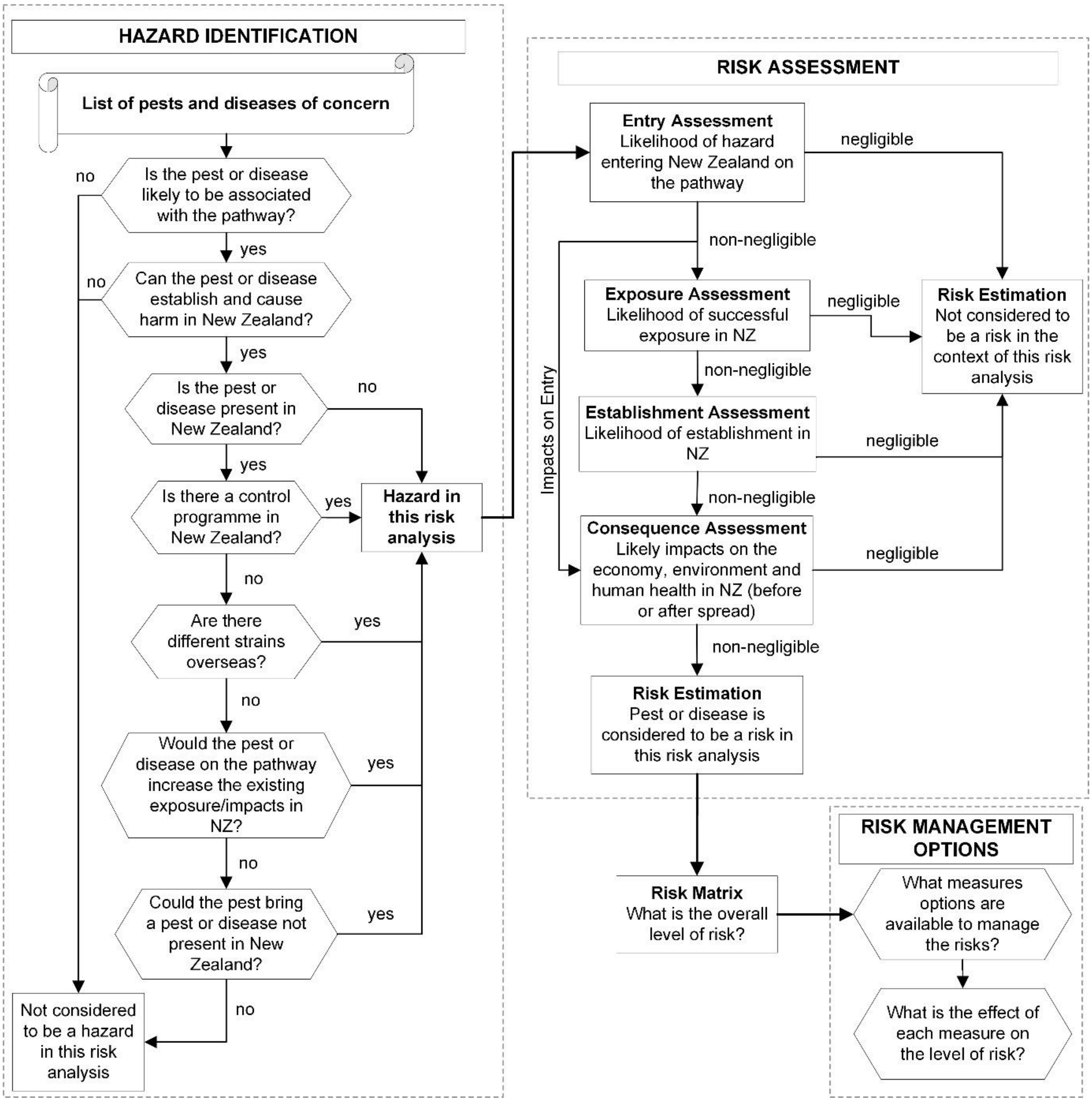

Figure 1: Biosecurity New Zealand process and methodology for undertaking an import risk analysis

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”[11].

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 import health standard for recommendation to the Director-General. A number of the matters are part of an import risk analysis, as described by the OIE and IPPC:

- The likelihood that the goods will import organisms[12]
- The nature of the organism that the goods may import

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[11] Section 23(1) Biosecurity Act 1993

[12] 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”

- The possible effect on human health, the New Zealand environment[13], 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 goods[14].

1.1 Hazard identification[15]

Hazard identification is the process for identifying pests and diseases associated with imported risk goods and that 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 present in 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.
    - 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 goods[16]).
- AND does the species have the potential to establish in New Zealand and harm “human health, the New Zealand environment, and the New Zealand economy[17]?”

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 or disease 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 preliminary hazards must be compiled using the methods documented in the plan
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 in compiling and presenting the list of potential hazards, depending on the information needed for each group of pest or disease. 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 IRA 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. The plan will also need to be updated if there are other changes, such as a change to the commodity description or the methods for hazard identification.

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[13] 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)”

[14] Sections 23(4)(b) and (d) Biosecurity Act 1993

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

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

[17] Biosecurity Act 1993

1.2 Risk assessment

At the end of hazard identification, the list of hazards that require risk assessment is discussed and agreed on by the project team.

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 consider 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 damage 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 used (see Chapter 4).

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 and documented in the plan.**

1.3 CASE format as a pilot

As a pilot to improve readability, the pest risk assessments in this project 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.

To follow the CASE schema, the pest risk assessments will apply the following basic format:

- Description of the pest/pathogen: This is a sentence or two describing the pest or disease for a non-expert, the taxonomy and the other names used.

- Statement: This explains whether or not the pest or disease meets the criteria for additional measures (or is a bit marginal or meets some of these criteria but not others, partly meets criteria, etc.).

For each section of the hazard identification or risk assessment, the following format is then applied:

Contention (e.g. Given the arguments and evidence below, the pest or disease meets/does not meet the criteria to be a quarantine pest for New Zealand.)

Argument 1 (e.g. The pest or disease is known/not known to be present in New Zealand.)

- **Evidence** and **sources** appear as bullets underneath, unless there is a good reason to use paragraphs.

Argument 2 (e.g. The pest or disease has/does not have the potential to establish and spread in New Zealand.)

- **Evidence** and **sources** appear as bullets underneath, unless there is a good reason to use paragraphs.

Care has been taken to present the supporting arguments and evidence, along with evidence that includes objections and/or counterevidence.

1.4 Assessment of uncertainties

The SPS Agreement requires measures to be applied *only to the extent necessary* and to be supported by *sufficient scientific evidence*[18]. Therefore, if there is insufficient evidence indicating that an organism meets the criteria requiring additional measures (the risk evaluation criteria), then the lack of evidence suggests that it does not meet the criteria to be a hazard (see section 1.3.5). 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). Following discussion with the commissioning team, that pest or pathogen may be assessed further. If there is insufficient evidence but significant uncertainty, then the decision-maker may apply measures. Under those circumstances, the measures are provisional, and certain conditions may be required[19].

Therefore, 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 import risk analysis. Where the risk assessment identifies significant uncertainty affecting the conclusion, this is indicated in the conclusion. The risk management proposal (see section 1.3.5) considers these risk assessments further. See Chapter 4 for more information on how uncertainty is documented.

1.5 Review and consultation

Peer review is a fundamental component of a risk analysis that helps ensure the analysis is based on the most up-to-date and credible information available.

The import risk analysis may be reviewed to check that the plan has been followed; that the IRA 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 import risk analysis and with relevant conclusions in other assessments. The peer review process involves relevant experts within MPI and may involve experts from outside MPI, either from New Zealand or overseas where necessary. A representative from the team commissioning the import risk analysis is included in the peer review process.

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

For an import risk analysis peer review:

a) **The import risk analysis must be reviewed by relevant staff from within MPI, including a representative of the team commissioning the import risk analysis, determined by the team manager responsible for the import risk analysis.**
b) **Individual pest or pathogen assessments should 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, when the team manager considers it necessary.**
c) **All peer review comments must be considered, and if internal or external reviewers' feedback[20] is not incorporated into the import risk analysis, the rationale for the decision not to include that feedback must be clearly documented and, where necessary, discussed with the reviewer.**

1.6 Conclusions of the risk analysis

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

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

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[18] SPS Agreement 1995, Article 2.2
[19] SPS Agreement 1995, Article 5.7
[20] This point does not apply to corrections to spelling, punctuation or grammar.

1.7 References for Chapter 1

FAO (1995) International Standards for Phytosanitary Measures (ISPM) No. 2. Guidelines for pest risk analysis. Secretariat of the International Plant Protection Convention, Food and Agricultural Organization of the United Nations, Rome.

FAO (2013) International Standards for Phytosanitary Measures (ISPM) No. 11. Pest risk analysis for quarantine pests. Secretariat of the International Plant Protection Convention, Food and Agricultural Organization of the United Nations, Rome.

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PBI (2020) Plant Biosecurity Index (Version: 02.01.00) Ministry for Primary Industries Internal database.

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

2 Scope and objectives

This import risk analysis (IRA) has been developed in response to a request to review the import health standard (IHS) for germplasm of all *Citrus* species listed in the Plant Biosecurity Index from all countries. An IRA was completed for this commodity in 2016 (https://www.mpi.govt.nz/dmsdocument/14338-Citrus-spp.-nursery-stock-Pest-Risk-Assessment).

Biosecurity New Zealand's objective in reviewing the import health standard for citrus germplasm is to ensure that the known biosecurity risk from pathogens associated with imported *Citrus* budwood is managed appropriately.

The purpose of the import risk analysis is to identify and assess biosecurity risks associated with imported leafless *Citrus* budwood, to inform decisions on risk management. The decisions that this import risk analysis will inform are:

a. whether any pathogens on *Citrus* budwood require additional measures, and
b. whether to remove any pathogens that do not require additional measures any more in the current import health standard, due to new scientific evidence.

The objective of the import risk analysis is to:

a. identify any pathogens in the 2016 import risk analysis for which the measures were changed without a documented risk assessment;
b. identify any new pathogens since the 2016 import risk analysis that meet the criteria for additional measures (or anything that was missed, e.g. the pest may not be new since 2016 but literature may not have been found or available);
c. identify any pathogens that are not listed as requiring additional measures in Level 3B post entry quarantine facilities but may meet the criteria for additional measures if the minimum requirements are Level 3A post-entry quarantine;
d. assess those pathogens using a method that provides sufficient evidence about the biosecurity risks, for a robust and transparent decision on whether to apply additional measures.

The minimum risk management requirements for this import risk analysis are based on the import risk analysis completed in 2016.

2.1 Scope and approach of this risk analysis

For the purposes of this IRA, the risk evaluation criteria are based on the minimum intervention considered sufficient to manage pest risks on leafless budwood that does not come from approved offshore facilities. These interventions are referred to as the minimum requirements. The import risk analysis process aims to determine which pathogens might not be managed by minimum requirements and therefore require additional measures. The following minimum requirement for leafless budwood of *Citrus* spp. was proposed in the 2016 risk management proposal:

- **one growing season in Level 3A post-entry quarantine (PEQ)**

The pests that the risk management question applies to are pathogens (viruses, viroids, bacteria, fungi and oomycetes), as well as diseases of unknown aetiology and nematodes. Insects and mites will not be assessed in the import risk analysis, because they are currently managed by insecticide and fungicide treatments before plants enter post-entry quarantine, as required under the Importation of Nursery Stock Standard (MPI Standard 155.02.06). Therefore, reviewing the risks of these pests are not in scope.

Pathogens that meet, or potentially meet, the criteria for additional measures are those that:

1. are associated with leafless *Citrus* budwood of all *Citrus* species listed on the MPI Plant Biosecurity Index
2. are 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 or is under official control)
3. have traits which indicate that they cannot be contained in a Level 3A post entry quarantine facility and/or be detected during one growing season in Level 3A post entry quarantine

One growing season in Level 3A post-entry quarantine may not reduce the risk of the following types of pathogens (for example):

- Pathogens that can be latent for long periods (more than one growing season, such as fungi that can be endophytic)
- Pathogens that only causes symptoms under certain growing conditions, such as when the plants are stressed
- Pathogen that can rapidly produce wind-dispersed spores
- Pathogens that are vector-transmitted, **if** there are vectors present in New Zealand, **and if** the vectors are small and mobile enough to enter a 3A post-entry quarantine facility, acquire the pathogen and then leave the facility.

Pathogens that meet the criteria above will undergo a risk assessment that considers the following factors:

a. The strength or frequency of the association with *Citrus* germplasm; and
b. The extent to which the minimum requirements will reduce the risk; and
c. the suitability of the environment in New Zealand for the pathogen (including climate, host plant(s) availability, ability to spread and available vectors; and
d. The economic, environmental, social and cultural impact on New Zealand (*Citrus* and other plants, including native species); and
e. The impact on human health.

2.2 Commodity description

The commodity for the IRA is leafless budwood[21] of all *Citrus* species (including *Fortunella* and *Poncirus*) as listed on the Plant Biosecurity Index (PBI), from all countries. Although *Citrus* species don't generally have a leafless dormancy period, cuttings have the leaves removed before importation.

Table 1 puts the risk associated with *Citrus* germplasm 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 exposure of pests and diseases will be used in the IRA when assessing the risk of pests that may meet the criteria for additional measures. Further detail is given in subsequent sections.

Table 1: General commodity risk explanation

Question	Factors to consider
What is the relative risk associated with the commodity class?	Germplasm is the highest risk commodity class overall[22]. This is because plants are grown from germplasm in conditions designed to maximise the survival and growth of the plants. As a result, conditions are also maximised for the associated pests and pathogens to establish.
What is the relative risk associated with the type of material making up the commodity?	Leafless budwood are in the middle of the scale for relative risks associated with germplasm. This is because the greater the number of plant parts and the greater the size of the individual pieces of material imported, the greater the number and type of organisms and diseases that can be associated with the material. Whole plants and cuttings with leaves on, have a greater number of associated species. Tissue culture is similar to cuttings in terms of viruses, viroids, diseases of unknown aetiology and some bacteria, but has fewer species of associated fungi, oomycetes and other bacteria.
How likely is the commodity to carry pests and diseases which can establish in New Zealand?	*Citrus* 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. *Citrus* is therefore intermediate in terms of risk

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[21] Budwood is a portion of a stem or branch (aerial plant parts only) with a vegetative bud(s) used in propagation for budding or grafting

[22] ISPM 32 https://www.ippc.int/static/media/files/publication/en/2016/01/ISPM_32_2009_En_2015-12-22_PostCPM10InkAmReformatted.pdf

Question	Factors to consider
	likelihood – it is higher than species grown in very specific climates, for example, mango, but lower than temperate species, for example, cherries. *Citrus* is grown commercially and in home gardens in New Zealand, although wild records are rare[23]. Therefore, associated pests and diseases, including those that are host-specific, are likely to come into contact with host plants in New Zealand.
How likely is the commodity to carry pests which cause major impacts in New Zealand? What are the values associated with the commodity species and the related species in New Zealand?	The pests and diseases associated with *Citrus* budwood 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 *Citrus.* There is a strong relationship between how closely related plant species are and how likely they are to share pests and diseases (Gilbert and Webb 2007). Therefore, the host plants most likely to be affected by pests and diseases carried on *Citrus* germplasm are *Citrus* species. The next most likely are members of the same family (Rutaceae). There are both native (*Melicope* and *Leionema*) and introduced ornamental (e.g. *Choisya, Coleonema*) genera of the Rutaceae family in New Zealand. Some pests and diseases associated with *Citrus* affect a wide range of other species, for example, some fungi. Pests and diseases that are associated with *Citrus* but affect other members of the family have the potential for environmental impacts as well as impacts on amenity values. The native genera *Melicope* and *Leionema* do not occur overseas in regions where *Citrus* is native or cultivated, e.g. Hawaiian Islands, across the Pacific to tropical Asia and Australia. Ornamentals in the family Rutaceae, such as *Choisya, Coleonema* are widely grown around the world. Therefore, many common *Citrus* pests and diseases have had the opportunity to switch hosts onto these genera. This means that, if pests of *Citrus* have not been recorded on these genera overseas, they are less likely to affect members of these genera in New Zealand. *Citrus* is an important crop in New Zealand. The New Zealand citrus industry comprises around 1,600 hectares located in the Bay of Plenty, Gisborne and Northland regions. In 2019, the domestic and export sales of fresh citrus fruit were $58.5 million and $12 million, respectively (Plant & Food Research 2019).
What is the level of knowledge about the pests associated with the commodity and related species in New Zealand and overseas?	*Citrus* is a well-known crop that is widely cultivated. Thus, there are reliable literature sources for some pests and pathogens associated with *Citrus* across a wide range of countries/continents. There is likely to be less information on native Rutaceae in New Zealand and abroad.
Conclusion	There is a high risk associated with the importation of *Citrus* spp. for propagation. However, the risk is lower than for commodities that may be more temperate in their distribution or that have many related native and economically important plant species in New Zealand (e.g. *Prunus* and *Malus*).

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

2.3 Taxonomy of the plant commodity 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 fruits is derived from 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 or nucellar embryony (where one or more vegetative embryo forms from cells of the nucellus of the ovule) (i.e. apomixis (Zhang et al. 2018)).

As a result of this complex history, there are various names applied to different types of fruit, and many 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.

In 2002, INRA-CIRAD[24] published a review of all known cultivars, varieties, hybrids and species of *Citrus* in cultivation from around the world (INRA-CIRAD 2002). The review lists all of 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 (see **Table 2**). Although the complexity of the *Citrus* taxonomy presents difficulties when it comes to categorising and grouping commodities for fresh produce IHSs, this is not a significant issue for this IRA which considers all *Citrus* species listed in the PBI (PBI 2020).

Table 2: List of common *Citrus* commodities based on the Swingle naming system, using INRA-CIRAD (2002).

***Citrus* species (or hybrids)**	**Synonyms**	**Common names**
Citrus aurantiifolia (Christ.) Swingle	*Citrus limettioides*	Lime, Sweet lime, Key lime, Mexican lime
Citrus aurantium L.		Sour orange
Citrus latifolia (Yu. Tanaka) Tanaka		Tahitian lime
Citrus limon (L.) Burum.f.	*Citrus limonia, Citrus meyeri*	Lemon, Meyer lemon
Citrus maxima (Burman) Merr.	*Citrus grandis*	Pomelo, Pummelo
Citrus medica L.		Citron
Citrus paradisi McFad.	*Citrus hassaku*	Grapefruit, Hassaku
Citrus reticulata L.	*Citrus unshiu, Citrus deliciosa*	Mandarin, Tangerine, Unshu
Citrus sinensis (L.) Osbeck	*Citrus iyo*	Orange, Iyokan
Citrus reticulata × *Citrus paradisi*		Tangelo
Citrus reticulata × *Citrus sinensis*		Tangor, Satsuma

2.4 General information related to the likelihood of entry

2.4.1 Pathway description

Because the scope of the import risk analysisincludes all growing conditions and production methods, the import risk analysis needs to consider pathogens that occur in some ecological and environmental conditions and not others.

While it is reasonable to consider that obviously diseased plants would not be used as a source of germplasm, many pathogens are not visible on the plant surface. Several of the pathogens discussed have obvious symptoms on leaves, flowers, or fruit, but not stems. Plants infected with such pathogens are unlikely to be used as a source of budwood by commercial growers using known source plants. However, infected plants may be used for other purposes, such as for breeding

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

programmes, or budwood may be harvested from plants that have not been observed over a long period of time.

The import risk analysis therefore covers several pathogens with a limited distribution or infrequent association with *Citrus* or pathogens that have obvious symptoms during at least part of the year. These pathogens have a much lower likelihood of being present in *Citrus* nursery stock than more widespread *Citrus* pathogens; however, they cannot be ruled out as a risk, given the import risk analysis scope.

In a Level 3A post-entry quarantine facility, all water leaving the facility must be decontaminated using a method proven to kill plant pathogens. The facility must have vents screened with insect-proof mesh with a maximum aperture of 0.2 mm, must be monitored for insects and must be built in such a way that no plants are within 1 m of the facility (MPI 2019). Additionally, plants are inspected for signs of disease twice a week during active growth and once a week during dormancy (MPI 2019). If found, any symptoms are diagnosed and controlled. Therefore, if symptoms are due to fungal infection, spore production will be minimised.

A summary of the import pathway of leafless *Citrus* budwood into New Zealand from non-MPI accredited facilities is given in **Figure 2**.

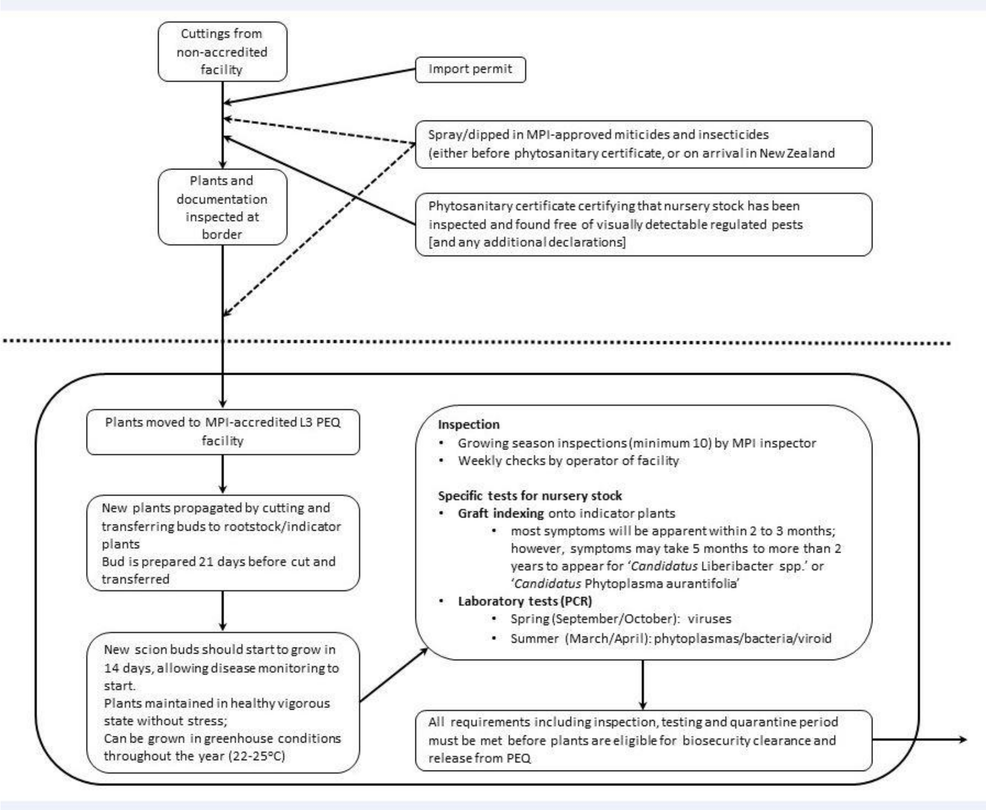

Figure 2: Summary of the pathway for the import of leafless *Citrus* budwood from non-MPI accredited facilities

2.5 General information related to the likelihood of establishment

2.5.1 Exposure

When a pathogen arrives in a new area, it usually needs to find or come into contact with a growing host plant in order to establish. In the case of nursery stock, imported plant material is maintained in a habitat favourable for plant growth and is likely to be multiplied up to substantial numbers. Promoting the survival and persistence of the plant material also promotes the survival and persistence of the associated pathogens. The process of a pathogen coming into contact with a growing host plant is termed "exposure" in MPI risk assessments. Previous import risk analyses for germplasm, such as *Actinidia* tissue culture (MPI 2018), have determined exposure to have a high likelihood with low uncertainty, regardless of the pathogen type being assessed. Pest risk assessments for *Citrus* nursery stock (MPI 2016) similarly reported a high likelihood for exposure for all assessed pathogens. Exposure has therefore not been assessed for individual pathogens in this import risk analysis.

2.5.2 New Zealand climates

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 areas of the West Coat areas[25]. 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 (**Figure 3**). This represents the average monthly temperature and precipitation for each month of the year for 42 New Zealand climate stations.

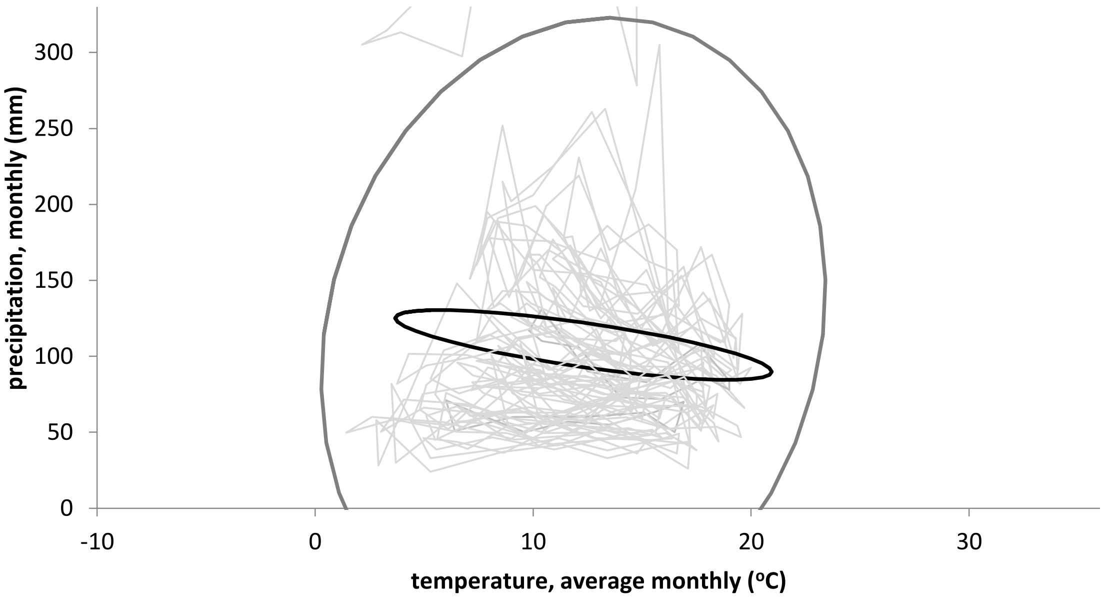

Figure 3: Climate niches of New Zealand. Thin grey lines: average monthly temperature (1981–2010) for 42 New Zealand climate stations (data from NIWA (2020)). Each polygon is composed of the 12 months of the year. Small black ellipse: average conditions for those 42 sites. Large ellipse: 95% inclusive ellipse.

As a consequence of being a small land mass 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.

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 adaptions (Halloy and Mark 1996).

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

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[25] 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.

The northern part of New Zealand is the most climatically suitable for the establishment of new pests and pathogens from sub-tropical or tropical climates, due to the climate suitability of this area. The area includes Kaitaia, Kerikeri, Whangarei, Auckland and Tauranga. Auckland and Tauranga contain large, active seaports.

2.5.3 Distribution of *Citrus* in New Zealand

Citrus species are native to 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. *Citrus* × *aurantium* L. (sour orange) and *C.* × *limon,* especially cv. 'Meyer' (Meyer lemon), *C. reticulata* Blanco (mandarin/tangerine/satsuma) and *C. sinensis* (orange), are very commonly grown in warmer North Island areas. The Bearss cultivar of Tahitian lime, *C.* × *latifolia* cv. (Yu. Tanaka) Tanaka, is also common and will also grow in cooler areas of the North Island. Nevertheless, on the New Zealand mainland, no *Citrus* spp. has been reliably reported in the wild.

The main citrus-growing areas of New Zealand are the Northland, Auckland, Bay of Plenty and Gisborne regions (Plant and Food Research 2019). 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 and Food Research 2019).

The northern part of New Zealand is the most climatically suitable for the establishment of new pests, pathogens and vectors from sub-tropical or tropical climates. The area includes Kaitaia, Kerikeri and Whangarei (Northland), Auckland, and Tauranga (Bay of Plenty).

Climate in the regions where citrus is grown commercially:

- **Northland:** Kerikeri is an orcharding town, with many varieties of *Citrus* fruit grown there. Avocados, kūmara, macadamias and tamarillos are the other main crops grown there (HortResearch 2005; Plant and Food Research 2010). This is a sub-tropical 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 produces a variety of crops including *Citrus* species such as mandarins. The region also produces strawberries, herbs, Asian vegetables, brassicas, chestnuts, greenhouse crops, lettuce, olives, onions, persimmons, pumpkin and silverbeet (HortResearch 2005; Plant and Food Research 2011). It has a moderate climate favouring plant species from many climatic zones (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:** Has 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 that have high productivity for fruits and vegetables (NIWA 2016). Prominent crop species include citrus, wine grapes, apples and squash (Plant and Food Research 2019).

The large number of pests associated with *Citrus* species, and the fact that a number of the assessed pathogens are recently described, 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. Although climate is not the primary indicator of a pathogen's ability to establish, it is a useful when considering the extent of disease expression, particularly if pathogen spread is dependent on a vector. The climate overlap between New Zealand and where a pathogen has been reported is assessed using the tool described in Phillips et al. (2018). This tool is based on the climate match index (CMI) CLIMEX-MCR of CLIMEX version 3.3. The tool allows the comparison of New Zealand's climate in general with areas where a pest/pathogen occurs overseas. The CMI range extends from 0 to 1; 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 pathogen indicates a more similar climate and therefore a higher likelihood of establishment. A CMI of less than 0.7 indicates less similarity between New Zealand and the pathogen's existing range (Phillips et al. 2018).

For many of the pest/pathogens assessed, this tool is likely to be a sufficient indication of climatic suitability in New Zealand for the pest to establish. **Figure 4** 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.

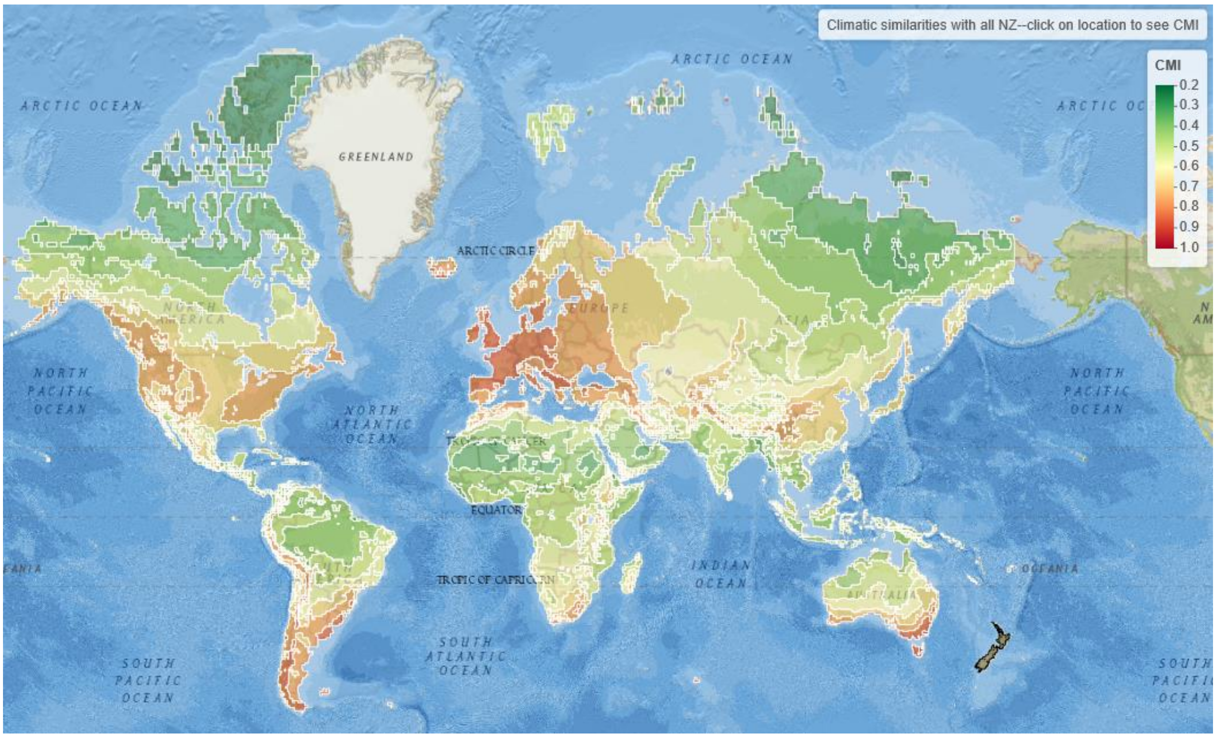

Figure 4: Climate Match Index (CMI). World climate similarities with all New Zealand (Phillips et al. 2018)

2.6 General information related to impacts of pests and diseases

2.6.1 Potential impacts on non-*Citrus* species

When considering impacts, MPI assesses close family relatives to be the most likely to be affected by pests and pathogens associated with *Citrus* spp. *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 genera that provide fruit, such as *Casimiroa*, and species in other genera that provide flavouring, for example *Galipea officinais,* which is the source of angostura bitters, and *Bergera koenigii,* used in Indian and Sri Lankan cooking (Mabberley 2008). There are also a number of ornamental species from other Rutaceae genera 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. ternate* (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 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).

2.6.2 Potential for economic impacts to the *Citrus* industry

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 Hawkes's Bay, with much less in other regions throughout the North Island and in parts of the South Island (Plant and Food Research 2019).

Growers were estimated to have produced 34,096 tonnes of citrus in 2018/2019 (Plant and Food Research 2019). Most product is grown for the domestic market (NZIER 2016). In 2018/19, New Zealand domestic sales of fresh citrus fruit were worth NZ$58.5 million (mandarins NZ$25.2 million, oranges NZ$18.0 million, lemons $12.0 million, limes NZ$2.0 million, tangelos NZ$1.0 million, grapefruit NZ$0.3 million) (Plant and Food Research 2019).
In 2019, export sales (free-on-board value) of fresh fruit were worth NZ$12 million (lemons $9.8 M, oranges NZ$1.7 million, mandarins NZ$0.4 million, tangelos NZ$0.1 million) (Plant and Food Research 2019). Processing mainly involves juicing citrus and other human consumption items (NZIER 2016). Domestic and export sales in relation to the processing of citrus have been estimated to be worth NZ$55.4 million, with the citrus processing value estimated as NZ$11.7 million (NZIER 2016). In 2012/2013 (April year), the impact of citrus on the GDP was estimated to be NZ$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 3**.

Table 3: How big is the New Zealand citrus industry? (NZCGI, accessed 23 Oct 2020)

	Growers*	Hectares planted	Number of Trees	Tonnes (Fruit)	Domestic Sales (NZ$ M)	Export (NZ$ M)
Citrus, total	**320**	**1,663**	**1 million+**	**29,740**	**$58.3 M**	**$12 M**
Mandarins	198	556	513,871	10,920	$25 M	$0.4 M
Oranges	183	783	320,840	10,100	$18 M	$1.7 M
Tangelos	28	22	11,105	640	$1 M	$0.1 M
Lemons	180	260	153,730	7,000	$12 M	$9.8 M
Limes	50	27	8,960	710	$2 M	–
Grapefruit	18	15	4,247	370	$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 season is provided in **Figure 5**.

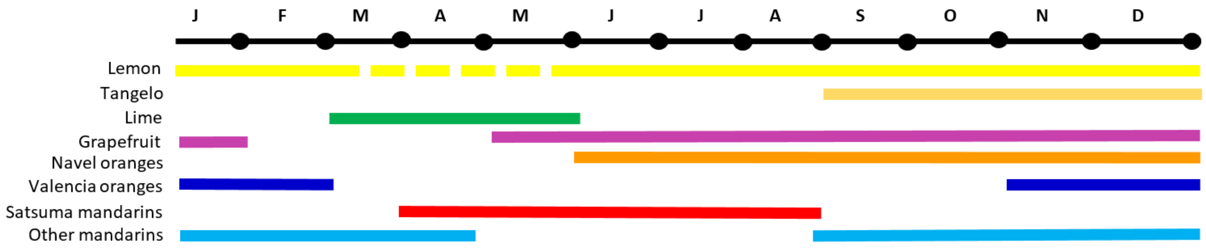

Figure 5: When is citrus in season in New Zealand? (NZCGI, accessed 23 Oct 2020)

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3 Hazard identification

In order to identify hazards that potentially meet risk evaluation criteria, hazard identification was conducted as a 'gap analysis' of the 2016 work, focusing on the following:

- Pathogens, nematodes, or diseases associated with the commodity; and,
- Not assessed in the 2016 draft review; OR,
- Measures were proposed in 2016 but the decision was not supported by risk assessment;
- The pathogen, nematode or disease has traits that mean that it may not be detected or contained during one growing season in level 3A post-entry quarantine such as:
    - the ability to be latent for long periods (more than one growing season, such as fungi which can be endophytic);
    - the tendency to only produce symptoms under certain growing conditions, such as when the plants are stressed;
    - the ability to rapidly produce wind-dispersed spores.

The hazard identification search did not identify any nematodes or diseases that were considered hazards; however, a number of pathogens were identified. Therefore, in the remaining sections, only pathogens are considered.

Because this import risk analysis will be used to develop an import health standard for all *Citrus* spp. listed in the Plant Biosecurity Index, the hazard identification needs to take this into account (identified pathogens may only be reported from a restricted number of *Citrus* species).

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

- CABI Crop Protection Compendium (2018/2019/2020)
- CAB Abstracts
- Google Scholar
- Google
- EPPO Global Database
- Existing pest lists from the *Citrus* germplasm IHS and the draft 2016 pest list
- Farr & Rossman (2017/2018/2020) (for fungi and oomycetes)
- 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, not present in New Zealand, not assessed in the 2016 draft review, and therefore requiring further assessment (a Pest Risk Assessment) is provided in **Table 4**.

Table 4: Results of hazard identification for citrus cuttings.

Pest group	Species requiring pest risk assessment (PRA)
Fungi	*Colletotrichum abscissum*
	Colletotrichum limetticola
	Diaporthe baccae, D. hongkongensis, D. novem
	Elsinoe australis
	Erysiphe quercicola, Fibroidium tingitaninum
	Lasiodiplodia brasiliensis, L. citricola, L. hormozganensis, L. iranensis, L. mediterranea, L. mitidjana, L. pseudotheobromae, L. subglobosa
	Phyllosticta citrocarpa
	Plenodomus tracheiphilus
Virus	Citrus leprosis viruses: *Citrus leprosis virus C* (CiLV-C), *Citrus leprosis virus C2* (CiLV-C2), *Hibiscus green spot virus 2, Orchid fleck dichorhavirus* [citrus strain], *Citrus leprosis N dichorhavirus, Citrus chlorotic spot dichorhavirus, Citrus chlorotic spot virus*

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

CABI Crop Protection Compendium. Information on crop pests. https://www.cabi.org/cpc/
EPPO Global Database. European and Mediterranean Plant Protection Organization (EPPO) database for all pest-specific information that has been produced or collected by EPPO. https://gd.eppo.int/

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Ferris, H (2020) Nemaplex. The nematode-plant expert information system. Department of Entomology and Nematology, University of California, Davis. http://nemaplex.ucdavis.edu/

4 Risk assessment criteria

The purpose of the risk assessments in this import risk analysis (IRA) is to assess the level of risk that hazards (e.g. 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?[26]
2. Does the pest or disease meet (or potentially meet) the criteria for additional measures?

4.2 Criteria and traits for additional measures

Pathogens that meet or potentially meet the criteria for additional measures are those that:

- Are associated with leafless *Citrus* budwood; and
- Are unlikely to be detected or contained during one growing season in Level 3A post-entry quarantine, for example:
    - if the pathogen can be latent for long periods without showing symptoms,
    - if the pathogen rapidly produces copious quantities of wind-dispersed spores,
    - if the pathogen is vector-transmitted, and there are vectors present in New Zealand, and the vectors are small and mobile enough to enter a 3A post-entry quarantine facility, acquire the pathogen and then escape the facility.

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* nursery stock import risk analysis, the risk management question is specific, aiming to identify pests and diseases that meet the criteria for needing additional measures over basic conditions.

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

- Does the pest or disease meet the criteria to be a quarantine pest under the IPPC?
- Is the pathogen associated with the commodity?[27]
- Does the pest or disease meet the criteria for requiring additional measures over the basic conditions?

The questions above require a binary answer—either the pests or diseases meet the criteria, or they do not. Where the uncertainty is limited or does not affect the conclusion, the answer to the risk management question is given as either:

- *The pest or disease meets the criteria for requiring additional measures.*
- *The pest or disease does not meet the criteria for requiring additional 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 meet some 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.

Where there is some evidence for the pest or disease meeting the criteria, but there is substantial uncertainty, this uncertainty is stated in the conclusion. For example: the overall conclusion is given as:

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[26] 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.

[27] These first two questions are part of hazard identification but are included if further risk assessment is done.

- *The pest or disease may meet the criteria for requiring additional measures, but this is uncertain.*

To answer these questions, the pest risk assessments 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 nursery stock 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 material
    - **b.** Likelihood of entry given the application of basic conditions
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, socio-cultural).

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.

Entry

1a. Strength or frequency of association with the commodity

Strong	There is a clear biological reason that the pathogen is inside citrus budwood or strongly attached to the outside of citrus budwood.
Moderate	There is a link between the pathogen and citrus budwood but not under all circumstances, for example, only when the pest or pathogen is at high incidence levels, or there is another less strong or frequent relationship.
Weak	The pathogen is only rarely associated with the commodity.
Negligible	There is no association of the pathogen with the commodity as described in this import risk analysis.

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 the minimum requirements

Criteria	The effect the biology and epidemiology of the pest or disease, the commodity description, the trade pathway, and the application of the basic conditions affect the likelihood that the pest or disease will be associated with the commodity on arrival in New Zealand.

Establishment

2. Suitability of the New Zealand environment

Criteria	The effect the biology and epidemiology of the pest or disease affect 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.

Impacts

3. The economic, sociocultural, environmental, and human health impacts to New Zealand

Criteria	The effect the biology and epidemiology of the pest or disease affect the extent to which the pest or disease will cause impacts on New Zealand plants and subsequently cause wider impacts on the economy, environment, socio-cultural, and/or human health.

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. EFSA (2014) is used as guidance for weighing the evidence. In the pest risk assessments 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. The uncertainty is ranked according to DEFRA (2011), see **Table 5**.

Table 5: Rankings used for uncertainty in the pest risk assessments (DEFRA 2011).

High	• Scarce or no data available; evidence provided in unreliable reports; or • Very few personal communications/observations; and/or • Authors' or experts' conclusions vary considerably
Moderate	• Some or only incomplete data available; evidence provided in small number of references; authors' experts' conclusions 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	• 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

Defra (2011) Department for Environment, Food and Rural Affairs: Guidelines for Environmental Risk Assessment and Management - Green Leaves III. Prepared by Defra and the Collaborative Centre of Excellence in Understanding and Managing Natural and Environmental Risks, Cranfield University, November 2011. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69450/pb13670-green-leaves-iii-1111071.pdf

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5 Pest risk assessments: Fungi

5.1 *Colletotrichum abscissum* (post-bloom fruit drop)

Colletotrichum abscissum causes brown and necrotic lesions on the petals of blossoms and early fruit drop in sweet orange, lemon, lime and other citrus varieties.

Taxonomy
Scientific name: *Colletotrichum abscissum* Pinho & O.L. Pereira (2015)
Order/family: Glomerellales/Glomerellaceae
Synonyms: *Colletotrichum acutatum* J.H. Simmons [post-bloom fruit drop strain]; *Colletotrichum gloeosporioides* [slow-growing orange strain]
Common names: Post-bloom fruit drop; PFD
Notes: *Colletotrichum abscissum* was only recently named and was historically referred to as the post-bloom fruit drop strain of *C. acutatum* (Crous et al. 2015) and the slow-growing orange strain of *C. gloeosporioides* (Brown et al. 1996). Molecular comparisons showed that *C. abscissum* ITS and GAPDH sequences had 100% identity with sequences in Genbank from the citrus post-bloom fruit drop strain designated as *C. acutatum* by Peres et al. (2008) (Crous et al. 2015). In this pest risk assessment, information from older references relating to the post-bloom fruit drop strain of *C. acutatum* and the slow-growing orange strain of *C. gloeosporioides* (e.g. Brown et al. 1996, Peres et al. 2008, Lima et al. 2011, Dewdney 2015, Timmer and Peres 2015) has been understood to refer to what is now known as *C. abscissum.* In addition, approximately 20% of post-bloom fruit drop in Brazil is caused by *C. gloeosporioides* (Lima et al. 2011; Silva et al. 2017). This strain has not been assessed separately.

5.1.1 Summary of conclusions

- *Colletotrichum abscissum* meets the criteria to be a quarantine pest for New Zealand.
- The association of *C. abscissum* with leafless budwood of *Citrus* spp. is considered weak with low uncertainty.
- The likelihood of *C. abscissum* entering New Zealand in association with citrus nursery stock is considered negligible, with low uncertainty.
- Given that *C. abscissum* is not expected to enter New Zealand associated with leafless *Citrus* budwood, further assessment is not required.
- *Colletotrichum abscissum* may not need to be considered for additional measures on *Citrus* budwood.

5.1.2 Hazard identification: regulatory status

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

Criteria for being a regulated quarantine pest, relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand) and is of potential importance (able to establish and cause harm[28]).

Colletotrichum abscissum is not known to be present in New Zealand:

- *Colletotrichum abscissum* is not recorded in either NZFungi2 (2020) or PPIN (2020).
- *Colletotrichum abscissum* is only recently named and was historically referred to as the slow-growing orange strain of *C. gloeosporioides* or post-bloom fruit drop strain of *C. acutatum* (Crous et al. 2015). Both *C. acutatum* and *C. gloeosporioides* are recorded as present in New Zealand (NZFungi2 2020; PPIN 2020).
- NZFungi2 (2020) and PPIN (2020) have collection records of *C. acutatum* from lemon, mandarin, Meyer lemon and tangelo, and *C. gloeosporioides* from orange, lemon and unspecified citrus from several different regions. Where there is a record of the plant part that

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[28] 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".

fungal isolates were collected from, it is usually fruit, sometimes leaf or stem but none of the isolates identified as *C. acutatum* or *C. gloeosporioides* were collected from citrus flowers, blossoms or petals in New Zealand (NZFungi2 2020; PPIN 2020).
- The regulatory status of *C. abscissum* has not yet been determined (BRAD 2020; ONZPR 2020).

Colletotrichum abscissum has the potential to establish and spread in New Zealand:

- Hosts of *C. abscissum* include most citrus species, but the disease is most severe on sweet oranges, lemons, and limes, and less severe on grapefruit and tangerines (Peres et al. 2005).
- Citrus species are widely grown in New Zealand, both commercially (27 ha; approximately 9,000 commercial trees) and by home gardeners (section 2.6). Therefore, suitable host plants are likely to be present to support establishment.
- *Colletotrichum abscissum* was only recently described in São Paulo, Brazil (Crous et al. 2015), but post-bloom fruit drop, highly likely to be caused by *C. abscissum,* is reported in the tropical and subtropical areas of the Americas, from Florida (USA) in North America to Uruguay in South America (Timmer and Peres 2015). Some parts of its distribution (e.g. much of Uruguay, parts of Florida, Mexico and Brazil) represent areas with similar climatic conditions with New Zealand indicated by a CMI (climate match index) ≥0.7, while much of its current distribution has CMI <0 7 indicating that the climate is not very similar to New Zealand (Phillips et al. 2018).
- If *C. abscissum* was to enter the New Zealand environment, there would be no barrier to spread *because C. abscissum* produces abundant conidia (asexual spores), which can be spread by water splash or windblown rain and pollinators, such as bees (Agostini and Timmer 1994; Peres et al. 2005; Timmer and Peres 2015).

Colletotrichum abscissum has the potential to have economic and sociocultural impacts by causing yield losses in citrus:

- Post-bloom fruit drop caused by *C. abscissum* is most severe on sweet orange (*C. sinensis*), lemon (*C. limon*), and Tahitian lime (*C. latifolia*), and less severe on grapefruit (*C. paradisi*) and tangerine (*C. reticulata*) (Peres et al. 2005). Economic impacts of *C. abscissum* are likely to be limited to the citrus industry.
- *Colletotrichum abscissum* causes orange to reddish-brown necrotic lesions on the petals of blossoms, and early fruit drop in sweet orange, lemon and Tahitian lime (Crous et al. 2015; Dewdney 2015; Timmer and Peres 2015). The fruitlets detach between the calyxes and young fruit, and the calyxes (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).
- Sweet orange, lemon, Tahitian lime and other citrus crops are commercially produced in New Zealand. In 2019, export sales of fresh citrus fruit were worth NZ$12 million, and the value of domestic citrus sales was NZ$58.5 million (Plant and Food Research 2019).
- Post-bloom fruit drop is considered a limiting factor for citrus production (causing yield losses of approximately 90%) in regions of Central America and Brazil with predominantly tropical climates (Rodrigues Marques et al. 2020).
- In Florida, impacts of the disease are more sporadic, but the disease can cause production losses in seasons when conditions favour disease development (Dewdney 2015).
- The fungi may cause impacts to home gardeners who grow *Citrus* spp., as lemons and other citrus are commonly grown in home gardens across New Zealand.
- Since *C. abscissum* is mostly reported as a citrus pathogen and there are no native species of *Citrus* (Allan Herbarium 2021), the likelihood of the pathogen causing environmental impacts is considered very low.

5.1.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *C. abscissum* with leafless budwood of *Citrus* spp. is considered weak, with low uncertainty.

Colletotrichum abscissum does not colonise stems or shoots of citrus plants:

- *Colletotrichum abscissum* is usually reported to survive between flowering periods as appressoria on surfaces of citrus leaves and persistent calyxes (Dewdney 2015; Waculicz-Andrade et al. 2017) and would not be expected to be on budwood.

- In the next season, substances from petals stimulate germination of appressoria to form conidia on the surface. These conidia are splash-dispersed to flowers in the same tree and reinitiate the cycle (Timmer and Peres 2015). *Colletotrichum abscissum* does not reproduce in the absence of flowers and does not usually colonise other plant parts (Timmer and Peres 2015). *Colletotrichum abscissum* does not colonise leaves as an endophyte (Dewdney 2015; Nicoletti 2019; Waculicz-Andrade et al. 2017).
- However, orange leaves from nursery plants and budwood increase blocks at four commercial citrus farms in São Paolo, Brazil were contaminated with *C. abscissum* conidia, suggesting that the fungus may also be associated epiphytically on the surface of budwood, especially in areas where the fungus is widespread (Vargas Munõz 2018).

5.1.4 Risk assessment: entry

Given the arguments and evidence below, the likelihood of *C. abscissum* entering New Zealand associated with leafless budwood of *Citrus* spp. is considered negligible, with low uncertainty.

There is only a weak association between *C. abscissum* and citrus budwood (see above). Minimum requirements reduce the likelihood of entry to negligible:

- Plants in areas with recent *C. abscissum* outbreaks are likely to have persistent calyxes attached, a visible symptom of post-bloom fruit drop (Dewdney 2015; Timmer and Peres 2015) and are, therefore, highly unlikely to be used as a source of commercial budwood.
- Budwood will not have leaves or persistent calyxes attached.
- Conidia are highly unlikely to remain viable on the surface of budwood and buds through pre-import fungicide treatments, transit, grafting procedures and a growing season in post-entry quarantine.
- Of the countries where *C. abscissum* is reported to occur, citrus budwood has only ever been imported to New Zealand from the USA, the last time in 2005 (Quancargo 2020). As this pathway is inactive and other potential pathways have never had trade, material is unlikely to be sourced from countries where post-bloom fruit drop is known to occur. However, trade on these pathways cannot be ruled out in the future.

There is low uncertainty in this conclusion. The symptoms described in the literature suggest that infected plants would usually be easily detectable, and recently infected plants would not be used to produce budwood.

5.1.5 References

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5.2 *Colletotrichum limetticola* (Key lime anthracnose)

Colletotrichum limetticola is the fungus that causes key lime anthracnose disease. Symptoms include necrotic lesions on leaves, fruits, twigs, flowers, premature fruit drop and blight of entire shoots of key lime (*Citrus aurantiifolia*).

Taxonomy
Scientific name: *Colletotrichum limetticola* (R.E. Clausen) Damm, P.F. Cannon & Crous (2012)
Order/family: Glomerales/Glomeraceae
Synonyms: *Colletotrichum acutatum* J.H. Simmons [lime anthracnose strain or lime withertip strain]; *Gloeosporium limetticola* R. E. Clausen 1912; *Gloeosporium fructigenum* f. *limetticola* (R.E. Clausen) G.J.M. Gorter (1962)
Common names: Key lime anthracnose; lime anthracnose; lime withertip (Damm et al. 2012)
Notes: In the past, *C. limetticola* was usually described as the key lime anthracnose strain of *C. acutatum* or *C. gloeosporioides*, and sometimes classified as *G. limetticola* (Damm et al. 2012). *Gloeosporium limetticola* was reported as the cause of withertip disease of *C. aurantiifolia* in Cuba. However, a recent phylogenetic study found that the withertip disease of *C. aurantiifolia* was apparently identical to key lime anthracnose (KLA), a specific disease of leaves, twigs, flowers and fruits of key lime, and reclassified both as *C. limetticola* (Damm et al. 2012). In this pest risk assessment, information from references relating to the lime anthracnose strain of *C. acutatum* (e.g. Peres et al. 2005; 2008; MacKenzie et al. 2009; Serrano et al. 2010; Ruiz et al. 2014) is understood as referring to what we now call *C. limetticola.*

5.2.1 Summary of conclusions

- *Colletotrichum limetticola* meets the criteria to be a quarantine pest for New Zealand.
- The association of *C. limetticola* with leafless *Citrus* budwood is considered high, with low uncertainty.
- The likelihood of *C. limetticola* entering New Zealand in association with leafless *Citrus* budwood is considered negligible, with low uncertainty.
- Given that *C. limetticola* is not expected to enter New Zealand associated with leafless *Citrus* budwood, further assessment is not required.
- *Colletotrichum limetticola* may not be considered for additional measures on citrus budwood.

5.2.2 Hazard identification: regulatory status

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

Criteria for being a regulated quarantine pest, relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand) and is of potential importance (able to establish and cause harm[29]).

Colletotrichum limetticola is not known to be present in New Zealand:

- *Colletotrichum limetticola* is not recorded in either NZFungi2 (2020) or PPIN (2020)
- In the past, *C. limetticola* was classified as *Gloeosporium limetticola* or the lime anthracnose strain of *C. acutatum* or *C. gloeosporioides.* Both *C. acutatum* and *C. gloeosporioides* are recorded as present in NZ (NZFungi2 2020). NZFungi2 (2020) records *G. limetticola* as a synonym of *C. acutatum*.
- NZFungi2 (2020) and PPIN (2020) have collection records of *C. acutatum* from lemon, mandarin, Meyer lemon and tangelo, and *C. gloeosporioides* from orange, lemon and unspecified citrus from several different regions. There are no collections of *Gloeosporium limetticola* in New Zealand recorded in either database, and there is no record of any *Colletotrichum* species collected from *C. aurantiifolia*.
- The regulatory status of *C. limetticola* has not yet been determined (BRAD 2020; ONZPR 2020).

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[29] 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”.

Colletotrichum limetticola has the potential to establish and spread in New Zealand:

- *Colletotrichum limetticola* is mainly reported in the Americas, including the United States (Florida, Texas), Brazil (São Paulo), Mexico, Belize, Costa Rica, Cuba and the Dominican Republic (Peres et al. 2008; Damm et al. 2012; Ruiz et al. 2014). Some areas where *C. limetticola* is found have a similar climate to the whole of New Zealand, based on a climate match index ≥ 0.7 (Phillips et al. 2018).
- Key or Mexican lime (*Citrus aurantiifolia*) is the major host of *C. limetticola* (Peres et al. 2008) and is grown in New Zealand both commercially and occasionally by home gardeners (section 2.6).
- Therefore, suitable host plants in suitable environmental conditions are likely to be present to support establishment, at least in some parts of New Zealand.
- *Colletotrichum limetticola* produces conidia (asexual spores) on susceptible tissues (Peres et al. 2005). Conidia are spread by rain-splash to nearby hosts and can be dispersed by windblown rain over greater distances. Therefore, if the fungus entered the New Zealand environment, in an area where key lime plants were grown, there would be no barrier to spread. However, potential spread of *C. limetticola* is likely to be limited by host availability, since key lime is not commonly grown in many parts of New Zealand.

Colletotrichum limetticola has the potential to have economic and sociocultural consequences by causing symptoms in key lime and, potentially, sweet orange and apple:

- The reported impacts of *C. limetticola* are limited to *C. aurantiifolia* (Peres et al. 2005; 2008).
- Limes are commercially grown in New Zealand for the domestic market, with a domestic sales value of NZ$2 million (Plant and Food Research 2019). However, the information on sales value does not differentiate between key lime and Tahitian lime (*C. latifolia*). Given that Tahitian lime (*C. latifolia*) is not a susceptible host, economic impacts of *C. limetticola* would be limited to an unknown proportion of the New Zealand lime crop.
- Key limes are occasionally grown in home gardens in New Zealand.
- *Colletotrichum limetticola* causes severe anthracnose symptoms on twigs, shoots, leaves and flowers of key lime plants and premature fruit drop (**Figure 6**) (Chen et al. 2005; Serrano et al. 2010). It causes necrosis in key lime plants, with symptoms ranging from small lesions to blight of entire shoots and inflorescences (Peres et al. 2005).
- Lesions on leaves are circular to oval brown spots, and lesions on mature leaves may have a shot hole appearance (i.e. a hole in the centre of the lesion) (Serrano et al. 2010; Ruiz et al. 2014).
- Twigs show severe blight, wilt, and dieback symptoms (Serrano et al. 2010; Ruiz et al. 2014).
- In flowers, water-soaked lesions form on the petals (Chen et al. 2005; Ruiz et al. 2014).
- Infection of young fruit usually results in premature fruit drop (similar to that caused by *C. abscissum,* see section 5.1), leaving persistent calyxes on the plant (Chen et al. 2005; Serrano et al. 2010; Ruiz et al. 2014). Late fruit infections produce lesions that are often large and deep, and the fruit becomes misshapen (Serrano et al. 2010).


Dan Robl, USDA

Hilda Gomez, USDA

Figure 6: Key lime anthracnose symptoms on fruit twigs and shoots (Serrano et al. 2010).

- In artificial inoculation studies, *C. limetticola* caused lesions on blossoms and postbloom fruit drop symptoms in sweet orange (*C. sinensis*) (Peres et al. 2005; 2008; MacKenzie et al. 2009). Consequently, sweet orange is sometimes reported as a host. However, although key lime anthracnose was a severe problem in key lime production in Western Mexico, post-bloom fruit drop was not observed on oranges or Tahitian limes grown in the area (Peres et al. 2008). Furthermore, searches of the literature using '*Colletotrichum*' and 'citrus' (Google Scholar, CAB Abstracts) found no primary records of *C. limetticola* or the key lime anthracnose strain of *C. acutatum* infecting stems or shoots of orange in natural infections.
- *Colletotrichum limetticola* was one of the *Colletotrichum* species recently isolated from lesions on apple leaves and flowers in Paraná and Rio Grande do Sul, Brazil, and the isolates caused leaf spot symptoms in pathogenicity tests (Moreira et al. 2019). Nevertheless, *C. limetticola* was much less frequently isolated from apples than other *Colletotrichum* species, and it is uncertain whether it contributed to disease symptoms in natural infection.

5.2.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *C. limetticola* with leafless *C. aurantiifolia* budwood is considered strong with low uncertainty, but *C. limetticola* is highly unlikely to be associated with budwood of other citrus species.

Colletotrichum limetticola can be present in the stems of infected key lime plants:

- Symptoms of key lime anthracnose include necrotic lesions on leaves, fruits, twigs and flowers, and blight of entire shoots (Peres et al. 2008).
- All young tissues of key lime are susceptible and severely attacked by *C. limetticola* (as *C. acutatum*) (Peres et al. 2005).

5.2.4 Risk assessment: entry

Given the arguments and evidence below, the likelihood of *C. limetticola* entering New Zealand associated with leafless *C. aurantiifolia* budwood is considered negligible, with low uncertainty.

Colletotrichum limetticola has a strong association with leafless *C. aurantiifolia* budwood.

- The fungus infects all young key lime tissues, including twigs and shoots (see above).

However, *C. aurantiifolia* plants infected with *C. limetticola* are unlikely to be imported into New Zealand

- Key lime plants with visible necrosis caused by *C. limetticola* are highly unlikely to be used to produce budwood for export to New Zealand.
- Of the countries where the disease is reported to occur, citrus budwood has only ever been imported to New Zealand from the USA, the last time in 2005 (Quancargo 2020). As this pathway is inactive and other potential pathways have never had trade, material is unlikely to be sourced from countries where lime anthracnose is known to occur. However, trade on these pathways cannot be ruled out in the future.

Minimum requirements reduce the likelihood of entry to negligible.

- *Colletotrichum limetticola* will produce visibly detectable symptoms within one growing season. Symptoms of *C. limetticola* develop rapidly on young key lime tissues (Peres et al. 2008). In pathogenicity tests, all shoots of key lime seedlings or rooted cuttings sprayed with conidial suspensions of *C. limetticola* developed necrotic lesions within 3–6 days (e.g. Agostini et al. 1992; Brown et al. 1996; Peres et al. 2008)
- Therefore, plants infected with *C. limetticola* are highly unlikely to be used as a source of commercial budwood, because disease symptoms are likely to be obvious, and the fungus will be detected by visual inspection.
- Any dried conidia (spores) would be highly unlikely to remain viable on the surface of budwood and buds through pre-import fungicide treatments and grafting procedures. If conidia did survive, symptoms would develop rapidly in post-entry quarantine, once the conidia were wetted and dispersed to young actively growing host tissues.

> There is low uncertainty in this conclusion. The symptoms described in the literature suggest that heavily infected material would be easily detectable and would not be used to produce budwood, or that symptoms of *C. limetticola* would develop rapidly and be noticed at the border or in post-entry quarantine.

Furthermore, if *C. limetticola* were to produce symptoms in post-entry quarantine, any spores would be contained in level 3A:

- *Colletotrichum limetticola* is spread via splash-dispersed conidia (Peres et al. 2008), and there is no evidence for spread by airborne ascospores (Peres et al. 2005).Therefore, it is highly likely that *C. limetticola* would be contained in level 3 post-entry quarantine, because there are measures in place to contain waterborne pathogens (MPI 2019).
- Other measures in place within level 3A glasshouses (including protective clothing and hand washing) (MPI 2019) would reduce the likelihood of viable conidia leaving a glasshouse and then transferring to a suitable host to a very low level.

Given that C. *limetticola* is not expected to enter New Zealand associated with leafless citrus budwood, further assessment is not required.

5.2.5 References

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5.3 *Diaporthe* spp. associated with citrus: *Diaporthe baccae*, *D. hongkongensis* and *D. novem*

Diaporthe baccae, D. hongkongensis and *D. novem* are fungal pathogens that are reported to cause stem-end rot of fruit, lesions on leaves, twig and branch cankers, and dieback in citrus, grapevine or other plants. *Diaporthe* (*Phomopsis*) species often have broad host ranges and broad geographical distributions and are frequently reported as pathogens, endophytes or saprobes in plants. They can be opportunistic pathogens that remain latent in plants for long periods but cause disease in older plants, during periods of environmental stress or when plants are injured or weakened by other pathogens.

Taxonomy
Scientific name: *Diaporthe baccae* L. Lombard, Polizzi & Crous (2014)
Synonyms: None in Mycobank, Species Fungorum or Farr and Rossman (2020)
Order/family: Diaporthales/Diaporthaceae
Notes: *Diaporthe baccae* is closely related to *D. foeniculina* (which is present in New Zealand), and some authors consider them to be the same species. Hyde et al. (2017) suggest that *D. baccae* should be synonymised with *D. rhusicola* (or *D. rhoicola*). Farr and Rossman list *D. rhusicola* as a synonym of *D. foeniculina*. Species Fungorum (2020) and Mycobank (2020) record *D. rhoicola* Crous (2011) as the current name of *D. rhusicola* but do not record it as a synonym of *D. foeniculina*. NZFungi2 (2020) and PPIN (2020) record *D. foeniculina* as present in New Zealand but have no record of these other species. Farr and Rossman do not record *D. baccae* and *D. foeniculina* as synonyms. For the purposes of this assessment, *D. baccae* is considered a separate species.

Scientific name: *Diaporthe hongkongensis* R. R. Gomes, C. Glienke & Crous (2013)
Synonyms: *Diaporthe lithocarpus* Y. H. Gao, W. Sun & L. Cai 2014
Order/Family: Diaporthales/Diaporthaceae

Scientific name: *Diaporthe novem* J. M. Santos, Vrandečić & A. J. L. Phillips (2011)
Synonyms: *Diaporthe pseudolongicolla* Petrović (2012); *Diaporthe pseudolongicolla* K. Petrović, L. Riccioni & M. Vidić (2018)
Order/family: Diaporthales/Diaporthaceae

General information about *Diaporthe* spp.
Diaporthe is a genus of fungi that often have broad host ranges and geographical distributions and can be associated with plants as pathogens, endophytes or saprobes (Gomes et al. 2013). Some plant associated *Diaporthe* species are also reported as pathogens of humans and other mammals (Gomes et al. 2013). *Diaporthe* spp. are known to cause root and fruit rots, dieback, cankers, leaf spots, blights, decay and wilt in plant hosts (Gomes et al. 2013). Historically, new *Diaporthe* species were identified based on host association (e.g. *D. citri* on *Citrus*, *D. ampelina* on grapes), which led to numerous species names (Dissanayake et al. 2017). This means that *Diaporthe* pathogens of *Citrus* are frequently identified as *D. citri* or its asexual state *Phomopsis citri* in taxonomic and plant pathological studies and regional checklists (Udayanga et al. 2014). Other *Diaporthe* or *Phomopsis* species described from citrus such as *D. citrincola*, *P. californica*, *P. caribaea*, *P. cytosporella* and *D. medusaea* were also considered synonyms of *D. citri* by some authors. Canker, gummosis and melanose symptoms in citrus from Japan and China were sometimes attributed to *D. meduseae* (current name *D. rudis*) and *P. cytosporella* (Huang et al. 2013; Yamoto 1976; Zhang et al. 2008). Recent phylogenetic studies are identifying an increasing number of *Diaporthe* species from citrus plants as endophytes or isolated from disease lesions (e.g. Guarnaccia and Crous 2017; Huang et al. 2013 and 2015). Many of these species are not host-specific and can cause disease in other plants. A single species can be found on more than one host, and conversely, several *Diaporthe* species can be found on a single host (Dissanayake et al. 2017).
The biology and epidemiology of cankers on trunks, branches and twigs, melanose and fruit rots on *Citrus* have been described (although attributed to *D. citri* or *D. medusaea*). Searches (Google Scholar, CAB Abstracts, August 2020) with the species names and ‘citrus’ as search terms found very little specific information about the biology of the recently described citrus-associated species *D. baccae, D. hongkongensis* and *D. novem*, so older information about *D. citri*, *D. medusaea* and other *Diaporthe* species has been used as a surrogate.

5.3.1 Summary of conclusions

- The association of *Diaporthe* spp. with *Citrus* spp. budwood is considered strong with low uncertainty.
- The likelihood of *D. hongkongensis* entering associated with citrus nursery stock is considered high, with moderate uncertainty.
- The likelihood of *D. baccae* or *D. novem* entering associated with citrus nursery stock is considered very low to moderate with moderate uncertainty.
- The likelihood of *D. baccae, D. hongkongensis* or *D. novem* establishing is considered high, with low uncertainty.
- The introduction of *D. baccae, D. hongkongensis* or *D. novem* is considered likely to cause moderate economic impacts for New Zealand, with moderate uncertainty.
- The introduction of any one of any of these *Diaporthe* spp. associated with citrus is considered likely to cause low socio-cultural impacts in New Zealand, with moderate uncertainty.
- The introduction of any one of these *Diaporthe* spp. associated with *Citrus* is considered likely to cause very low to moderate environmental impacts in New Zealand, with moderate uncertainty.
- The introduction of any one of these *Diaporthe* spp*.* associated with *Citrus* is considered likely to cause very low human health impacts in New Zealand, with moderate uncertainty.
- *Diaporthe baccae, D. hongkongensis* and *D. novem* may be considered for additional measures on citrus budwood.

The moderate uncertainty in many of these conclusions is because *D. baccae, D. hongkongensis* and *D. novem* are emerging pathogens, each with only a few published reports.

- In the past, *Diaporthe* species affecting each host were often grouped together, with a species and disease name related to that host (e.g. *D. citri*). However, many of the *Diaporthe* species recently found in citrus, even those that have only been reported as symptomless endophytes in citrus, apparently cause disease symptoms in a range of other hosts.

- In pathogenicity tests, *D. baccae, D. hongkongensis* and *D. novem* can cause disease symptoms in many of their known hosts. However, such tests often involve inoculating the plant with high concentrations of spores or mycelium. It is uncertain to what extent these *Diaporthe* species cause disease under natural infection conditions.

- Disease symptoms attributed to *Diaporthe* are more frequent and severe in older plants, suggesting that they may be opportunistic rather than primary pathogens. *Diaporthe* species can have long latent periods as asymptomatic endophytes, but they can sporadically cause severe outbreaks of disease, particularly when plants are injured or stressed by environmental conditions or other pathogens.

- *Diaporthe baccae, D. hongkongensis* and *D. novem* have been isolated from disease lesions in natural infections of plant hosts. However, *Diaporthe* species have been reported in coinfection with each other and other plant pathogens (e.g. Pintos et al. 2018). Therefore, it is not always clear how often each of these was the only fungal species isolated from a particular lesion and whether *D. baccae, D. hongkongensis* or *D. novem* caused the disease symptoms. It is possible that these *Diaporthe* species were secondary invaders of the disease lesions or were present in the plant as endophytes with no role in disease.

- New hosts of *D. baccae, D. hongkongensis* and *D. novem* are likely to be reported in the future, given there have been several recent reports of new host associations and economically significant diseases caused by these species.

5.3.2 Hazard identification: regulatory status

Diaporthe baccae, *D. hongkongensis* and *D. novem* meet the criteria to be quarantine pests for New Zealand.

Criteria for being a regulated quarantine pest, relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand) and is of potential importance (able to establish and cause harm[30]).

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[30] 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".

These *Diaporthe* species are not known to be present in New Zealand:

- *Diaporthe baccae, D. hongkongensis* and *D. novem*[31] are not known to occur in New Zealand. *Diaporthe hongkongensis* is recorded as absent and *D. baccae,* and *D. novem* are not recorded in NZFungi2 (2020). None of these species are recorded in PPIN (2020).
- *Diaporthe baccae, D. hongkongensis* and *D. novem* do not have a quarantine status recorded in BRAD or ONZPR.

Diaporthe baccae, D. hongkongensis and *D. novem* have the potential to establish and spread in New Zealand:

- These *Diaporthe* species have been reported from areas that have a very similar climate to the whole of New Zealand (climate match index with New Zealand of 0.7–0.9) including Italy, France, Spain, California and parts of China, eastern Australia and Turkey (Phillips et al. 2018). *Diaporthe baccae* is reported from Croatia, France, Italy and Spain (Lombard et al. 2014; Guarnaccia and Crous 2017; Guarnaccia et al. 2018), *D. hongkongensis* is reported from China and Turkey (Huang et al. 2015; Erper et al. 2017), and *D. novem* is reported from Italy, Iran, eastern Australia, USA (northern California), South Africa, France and Spain (Alavi and Faraki 2016; Guarnaccia and Crous 2017; Lawrence et al. 2015, Lesuthu et al. 2019; Pintos et al. 2018; Thompson et al. 2018).
- Suitable hosts are widespread in New Zealand. For example, all these *Diaporthe* species have been reported from citrus and grapevines (*Vitis vinifera*) (Dissanayake et al. 2015; Guarnaccia and Crous 2017; Guarnaccia et al. 2018; Huang et al. 2015; Pintos et al. 2018; Udayanga et al. 2014). Citrus and grapes are commonly grown in domestic gardens and are grown commercially in New Zealand.

Diaporthe baccae, D. hongkongensis and *D. novem* have the potential to have economic and sociocultural impacts by causing disease symptoms on citrus and other plants:

- *Diaporthe baccae* and *D. novem* have been described as causing disease symptoms in citrus plants, such as leaf scabs, branch cankers and twig dieback (Guarnaccia and Crous 2017). Citrus is an important commercial crop for New Zealand and is commonly grown by home gardeners (section 2.6.2).
- *Diaporthe baccae, D. hongkongensis* and *D. novem* have been isolated from grapevines (*Vitis vinifera*) with cankers and dieback symptoms (Dissanayake et al. 2015; Guarnaccia et al. 2018; Lesuthu et al. 2019; Lawrence et al. 2015). Wine represents New Zealand's second largest horticultural export, with a value of NZ$1.8 billion (Plant and Food Research 2019).
- *Diaporthe hongkongensis* has been reported to cause rot in kiwifruit, both pre-harvest and post-harvest (Li et al. 2016; Erper et al. 2017). In 2019, kiwifruit exports from New Zealand earned more than NZ$2.3 billion (Plant and Food Research 2019).
- *Diaporthe hongkongensis* and *D. novem* have been described as causing disease symptoms such as leaf spots and dieback in a broad range of hosts, including ornamental and amenity species such as camellia (Gao et al. 2016), sunflower and hydrangea (Thompson et al. 2018). These species have the potential for socio-cultural impacts on home gardeners and on public parks and amenity plantings.

5.3.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *D. baccae, D. hongkongensis* and *D. novem* with leafless *Citrus* budwood is considered strong, with low uncertainty.

These *Diaporthe* species have all been reported from twigs and branches of citrus plants:

- *Diaporthe hongkongensis* has been isolated from asymptomatic twigs of *Citrus reticulata, C. unshiu, C. grandis and C. sinensis,* as well as from citrus scab on leaves of *C. reticulata* and *C unshiu* (Huang et al. 2015).

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[31] Although Udayanga et al. (2015) included a *D. novem* sample from carrot in New Zealand in their taxonomy, there is no record of *Diaporthe* or *Phomopsis* on carrots in NZFungi2 or PPIN. There are no collection details for the fungal sample used in the study. Currently, the status of *D. novem* in New Zealand is absent (Wellcome Ho, Plant Health and Environment Laboratory, MPI, pers. comm., 10 August 2020).

- *Diaporthe baccae* and *D. novem* were isolated from symptomatic twigs, branches and trunks of citrus (Guarnaccia and Crous 2017).
- There are only a few reports of *D. baccae, D. hongkongensis* and *D. novem* associated with citrus plants, and only *D. hongkongensis* has been described from citrus plants without disease symptoms. Literature searches in CAB abstracts and Google Scholar (August 2020) using the species name and 'citrus' as search terms found only the records cited in **Table 6** and references to these studies in taxonomic studies but no specific evidence for asymptomatic infections of citrus with *D. baccae* or *D. novem*. However, *D. novem* has been isolated from healthy grapevines (Pintos et al. 2018), so it can infect plants asymptomatically, at least in some hosts.

5.3.4 Risk assessment: entry

Diaporthe baccae, D. hongkongensis and *D. novem* have a strong association with *Citrus* budwood, as they have been isolated from citrus twigs and branches (see Hazard identification: commodity association).

Diaporthe species are more likely to show symptoms in old, poorly managed or stressed plants (Gao 2006; Zhang et al. 2008; Aguilera-Cogley and Vicent 2019), but such plants are extremely unlikely to be used to produce budwood material for export to New Zealand. Trees harbouring endophytic *Diaporthe* fungi may show no symptoms at all. Therefore, there is the potential for infected asymptomatic material to be used for propagation.

Given the arguments and evidence below, the likelihood of *D. hongkongensis* entering New Zealand associated with citrus budwood is high, with moderate uncertainty.

- In a study of endophytic *Diaporthe* in citrus in China, *D. hongkongensis* was isolated from asymptomatic twigs of *Citrus reticulata* and *C. sinensis* in Jiangxi*, C unshiu* in Zhejiang and *C. grandis* in Fujian, as well as two isolates from citrus scab on leaves of *C. reticulata* and *C. unshiu* in Fujian (Huang et al. 2015). This study isolated 44 endophytic *Diaporthe* strains in twigs and branches of citrus and *Fortunella* plants, of which five isolates from asymptomatic twigs (1–2 years old) were identified as *D. hongkongensis.*
- *Diaporthe hongkongensis* has only been reported from China and Turkey, and there is no record of *Citrus* nursery stock being imported from these countries (Quancargo 2020), although trade on these pathways cannot be ruled out in future.
- There is moderate uncertainty in this conclusion, since the evidence for an asymptomatic association is based on a single study and comparison with other species in the genus. Nevertheless, this study sampled healthy twigs from only 30 citrus trees (five trees randomly selected from each of six study sites). *Diaporthe hongkongensis* was isolated from four twig samples, suggesting that asymptomatic *D. hongkongensis* infection of citrus in China is not uncommon. Furthermore, the low likelihood of entry is based on the current recorded distribution of *D. hongkongensis,* and, given the possibility of latent infections, the pathogen may be more widespread than is currently reported.

Given the arguments and evidence below, the likelihood of *D. baccae* or *D. novem* entering New Zealand associated with citrus budwood is very low to moderate, with moderate uncertainty.

- There is no specific information about whether *D. baccae* and *D. novem* can be latent and asymptomatic in citrus plants, because they have only been reported in studies of plants with disease symptoms (Alavi and Faraki 2016; Guarnaccia and Crous 2017).
- *Diaporthe baccae* was isolated in a survey of orange, lemon, grapefruit and mandarin plants with twig dieback and branch and trunk cankers and was one of the more frequent *Diaporthe* species found in Italy (Guarnaccia and Crous 2017).
- *Diaporthe novem* was isolated from twigs of *C. japonica* and *C. aurantiifolia* with dieback symptoms in Italy in the same survey (Guarnaccia and Crous 2017) and from citrange rootstock (cross between *C. sinensis* and *P. trifoliata*) in Iraq, with symptoms including rot, discoloration of wood, yellowing and decline (Alavi and Faraki 2016).

- The very low likelihood estimates for *D. baccae* and *D. novem* entering New Zealand associated with citrus budwood is based on the assumption that systemic symptomless infections with these fungi can occur in citrus but are rare, especially in young healthy plants. *Diaporthe* species have been reported as latent pathogens in other species, sometimes at high rates and in coinfection with other fungal pathogens. In a survey of 150 young grapevine plants from two commercial nurseries in Spain and one in France, 93% of the plants were infected by at least one grapevine trunk pathogen (Pintos et al. 2018). Most vines were infected with more than one pathogen per plant (40% were infected by two, 31% by three and 9% by four grapevine trunk pathogens) (Pintos et al. 2018). Although these plants appeared to be in good condition, *Diaporthe* including *D. novem*, as well as other latent pathogens (e.g. Botryosphaeriaceae, Nectriaceae, petri disease fungi), were present (Pintos et al. 2018). The *Diaporthe* species were usually associated with the rootstock or graft union, but a small number were isolated from the scion (Pintos et al. 2018), although infection of the scion may have occurred after grafting.
- However, there is moderate uncertainty around this conclusion, because the frequency of association of these *Diaporthe* species with citrus is unknown, and there are no reports of *D. baccae* and *D. novem* from citrus twigs or branches without visible disease lesions. As previously mentioned, these *Diaporthe* species were only recently described, and the literature about them is currently limited to a small number of studies. Furthermore, most research has focused on diseased plants. Nevertheless, some recent surveys have focussed on fungal endophytes in citrus or other species (e.g. Huang et al. 2015; Gao et al. 2016; Pintos et al. 2018). These studies demonstrate that *Diaporthe* spp. can be associated with plants that appear healthy, but do not provide specific evidence relating to latent asymptomatic association of *D. baccae* or *D. novem* with citrus.

The minimum requirements do not significantly reduce the likelihood of entry because *Diaporthe* spp. have been reported from asymptomatic plants and may not develop visible symptoms within one growing season:

- Visual inspection of budwood and the mother plants is likely to detect symptomatic material, but not asymptomatic infection.
- Symptoms of *Diaporthe* disease are unlikely to be expressed during post-entry quarantine, as plants would be young, well maintained and grown under conditions that enhance growth. Such plants are unlikely to encounter the stresses that promote disease (such as drought, flooding and extreme cold/heat).

Note. If *D. baccae, D. hongkongensis* or *D. novem* were to produce symptoms in post-entry quarantine, symptoms are likely to be detected well before spores are produced, so this risk is likely to be managed in level 3A:

- These *Diaporthe* species are reported from lesions on twigs, leaves, branches and/or trunks, but conidia (asexual spores) and ascospores (sexual spores) of *Diaporthe* species are usually only produced on dead twigs or dead wood (Mondal et al. 2004, 2007; Punithalingam and Holliday 1973; Zhang et al. 2008; Yamoto 1976) (see below).
- It is highly unlikely that dead citrus would be left in post-entry quarantine for long enough for spores to be produced.
- Waste treatment measures in place within level 3A glasshouses (MPI 2019), would prevent any material from infected plants that died in post-entry quarantine from being discarded into the environment.

5.3.5 Risk assessment: likelihood of establishment and spread

These *Diaporthe* species are reported from citrus and other hosts that are commonly grown in New Zealand commercially and in domestic gardens, as well as from some wild plants and weeds. Climate is unlikely to limit the establishment of these species, since most reports of these species are from geographical areas with climate match indices of ≥ 0.7 with the whole of New Zealand, indicating that these areas have very similar climates to New Zealand (Phillips et al. 2018) (see **Table 6** and more detailed information for each species below). As *D. baccae, D. hongkongensis* and *D. novem* are only recently described, they are likely to have even broader geographical distributions and host ranges than those recorded here.

Table 6: Records of hosts and geographic location of *D. baccae*, *D. hongkongensis* and D. *novem* with climate match indices of location to New Zealand

***Diaporthe* Species**	**Host plants**	**Region and country**	**CMI range (Philips et al. 2018).**	**Reference**
D. baccae	Blueberry	Italy	0.8–0.9 with small areas of 0.7	Lombard et al. 2014
	Citrus	Italy	0.8–0.9 with small areas of 0.7	Guarnaccia and Crous 2017
	Grapevine	Croatia; France, Spain	0.8–0.9 with small areas of 0.7	Guarnaccia et al. 2018
D. hongkongensis	Citrus (mandarin, unshiu, pomelo and orange)	China (Fujian, Jiangxi, Zhejiang)	0.6–0.7	Huang et al. 2015
	Camellia sinensis and numerous other species, including species or families that are grown in New Zealand, e.g. *Miscanthus sinensis* [Gramineae]; *Castanopsis eyrie, Castanopsis carlesii, Quercus glauca* (as synonym *Cyclobalanopsis glauca*) and *Herba Patriniae* [Fagaceae]; *Ilex latifolia* [Aquifoliaceae]	China (Guangxi, Jiangxi, Nanchang, Ganzhou, Zhejiang)	0.6–0.7	Gao et al. 2015
	Kiwifruit	Sichuan, China; Turkey	0.7–0.8	Li et al. 2016; Erper et al. 2017
	Grapevines	Hunan, China	0.7	Dissanayake et al. 2015
D. novem	Citrange (cross between *C. sinensis* and *P. trifoliata*) Citrus (*C. japonica* and *C. aurantiifolia*)	Mazandaran, Iran; Italy	0.7–0.9 (with small areas of 0.5)	Alavi and Faraki 2016; Guarnaccia and Crous 2017
	Commercial sunflower (*Helianthus annuus*), other crop species including *Cicer arietinum* (chickpea), *Glycine max* (soybean), *Lupinus alba* (lupin), *Sorghum bicolor* (sorghum) *Vicia faba* (faba bean) and *Vigna radiata* (mungbean), and with the weed species *Datura stramonium* (common thornapple), *Malva parviflora* (small flowered mallow), *Rapistrum rugosum* (turnip weed), *Sambucus gaudichaudiana* (wild elderberry), *Sisymbrium orientale* (Indian hedge mustard), *Sonchus oleraceus* (sowthistle), *Verbena* sp., *Vicia sativa* (common vetch), and *Xanthium strumarium* (Noogoora burr)	Eastern Australia, from sites in Victoria, Queensland and New South Wales	0.7–0.9	Thompson et al. 2018

***Diaporthe* Species**	**Host plants**	**Region and country**	**CMI range (Philips et al. 2018).**	**Reference**
	Grapevines and *Vitis* sp. rootstock	Western cape, South Africa; northern California from Merced, Napa, San Benito, Solano counties; France, Spain	Mostly 0.7–0.9, with some areas of 0.6	Lesuthu et al. 2019; Lawrence et al. 2015; Pintos et al. 2018
	Willows (*Salix* sp.) and almond (*Prunus dulcis*)	California from Merced, Napa, San Benito, Solano counties	0.7–0.9	Lawrence et al. 2015
	Kiwifruit	Chile	Mostly 0.7–0.9, with some areas of 0.6	Diaz et al. 2014, 2017
	Asclepias syriaca, Aspalathus linearis (rooibos), soybean, *Hydrangea macrophylla* (hydrangea), sunflower	Croatia, Italy, Portugal and South Africa	Mostly 0.7–0.9, with some areas of 0.5–0.6	Santos et al. 2011

Notes on life cycle and spread of *Diaporthe* species

Diaporthe species are generally spread by rain splash of conidia (asexual) spores, and to a lesser extent by windblown ascospores (sexual spores). These fungi can also be graft-transmitted. For example:

- *Diaporthe citri* survives as quiescent infections in twigs and only colonises twigs and branches after they die (Gopal 2014).
- The main form of inoculum for *D. citri* is conidia, which are produced in pycnidia on dead twigs and branches and spread by rain splash (Punithalingam and Holliday 1973; Mondal et al. 2004, 2007).
- Ascospores of *D. citri* are produced in perithecia on decaying wood in the soil or dead branches remaining in the tree and are dispersed by wind (Mondal et al. 2007; Gopal 2014).
- Although ascospores are not considered a major source of inoculum for local spread of *D. citri* within an orchard, they play a significant role in long-distance dispersal (Gopal 2014).
- *Diaporthe medusaea* produces conidia on dead branches and invades wounded tissue (Zhang et al. 2008; Yamoto 1976). Annual pruning wounds provide many infection sites for *Diaporthe* pathogens each growing season (Pintos et al. 2018).
- In a survey that identified *D. baccae, D. novem* and several other new *Diaporthe* species from citrus in Europe, formation of pycnidia (asexual reproductive structures which produce conidia) was observed on dead twig tissue (Guarnaccia and Crous 2017).
- Literature searches in CAB Abstracts and Google Scholar (August 2020) using the species name as a search term found no records that specifically reported ascospore production in *D. baccae, D. hongkongensis* or *D. novem*.
- In other woody species, *Diaporthe* species are reported as graft-transmitted, e.g. in grapes, young vines may become infected with *D. ampelina* due to the use of infected mother vines or through cross-contamination during the grafting process (Pintos et al. 2018). The pathogen can therefore spread to new areas by movement of infected propagation material.
- It is assumed that *D. baccae, D. hongkongensis* and *D. novem* spread in the same way as other, better studied, *Diaporthe* species and therefore that they have the potential to spread in New Zealand.
- *Diaporthe* pathogens frequently have an extended latent asymptomatic phase or are asymptomatic endophytes in some hosts (Gao et al. 2016; Huang et al. 2015; Pintos et al. 2018), so there is the possibility that they may spread and establish undetected. Such infections would be very difficult to control by the time disease symptoms emerge.

Given the arguments and evidence below, the likelihood of *D. baccae* establishing in New Zealand is considered high, with low uncertainty.

- *Diaporthe baccae* has been reported from citrus and blueberries in Italy and from grapevines in Croatia, France, and Spain (Lombard et al. 2014; Guarnaccia and Crous 2017, Guarnaccia et al. 2018). These countries have climate match indices with the whole of New Zealand in the range 0.7–0.9, so environmental conditions are unlikely to limit the establishment or spread of *D. baccae*.
- Host availability would not be limiting for *D. baccae* since its hosts are extremely widespread in New Zealand. For example, in 2019, 1,660 ha were planted with commercial citrus, 640 ha with blueberries and more than 38,000 ha with grapevines for wine production (Plant and Food Research 2019).
- It is assumed that *D. baccae* would be able to spread to nearby hosts in New Zealand via water splash of conidia and over longer distances by wind dispersal of ascospores or through human movement of latently infected propagation material (see above).

Given the arguments and evidence below, the likelihood for *D. hongkongensis* establishing in New Zealand is considered high, with low uncertainty.

- *Diaporthe hongkongensis* has mainly been reported in China, but has also been reported in Artvin, Turkey (Dissanayake et al. 2015; Erper et al. 2017; Gao et al. 2015; Huang et al. 2015; Li et al. 2016; Manawasinghe et al. 2019). Some areas in China where *D. hongkongensis* has been reported have climate match indices of 0.7, and Artvin has a climate match index of 0.8 with the whole of New Zealand. Based on this, environmental conditions in New Zealand are unlikely to limit the establishment or spread of *D. hongkongensis.*
- *Diaporthe hongkongensis* has been isolated from citrus, grapevines, *Camellia sinensis* and kiwifruit (Huang et al. 2015; Dissanayake et al. 2015; Manawasinghe et al. 2019; Gao et al. 2015; Li et al. 2016). Gao et al. (2015) also identified *D. hongkongensis* in numerous wild hosts in Gutianshan nature reserve (China), including the common New Zealand weed *Miscanthus* and species in the Fagaceae, a plant family common in New Zealand. *Diaporthe hongkongensis* was also reported from kiwifruit in Artvin, Turkey (Erper et al. 2017; Li et al. 2016).
- Host availability would not be limiting for *D. hongkongensis*. Citrus and grapevines are widely grown commercially and in home gardens (see above). In New Zealand, more than 12,000 hectares are planted with commercial kiwifruit (Plant and Food Research 2019). Camellias are widespread throughout New Zealand in home gardens and as amenity plantings, and *Miscanthus* is a common weed. These widespread plants could provide a reservoir of inoculum to spread the fungus.
- It is assumed that *D. hongkongensis* would be able to spread to nearby hosts in New Zealand via water splash of conidia and over longer distances by wind dispersal of ascospores or through human movement of latently infected propagation material (see above).

Given the arguments and evidence below, the likelihood of *D. novem* establishing in New Zealand is considered high, with low uncertainty.

- *Diaporthe novem* has been identified in a wide range of commercial crops and weeds, many of which are widespread in New Zealand. *Diaporthe novem* is reported from citrus in Italy (Guarnaccia and Crous 2017) and Iran (Alavi and Faraki 2016), grapevines in Northern California (Lawrence et al. 2015), South Africa (Lesuthu et al. 2019), France and Spain (Pintos et al. 2018) and from kiwifruit in Chile (Díaz et al. 2014, 2017). A recent survey reported that *D. novem* was widespread in eastern Australia in numerous agricultural, horticultural and wild hosts, including sorghum, sunflowers, lupins, verbena and vetch (Thompson et al. 2018). It has also been reported from willow in California (Lombard et al. 2015) and hydrangea in Portugal (Santos et al. 2011). Most reports of *D. novem* are from geographical areas with climate match indices in the range 0.7–0.9 with the whole of New Zealand. This indicates that areas where *D. novem* are found have very similar climates to New Zealand and that environmental conditions are unlikely to limit its establishment or spread.

- Host availability would not be limiting for *D. novem* since its hosts are extremely widespread in New Zealand. Citrus, grapes and kiwifruit are grown commercially and in home gardens. Hydrangeas, lupins, sunflowers are widespread throughout New Zealand in home gardens and as amenity plantings. Lupins and sorghum are grown as forage. In addition, NZFlora (Allan Herbarium 2020) records many reported hosts of *D. novem* species as “Wild, Exotic (Fully naturalised)”, including willow, lupins, verbena, common thornapple, sowthistle, small-flowered mallow, turnip weed, Noogoora burr, vetch and a number of *Sambucus* (elder) species (although not *S. gaudichaudiana*). These widespread weeds could provide a reservoir of fungal inoculum to spread the disease.
- It is assumed that *D. novem* would be able to spread to nearby hosts in New Zealand via water splash of conidia and over longer distances by wind dispersal of ascospores or through human movement of latently infected propagation material (see above).

There is very low uncertainty in these conclusions, since existing reports of *D. baccae, D. hongkongensis* and *D. novem* are predominantly from regions with very similar climates to New Zealand and include commercial hosts that are widely produced in New Zealand. In addition, hosts of *D. hongkongensis* and *D. novem* include amenity plants, weeds and wild plants that are likely to be present in gardens and near production areas in New Zealand.

5.3.6 Risk assessment: impacts to New Zealand

Notes on dieback diseases caused by *Diaporthe*

- Impacts of new *Diaporthe* species are likely to become more severe as plants age (i.e. the impacts may be delayed for some years) and are likely to be sporadic and more severe in times of environmental stress such as extreme heat, cold, drought or heavy rainfall. High temperatures, cold injury, drought, rain in spring and early summer, and poor orchard management practices are reported to promote outbreaks of *D. medusaea* in citrus in China (Gao 2006; Zhang et al. 2008).
- Likewise, disease of citrus caused by *D. citri* becomes more severe as the tree ages. In a survey in Panama, melanose symptoms were observed mainly in sweet orange and grapefruit orchards older than 10 years, usually with poor management (Aguilera-Cogley and Vicent 2019).
- A 2011 outbreak of *D. novem* causing severe stem lesions and premature aging in a commercial sunflower crop in Queensland, Australia was triggered by sustained warm temperatures, above-average rainfall and subsequent flooding (Thompson et al. 2018).
- Impacts may be mitigated by good management practices (e.g. prompt removal of damaged and dead branches).

Given the arguments and evidence below, the introduction of *D. baccae* is considered likely to cause moderate economic impacts for New Zealand, with moderate uncertainty.

Diaporthe baccae has been reported to cause disease in mandarin, grapevines and blueberry plants in countries with climates similar to New Zealand:

- *Diaporthe baccae* was isolated from orange, lemon, grapefruit and mandarin plants with twig dieback and branch and trunk cankers in a survey in Italy (Guarnaccia and Crous 2017). In pathogenicity tests, however, *D. baccae* only caused symptoms in mandarin. Melanose and stem-end rot of fruit were not observed in any of the citrus plants surveyed. Yield losses caused by *D. baccae* were not described. However, worldwide, trunk canker (caused by all pathogens) is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that cankers caused by *D. baccae* have the potential to result in losses.
- *Diaporthe baccae* was isolated from grapevines in Croatia, France and Spain during a survey of grapevine-associated *Diaporthe* in Europe and Israel (Guarnaccia et al. 2018). Disease symptoms associated with *Diaporthe* included cane and leaf spot, cane bleaching and additionally vascular browning and sectorial necrosis in grapevine wood. *Diaporthe baccae* caused stem lesions in grapevines in pathogenicity tests (Guarnaccia et al. 2018). However,

since samples for the study were collected from asymptomatic and symptomatic grapevines, it is not certain whether *D. baccae* was associated with disease symptoms in natural infection.

- Wine is the second most valuable horticultural export for New Zealand (value NZ$1.8 billion) (Plant and Food Research 2019). Therefore, crop losses and loss of productive grapevines have the potential to cause significant economic consequences for New Zealand.
- *Diaporthe baccae* was collected in a 2012 survey in Sicily, Italy (CMI=0.7–0.8) from blueberry plants with cankers at their bases and brown lesions developing on the green stems and twigs, which led to twig blight (Lombard et al. 2014). Cankers in the crowns of plants led to plant death. In pathogenicity tests on blueberry plants, *D. baccae* replicated these symptoms.
- In 2019, blueberries were New Zealand's most valuable berry crop, with a domestic sales value of NZ$23 million and exports earning $38.9 million. Losses in this crop and damage or death of plants at commercial production sites have the potential to cause significant economic consequences for New Zealand.

Given the arguments and evidence below, the introduction of *D. hongkongensis* is considered likely to cause moderate economic impacts for New Zealand, with moderate uncertainty.

- *Diaporthe hongkongensis* is reported as a grapevine pathogen, isolated in Hunan, China, a region with a climate similar to the whole of New Zealand (climate match index = 0.7), from grapevine wood from vines showing poor growth, bark and discolouration of the pedicels in grape bunches (Dissanayake et al. 2015). *Diaporthe hongkongensis* caused stem lesions in pathogenicity tests (Dissanayake et al. 2015).
- Wine is the second most valuable horticultural export for New Zealand (value NZ$1.8 billion) (Plant and Food Research 2019). Therefore, crop losses and loss of productive grapevines have the potential to cause significant economic consequences for New Zealand.
- In Artvin, Turkey (CMI = 0.8), *D. hongkongensis* caused necrotic and collapsed lesions at the stem ends of ripening kiwifruit on vines, reducing fruit production in three commercial orchards (Erper et al. 2017). In this study, *D. hongkongensis* was the only pathogen reported, and it caused symptoms in pathogenicity testing. *Diaporthe hongkongensis* (as *D. lithocarpus*) was also reported as one of the *Diaporthe* species causing post-harvest rot of kiwifruit in Sichuan (Li et al. 2015).
- In 2019, kiwifruit exports earned more than NZ$2.3 billion (Plant and Food Research 2019), so crop losses through pre-harvest and post-harvest rots are likely to cause economic impacts.

Given the arguments and evidence below, the introduction of *D. novem* is considered likely to cause moderate economic impacts for New Zealand, with moderate uncertainty.

- *Diaporthe novem* was isolated from lime and kumquat plants with twig dieback in a survey in Italy (although it occurred less frequently than *D. foeniculina* and *D. baccae*) (Guarnaccia and Crous 2017). In pathogenicity tests, lime, lemon, and mandarin plants were susceptible to *D. novem*, although it was only weakly aggressive compared with the other citrus-associated *Diaporthe* tested. In east Mazandaran (Iran), an area which generally has a similar climate to the whole of New Zealand (climate match index = 0.6–0.8), *D. novem* was reported as the cause of gummosis, with symptoms including rot, wood discolouration and decline in citrange (*C. sinensis* × *P. trifoliata*) rootstock (Alavi and Faraki 2016).
- Yield losses caused by *D. novem* were not described. However, it is assumed that trunk disease and damage to rootstocks caused by *D. novem* has the potential to cause economic impacts through yield losses or loss of productive plants.
- *Diaporthe novem* was isolated from dormant *Vitis* sp. rootstock canes, rootstock and *Vitis champinii* in the Western Cape province of South Africa (CMI = 0.6–0.9) (Lesuthu et al. 2019) and from wood cankers on grapevines in California (Lawrence et al. 2015). *Diaporthe novem* caused stem lesions in pathogenicity tests (Lawrence et al. 2015; Lesuthu et al. 2019).
- New Zealand wine exports are very significant (NZ$1.8 billion), and therefore, yield losses or damage to grapevines would have economic consequences.

- *Diaporthe novem* was reported as one of the *Diaporthe* species causing post-harvest rot of kiwifruit in Chile (Díaz et al. 2014, 2017). In 2019, kiwifruit exports earned more than NZ$2.3 billion (Plant and Food Research 2019), so losses through post-harvest rot are likely to result in economic impacts.
- *Diaporthe novem* also causes disease symptoms (e.g. stem lesions) in a range of forage crops, legumes and ornamental plants (e.g. lupin, sorghum, sunflower, chickpea, soybean, faba bean, mung bean) (Thompson et al. 2018). It has potential for impacts on the pastoral sector, cut flower production and horticulture.

There is moderate uncertainty around the potential for *D. baccae, D. hongkongensis* and *D. novem* to have economic impacts in New Zealand for the following reasons.

- *Diaporthe baccae, D. hongkongensis* and *D. novem* have been isolated from disease lesions in natural infections of plant hosts. However, it is not always clear how often they were the only fungal species isolated and whether they caused the disease symptoms observed in the host. It is possible that these *Diaporthe* species were secondary invaders of the disease lesions or were present in the plant as endophytes with no role in disease.
- Several other economically significant *Diaporthe* species including *D. ampelina, D. citri* sensu stricto*, D. eres, D. foeniculina, D. rudis* and *D. sojae* are present in New Zealand, often closely related and with overlapping host ranges (including citrus, grape, kiwifruit, etc). For example, taxonomic studies suggest that *D. baccae* is very closely related to *D. foeniculina* (Hyde et al. 2017), which is reported as a shoot blight, leaf spot, and opportunistic fruit rot, with hosts including citrus, grapevines, blueberries, camellias, kiwifruit and many others (Farr and Rossman 2020). Therefore, it is highly uncertain whether *D. baccae, D. honkongensis* and *D. novem* will have greater or different impacts beyond the impacts of the *Diaporthe* species already established here.
- *Diaporthe* species often occur in coinfection with each other and/or other latent pathogen species (e.g. Botryosphaeriaceae). However, pathogens may compete, leading to no change or even reduction in disease severity. For example, the presence of *Neofusicoccum mediterraneum* spores significantly reduced germination of *D. rhusicola* spores in in vitro experiments (Agustí-Brisach et al. 2019). Inoculating walnut shoots and hulls with *D. rhusicola* four days before introducing *N. mediterraneum* caused a delay in lesion development in shoots and hulls compared with the other two interaction treatments (simultaneous or the other way around) (Agustí-Brisach et al. 2019).
- *Diaporthe baccae, D. hongkongensis* and *D. novem* can cause disease symptoms in many of their known hosts in pathogenicity tests. However, such tests often involve inoculating the plant with high concentrations of spores or mycelium. It is uncertain to what extent these *Diaporthe* species cause disease under natural infection conditions.
- Disease symptoms attributed to *Diaporthe* are more frequent and severe in older plants, suggesting they may be opportunistic rather than primary pathogens. *Diaporthe* pathogens can have long latent periods as asymptomatic endophytes but cause occasional severe outbreaks of disease, particularly when plants are injured or stressed by environmental conditions or other pathogens. This means that impacts from *D. baccae, D. hongkongensis* and *D. novem* may be delayed, sporadic and difficult to separate from impacts from other pathogens and adverse environmental events.
- Given that *D. baccae, D. hongkongensis* and *D. novem* were only recently described and can cause disease symptoms in a range of species from different families, they may affect other hosts that are economically important in New Zealand.

Given the arguments and evidence below, the introduction of *D. baccae, D. hongkongensis* or *D. novem* is considered likely to cause low sociocultural impacts in New Zealand, with moderate uncertainty.

The fungi may cause impacts to home gardeners, public parks and amenity plantings:

- As mentioned above, *Diaporthe baccae, D. hongkongensis* and *D. novem* causes disease symptoms such as leaf scabs, branch cankers, twig dieback and fruit rots in plants such as blueberry, citrus, grapevines and kiwifruit which are often grown in New Zealand gardens. These species have the potential to reduce the productivity and yield of fruit crops for home gardeners, since these *Diaporthe* spp. have been reported to cause significant cankers that lead to loss of branches, or plant death in some hosts.

- Other hosts of *D. hongkongensis* and *D. novem* include amenity species such as camellia, hydrangea, sunflower and lupin (see **Table 6**). For example, *D. novem* caused stem lesions and lodging in patches of a commercial crop of sunflower in Australia (Thompson et al. 2018). In contrast, *D. hongkongensis* in camellia was sometimes associated with leaf lesions, and sometimes asymptomatic (Gao et al. 2016), but it is not clear whether *D. hongkongensis* seriously damaged the plants.
- The extent of impacts in home and civic gardens is uncertain. Impacts would most likely be sporadic, more common in older plantings, and linked to environmental conditions, stress, injury or infection with other pathogens. The uncertainty in the conclusion is moderate because of this, and the reasons outlined above.

Given the arguments and evidence below, the introduction of *D. baccae, D. hongkongensis* or *D. novem* is considered likely to cause very low to moderate environmental impacts in New Zealand, with moderate uncertainty.

- Literature searches in CAB Abstracts and Google Scholar (August 2020) using the species name as a search term found no reports of *D. baccae, D. hongkongensis* or *D. novem* infecting any plants that are native to New Zealand. However, *D. hongkongensis* and *D. novem* in particular have been isolated from a diverse range of wild hosts in many different families (Gao et al. 2015; Thompson et al. 2018). Therefore, it is possible that the fungi could cause disease in native species present in New Zealand.
- The uncertainty with this conclusion is high because the fungi are recently described and not described from New Zealand. Although no records were found of disease caused by these *Diaporthe* species in New Zealand native plants, the fungi may not have had the opportunity to infect such hosts if they are not common in the areas where these fungi are found.

Given the arguments and evidence below, the introduction of *D. baccae, D. hongkongensis* or *D. novem* is considered likely to cause very low human health impacts in New Zealand, with moderate uncertainty.

Some *Diaporthe* species are harmful to human or animal health:

- *Diaporthe* (Phomopsis) species (e.g. *Diaporthe phaseolorum*, *Diaporthe raonikayaporum*, *Diaporthe sojae*) have occasionally been reported to cause eye, skin and soft tissue infections, particularly in immunocompromised patients (Guégan et al. 2016; Howard et al. 2019; Mattei et al. 2017).
- *Diaporthe* species have occasionally been reported to produce harmful mycotoxins in animal or human food. For example, *Diaporthe toxica* produces Phomopsin A (PHO-A), a mycotoxin known to be responsible for fatal liver disease of lupin-fed sheep (Schloß et al. 2017).
- Literature searches in CAB abstracts and Google Scholar (August 2020) using the species name as a search term found no specific reports of *D. baccae, D. hongkongensis* and *D. novem* causing human or animal disease, either directly or through mycotoxins in food. However, there is moderate uncertainty in the conclusion because these species are recently described and human or animal health impacts cannot yet be ruled out.

5.3.7 References

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5.4 *Elsinoe australis* (sweet orange 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 orange and mandarin. This disease causes yield losses and reduces the market value of fresh citrus fruit.

Taxonomy
Scientific name: *Elsinoe australis* Bitancourt and Jenkins (1936)
Order/family: Myriangiales (previously Dothideales)/Elsinoaceae
Other names: *Sphaceloma australis* Bitancourt & Jenkins (1936), sweet orange scab, SOS (CABI 2020)
Notes: 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 orange (*Citrus sinensis*) is the major host (EFSA 2017).
- Hyun et al. (2007, 2009) reported a new pathotype of *E. australis* from fruit of natsudaidai (*C.* × *natsudaidai*) in Korea. This pathotype has also been detected in Honshu, Japan[32] and is recently invasive in the USA, where it causes lesions on a much wider range of citrus hosts, including sweet orange, lemon (*C. limon*), tangerine (*C. reticulata*) and grapefruit (*C. paradisi*) (Kunta et al. 2013).
- Two pathotypes of *E. australis* are reported from Australia, from finger lime (*Citrus australica*) fruit (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).

5.4.1 Summary of conclusions

- The association of *E. australis* with leafless *Citrus* budwood is considered weak with low uncertainty.
- The likelihood of *E. australis* entering associated with leafless *Citrus* budwood is considered to be negligible, with low uncertainty.
- *Elsinoe australis* may not be considered for additional measures.
- Given that *E. australis* is not expected to enter New Zealand associated with leafless *Citrus* budwood, further assessment is not required.

5.4.2 Hazard identification: regulatory status

Elsinoe australis meets the criteria to be a quarantine pest for New Zealand.

Criteria for being a regulated quarantine pest, relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand) and is of potential importance (able to establish and cause harm[33]).

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,

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[32] 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.
[33] 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”.

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 2020; 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, which is of economic importance to New Zealand.
- *Elsinoe australis* has the potential to have socio-cultural impacts: citrus is commonly planted in home gardens.

5.4.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *E. australis* with *Citrus* spp. is considered strong. However, the association with leafless budwood is considered weak with low uncertainty.

- The major host of *E. australis* is sweet orange (*C. sinensis*), and it has also been reported from many other citrus species (**Table 7**).

Table 7: Species of *Citrus* and related genera susceptible to sweet orange scab caused by *E. australis* (Kunta et al. 2013; Farr and Rossman 2020; CDFA 2020)

Scientific name	Common name
C. sinensis	Sweet orange
C. aurantiifolia	Mexican lime
C. aurantium	Bitter orange
C. australis	Finger lime
C. limon	Lemon
C. nobilis	Tangor
C. × *paradisi*	Grapefruit
C. reticulata	Mandarin/tangerine
C. unshiu	Satsuma mandarin
C. grandis/C.maxima	Pomelo (detected in a survey in Japan[34])
C. latifolia	Tahiti lime

Elsinoe australis is only occasionally associated with stems, shoots or twigs of citrus plants.
- *Elsinoe australis* mainly causes symptoms on fruit, and lesions caused by *E. australis* on twigs of citrus plants are rare (Bitancourt and Jenkins 1937).
- Most later authors do not mention symptoms of *E. australis* on twigs, stems or shoots (e.g. Timmer et al. 1996; Timmer 2000; Hyun et al. 2007; Chung 2011; Kunta et al. 2013).
- CDFA (2020) describe warty lesions and corky eruptions caused by *E. australis* on young twigs, shoots and stems of nursery plants, but evidence from other sources suggests that this is also a rare symptom in the USA (Schultz et al. 2013; UF/IFAS Citrus extension 2020; LSU AgCentre (accessed 29 November 2020) and other articles on the LSU AgCentre website; USDA-APHIS 2020).

5.4.4 Risk assessment: entry

Given the arguments and evidence below, the likelihood of *E. australis* entering associated with citrus budwood is considered negligible, with low uncertainty.

Elsinoe australis can be associated with citrus budwood (see above) but the likelihood is low.
- It is rare for *E. australis* to be associated with stems, shoots or twigs of citrus plants (see above).
- Although Chung (2011) states that *E. australis* probably survives solely in fruit, Bitancourt and Jenkins (1937) believed that infected twigs were almost certainly a source of inoculum for infections in the next season. Sivanesan and Critchett (1974) also believed old lesions on

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[34] 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.

twigs to be a probable source of infection at the start of each season (in addition to fruit and leaf lesions).

- Plants from areas with high levels of *E. australis* are extremely unlikely to be used for commercial budwood production.
- Since stem infections are rare and cause obvious, visible symptoms (warty lesions and corky eruptions), it is not likely that contaminated material will be used for propagative material.

The minimum requirements reduce the likelihood of entry to a negligible level because the latent period for symptoms of *E. australis* is short and symptoms are likely to be detected prior to export or within one growing season in post-entry quarantine.

- Bitancourt and Jenkins (1937) describe the twig lesions as comparatively rare and inconspicuous. However, the examples they photographed were clearly visible without magnification. Since imported budwood will not include leaves, any lesions are likely to be exposed and therefore easily detected by visual inspection.
- Although no studies were found that determined the rate of symptom development on twigs or shoots, evidence from leaf and fruit infections suggests that symptoms will develop within 10 days.
    - Scab symptoms developed 5–7 days after inoculation of grapefruit, sweet orange, lemon and tangerine with *E. australis* (the natsudaidai pathotype from the USA) in detached leaf assays (Kunta et al. 2013).
    - Fruit of grapefruit, tangerine, and sweet orange inoculated with *E. australis* isolates developed scab symptoms 8–10 days after inoculation (Bitancourt and Jenkins 1937; Kunta et al. 2013; EFSA 2017).

There is low uncertainty associated with this conclusion. Searches of CAB Abstracts, CABI and Google Scholar using the search terms ‘Elsinoe australis’ and ‘latent’ or ‘endophyte’ or ‘systemic’ returned no evidence to suggest that *E. australis* can remain latent in citrus budwood for long periods.

Given that *E. australis* is not expected to enter New Zealand associated with leafless *Citrus* budwood, further assessment is not required.

5.4.5 References

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5.5 *Erysiphe quercicola* and *Fibroidium tingitaninum* (powdery mildew of citrus)

The asexual forms of *Erysiphe quercicola* and *Fibroidium tingitaninum* are the causative agents of fungal powdery mildew disease on *Citrus* spp. The disease is typified by the appearance of white ‘powdery’ growth on the surfaces of leaves, shoots and young fruits.

Taxonomy
Scientific name: *Fibroidium tingitaninum* (Carter) Braun and Cook (2012)
Order/family: Erysiphales/Erysiphaceae
Synonyms: *Oidium tingitaninum, Acrosporium tingitaninum*
Common names: Powdery mildew of citrus
Notes: This fungus was originally recorded on leaves of *Citrus nobilis* (tangor), as *O. tingitaninum,* in California (Index Fungorum 2020).

Scientific name: *Erysiphe quercicola* Takam and Braun (2007)
Order/family: Erysiphales/Erysiphaceae
Synonyms: *Oidium citri, O. anacardii, Acrosporium anacardii, Pseudoidium anacardii, O. heveae, O. mangiferae.*
Notes: *Erysiphe quercicola* was first described by Takamatsu et al. (2007) from leaves of *Quercus phillyreoides* (black ridge oak) in Japan. Based on phylogenetic analysis powdery mildew occurring on several hosts, it was identified as asexual *E. quercicola* (Takamatsu et al. 2007). The asexual names *O. anacardia*, *O. citri, O. heveae* and *O. mangiferae* are considered synonyms.
The literature found concerning this species causing citrus powdery mildew refers to both *O. citri* and *E. quercicola*. Recent literature of the fungus on *Citrus* spp. and other hosts refers to *E. quercicola* (Tam et al. 2016; Baiswar et al. 2015; Siahaan et al. 2016; Fonseca et al. 2019). In keeping with the move away from the use of the *Oidium* spp. names, *E. quercicola* is used in this assessment.

Powdery mildew lifecycle
Fungi in the order Erysiphales are commonly referred to as powdery mildews (Glawe 2008). The complete life cycle of powdery mildews may involve an asexual stage as well as a sexual stage (Glawe 2008). During asexual reproduction, conidia are produced on the host. The conidia have a white, powdery appearance, and the conidia production stage is the state that is referred to as ‘powdery mildew’. Conidia are produced in large amounts, within a short space of time (3–7 days post infection under disease-promoting conditions) and therefore can cause rapid spread of the disease. Powdery mildews can overwinter as dormant asexual mycelia in buds of host plants or as sexual ascospores independent of a host (Glawe 2008).

The main disease symptoms of powdery mildew and spread of the disease are due to the asexual stage of the fungi. The literature on *F. tingitaninum* and *E. quercicola* on citrus (as well as other hosts) does not mention the sexual stages. Therefore, the asexual forms of citrus powdery mildews are of most concern.

Uncertainty
Identification and ecological studies of citrus powdery mildew have been hampered, as the disease is caused by the asexual form, and the sexual form often does not occur (particularly in the tropics where the disease is most prevalent), which is needed for species identification (Limkaisang et al. 2006). Formerly, the asexual forms (*Oidium* spp.) were described based on host plants and morphological characteristics, but this was not always sufficient to clearly differentiate the forms (Limkaisang et al. 2006). Recently, molecular methods have been successful in identifying the anamorphic forms of powdery mildews (Baiswar et al. 2015; Takamatsu et al. 2007), which has led to some previously identified records being reassigned (Holford et al. 2010).
Furthermore, the literature that refers to the causative agents of citrus powdery mildew disease does not always differentiate between the two species (as mentioned above). This is due to either the use of the disease name, the use of names that have since become synonyms, or records where the causative agent is given as *O. tingitaninum* but it is not clear what method was used in the identification (Whiteside et al. 1988; Gupta and Gupta 1992; Reddy 2010). Where possible, the two species have been assessed separately. However, where information either was not available for the individual species or did not differ between the species, they were assessed together.

5.5.1 Summary of conclusions

- The likelihood of *F. tingitaninum* and *E. quercicola* entering associated with leafless of *Citrus* budwood is considered low, with moderate uncertainty.
- The likelihood for *E. quercicola* establishing in New Zealand is considered high, with low uncertainty.
- The likelihood of *F. tingitaninum* establishing in New Zealand is considered moderate, with low uncertainty.
- The introduction of *E. quercicola* is considered to cause moderate economic impacts in New Zealand, with low uncertainty.
- The introduction of *F. tingitaninum* is likely to cause low economic impacts in New Zealand, with low uncertainty.
- The introduction of *E. quercicola* or *F. tingitaninum* is likely to cause low sociocultural impacts in New Zealand, with low uncertainty.
- The introduction of *E. quercicola* or *F. tingitaninum* is likely to cause very low environmental impacts in New Zealand, with low uncertainty.
- The introduction of *E. quercicola* or *F. tingitaninum* is likely to cause negligible human health impacts, with low uncertainty.
- *Fibroidium tingitaninum* and *E. quercicola* may be considered for additional measures on citrus budwood.

5.5.2 Hazard identification: quarantine pest status

Given the arguments and evidence below*, F. tingitaninum* and *E. quercicola* meet the criteria to be quarantine pests for New Zealand

Criteria for being a regulated quarantine pest relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand), and the pest is of potential importance (able to establish and cause harm[35]).

Oidium tingitaninum and *O. citri* are not known to be present in New Zealand.

- *Fibroidium tingitanium* is not known to occur in New Zealand. It is not recorded in PPIN (2020) or NZFungi (2020). The quarantine status of the fungus in New Zealand is ‘regulated’ in ONZPR and BRAD (2020), under the synonym *O. tingitanium*.
- *Erysiphe quercicola* is not known to occur in New Zealand. It is not recorded in PPIN (2020) and is listed as absent in NZFungi2 (2020). *Erysiphe quercicola* is not recorded in ONZPR (2021). *Oidium citri* is recorded in BRAD, but no regulatory status is assigned.

Fibroidium tingitaninum and *E. quercicola* have the potential to establish and spread in New Zealand:

- The fungi are reported to cause disease in countries with similar climates to New Zealand.
- High humidity is favourable for citrus powdery mildew expression (Whiteside et al. 1988). In New Zealand, most commercial citrus orchards are in the north of the North Island (Plant and Food Research 2019), which has a warm, humid, sub-tropical climate (section 2.6).
- Citrus species are also widely grown in New Zealand both commercially and by home gardeners throughout the country (section 2.6).
- Therefore, suitable host plants in suitable environmental conditions are likely to be present to support establishment.

Oidium tingitaninum and *E. quercicola* have the potential to have economic and sociocultural consequences by causing disease of citrus and oak.

- On citrus, powdery mildews cause symptoms on leaves, shoots and young fruits. Infection reduces the photosynthetic power of the tree and severely infected trees drop fruit early. Severe infection can have significant effects on fruit yield and marketability (Biosecurity Queensland 2011).
- All known citrus cultivars are affected, and there are no known resistant cultivars (Whiteside et al. 1988; Biosecurity Queensland 2011).

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[35] 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”.

- Citrus is an important commercial crop for New Zealand and is commonly grown by home gardeners (section 2.6).
- *Erysiphe quercicola* also causes powdery mildew of oak (Takamatsu et al. 2007), which is grown for timber, as a forage crop and as an amenity plant in New Zealand (Halliwell 1979; Horizons Regional Council 2017).

5.5.3 Hazard identification: commodity association

Given the arguments and evidence below*,* the association of *Fibroidium tingitaninum* and *E. quercicola* with leafless *Citrus* budwood is considered strong, with low uncertainty.

Mycelia of powdery mildews can be present in the buds of infected plants:

- These fungi affect all aerial parts of citrus plants (Reddy 2010). Powdery mildews are not internal pathogens, but rather, form mycelium that grows on the outside of (generally) new, green growth (Agrois 1978).
- The powdery mildew fungi overwinter in buds of infected plants, as dormant mycelia. (Whiteside et al. 1988; Reddy 2010; Brazee 2019). Therefore, mycelium may be present on leafless budwood produced from an infected mother plant.

5.5.4 Risk assessment: likelihood of entry

Given the arguments and evidence below, the likelihood of *F. tingitaninum* and *E. quercicola* entering New Zealand associated with leafless *Citrus* budwood is considered low, with low uncertainty.

Fibroidium tingitaninum and *E. quercicola* have a strong association with leafless citrus budwood, as powdery mildews overwinter in buds:

- Citrus powdery mildews overwinter in buds of infected plants as dormant mycelia, which are the source of new infection come spring, when conidia are produced and easily spread (Whiteside et al. 1988; Reddy 2010; Brazee 2019).
- In apple, the dormant shoots of plants heavily infected with powdery mildew the previous year are covered in dense, white fungal mycelium, and the terminal bud is pinched (Agriculture Victoria, undated). Therefore, such material is unlikely to be used to produce budwood. However, shoots may also appear normal but harbour overwintering mycelia in healthy-looking leaf buds (Agriculture Victoria undated). Such material may be unknowingly used for producing budwood.
- Citrus powdery mildew has a tropical/subtropical distribution and is reported from Asia, the Caribbean, Central and South America, Uganda and the USA (Florida and occasionally California on tangerines) (Whiteside et al. 1988; Thaung 2007; Chung 2011). Of the countries where the disease is reported to occur on *Citrus* spp., only the USA has ever exported citrus budwood to New Zealand, the last time in 2005 (QuanCargo 2020). As this pathway is inactive and other potential pathways have never had trade, material is unlikely to be sourced from countries where citrus powdery mildew is known to occur. However, trade on these pathways cannot be ruled out in the future.
- There is a low likelihood that severely infected plants would be used to produce budwood material. However, trees that were only mildly infected can appear healthy but harbour mycelium in dormant buds. Therefore, during times of mild disease infection, there is the potential for some contaminated material to be used for leafless budwood.

There is some uncertainty around the frequency by which plant material may be harbouring dormant powdery mildew mycelium, but otherwise appear healthy. The symptoms described in the literature suggest that heavily infected material would be easily detectable and would not be used to produce budwood or symptoms would be noticed at the border.

Minimum requirements reduce the likelihood of entry to low, as the fungi are likely to cause visibly detectable symptoms within one growing season:

- *Fibroidium tingitaninum* and *E. quercicola* overwinter in buds of infected plants as dormant mycelia, which are the source of new infection come spring (Whiteside et al. 1988; Reddy 2010; Brazee 2019). If the material is derived from heavily infected trees, disease symptoms would be visibly detectable. However, the material may also be infected and appear healthy early in the season.
- Following overwintering, when conditions become favourable in spring, the fungi resume growing and invade newly developing shoots and leaves (Brazee 2019).
- No evidence was found of *F. tingitaninum* or *E. quercicola* (syn. *O. citri*) causing asymptomatic infection of *Citrus* spp. Google Scholar and CAB Abstracts were searched using the terms: citrus powdery mildew or *Oidium tingitaninum/Fibroidium tingitaninum* or *Erysiphe quercicola/Oidium citri* + asymptomatic/dormant/latent.
- Sastra-Hidayat (1992) showed that the disease caused by *F. tingitaninum* has a four-day infection cycle, when conditions were conducive to disease. The optimal conditions for conidial germination were found to be 20–25°C and 70–80% relative humidity. Epidemic levels occurred when rainfall was low. Young leaves (up to three weeks following emergence) were most vulnerable to infection.

However, if *F. tingitaninum* and *E. quercicola* were to produce symptoms in post-entry quarantine, the conidia produced during the growing season may not be contained in level 3A:

- If leafless budwood infected with overwintering mycelia of *F. tingitaninum* and *E. quercicola,* any conidia produced while in post-entry quarantine may escape from the glasshouse between inspections of the plants. For level 3A facilities, there are no requirements for measures to contain airborne, fungal spores (MPI 2019).
- Exposure of the pathogens to the New Zealand environment may then occur if suitable hosts are present near the post-entry quarantine glasshouse, for example, if the facility is located near oak trees or a citrus orchard. However, the amount of inoculum likely to escape is small, and the conidia would have to land on a suitable host under suitable conditions to germinate and cause disease. The likelihood of this occurring is rated very low.
- Other measures in place within level 3A glasshouses (including protective clothing and hand washing) (MPI 2019) would reduce the likelihood of any spores/conidia leaving the glasshouse due to human activity, and then potentially transferring to a suitable hosts, to a very low level.

5.5.5 Risk assessment: likelihood of establishment and spread

The current distribution of *F. tingitaninum* and *E. quercicola* causing disease on *Citrus* spp. is difficult to determine.

- Much of this difficulty is due to the large number of synonyms for the powdery mildew pathogens, as well as the confusion in the literature between *E. quercicola* and *F. tingitaninum* (DROPSA undated). Furthermore, many records did not list the species in question and either referred to generic ‘powdery mildew’ or *Oidium* spp.
- **Table 8** gives the distribution information for citrus powdery mildew found during the review of the literature. Many sources did not give the specific fungal species causing the disease or the host it was found on.
- Literature where the specific fungal species causing powdery mildew of citrus was described is used for the assessment of establishment potential (**Table 9**). The reports of *O. tingitaninum* are restricted to a report from California, whereas *E. quercicola* is more widespread in both Asia and North America.
- After examining many specimens of powdery mildew fungi, Boesewinkel (1981) suggested that disease caused by asexual *F. tingitaninum* only occurred in California and that all other specimens of citrus powdery mildew represented asexual *E. quercicola* (Boesewinkel 1981, cited in de Jesús Yáñez-Morales et al. 2009). This hypothesis is supported by Holford et al. (2010), who identified the causative agent of citrus powdery mildew in Bhutan to be *E. quercicola*, rather than *F. tingitaninum* as previously reported. It is also representative of the recent literature, where the causative agent of citrus powdery mildew has been identified as *E. quercicola* (**Table 9**).

- The move towards more accurate diagnoses, based on molecular rather than morphological methods (Limkaisang et al. 2006), may mean that reports of *F. tingitaninum* in other countries are reclassified to *E. quercicola.*

Table 8: Distribution of citrus powdery mildew, as described in the literature. Specific species and host information was not necessarily available. Sources: CABI (2020), DROPSA (undated), Thaung (2007), Holford et al. (2010), Ray (2017), Tam et al. (2016), Chung (2011), Reddy (2010), de Jesús Yáñez-Morales et al. (2009)

Continent/Region	Countries
Asia	Myanmar, India, Taiwan, Viet Nam, Bhutan, Cambodia, China, Hong Kong, Israel, Indonesia (Java, Sumatra), Malaysia, Nepal, Philippines, Sri Lanka, Timor-Leste
Africa	Uganda
North America	**USA** (California, Florida), Mexico
Central America	Costa Rica, Guatemala, Panama, Honduras
South America	Brazil
Caribbean	Antigua, Cuba

Countries in bold are countries we have imported citrus nursery stock from (Quancargo 2020).

Table 9: Distribution of *Fibroidium tingitaninum* and *Oidium citri* (syn. *Erysiphe quercicola*) on *Citrus* spp. based on records where the fungal species responsible was described.

Species	Continent	Country	Host	Reference
Fibroidium tingitaninum (syn. *O. tingitaninum*)	North America	USA (California)	*Citrus* sp. (tangerine)	Boesewinkel 1981 cited in de Jesús Yáñez-Morales et al. (2009)
Erysiphe quercicola (syn. *O. citri*)	Asia	India	*Citrus reticulata* (Khasi mandarin)	Baiswar et al. (2015)
		Viet Nam	*C. reticulata* (mandarin)	Tam et al. (2016)
		Bhutan	*C. reticulata* (mandarin), *Citrus* × *insitorum* (Carrizo citrange), *Citrus* × *limon* (Rangpur lime), *Citrus* × *aurantium* (Tsunokaori tangor)	Holford et al. (2010)
		Nepal	*Citrus* sp.	Pandey and Adhikari (2005)
		Myanmar	*Citrus* spp.	Thaung (2007)
		Malaysia	*C. sinensis* (orange)	Braun and Cook 2012 cited in Tam et al. (2016)
	North America	Mexico	Citrus × *limon* (Rangpur lime)	de Jesús Yáñez-Morales et al. (2009)

Both *E. quercicola* and *F. tingitaninum* are wind-transmitted and mechanically transmitted:

- No evidence was found of the fungi requiring a vector for transmission.
- The fungal conidia that typify powdery mildew disease are wind-dispersed (Whiteside et al. 1988). Movement of infected plant material will spread the fungi and spread can also occur within orchards via human activity (conidia on clothing, equipment and vehicles) (Business Queensland 2019).
- Therefore, if the fungi were to enter the New Zealand environment, there would be no barrier to spread, and they are likely to spread to other suitable hosts.

Given the arguments and evidence below, the likelihood of *E. quercicola* establishing in New Zealand is considered high, with low uncertainty.

The fungus is described causing powdery mildew of *Citrus* spp. in some regions with climatic similarity to New Zealand:

- Of the countries/regions where *E. quercicola* is reported causing citrus powdery mildew (**Table 8**), four have areas with a similar climate with the whole of New Zealand: Nepal (composite match index (CMI) 0.4–0.8), Bhutan (0.4–0.7), India (0.4-0.8) and Mexico (0.4–0.8) (0.6–0.8) (Phillips et al. 2018). The other countries (Myanmar, Indonesia, Viet Nam and Malaysia) do not have a similar climate to New Zealand (CMI <0.7).

- This suggests that there are regions of New Zealand where the fungi have the potential to establish, most likely warmer regions such as the north of the North Island (where most of the commercial citrus is grown) (Plant & Food Research 2019).
- High humidity favours the expression of powdery mildew disease (Agrois 1978).
- Sastra-Hidayat (1992) found that the optimal conditions for conidial germination are 20–25°C temperatures and 70–80% relative humidity. Epidemic levels of citrus powdery mildew occur during periods of high relative humidity (Whiteside et al. 1988; Sastra-Hidayat 1992; Timmer et al. 2003).
- In Bhutan, powdery mildew caused by *E. quercicola* is found on *C. reticulata* in all growing regions and is a significant disease. It is most severe in the south of the country, where the climate is humid and sub-tropical. The disease is especially common in plant nurseries, as well as overcrowded, shady and poorly vented plantations on valley floors (Holford et al. 2010).
- In Viet Nam, citrus powdery mildew is most common in valley orchards in the north of the country between February and May (Tam et al. 2016); the time of year with the highest humidity, low rainfall and warm temperatures.
- In New Zealand, citrus in mainly grown in areas with high humidity and warm summers (Chappell 2013a, b; Chappell 2016). The high humidity is likely to be suitable for *E. quercicola* to establish and for citrus powdery mildew disease development.

The records of *E. quercicola* causing powdery mildew disease on *Citrus* spp. include countries with areas of climate similarity with New Zealand citrus-growing regions. Most commercial citrus orchards are found in the north of the North island, with a warm and humid climate, which is likely to be suitable for establishment and disease expression. The presence of suitable host plants in a suitable environment means that the likelihood of establishment is rated as high.

Erysiphe quercicola has been reported from hosts other than *Citrus* spp. in countries with a similar climate to New Zealand:

- *Erysiphe quercicola* has been found causing oak powdery mildew all over France and successfully overwinters there. It is noted that milder winters are favourable for the survival of the fungus (Marçais et al. 2017). Many *Quercus* spp. (oaks) are fully naturalised in New Zealand (Allan Herbarium 2020), and there is a high climate similarity between France and the generalised climate of New Zealand (CMI 0.9) (Phillips et al. 2018). The fungus has the potential to establish and overwinter in the New Zealand, as suitable host plants are widely available and the climate is suitable.
- The fungus was identified as one of the causative agents of powdery mildew of *Mangifera indica* (mango) in the Malaga region of Spain (Desprez-Loustau et al. 2017). *Erysiphe quercicola* was isolated from 97% of the 140 samples tested, from six different orchards. Although mango is not commonly grown in New Zealand, this report further suggests that the climate in New Zealand is suitable for establishment of *E. quercicola*, as the Malaga region has a high climate similarity with New Zealand (CMI 0.8) (Phillips et al. 2018).

Based on the reports of *E. quercicola* causing disease in a range of countries with climatic similarity to New Zealand (particularly France and Spain, which are highly similar), as well as the reports of the fungus affecting multiple hosts, citrus and oak being relevant for New Zealand, the likelihood of *E. quercicola* establishing in New Zealand is rated as high.

Given the arguments and evidence below, the likelihood of *F. tingitaninum* establishing in New Zealand is considered moderate, with low uncertainty.

The host range of *F. tingitaninum* is restricted to *Citrus* spp. and may only be present in California.

- It has been suggested that *F. tingitaninum* is restricted to California (Boesewinkel 1981, cited in de Jesús Yáñez-Morales et al. 2009). This is supported in recent literature, where asexual *E. quercicola* has been identified as the causative agent of citrus powdery mildew in many countries (**Table 8**), including where the causative agent has previously been identified as asexual *F. tingitaninum* (Holford et al. 2010).

- California has a similar climate to New Zealand (CMI 0.6–0.8), which suggests that at least some regions of New Zealand would have a climate suitable for establishment, most likely in the warmer regions such as the north of the North Island (where most of the commercial citrus is grown) (Plant and Food Research 2019).
- The species may also occur in Florida (Chung 2011) (CMI 0.5–0.7).
- Although present in California, citrus powdery mildew disease caused by the asexual form of *F. tingitaninum* only occurs occasionally (Whiteside et al. 1988).
- As described above, some of the citrus-growing regions of New Zealand experience high humidity, which favours powdery mildew disease.
- No records of *F. tingitaninum* on hosts other than *Citrus* spp. were found in the literature.

Fibroidium tingitaninum is reported from California, which has climatic similarity with New Zealand. However, due to the restricted host and geographical range, the likelihood of establishment is rated moderate.

5.5.6 Risk assessment: impacts to New Zealand

Given the arguments and evidence below, the introduction of *E. quercicola* is considered likely to cause moderate economic impacts for New Zealand, with low uncertainty.

Erysiphe quercicola has been reported causing significant yield losses in *Citrus* spp.

- *Erysiphe quercicola* has been reported from a range of *Citrus* spp. (**Table 8**). *Citrus reticulata* (mandarin) and *C. sinensis* (sweet orange) are commonly grown commercial species in New Zealand (section 2.6). Therefore, impacts to these species have the potential to cause consequences of economic significance.
- Mycelia growth of asexual *E. quercicola* is described as dense, “covering leaves with a thick, white coating” (Petch 1945 cited in Holford et al. 2010). Growth occurs on both the upper and lower leaf surface and can cause dieback and defoliation (Holford et al. 2010). Such symptoms reduce the productivity, yield and fruit quality (Holford et al. 2010).
- In Viet Nam, the mycelium of *E. quercicola* was found covering young leaves and fruit of *Citrus reticulata* (Tam et al. 2016). The affected young fruit dropped prematurely and resulted in up to 80% yield loss (Gupta and Gupta 1992; Tam et al. 2016).
- Severe powdery mildew infection can be debilitating for the relevant trees (Timmer et al. 2003).
- Such yield losses would have significant economic consequences to the affected growers. Furthermore, the rapid expression and spread of the disease (see life cycle section) would mean that during seasons of suitable conditions, losses are likely to occur in whole orchards.

Disease expression is likely to be limited to regions of New Zealand where citrus is grown and which experience periods of high humidity and moderate temperatures. Therefore, economic impacts to individual affected growers and the wider community in such areas may be significant. The impact for the citrus industry, at least in years with weather conditions that facilitate disease, may be significant. Therefore, the likelihood of the fungus causing economic impacts is rated moderate.

Given the arguments and evidence below, the introduction of *F. tingitaninum* is considered likely to cause low economic impacts for New Zealand, with low uncertainty.

The fungus appears to be restricted to causing occasional disease on citrus in California:

- Boesewinkel (1981) proposed that *E. quercicola,* rather than *F. tingitaninum*, is the major cause of citrus powdery mildew worldwide (Boesewinkel 1981, cited in de Jesús Yáñez-Morales et al. 2009; Holford et al. 2010).
- Although present in California, citrus powdery mildew disease caused by the asexual form of *F. tingitaninum* only occurs occasionally (Whiteside et al. 1988).

- The mycelium of the of *F. tingitaninum* are described as initially being sparse and then becoming denser but never felt-like in appearance. Mycelial growth arises on the upper surface of young leaves, causing leaf deformation but little other damage (Carter 1915, cited in Holford et al. 2010).
- Yield or crop loss specifically attributed to *F. tingitaninum* was not found in the literature.
- Based on the literature, the host range of the fungus is restricted to *Citrus* spp.

It has been suggested that *F. tingitaninum* is limited to California, where it causes occasional disease. The restricted host range, distribution and the limited accounts of disease caused by the fungus mean that the likelihood of *F. tingitaninum* causing economic impacts in New Zealand is rated low.

Given the arguments and evidence below, the introduction of *F. tingitaninum* or *E. quercicola* is considered likely to cause low sociocultural impacts in New Zealand, with low uncertainty.

The fungi may cause impacts for home gardeners who grow *Citrus* spp. in areas of the country where environmental conditions are suitable.

- As mentioned in the section above, citrus powdery mildew causes symptoms that would reduce the productivity and yield of citrus trees for home gardeners.
- However, such impacts would be restricted to gardeners in the limited regions of the country with suitable environmental conditions.

Quercus spp. are hosts of *Erysiphe quercicola.* However, the level of impact is likely to be negligible:

- Oaks are grown in New Zealand for timber and as an amenity or forage crop (Halliwell 1979; Horizons Regional Council 2017; NZWood undated).
- The host range of *E. quercicola* is not restricted to a narrow group of plant taxa and is reported from a range of woody trees, including *Quercus* spp. (oaks) (Takamatsu et al. 2007; Gautam 2015; Meeboon and Takamatsu 2020).
- *Erysiphe quercicola* causes foliar symptoms, indistinguishable to those caused by another oak powdery mildew *E. alphitoides* (Marçais et al. 2017). *Erysiphe alphitoides* is present in New Zealand on *Quercus* spp. (NZFungi 2020).
- Although *E. alphitoides* is described as causing significant impact to plants at a foliar level, it is not usually considered a problem beyond the individual plant level (Marçais and Desprez-Loustau 2014). Therefore, it can be assumed that although *E. quercicola* may cause unsightly symptoms on the leaves, it is unlikely to have significant consequences for the trees. Furthermore, the impacts are unlikely to be above those already caused on *Quercus* spp. in New Zealand by *E. alphitoides.*
- No evidence was found in the literature of *F. tingitaninum* affecting hosts other than *Citrus* spp. Therefore, the fungus appears to have a restricted host range, and it does not appear that this species would have any consequences on other hosts.

There are reports of the powdery mildew fungi causing foliar and fruit symptoms, as well as significant yield losses. However, these are likely to be restricted to certain areas of New Zealand and may only occur sporadically during years of suitable climatic conditions and are therefore rated low.

Given the arguments and evidence below, the introduction *F. tingitaninum* or *E. quercicola* is considered likely to cause very low environmental impacts in New Zealand, with low uncertainty.

- The asexual form of *Erysiphe quercicola* has been isolated from a range of tree hosts, in multiple plant families (Siahaan et al. 2016; Meeboon and Takamatsu 2020). As the fungus has a broad host range, it may be that it could infect environmental species, including native species present in New Zealand.
- However, such reports are from tropical regions, where citrus powdery disease is most prevalent, and the fungi are therefore unlikely to occur in the New Zealand environment, except in some restricted areas with sufficiently warm temperatures and high humidity.
- *Fibroidium tingitaninum* appears to have a restricted host range, as no evidence was found of the species affecting hosts other than *Citrus* spp. As there are no native *Citrus* spp. in

New Zealand (Allan Herbarium 2020), the likelihood of *F. tingitaninum* having environmental consequences in New Zealand is very low.

Given the arguments and evidence below, the introduction of *F. tingitaninum* or *E. quercicola* is considered likely to cause negligible human health impacts in New Zealand, with low uncertainty.

Powdery mildews are not known to pose risks to human health:

- No evidence was found of these fungi, or other powdery mildew fungi, causing human health issues.

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5.6 *Lasiodiplodia* species associated with disease of *Citrus* trees

Members of the fungal genus *Lasiodiplodia* are opportunistic pathogens and are reported causing stem-end rot, fruit rot, tree canker, root and collar rot of a range of hosts plants including *Citrus* spp.

Taxonomy
Scientific name: *Lasiodiplodia brasiliensis* Netto et al. (2014)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: Phylogenetically, *L. brasiliensis* is closely related to *L. viticola* but is differentiated by unique fixed alleles at one locus as well as by the conidia of *L. brasiliensis* being longer and wider (Netto et al. 2014). The fungus was first reported from *Carica papaya* (papaya) with stem-end rot in Brazil (collected in 2007) and later from *Mangifera indica* (mango) collected in 2010 (Netto et al. 2014). Since the first report, the fungus has been isolated from a wide range of countries and multiple hosts including *Citrus latifolia* (Persian lime) in Mexico (Bautista-Cruz et al. 2019).

Scientific name: *Lasiodiplodia citricola* Abdollahzadeh et al. (2010)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: Phylogenetically, *L. citricola* is closely related to *L. parva,* although the former produces longer and wider conidia (Abdollahzadeh et al. 2010). The fungus was first reported from *Citrus* sp. in Iran (Abdollahzadeh et al. 2010) and has since been reported from a broad range of hosts and locations, including *Juglans regia* (European walnut) and *Prunus persica* (peach) in California (Chen et al. 2013a; Chen et al. 2013b), *Citrus latifolia* (Persian lime) in Mexico (Bautista-Cruz et al. 2019) and *Vitis vinifera* (grapevine) in Australia (Burgess et al. 2019).

Scientific name: *Lasiodiplodia hormozganensis* Abdollahzadeh et al. (2010)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: Phylogenetically, *L. hormozganensis* is closely related to *L. citricola* and *L. parva* but can be distinguished based on the dimensions of conidia and paraphyses (Abdollahzadeh et al. 2010). The fungus was first reported from diseased mango and *Olea* sp. (olive) in Iran (Abdollahzadeh et al. 2010) and has since been reported from multiple hosts and countries, including *Citrus* spp. in Oman (Al-Sadi et al. 2013).

Scientific name: *Lasiodiplodia iraniensis* Abdollahzadeh et al. (2010)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: This species is clearly distinct from the other *Lasiodiplodia* species but is most closely related to *L. theobromae* (Abdollanhzadeh et al. 2010). The fungus was first described from mango, *Citrus* sp., *Eucalyptus* sp., *Salvadora persica* (kharijal), *Terminalia catappa* (country almond) and *Juglans* sp. (walnut) in Iran (Abdollahzadeh et al. 2010). It has also been reported from *Citrus* spp. in Oman (Al-Sadi et al. 2013).

Scientific name: *Lasiodiplodia mediterranea* Linaldeddu et al. (2015)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: *Lasiodiplodia mediterranea* is phylogenetically closely related to *L. pseudotheobromae* but differentiated by the shape and size of the conidia and the paraphyses (Linaldeddu et al. 2015). The fungus has been reported from *Citrus sinensis* (orange) in Algeria as well as grapevine and *Quercus ilex* (holm oak) in Italy (Sardinia) (Linaldeddu et al. 2015) and *Vaccinium corymbosum* (blueberry) in the USA (Wiseman et al. 2017).

Scientific name: *Lasiodiplodia mitidjana* Berraf-Tebbal et al. (2020)
Order/Family: Botryosphaeriales/Botryosphaeriaceae

Synonyms: None found
Notes: The species is phylogenetically very closely related to *L. citricola,* being distinguished based on the size of the conidia (Berraf-Tebbal et al. 2020). The fungus has been reported from diseased orange trees in Algeria (Berraf-Tebbal et al. 2020).

Scientific name: *Lasiodiplodia pseudotheobromae* Alves et al. (2008)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: This fungus was identified as a cryptic species[36] of *L. theobromae* based on ITS and EFI-α sequence analysis and was first described from samples previously identified as *L. theobromae*, including one from *Citrus aurantium* (bitter orange) in Suriname (Alves et al. 2008). The fungus has now been isolated from numerous hosts and countries including grapevine and blueberry in Australia (Burgess et al. 2019) and causing post-harvest fruit rot of *Citrus limon* (lemon) in Turkey (Awan et al. 2016).

Scientific name: *Lasiodiplodia subglobosa* Machado et al. (2014)
Order/Family: Botryosphaeriales/Botryosphaeriaceae
Synonyms: None found
Notes: Described following phylogenetic analysis (ITS and EFI-α sequences) of fungal isolates from *Jatropha carcas* trees with collar and root rot disease in Brazil. Compared to the other species, there were not many reports beyond the first identification. The fungus has been reported from diseased *Citrus latifolia* (Persian lime) in Mexico (Bautista-Cruz et al. 2019).

The species of *Lasiodiplodia* identified as associated with disease of *Citrus* trees are considered together for the commodity association and entry sections, as, based on the literature, there is little difference between the species for these sections. In the establishment and economic impacts sections, they are assessed separately. Many of these species are newly described, and there is very limited literature available, resulting in high uncertainty associated with several of the conclusions.

5.6.1 Summary of conclusions

Summary table 2: Summary of conclusions for the identified *Lasiodiplodia* spp.

Species		Criteria					
		Entry	**Establishment**	**Economic impacts**	**Socio-cultural impacts**	**Environmental impacts**	**Human health impacts**
Lasiodiplodia brasiliensis	**Rating**	low	low	moderate	low	low	very low
	Uncertainty	high	low	high	low	high	low
Lasiodiplodia citricola	**Rating**	low	high	low	low	low	very low
	Uncertainty	high	low	high	low	High	low
Lasiodiplodia hormozganensis	**Rating**	low	low	moderate	low	low	very low
	Uncertainty	high	low	high	low	high	low
Lasiodiplodia iranensis	**Rating**	low	moderate	low	low	low	very low
	Uncertainty	high	high	high	low	high	low
Lasiodiplodia mediterranea	**Rating**	low	high	moderate	low	low	very low
	Uncertainty	high	high	low	low	high	low
Lasiodiplodia mitidjana	**Rating**	low	moderate	low	low	low	very low
	Uncertainty	high	high	high	low	high	low
Lasiodiplodia pseudotheobromae	**Rating**	low	moderate	high	low	low	very low
	Uncertainty	high	moderate	moderate	low	high	low
Lasiodiplodia subglobosa	**Rating**	low	moderate	low	low	low	very low
	Uncertainty	high	low	high	low	high	low

The identified *Lasiodiplodia* spp. may be considered for additional measures.

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[36] 'Cryptic species' refers to a species that cannot easily be distinguished from another based entirely on morphology. However, molecular marker analysis shows that the species forms a distinct phylogenetic lineage.

5.6.2 Hazard identification: quarantine pest status

Given the arguments and evidence below, the identified *Lasiodiplodia* species meet the criteria to be quarantine pests for New Zealand.

Criteria for being a regulated quarantine pest relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand) and is of potential importance (able to establish and cause harm[37]).

The identified *Lasiodiplodia* spp. are not known to be present in New Zealand.

- *Lasiodiplodia pseudotheobromae* is listed as absent (NZFungi2 2020) and is not recorded in PPIN (2020). There is no record for the species in ONZPR (2020) or BRAD (2020).
- *Lasiodiplodia brasiliensis, L. citricola, L. hormozganensis, L. iraniensis, L. mediterranea, L. mitidjana* and *L. subglobosa* are not listed in NZFungi2 (2020), PPIN (2020), BORIC (2020) or BRAD (2020).

The identified *Lasiodiplodia* spp. have the potential to establish in New Zealand.

- The assessed *Lasiodiplodia* species have been reported from countries with a similar climate to, or regions with, a similar climate to New Zealand (including Australia, Italy, Algeria and Mexico) (**Table 10**).
- The species have been isolated from hosts commonly grown in New Zealand, both commercially and by home gardeners (including *Citrus* spp., *Rosa* sp., *Solanum melongena* (eggplant), *Malus* spp. (apples), *Vitis vinifera* (grapevine), *Prunus persica* (peach), *Eucalyptus* sp. and *Vaccinium corymbosum* (blueberry). See **Table 10**.
- Therefore, suitable host plants in suitable environmental conditions are likely to be present to support establishment.

The identified *Lasiodiplodia* spp. have the potential to cause economic and sociocultural consequences by causing disease on citrus and other hosts:

- The assessed *Lasiodiplodia* spp. have all been described as associated with disease of *Citrus* spp. (Bautista-Cruz et al. 2019; Al-Sadi et al. 2013; Berraf-Tebbal et al. 2020). Disease symptoms associated with these fungi on *Citrus* spp. are described as gummosis, stem/trunk canker and branch dieback (**Table 10**).
- Citrus is an important commercial crop for New Zealand and is commonly grown by home gardeners (section 2.6). Therefore, symptoms reducing the longevity or production of the plant has the potential to cause both economic and social consequences.
- *Lasiodiplodia brasiliensis, L. citricola, L. hormozganensis* and *L. pseudotheobromae* have been associated with diseased grapevines (Carlucci et al. 2015; Dissanayake et al. 2015; Correia et al. 2016). Wine represents New Zealand's second largest horticultural export, with a value of $1.8 billion (Plant and Food Research 2019).

5.6.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of the identified *Lasiodiplodia* spp. with leafless *Citrus* budwood is considered strong, with low uncertainty.

All the assessed *Lasiodiplodia* spp. have been isolated from aboveground plant parts of *Citrus* spp.

- All the assessed *Lasiodiplodia* spp. infect aboveground plant parts including the trunk, branches and fruit (Abdollahzadeh et al. 2010; Bautista-Cruz et al. 2019; Berraf-Tebbal et al. 2020).
- The fungi are opportunistic and enter hosts via wounds and natural openings such as lenticels and stomata (Slippers and Wingfield 2007). Therefore, there are no barriers as to which tissues the fungi may infect.
- The related species *L. theobromae* causes fruit stem-end rot in multiple crop species, including avocado, mango and citrus, by growing into the fruit stem from the branches

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[37] 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".

(Queensland Dept. of Agriculture and Fisheries 2018). Al-Sadi et al. (2013) also reported dieback and gummosis of acid lime (*C. aurantifolia*) in Oman (and sweet lime, location unspecified).

- It is considered that all members of the Botryosphaeriaceae have an endophytic phase (Slippers and Wingfield 2007). Therefore, the fungi may be associated with material used for budwood without causing symptoms.
- The Botryosphaeriaceae overwinter as pycnidia in diseased woody plant parts and in woody plant debris (Úrbez-Torres 2013). Other endophytic fungi overwinter within their host plant (Dutta et al. 2014).
- There are reports of the fungi causing disease of *Citrus* in nine countries around the world (**Table 10**).

5.6.4 Risk assessment: likelihood of entry

Given the arguments and evidence below, the likelihood of any one of the assessed *Lasiodiplodia* spp. entering New Zealand associated with leafless *Citrus* budwood is considered low, with high uncertainty.

Individually, the *Lasiodiplodia* spp. have a moderate association with *Citrus* budwood:

- All the assessed *Lasiodiplodia* spp. have been isolated from above ground plant parts of *Citrus* spp. (**Table 10**). They are opportunistic pathogens and can infect any part of the plant through wounds or natural openings (Slipper and Whiteside 2017).
- Botryosphaeriaceae cause asymptomatic infections of hosts (Slipper and Whiteside 2017). In mango, the related species *L. theobromae* has been found to occur endophytically in stem tissue (Johnson et al. 1992). Although there are no published papers confirming that the assessed *Lasiodiplodia* spp. have an asymptomatic phase, there has not been any work testing asymptomatic tissue. Therefore, there is the potential for infected material to unknowingly be used for budwood production.
- There are no records of citrus nursery stock being imported to New Zealand from the countries where the identified *Lasiodiplodia* spp. have been reported on *Citrus* spp.[38] (**Table 10**) (QuanCargo 2020). Therefore, current trade patterns suggest that material is unlikely to be sourced from countries where the fungi occur on citrus. However, trade from further countries cannot be ruled out in the future.
- Some of the *Lasiodiplodia* spp. (*L. brasiliensis, L. citricola, L. hormozganensis, L. iranensis, L. mediterranea* and *L. pseudotheobromae)* have been reported from countries where citrus nursery stock has been imported (USA) (Wiseman et al. 2017), but from hosts other than *Citrus* spp.
- *Lasiodiplodia pseudotheobromae* has been most frequently reported from citrus hosts (Table 6.5) and has the strongest association with leafless citrus budwood of the assessed species.

The minimum requirements reduce the likelihood of entry as *Lasiodiplodia* spp. to a moderate degree, with high uncertainty:

- Visual inspection of budwood and the mother plants is likely to detect symptomatic material.
- Symptoms that develop within post-entry quarantine would also be determined.
- The environmental conditions required for disease expression of the *Lasiodiplodia* species are not currently reported in the literature.
- The time between host plant infection and disease expression of naturally infected hosts in the field was not reported in the literature. In the pathogenicity tests described below, the symptoms developed in less than one growing season.
- The fungi have successfully induced symptoms on citrus in pathogenicity tests:
    - Bautista-Cruz et al. (2019) tested the pathogenicity of *L. subglobosa, L. iraniensis, L. pseudotheobromae, L. theobromae, L. brasiliensis* and *L. citricola* on *C. latifolia* (Persian lime). The assays were conducted on 18-month-old plants that were wound-inoculated with a mycelial plug. The plants were covered with plastic to maintain

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[38] Mexico, Iran, Oman, Algeria, Suriname, Turkey, Bangladesh, Pakistan, Puerto Rico

humidity for three days following inoculation and maintained in a glasshouse under natural light conditions. The temperature was maintained at 30±5°C. After 30 days under these conditions, all species tested produced gum exudation and lesions.
    - Ahmed et al. (2020) used artificial inoculations to fulfil Koch's postulates of *L. pseudotheobromae* on *C. reticulata* (mandarin). One-year-old plants were wounded, inoculated with a mycelial plug and sealed with parafilm. The plants were incubated at 25±2°C under greenhouse conditions. After five weeks, symptoms of gum exudation and bark cankers were observed.
    - Plants in post-entry quarantine are held at temperatures between 18–25°C (MPI Standard 155.02.06). Therefore, conditions within the post-entry quarantine glasshouses may be suitable for disease expression. However, this is not certain.
- Other members of the Botryosphaeriaceae cause asymptomatic infections of hosts and only induce disease under stress conditions (Slipper and Whiteside 2017). In mango, the related species *L. theobromae* has been found to occur endophytically in stem tissue (Johnson et al. 1992). Due to a wide range of such examples, it is believed that all the Botryosphaeriaceae experience an endophytic phase (Slippers and Wingfield 2007). No records were found in the literature of the assessed *Lasiodiplodia* spp. being associated with asymptomatic infection. However, the studies found all looked at symptomatic material.
- The minimal requirements have the potential to reduce the likelihood of entry if the fungi produce visible symptoms, but not for endophytic fungi.

There is high uncertainty associated with this conclusion, and the likelihood of entry may in fact be higher. As these are emerging pathogens, the literature is currently limited, and many of the reports of the fungi from citrus have been made in recent years. Furthermore, there is the potential for these fungi to infect hosts endophytically, as is the case for other Botryosphaeriaceae, including *L. theobromae* (Johnson et al. 1992). However, there are no reports of the assessed species occurring as endophytes. If evidence becomes available, the risk will need to be reassessed.

5.6.5 Risk assessment: likelihood of establishment and spread

Given the arguments and evidence below, the likelihood of *L. brasiliensis* establishing in New Zealand is considered low, with low uncertainty.

- Of the 10 records of *L. brasiliensis* found in the literature, eight are from regions with poor climate similarity to New Zealand (CMI <0.7), with the other two from regions with low similarity (CMI 0.5–0.8) (**Table 10**).
- Burgess et al. (2019) divided Australia into climate zones based on temperature and humidity and matched the locations where *Lasiodiplodia* spp. have been isolated in Australia to these climate zones. A comparison of these climate zones with the New Zealand climate (Phillips et al. 2018) suggests that the New Zealand climate is unlikely to be suitable for the establishment of *L. brasiliensis*.
- The reported host range of the fungus includes tropical plants not grown in New Zealand (such as *Dimocarpus longan* (longan), papaya and mango).
- There are three records of the fungus from plants commonly grown commercially or by home gardeners (grapevine, apple, Persian lime) (**Table 10**). New Zealand has 8,615 ha of apple trees and 33,981 ha of grapevines (Plant and Food Research 2019). Apple trees and grapevines can both support establishment. However, they are unlikely to be present in a suitable climate.
- Due to the poor climate similarity between New Zealand and where the species has been reported as well as the mostly tropical host range, the likelihood of establishment is considered low.

Given the arguments and evidence below, the likelihood of *L. citricola* establishing in New Zealand is considered high, with low uncertainty.

- All records of *L. citricola* found in the literature are from countries with some climate overlap with New Zealand (CMI >0.7), including some regions with high similarity (Italy CMI 0.8–0.9;

Australia CMI 0.7–0.9) (**Table 10**). This suggests that regions of New Zealand would have a climate suitable for establishment.
- Burgess et al. (2019) divided Australia into climate zones based on temperature and humidity and matched the locations where *Lasiodiplodia* spp. have been isolated in Australia to these climate zones. The Australian climate zones where the fungus is present have a strong similarity to all of New Zealand (Phillips et al. 2018), which suggests that there are regions of New Zealand suitable for establishment of *L. citricola*.
- The currently reported host range of *L. citricola* represents plants that are all grown in New Zealand, including the commercial crops grape, peach and citrus (**Table 10**). Grapes in particular have a large commercially planted area of 33,981 ha (Plant and Food Research 2019). Such plants are also commonly grown by home gardeners.
- *Lasiodiplodia citricola* has also been reported from *Juglans regia* (European walnut) Chen et al. (2013a), which is fully naturalised in New Zealand (Allan Herbarium 2020).
- Due to the high climate overlap between the reported geographic range of the species and New Zealand, as well as the abundance of suitable hosts in New Zealand, the likelihood of establishment is considered high.

Given the arguments and evidence below, the likelihood of *L. hormozganensis* establishing in New Zealand is considered low, with low uncertainty

- The geographic distribution of *L. hormozganensis* does not represent countries with a similar climate to New Zealand (CMI <0.7), with most records from Asia and the Caribbean (**Table 10**).
- Burgess et al. (2019) divided Australia into climate zones based on temperature and humidity and matched the locations where *Lasiodiplodia* spp. have been isolated in Australia to these climate zones. A comparison of these climate zones with the New Zealand climate (Phillips et al. 2018) suggests that the New Zealand climate is unlikely to be suitable establishment of *L. hormozganensis*.
- The host range of the species is largely tropical plants that are not present in New Zealand, including crop plants such as *Phoenix dactylifera* (date palm), *Mangifera indica* (mango), *Dimocarpus longan* (longan) and *Carica papaya* (papaya) as well as environmental species *Adansonia* spp. (see **Table 10**). However, the host range does include *Vitis vinifera* (grapevine), *Solanum melongena* (eggplant) and *C. sinensis* (sweet orange), which are common crop species in New Zealand.
- The tropical distribution and tropical plant host range suggests that the likelihood of *L. hormozganensis* establishing in New Zealand is low.

Given the arguments and evidence below, the likelihood of *L. iranensis* establishing in New Zealand is considered moderate, with high uncertainty.

- The reports of *L. iranensis* found in the literature include reports from regions with climate overlap with New Zealand (CMI ≥0.7) as well as from areas with poor climate similarity (CMI <0.7) (**Table 10**).
- This suggests that although there may be regions in New Zealand that have a suitable climate for establishment, these are likely to be limited and most likely restricted to the warmer areas of New Zealand, such as the northern regions of the North Island.
- Burgess et al. (2019) divided Australia into climate zones based on temperature and humidity and matched the locations where *Lasiodiplodia* spp. have been isolated in Australia to these climate zones. A comparison of these climate zones with the New Zealand climate (Phillips et al. 2018) suggests that the New Zealand climate is unlikely to be suitable establishment of *L. iranensis*.
- The current reported host range of *L. iranensis* includes many tropical species that are not grown in New Zealand (**Table 10**). However, it does include plants commonly grown both commercially and by home gardeners, including *Eucalyptus* sp., grapevine, olive, *Citrus* sp. (see table). Grapes in particular have a large area planted for commercial production (33,981 ha) as well as olives (921 ha) (Plant and Food Research 2019).

- Based on the reports of the species from areas with climate overlap and from hosts commonly grown in New Zealand, the likelihood of establishment is rated as moderate. Establishment would be restricted to warmer regions of New Zealand.
- However, there is high uncertainty associated with this conclusion. The related species *L. theobromae* is present in New Zealand but has not thrived (NZFungi2 2020). Furthermore, the most frequently reported hosts of the species are tropical plants, and it is not clear how important species such as grapevine and olive are for *L. iranensis.*

Given the arguments and evidence below, the likelihood of *L. mediterranea* establishing in New Zealand is considered high, with low uncertainty.

- This species has been reported in three locations, all of which have climatic similarity to New Zealand: Italy (CMI 0.8–0.9), Oregon, USA (CMI 0.7–0.8), north of Algeria (Oued El Alleug and Boufarik) (CMI of 0.7) (**Table 10**).
- This suggests the New Zealand climate is suitable for the establishment of the species.
- As well as *C. sinensis, L. mediterranea* has been reported from grapevine and blueberry, which are commercially grown in New Zealand (Plant and Food Research 2019). Grapes in particular have a large commercially planted area (33,981 ha in 2017) (Plant and Food Research 2019). It has also been isolated from holm oak (Linaldeddu et al. 2015), which is fully naturalised in New Zealand (Allan Herbarium 2020). Therefore, suitable hosts are likely to be present in suitable conditions to support establishment.

Given the arguments and evidence below, the likelihood of *L. mitidjana* establishing in New Zealand is considered moderate, with high uncertainty.

- As this fungus has only recently been described, there is only one record of this fungus in the literature—from *C. sinensis* in Algeria (Berraf-Tebbal et al. 2020). The fungus was reported from the north of the country (Oued El Alleug and Boufarik), which has a CMI of 0.7 with New Zealand (**Table 10**). This suggests that although there are likely to be regions of New Zealand suitable for establishment, these are likely to be limited and are most likely the warmer regions of New Zealand (such as the north of the North Island).
- *Citrus* crops are mostly grown in the warmer regions of New Zealand (section 2.6) and therefore suitable hosts may be present in suitable conditions for establishment.
- Based on the current information, the likelihood of establishment is rated as moderate, as although the climate suggests some regions of New Zealand may be suitable, the host range is limited to *C. sinensis.* There is high uncertainty due to the lack of literature. As this is a recently reported pathogen, new information (such as through the emerging risk system) may mean that the risk needs to be reassessed.

Given the arguments and evidence below, the likelihood of *L. pseudotheobromae* establishing in New Zealand is considered moderate, with moderate uncertainty.

- The reports of *L. pseudotheobromae* found in the literature include reports from regions with climate overlap with New Zealand (CMI ≥0.7) as well as from areas with poor climate similarity (CMI <0.7) (**Table 10**). There is a record on *Rosa* sp. from the Netherlands but based on the knowledge of how these plants are grown in the Netherlands (Alves et al. 2008), this may be from a glasshouse.
- This suggests that although there may be regions in New Zealand that have a suitable climate for establishment, these are likely to be limited and most likely restricted to the warmer areas of New Zealand, such as the northern regions of the North Island.
- This is supported by Burgess et al. (2019) who divided Australia into climate zones based on temperature and humidity and matched the locations where *Lasiodiplodia* spp. have been isolated in Australia to these climate zones. By comparing these climate zones to the New Zealand climate (Phillips et al. 2018), it suggests that some regions of New Zealand may be suitable for *L. pseudotheobromae* to establish.

- Correia et al. (2016) noted that although the optimal mycelial growth temperatures of *L. pseudotheobromae* on agar is 30.1°C, it was able to grow at 10°C.
- The fungus has been isolated from a *Rosa* sp. (Burgess et al. 2019; Alves et al, 208), *Citrus* spp. (Abdollahzadeh et al. 2010; Awan et al. 2016; Ahmed et al. 2020), blueberry (Burgess et al. 2019) and grapevine (Dissanayake et al. 2015; Burgess et al. 2019). Such plants are commonly grown in New Zealand as both commercial crops (Plant and Food Research 2019) and by home gardeners. Grapes in particular have a large commercially planted area (33,981 ha in 2017) (Plant and Food Research 2019). Therefore, suitable hosts are likely to be present to support establishment, especially citrus and grapes, as commercial orchards are mostly in the warmer regions of the North Island (Plant and Food Research 2019).
- The closely related species *L. theobromae* is present in New Zealand (NZFungi 2020). Although this has been reported from hosts commonly grown in New Zealand (EPPO 2020) and from countries with a similar climate (CABI 2020), the collections in New Zealand are limited to one from *Begonia* × *hiemalis* (Hiemalis begonia) and two from *Ipomoea batatas* (kūmara) in Auckland (NZFungi2 2020). This suggests that the conditions in New Zealand are not conducive for establishment of the fungus outside this limited area.

The climatic conditions from where the fungus has been isolated suggest that only limited regions of New Zealand would be suitable for the fungus (restricted to warmer regions such as the north of the North Island). However, the wide reported host range, including hosts that are grown in these warmer regions are likely to be present to support establishment. Therefore, the likelihood of establishment is rated moderate. There is uncertainty associated with this conclusion, as although the closely related species *L. theobromae* is present in New Zealand, it is not widespread.

Given the arguments and evidence below, the likelihood of *L. subglobosa* establishing in New Zealand considered to be moderate, with high uncertainty.

- All records of *L. subglobosa* are from regions with some climate similarity with New Zealand (CMI ≥0.7) (**Table 10**).
- The current described host list of *L. subglobosa* is limited to Persian lime (Bautista-Cruz et al. 2019), *Jatropha carcas* (Machado et al. 2014) and *Annona muricata* (soursop) (Machado et al. 2019). Of these species, only Persian lime is grown in New Zealand (Allan Herbarium 2020).
- The likelihood of establishment is rated moderate based on the suitability of the New Zealand climate, even though the host range is currently limited. This is because there are recent reports of new hosts of the fungus, and if these represented plants are grown in New Zealand, there is a good likelihood that the fungus could establish.
- There is high uncertainty associated with this conclusion due to the lack of available literature. Further information received (i.e. via the emerging risk system) may warrant the risk being reassessed.

If the fungi were to enter, they would be able to spread between suitable hosts:

- The Botryosphaeriaceae produce asexual spores (conidia) that are spread to other hosts by watersplash (e.g. from overhead irrigation), rainfall events and wind (Úrbez-Torres et al. 2010).
- Therefore, there are pathways of spread for the fungi between suitable hosts if the fungi enter New Zealand.
- As *Lasiodiplodia* spp. are predicted to have an asymptomatic phase (Slippers and Wingfield 2007), there is the possibility that they may spread via the movement of infected plant material before the infection is detected.

Table 10: Hosts and distributions of the *Lasiodiplodia* spp. reported from *Citrus* spp.

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia brasiliensis	Asia	Malaysia	Kelantan, Pahang, Perak, Sabah, Sarawak, Selangor	*Sansevieria trifasciata* (snake plant)	Leaf blight	0.4–0.5	Yee et al. (2019)
	Caribbean	Puerto Rico	Country-wide	*Dimocarpus longan* (longan)	Inflores	0.5–0.6	Serrato-Diaz et al. (2019)
			Country-wide	*Mangifera indica* (mango)	Inflores	0.5–0.6	Serrato-Diaz et al. (2019)
	South America	Brazil	Minas Gerais State	*Manihot esculenta* (cassava)	Black root rot, stem cutting dry rot	0.5–0.7	Brito et al. (2020)
		Brazil	São Francisco Valley	*Vitis vinifera* (grapevine)	Dieback	0.5	Correia et al. (2016)
		Brazil	Bahia, Paraíba, Rio Grande do Norte	*Carica papaya* (papaya)	Stem end rot	0.4–0.6	Netto et al. 2014
		Brazil	Bahia, Paraíba, Rio Grande do Norte	*Mangifera indica* (mango)	Unknown	0.4–0.6	Netto et al. (2014)
		Brazil	Paraipaba county	*Malus* sp. (apple)	Stem canker, branch dieback	0.4–0.5	Martins et al. (2018)
	North America	Mexico	Puebla and Veracruz	*Citrus latifolia* (Persian lime)	Gummosis, stem canker, branch dieback	0.5–0.8	Bautista-Cruz et al. (2019)
	Oceania	**Australia**	Emerald (QLD)	*Gossypium hirsutum* (upland cotton)	Unknown	0.6	Burgess et al. (2019)
Lasiodiplodia citricola	Asia	Iran	Chaboksar, Sari	*Citrus* sp.	Twig dieback	0.5–0.8	Abdollahzadeh et al. (2010)
	North America	Mexico	Puebla and Veracruz	*Citrus latifolia* (Persian lime)	Gummosis, stem canker, branch dieback	0.5–0.8	Bautista-Cruz et al. (2019)
		USA	Kings, Yuba and Fresno counties, California	*Prunus persica* (peach)	Stem canker	0.6–0.8	Chen et al. (2013b)
			Tulare County, California	*Juglans regia* (European walnut)	Graft union death	0.6–0.8	Chen et al. (2013a)
			Madera, California	*Pistacia vera* (pistachio)	Panicle and shoot blight	0.6–0.7	Chen et al. (2014)
	Europe	Italy	Southern	*Vitis vinifera* (grapevine)	Unknown	0.8–0.9	Raimondo et al. (2014)

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia citricola	Oceania	**Australia**	Waikerie (SA), Canowindra (NSW), Irymple (VIC)	*Vitis vinifera* (grapevine)	Unknown	0.7–0.9	Burgess et al. (2019)
Lasiodiplodia hormozganensis	Asia	Iran	Hormozgan	*Mangifera indica* (mango)	Twig dieback	0.4–0.5	Abdollahzadeh et al. (2010)
		Oman	Unknown	*Citrus limetta* (sweet lime)	Dieback and gummosis	0.4–0.5	Al-Sadi et al. (2013)
			Unknown	*Citrus latifolia* (acid lime)	Dieback and gummosis	0.4–0.5	Al-Sadi et al. (2013)
			Unknown	*Citrus sinensis* (sweet orange)	Dieback and gummosis	0.4–0.5	Al-Sadi et al. (2013)
			Seeb, Barka and Musanaa	*Mangifera indica* (mango)	Dieback and gummosis	0.3–0.4	Al-Sadi et al. (2013)
			Unknown	*Phoenix dactylifera* (date palm)	Necrotic roots	0.4-0.5	Al-Sadi et al. (2013)
		UAE	Unknown	*Phoenix dactylifera* (date palm)	Unknown	0.3–0.4	Al-Sadi et al. (2013)
		Malaysia	Kelantan, Pahang, Perak, Sabah, Sarawak, Selangor	*Sansevieria trifasciata* (snake plant)	Leaf blight	0.4–0.5	Yee et al. (2019)
	Caribbean	Puerto Rico	Country-wide	*Dimocarpus longan* (longan)	Fruit rot	0.5–0.6	Serrato-Diaz et al. (2019)
		Haiti	Montrouis	*Solanum melongena* (eggplant)	Fruit rot	0.5	Fayette et al. (2019)
	Oceania	**Australia**	Broome (WA), Darwin (NT)	*Adansonia gregorii* (baobab)	Unknown	0.4	Burgess et al. (2019)
		Australia	Darwin (NT)	*Adansonia za*	Unknown	0.4	Burgess et al. (2019)
		Australia	Darwin (NT)	*Adansonia digitata* (African baobab)	Unknown	0.4	Burgess et al. (2019)
	South America	Brazil	Minas Gerais	*Manihot esculenta* (cassava)	Black root rot, stem cutting dry rot	0.5–0.7	Brito et al. (2020)
		Brazil	Minas Gerais, Bahia	*Annona squamosa* (sugar apple)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Bahia, Paraíba	*Ricinus communis* (castorbean)	Basal stem rot	0.5–0.6	Custódio et al. (2018)

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia hormozganensis		Brazil	São Francisco Valley	*Vitis vinifera* (grapevine)	Dieback	0.5	Correia et al. (2016)
		Brazil	Bahia, Paraíba, Rio Grande do Norte	*Carica papaya* (papaya)	Stem-end rot	0.4–0.6	Netto et al. (2014)
Lasiodiplodia iranensis	Africa	Mozambique	Unknown	*Adansonia digitata* (African baobab)	Unknown	0.5–0.6	Bautista-Cruz et al. (2019)
	North America	Mexico	Puebla and Veracruz	*Citrus latifolia* (Persian lime)	Gummosis, stem canker, branch dieback	0.5–0.8	Bautista-Cruz et al. (2019)
	South America	Brazil	Minas Gerais	*Manihot esculenta* (cassava)	Black root rot, stem cutting dry rot	0.5–0.7	Brito et al. (2020)
		Brazil	Minas Gerais, Bahia	*Annona muricata* (soursop)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Minas Gerais, Bahia	*Annona squamosa* (sugar apple)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Minas Gerais, Bahia	*Annona atemoya* (atemoya)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Unknown	*Jatropha carcas*	Unknown	-	Bautista-Cruz et al. (2019)
		Brazil	São Francisco Valley	*Vitis vinifera* (grapevine)	Dieback	0.5	Correia et al. (2016)
		Peru	Piura district	*Mangifera indica* (mango)	Dieback	0.4–0.7	Rodríguez-Gálvez et al. (2016)
	Asia	Iran	Unknown	*Citrus* sp.	Twig dieback	-	Abdollahzadeh et al. (2010)
		Iran	Unknown	*Mangifera indica* (mango)	Twig dieback	-	Abdollahzadeh et al. (2010)
		Iran	Unknown	*Eucalyptus* sp.	Twig dieback	-	Abdollahzadeh et al. (2010)
		Iran	Unknown	*Olea* sp.	Twig dieback	-	Abdollahzadeh et al. (2010)
		Iran	Golestan Province	*Juglans* sp. (walnut)	Twig dieback	0.6–0.7	Abdollahzadeh et al. (2010)
		Iran	Hormozgan Province	*Salvadora persica* (kharijal)	Twig dieback	0.4–0.5	Abdollahzadeh et al. (2010)
		Iran	Unknown	*Terminalia catappa* (country almond)	Twig dieback	-	Abdollahzadeh et al. (2010)
		Malaysia	Kelantan, Pahang, Perak, Sabah, Sarawak, Selangor	*Sansevieria trifasciata* (snake plant)	Leaf blight	0.4–0.5	Yee et al. (2019)

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia iranensis	Caribbean	USA	Puerto Rico	*Nephelium lappaceum* (rambutan)	Branch dieback and leaf blight	0.5–0.6	Serrato-Diaz et al. (2019)
			Puerto Rico	*Dimocarpus longan* (longan)	Inflorescences and fruit rot	0.5–0.6	Serrato-Diaz et al. (2019)
			Puerto Rico	*Mangifera indica* (mango)	Inflorescences	0.5–0.6	Serrato-Diaz et al. (2019)
	Oceania	**Australia**	Colignan (Vic)	*Dodonaea viscosa* (hopbush)	Unknown	0.7	Burgess et al. (2019)
		Australia	Broome (WA)	*Adansonia gregorii* (boab)	Unknown	0.4	Burgess et al. (2019)
		Australia	Kimberley (WA)	*Eucalyptus* sp.	Unknown	0.4–0.5	Burgess et al. (2019)
		Australia	Kununurra (WA)	*Mangifera indica* (mango)	Unknown	0.4	Burgess et al. (2019)
Lasiodiplodia mediterranea	Africa	Algeria	Oued El Alleug, Boufarik	*Citrus sinensis* (sweet orange)	Trunk canker	0.7	Berraf-Tebbal et al. (2020)
	North America	**USA**	Oregon	*Vaccinium corymbosum* (blueberry)	Cane dieback	0.7–0.8	Wiseman et al. (2017)
	Europe	Italy	Sardinia	*Vitis vinifera* (grapevine)	Dieback	0.8–0.9	Linaldeddu et al. (2015)
			Sardinia	*Quercus ilex* (holm oak)	Branch canker	0.8–0.9	Linaldeddu et al. (2015)
Lasiodiplodia mitidjana	Africa	Algeria	Oued El Alleug, Boufarik	*Citrus sinensis* (sweet orange)	Trunk canker	0.7	Berraf-Tebbal et al. (2020)
Lasiodiplodia pseudotheobromae	North America	Mexico	Puebla and Veracruz)	*Citrus latifolia* (Persian lime)	Gummosis, stem canker, branch dieback	0.5–0.8	Bautista-Cruz et al. (2019)
	South America	Suriname	Unknown	*Citrus aurantium* (bitter orange)	Unknown	0.4–0.5	Alves et al. (2008)
		Brazil	Minas Gerais State	*Manihot esculenta* (cassava)	Black root rot, stem cutting dry rot	0.5–0.7	Brito et al. (2020)
		Brazil	São Francisco Valley	*Vitis vinifera* (grapevine)	Dieback	0.5	Correia et al. (2016)
		Brazil	Piracicaba	*Diospyros kaki* (persimmon)	Post-harvest fruit rot	0.6	Nogueira et al. (2017)

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia pseudotheobromae	South America	Peru	Piura	*Mangifera indica* (mango)	Dieback	0.4–0.7	Rodríguez-Gálvez et al. (2016)
		Brazil	Bahia, Paraiba, Rio Grande do Norte	*Carica papaya* (papaya)	Stem-end rot	0.4–0.6	Netto et al. (2014)
		Brazil	Minas Gerais, Bahia	*Annona crassiflora* (marolo)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Minas Gerais, Bahia	*Annona muricata* (soursop)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Minas Gerais, Bahia	*Annona squamosa* (sugar apple)	Dieback	0.5–0.7	Machado et al. (2019)
		Brazil	Minas Gerais, Bahia	*Annona atemoya* (atemoya)	Dieback	0.5–0.7	Machado et al. (2019)
	Asia	Turkey	Çukurova	*Citrus limon* (sweet lemon)	Post-harvest fruit rot	0.7–0.8	Awan et al. (2016)
		Bangladesh	Rajshahi	*Citrus* sp.	Stem-end rot	0.4	Sultana et al. (2018)
		Pakistan	Sargodha, Bhulwal, Kot Momin, Faisalabad, Toba Tek Singh	*Citrus reticulata* (mandarin)	Trunk cankers	0.4–0.6	Ahmed et al. (2020)
		Iran	Unknown	*Citrus* sp.	Twigs	-	Abdollahzadeh et al. (2010)
		Malaysia	Kelantan, Pahang, Perak, Sabah, Sarawak, Selangor	*Sansevieria trifasciata* (snake plant)	Leaf blight	0.4–0.5	Yee et al. (2019)
		China	Hubei, Jiangsu	*Vitis vinifera* (grapevine)	Pedicel and penduncle discolouration	0.7	Dissanayake et al. (2015)
		China	Yantai, Shandong	*Malus pumila* (syn. *Malus × domestica*) (apple)	Canker and shoot dieback	0.7	Xue et al. (2019)
		China	Jiangsu	*Celtis sinensis* (hackberry)	Stem canker	0.7	Liang et al. (2019)
	Africa	Zaire	Unknown	*Coffea* sp.	Unknown	0.5–0.6	Abdollahzadeh et al. (2010)
	Central America	Costa Rica	Unknown	*Gmelina arborea* (Candahar tree)	Unknown	0.4–0.6	Abdollahzadeh et al. (2010)
	Caribbean	USA	Puerto Rico	*Citrus* sp. (tangerine)	Branch dieback	0.5–0.6	Serrato-Diaz et al. (2019)

Species	Continent	Country	State/Region	Host	Symptoms / plant parts affected	CMI (Phillips et al. 2018)	Reference
Lasiodiplodia pseudotheobromae	Caribbean	USA	Puerto Rico	*Nephelium lappaceum* (rambutan)	Branch dieback and fruit rot	0.5–0.6	Serrato-Diaz et al. (2019)
			Puerto Rico	*Dimocarpus longan* (longan)	Inflorescences	0.5–0.6	Serrato-Diaz et al. (2019)
			Unknown	*Acacia mangium* (mangium)	Unknown	0.5–0.6	Alves et al. (2008)
	Europe	Netherlands	Unknown	*Rosa* sp.	Unknown	0.9	Alves et al. (2008)
	Oceania	**Australia**	Broome (WA), Gumlu (QLD)	*Mangifera indica* (mango)	Unknown	0.4–0.5	Burgess et al. (2019)
		Australia	Canarvon (QLD), Swan District (WA)	*Vitis vinifera* (grapevine)	Unknown	0.5–0.7	Burgess et al. (2019)
		Australia	Tolga (QLD)	*Rosa* sp.	Unknown	0.4	Burgess et al. (2019)
		Australia	Tolga (QLD)	*Macadamia* sp.	Unknown	0.4	Burgess et al. (2019)
		Australia	Kuranda (QLD)	*Eucalyptus pellita* (large fruited red mahogany)	Unknown	0.5	Burgess et al. (2019)
		Australia	Mareeba (QLD)	*Dimocarpus longan* (longan)	Unknown	0.5	Burgess et al. (2019)
		Australia	Tully (QLD)	*Annona muricata* (soupsop)	Unknown	0.5	Burgess et al. (2019)
		Australia	Corindi (NSW)	*Vaccinium corymbosum* (blueberry)	Unknown	0.7	Burgess et al. (2019)
		Australia	Kununurra (WA)	*Santalum album* (Indian sandalwood)	Unknown	0.4	Burgess et al. (2019)
Lasiodiplodia subglobosa	North America	Mexico	Puebla, Veracruz	*Citrus latifolia* (Persian lime)	Gummosis, stem canker, branch dieback	0.5–0.8	Bautista-Cruz et al. (2019)
	South America	Brazil	Minas Gerais, Espírito Santo, Piauí, São Paulo	*Jatropha carcas*	collar and root rot	0.5-0.7	Machado et al. (2014)
		Brazil	Minas Gerais, Bahia	*Annona muricata* (soursop)	Dieback	0.5–0.7	Machado et al. (2019)

Countries in bold represent countries where *Citrus* nursery stock has been exported to New Zealand (Quancargo 2020)

5.6.6 Risk assessment: impacts to New Zealand

Given the arguments and evidence below, the introduction of *L. brasiliensis* is likely to cause moderate economic impacts for New Zealand, with high uncertainty.

The species has been reported from diseased *C. latifolia* trees.

- *Lasiodiplodia brasiliensis* has been isolated from *C. latifolia* trees with symptoms of gummosis, stem canker and branch dieback in Mexico (Bautista-Cruz et al. 2019).
- This species was the third most frequently isolated (12.5% of all isolates) (Bautista-Cruz et al. 2019). It was found in the both populations in Puebla state (six orchards), but not from the Veracruz populations. In artificial inoculation assays of one-year old Persian limes, *L. brasiliensis* induced necrotic lesions and gum exudation but was found to be less virulent than *L. subglobosa, L. pseudotheobromae* and *L. iranensis* (Bautista-Cruz et al. 2019).
- Yield losses caused by the pathogen were not described, however worldwide trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. brasiliensis* has the potential to result in similar losses.
- In 2019, limes had a domestic value of NZ$2 million (Plant and Food Research 2019).

There are reports of *L. brasiliensis* being associated with disease of other economically significant hosts.

- In Brazil, *L. brasiliensis* has been identified as a causative agent of canker and branch dieback of apple (Martins et al. 2018). The fungus was isolated from symptomatic tissue and pathogenicity was confirmed via artificial inoculation assays (Martins et al. 2018). The level of yield loss associated with infection with *L. brasiliensis* was not described.
- Apples are the third most significant horticulture export for New Zealand, worth NZ$828.8 million in 2019 (Plant and Food Research 2019). Therefore, losses for this industry have the potential to cause significant consequences for the New Zealand economy.
- Correia et al. (2016) isolated *L. brasiliensis* during a survey of *Lasiodiplodia* spp. associated with Botryosphaeria dieback of grapes in eastern Brazil; the species represented 15% of the isolates. In pathogenicity tests on detached shoots, *L. brasiliensis* induced the longest lesions of all the species tested (Correia et al. 2016). In Brazil, grapevine dieback caused by members of the Botryosphaeriaceae is becoming increasingly significant, reducing the longevity and production of plants (Correia et al. 2016).
- Wine is the second most valuable horticultural export for New Zealand (value NZ$1.8 billion) (Plant and Food Research 2019). Therefore, losses in grape crops have the potential to cause significant economic consequences for New Zealand.
- Other reported hosts are tropical species that are not important crops for New Zealand (**Table 10**).

Due to the potential to cause impacts to grape and apple crops, as well as limes, the economic impact of *L. brasiliensis* is rated as moderate. There is high uncertainty associated with the conclusion, which is further discussed below.

Given the arguments and evidence below, the introduction of *L. citricola* is considered likely to cause low economic impacts for New Zealand, with high uncertainty.

The species has been reported from diseased *C. latifolia* trees:

- It has also been isolated from *C. latifolia* trees with symptoms of gummosis, stem canker and branch dieback in Mexico (Bautista-Cruz et al. 2019).
- This species was the least frequently isolated by Bautista-Cruz et al. (2019) (3% of all isolates). It was only found in one orchard in Puebla state. In artificial inoculation assays of one-year-old Persian limes, *L. citricola* induced necrotic lesions and gum exudation but was found to be less virulent than *L. subglobosa, L. pseudotheobromae* and *L. iranensis* (Bautista-Cruz et al. 2019).

- Yield losses caused by the pathogen were not described. However, worldwide, trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. citricola* has the potential to result in similar losses.
- In 2019, limes had a domestic value of NZ$2 million (Plant and Food Research 2019).
- This species was also reported from *Citrus* sp. in Iran during a survey of Botryosphaeriaceae in diseased orchards (Abdollahzadeh et al. 2010). How frequently the species was isolated was not reported, and Koch's postulates were not fulfilled. Furthermore, as the species was not identified, there is currently no evidence of the species infecting other members of the *Citrus* genus.

This species has been reported from other significant hosts for New Zealand:

- *Lasiodiplodia citricola* was identified causing stem canker in *Prunus persica* (peach) in California (Chen et al. 2013b). The disease was found on young trees and caused the death of 30 trees in the Fresno and Yuba counties and a further six in Kings County (Chen et al. 2013b).
- In 2019, peaches had a domestic value of NZ$9 million and an export value of NZ$0.4 million (Plant and Food Research 2019).
- There is no evidence of the fungal species infecting other species of *Prunus.* However, the broad reported host range reported suggests that there is the potential for the fungus to do so.
- The fungus has also been isolated from grapevine in Australia and Italy, although it is not known if these plants displayed symptoms (Raimondo et al. 2014; Burgess et al. 2019). However, the symptoms caused by this species on this host are not described.

Based on the current evidence of the host range, the potential economic impacts associated with the species is rated as low. There is high uncertainty associated with this conclusion. For example, it is not known if it is able to infect other members of *Citrus* or *Prunus,* however if it does there is the potential for further impacts. The uncertainty is further discussed below.

Given the arguments and evidence below, the introduction of *L. hormozganensis* is considered likely to cause moderate economic impacts for New Zealand, with high uncertainty.

The species is reported causing disease on multiple citrus species:

- This species has been reported associated with *C. limetta* (sweet lime), *C. latifolia* (sour lime) and *C. sinensis* (orange) in Oman (Al-Sadi et al. 2013). The trees showed symptoms of dieback and gummosis.
- The species represented 45% of isolated *Lasiodiplodia* spp. and in pathogenicity assays caused wilting in 30–73% of inoculated seedlings (Al-Sadi et al. 2013).
- Losses associated with this species were not described, however it is assumed that the symptoms would cause a decrease in the productivity and/or longevity of the plant.
- In 2019 limes has a domestic value of NZ$2 million and oranges had a domestic value of NZ$18 million and an export value of NZ$1.7 million (Plant and Food Research 2019).

There are reports of *L. hormozganensis* associated with disease of other economically significant hosts:

- The other economically significant hosts reported for the fungus are eggplant and grape (**Table 10**)
- Correia et al. (2016) isolated *L. hormozganensis* during a survey of *Lasiodiplodia* spp. associated with Botryosphaeria dieback of grapes in eastern Brazil; the species represented 7% of the isolates. In pathogenicity tests on detached shoots, *L. hormozganensis* induced visible lesions and was assessed to have intermediate aggressiveness compared to the other species tested (Correia et al. 2016). In Brazil, grapevine dieback caused by members of the Botryosphaeriaceae is becoming increasingly significant, reducing the longevity and production of plants (Correia et al. 2016).
- Wine is the second most valuable horticultural export for New Zealand (value NZ$1.8 billion) (Plant and Food Research 2019). Therefore, losses in this crop have the potential to cause significant economic consequences for New Zealand.

- In Haiti, the species was identified causing fruit rot of eggplant, with a disease incidence of approx. 20% (Fayette et al. 2019). Eggplants are grown in New Zealand for the domestic market, with a value of NZ$8.5 million (Plant and Food Research 2019).

Due to the potential to cause losses to citrus, grape and eggplant crops the potential for economic impacts is rated as moderate. There is high uncertainty associated with this conclusion, which is further discussed below.

Given the arguments and evidence below, the introduction of *L. iraniensis* is considered likely to cause low economic impacts for New Zealand, with high uncertainty.

The species is reported causing disease on multiple citrus species:

- This species has been isolated from *C. latifolia* (Persian lime) trees with gummosis, stem canker and branch dieback in Mexico (Bautista-Cruz et al. 2019). *Lasiodiplodia iranensis* was the least frequently isolated by Bautista-Cruz et al. (2019) (3% of all isolates). It was only found in one population from Veracruz state (three orchards). In artificial inoculation assays of one-year old Persian limes, *L. iranensis* induced necrotic lesions and gum exudation but was found to be more virulent than *L. brasiliensis, L. theobromae* and *L. citricola* (Bautista-Cruz et al. 2019).
- Yield losses caused by the pathogen were not described. However, worldwide, trunk canker (caused by all pathogens) is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. iranensis* has the potential to result in similar losses.
- This species has also been isolated from *C. reticulata* (mandarin) in Oman, during a survey of trees with dieback and gummy exudate symptoms (Al-Sadi et al. 2013). The species represented 10% of isolated *Lasiodiplodia* spp. and in pathogenicity assays caused wilting in 17–77% of inoculated seedlings (Al-Sadi et al. 2013).
- In 2019 limes and mandarins had a domestic value of NZ$2 million and NZ$25 million respectively, with mandarins also having an export value of NZ$0.4 million.
- The species was also isolated from *Citrus* sp. with twig dieback in Iran (Abdollahzadeh et al. 2010). How frequently the species was isolated was not reported, and Koch’s postulates were not fulfilled.

The species has been isolated from other significant hosts with disease symptoms. However, its role as the causative agent is not confirmed.

- The fungus has been isolated from *Eucalyptus* sp. with twig dieback in Iran (Abdollahzadeh et al. 2010) and from *Eucalyptus* sp. in Australia (Burgess et al. 2019), although symptoms are not described. In the study by Abdollahzadeh et al. (2010), Koch’s postulates were not fulfilled.
- Eucalyptus is grown as a timber species in both the North Island and South Island, with a total planted area of 22,307 ha, which contributed NZ$41 million to the New Zealand GDP in 2018 (FOA 2018). Therefore, losses for this industry could have significant impacts for the New Zealand economy. However, further evidence is needed before this species can be considered the causal agent of disease on this host. If this was the case, the potential for economic impacts would be higher.

Based on the current evidence of the species causing disease symptoms on citrus, the potential economic impacts are rated low. There is high uncertainty associated with this conclusion, which is discussed further below.

Given the arguments and evidence below, the introduction of *L. mediterranea* is considered likely to cause moderate economic impacts for New Zealand, with high uncertainty.

The species has been reported from diseased *C. sinensis* trees:

- The only record of *L. mediterranea* on citrus is from Algeria, where it was isolated from *C. sinensis* (orange) trees with trunk canker (Berraf-Tebbal et al. 2020).
- Ten orange orchards in northern Algeria were surveyed for the causal agents of canker and dieback. *Lasiodiplodia mitidjana, L. mediterranea, Diplodia* spp. plus a *Dothiorella* sp. were isolated. In all the orchards, at least two species were found, and the *Lasiodiplodia* spp. were

most frequently detected (Berraf-Tebbal et al. 2020). In pathogenicity tests on orange shoots, *L. mediterranea* induced internal necrotic lesions.
- Yield losses caused by the pathogen were not described. However, worldwide, trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. brasiliensis* has the potential to result in similar losses.
- There is no evidence of the species infecting other species of *Citrus.* However, given the reports from other host species, there is the potential for *L. mediterranea* to infect other *Citrus* spp.
- Oranges had a domestic value of NZ$18 million and an export value of NZ$1.7 million in 2019 (Plant and Food Research 2019).

The species has been reported from diseased grapevine.
- *Lasiodiplodia mediterranea* has also been reported from two grapevine samples in Sardinia, Italy, displaying dieback symptoms (Linaldeddu et al. 2015). The species was isolated from declining grapevines from a single site in Sardinia. In pathogenicity studies. the species caused discolouration of the bark and vascular tissue (Linaldeddu et al. 2015). The losses associated with this species were not described.
- Wine is the second most valuable horticultural export for New Zealand (value NZ$1.8 billion) (Plant and Food Research 2019). Therefore, losses in this crop have the potential to cause significant economic consequences for New Zealand.

Due to the potential to cause losses to citrus and grape, the economic impacts are rated moderate. There is high uncertainty associated with this conclusion, which is further discussed below.

Given the arguments and evidence below, the introduction of *L. mitidjana* is considered likely to cause low economic impacts for New Zealand, with high uncertainty.

The species has been reported from diseased *C. sinensis* trees.
- *Lasiodiplodia mitidjana* is recently described, and there is only one report of the species in the literature, from *C. sinensis* (orange) in Algeria with trunk canker symptoms (Berraf-Tebbal et al. 2020).
- Ten orange orchards in northern Algeria were surveyed for the causal agents of canker and dieback. *Lasiodiplodia mitidjana, L. mediterranea, Diplodia* spp. and a *Dothiorella* sp. were isolated. In all the orchards, at least two species were found, and the *Lasiodiplodia* spp. were most frequently detected (Berraf-Tebbal et al. 2020). In pathogenicity tests on orange shoots, *L. mitidjana* induced internal necrotic lesions.
- Yield losses caused by the pathogen were not described. However, worldwide, trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. mitidjana* has the potential to result in similar losses.
- In 2019, oranges had a domestic value of NZ$18 million and an export value of NZ$1.7 million.

Based on the current, restricted host range of the species the potential economic impacts are rated as low. There is high uncertainty associated with this conclusion, which is further discussed below.

Given the arguments and evidence below, the introduction of *L. subglobosa* is considered likely to cause low economic impacts for New Zealand, with high uncertainty.

The species has been reported from diseased *C. latifolia* trees.
- This species has been reported from *C. latifolia* (Persian lime) in Mexico with gummosis, stem canker and branch dieback (Bautista-Cruz et al. 2019).
- In Mexico, this species was the least frequently isolated by Bautista-Cruz et al. (2019) (3% of all isolates). It was only found in one population from Veracruz state (n=three orchards). In artificial inoculation assays of one-year-old Persian limes, *L. iranensis* induced necrotic lesions

and gum exudation but was found to be more virulent than *L. brasiliensis, L. theobromae* and *L. citricola* (Bautista-Cruz et al. 2019).
- Yield losses caused by the pathogen were not described, however worldwide trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999). Therefore, it is assumed that trunk canker caused by *L. subglobosa* has the potential to result in similar losses.
- In 2019, limes had a domestic value of NZ$2 million (Plant and Food Research 2019).
- There is no evidence of the species infecting other species of *Citrus.* However, given the reports from other host species there is the potential for *L. subglobosa* to infect other *Citrus* spp.

This species has not been reported from any other host that has economic significance for New Zealand (**Table 10**).

Based on the current available evidence for this species, the potential economic impacts associated with the species are rated low. There is high uncertainty associated with this conclusion, which is further discussed below.

Uncertainty

There is high uncertainty associated with the impact conclusions.

- These are emerging pathogens, and currently, there are limited data available in some areas, such as the frequency of disease and level of impact for each species and full host range. Because these are emerging pathogens and there is recent new information, new evidence may become available that would require the risk to be reassessed. Such information would be captured by the emerging risk system.
- There are several reports of the *Lasiodiplodia* spp. occurring in hosts as mixed infections (Chen et al. 2013a; Bautista-Cruz et al. 2019; Yee et al. 2019). Furthermore, Botryosphaeria dieback of grape is reported to be caused by a complex of fungi (Correia et al. 2016). It may be that individually the assessed species have the potential to only cause low economic consequences, but the introduction of multiple species may have a cumulative effect increasing disease severity and economic impact.
- For the *Lasiodiplodia* species reported from only one citrus (or *Prunus*) species (**Table 10**) it is not clear whether they can infect other species within the genus. If this was found to be the case, the risk would need to be reassessed.
- The different species have largely been separated based on phylogenetic analysis (Alves et al. 2008; Abdollahzadeh et al. 2010) and the fully biological differences associated with these new species are not investigated.
- As shown in **Table 10**, it appears that different species have different host ranges and climatic requirements. However, as a number of these species are newly described, there is uncertainty as to whether this is the fully elucidated host and geographic range.
- The conditions required to induce disease symptoms are not described.
- Although the type species of the genus *Lasiodiplodia theobromae* is present in New Zealand, the records are limited to one from *Begonia × hiemalis* (Hiemalis begonia) and two from *Ipomoea batatas* (kumara) in Auckland (NZFungi2 2020). No evidence was found of this species causing serious disease in New Zealand (Google scholar 'lasiodiplodia theobromae disease New Zealand'). Furthermore, although it is a known pathogen of grapevines overseas (Burruano et al. 2008; Rodriguez-Gálvez et al. 2015) it is not found in New Zealand vineyards (Baskarathevan et al. 2012; Billones-Baaijens and Savocchia 2018). Therefore, there is the potential that this may be the case for *L. pseudotheobromae*. There is less uncertainty associated with this species, as there are reports from multiple countries of this species being the sole causative agent of disease, and there is more literature available.

Given the arguments and evidence below, introduction of *L. pseudotheobromae* is considered likely to cause high economic impacts for New Zealand, with moderate uncertainty.

The species is reported causing disease on multiple citrus species.

- There are multiple records of *L. pseudotheobromae* associated with *Citrus* spp. in several countries (**Table 10**).
- This species has been isolated from trees with gummosis, stem/trunk canker and branch dieback (Sultana et al. 2018; Bautista-Cruz et al. 2019; Serrato-Diaz et al. 2019; Ahmed et al. 2020) as well as from fruit with post-harvest (Awan et al. 2016) and stem-end rot (Sultana et al. 2018).
- *Lasiodiplodia pseudotheobromae* was the most frequently isolated species from diseased Persian limes in Mexico, accounting for 47% of all isolates (Bautista-Cruz et al. 2019). In pathogenicity studies on one-year old Persian limes, necrotic lesions and gum exudates were induced. This species was more virulent than *L. brasiliensis, L. theobromae* and *L. citricola* (Bautista-Cruz et al. 2019).
- In Pakistan, Ahmed et al. (2020) reported tree canker caused, by *L. pseudotheobromae,* in orchards of *C. reticulata* reached disease incidence of 40%. Yield losses were not reported, however worldwide trunk canker disease is responsible for 10–30% of losses in citrus orchards (Timmer et al. 1999).
- *Lasiodiplodia pseudotheobromae* has also been described as a causative agent of post-harvest rot of lemon (Awan et al. 2016). In pathogenicity studies, the fungus was found to be highly pathogenic, damaging 40–50% of the fruit surface after five days (Awan et al. 2016). Such symptoms would reduce yields post-harvest and the marketability of infected fruits.
- In 2019 limes, lemons and mandarins had a domestic value of NZ$2million, NZ$12 million and NZ$25 million respectively, with lemons and mandarins having export values of NZ$9.8 million and NZ$0.4 million respectively (Plant and Food Research 2019).

There are reports of *L. pseudotheobromae* causing disease on other economically important hosts:

- The fungus has also been isolated from grapevines showing dieback symptoms (Correia et al. 2016), as well as pedicel and penduncle discolouration (Dissanayake et al. 2015).
- Correia et al. (2016) isolated *L. pseudotheobromae* during a survey of *Lasiodiplodia* spp. associated with Botryosphaeria dieback of grapes in eastern Brazil. The species was the least frequently isolated species, representing 3% of the isolates. In pathogenicity tests on detached shoots, *L. pseudotheobromae* induced visible lesions and was assessed to have intermediate aggressiveness compared to the other species tested (Correia et al. 2016). In Brazil, grapevine dieback caused by members of the Botryosphaeriaceae is becoming increasingly significant, reducing the longevity and production of plants (Correia et al. 2016).
- Wine is the second most valuable horticultural export for New Zealand (value $1.8 billion) (Plant and Food Research 2019). Therefore, losses in this crop have the potential to cause significant economic consequences for New Zealand.
- *Lasiodiplodia pseudotheobromae* was found to be a causative agent of post-harvest persimmon rot in Brazil (Nogueira et al. 2017). The disease incidence in the sampled fruit was estimated at 10% (Nogueira et al. 2017). Persimmons are grown in New Zealand for the domestic and export market, worth NZ$1.5 and NZ$10 million respectively (Plant and Food Research 2019).
- The species has also been found causing shoot and side branch die back and cankers of apple trees in China (Xue et al. 2019). Disease symptoms were different to other canker diseases described on apples (Xue et al. 2019). The fungus was isolated from diseased tissue and pathogenicity was confirmed by inoculation assays of detached twigs (Xue et al. 2019). The level of yield loss associated with this disease is not reported, however such symptoms can be assumed to reduce the productivity of infected trees and would reduce the yield.
- Apples are the third most significant horticulture export for New Zealand, worth NZ$828.8 million in 2019 (Plant and Food Research 2019). Therefore, losses for this industry have the potential to cause significant consequences for the New Zealand economy.

The records of the *L. pseudotheobromae* as the causative agent of post-harvest rot of economically important species, as well as associated with dieback and canker of trees means that the potential economic impacts are rated as high. There is moderate uncertainty associated with this conclusion

Given the arguments and evidence below, the introduction of any one of the identified *Lasiodiplodia* spp. is considered likely to cause low socio-cultural impacts in New Zealand, with high uncertainty.

The identified *Lasiodiplodia* spp. have been reported causing disease of socially important plants to New Zealand:

- Apples, citrus and grapes are hosts of some of the *Lasiodiplodia* spp. and are socially important plants grown by home gardeners.
- The species *L. hormozganensis, L. pseudotheobromae* and *L. brasiliensis* and *L. iraniensis,* along with *L. theobromae* have been found causing leaf blight symptoms in *Sansevieria trifasciata* (syn*. Dracaena trifasciata*) (snake plant), a popular ornamental plant (Yee et al. 2019). *Lasiodiplodia theobromae* is present in New Zealand but has not been reported from this host (NZFungi2 2020). There is the potential that if further *Lasiodiplodia* spp. were introduced disease of *S. trifasciata* may occur, but the risk is rated as low.

There is high uncertainty associated with this conclusion, as outlined in the economic impacts section.

Given the arguments and evidence below, the introduction of any one of the identified *Lasiodiplodia* spp. is considered likely to cause low environmental impacts in New Zealand, with high uncertainty

Lasiodiplodia spp. have not been reported causing disease in environmental plants present in New Zealand:

- Diseases caused by *Lasiodiplodia* spp. are mostly reported affecting crop species. However, the fungi have been isolated from environmental *Adansonia* spp. in Australia (Burgess et al. 2019).
- Burgess et al. (2019) also state that there is evidence that crop plants acquire Botryosphaeriaceae from environmental species in the local area. Suggesting that environmental plants can be infected and act as an inoculum source for infection of other plants.
- Based on the lack of reports of the fungi causing impacts in environmental hosts, and the highly sporadic nature of disease associated with *Lasiodiplodia* spp. the likelihood of environmental impacts associated with these fungi is rated as low.

There is high uncertainty associated with this conclusion, as outlined in the economic impacts section.

Given the arguments and evidence below, the introduction of any one of the identified *Lasiodiplodia* spp. is considered likely to cause very low human health impacts in New Zealand, with low uncertainty.

Only one report of the assessed *Lasiodiplodia* spp. causing human infection was found:

- In India *L. pseudotheobromae* was identified as the causative agent of fungal keratitis (inflammation of the cornea) in a farmer following injury by a mango tree branch (Vanam et al. 2019).
- All other reports found of human infection caused by *Lasiodiplodia* spp. (Google Scholar search terms ‘Lasiodiplodia human infection’) were identified as *L. theobromae.*
- *Lasiodiplodia theobromae* is present in New Zealand (NZFungi2 2020). No reports of this fungus causing human infection in New Zealand were found (Google Scholar search terms ‘Lasiodiplodia theobromae human infection New Zealand’).
- Based on the available literature no evidence was found to suggest that *L. pseudotheobromae,* or any of the other species, would cause any further human health

consequences beyond those potentially associated with *L. theobromae* (which is present in New Zealand).

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5.7 *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: Botryosphaeriales/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 misidentified as *P. citricarpa* (Glienke et al. 2011; Wang et al. 2012), which can lead to uncertainty in distribution records. 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 (ONZPR 2020).

5.7.1 Summary of conclusions

- *Phyllosticta citricarpa* meets the criteria to be a quarantine pest for New Zealand.
- The association of *P. citricarpa* with leafless *Citrus* budwood is considered moderate, with low uncertainty.
- The likelihood of *P. citricarpa* entering New Zealand associated with leafless *Citrus* budwood is considered to be low, with high uncertainty.
- The likelihood of *P. citricarpa* establishing in New Zealand is considered to be high, with low uncertainty.
- The introduction of *P. citricarpa* is considered likely to cause moderate economic impacts for New Zealand overall, but high for the citrus industry, with low uncertainty.
- The introduction of *P. citricarpa* is considered likely to cause low sociocultural impacts for in New Zealand, with low uncertainty.
- The introduction of *P. citricarpa* is considered likely to cause very low environmental impacts in New Zealand, with low uncertainty.
- The introduction of *P. citricarpa* is considered likely to cause very low human health impacts for in New Zealand, with low uncertainty.
- *Phyllosticta citrocarpa* may be considered for additional measures on citrus budwood.

The high uncertainty around the likelihood of entry results from limited information about frequency of association of *P. citricarpa* with young, healthy shoots and branches of citrus plants.

5.7.2 Hazard identification: regulatory status

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

Criteria for being a regulated quarantine pest relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand), and the pest is of potential importance (able to establish and cause harm[39]).

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). It is listed as ‘regulated’ in ONZPR (2020).

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

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[39] 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”.

- *Phyllosticta citricarpa* is reported from many areas with very similar climates 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 some parts of 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 trees are commercially grown in New Zealand and are commonly grown in home gardens (section 2.6).

Phyllosticta citricarpa has the potential to cause economic, sociocultural and environmental impacts to New Zealand.

- *Phyllosticta citricarpa* has the potential to harm citrus, which is of economic importance to New Zealand.
- *Phyllosticta citricarpa* has the potential to have sociocultural impacts, because citrus is commonly planted in home gardens.
- Given that the reported hosts of *P. citricarpa* are *Citrus, Poncirus* or *Fortunella* species and that there are no native species in New Zealand in these genera (NZFlora 2020), 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 has the potential to cause environmental impacts.

5.7.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *P. citricarpa* with leafless *Citrus* budwood is considered moderate, with low uncertainty.

Phyllosticta citricarpa is reported from most commercially grown citrus species.

- Hosts of *P. citricarpa* include lemon, sweet orange, mandarins and grapefruit (EFSA 2014, see **Table 11**). *Fortunella* spp. (kumquat) and *Poncirus trifoliata* (trifoliate orange) are also susceptible to *P. citricarpa* (EFSA 2014).
- Although Tahitian lime (*C. latifolia*) fruit does not show symptoms in natural infection, even in areas with high levels of inoculum, *P. citricarpa* was isolated from asymptomatic fruit and caused lesions on Tahitian lime leaves (Baldassari et al. 2008; Wang et al. 2016).
- Likewise, sour orange (*C. aurantium*) and its hybrids are often reported as not susceptible to the pathogen (Kotzé 1981; Baldassari et al. 2008; EFSA 2014), but the fungus has been isolated from lesions on fruit of this species (Baayen et al. 2002; Baldassari et al. 2008; Wulandari et al. 2009; Glienke et al. 2011).
- There is moderate uncertainty about the host status of pomelo (*C. maxima*/*C. grandis*). Wulandari et al. (2009) classified all the *Phyllosticta* isolates in their study that came from pomelo (as *C. maxima*) as *Phyllosticta 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.*

Table 11: Citrus and related species that can be infected by *P. citricarpa* (EFSA 2014)

Scientific name (EFSA 2014)	Common name (EFSA 2014)
C. limon	Lemon
C. sinensis	Sweet orange
C.reticulata	Mandarin
C. unshiu	Satsuma mandarin
C.paradisi	Grapefruit
C. medica	Citron
C.aurantiifolia	Key lime
C. limettioides	Sweet lime
C.hystrix	Kaffir lime
C. latifolia	Tahitian lime (does not produce symptoms on fruit)
C. aurantium	Sour orange (does not usually produce symptoms)

Scientific name (EFSA 2014)	Common name (EFSA 2014)
Fortunella spp.	Kumquat
Poncirus trifoliata	Trifoliate orange

Phyllosticta citricarpa is reported from twigs of citrus plants.

- Small (0.5–2 mm in diameter), round, slightly sunken lesions with a brown to black margin and a grey to light brown centre may occur on small twigs of citrus plants, most often in lemon (*C.* limon) (IPPC 2014). Pycnidia may occasionally be present in the centre of the lesions (IPPC 2014).

5.7.4 Risk assessment: likelihood of entry

Given the arguments and evidence below, the likelihood of *P. citricarpa* entering New Zealand with leafless *Citrus* budwood is considered low, with high uncertainty.

The association of *P. citricarpa* with leafless budwood of *Citrus* spp. is rated moderate (see above).

There is some evidence that *P. citricarpa* can colonise twigs and branches as an asymptomatic endophyte, although such infections are rarely detected, and it is uncertain whether they occur in young healthy tissues:

- *Citrus* budwood with visible lesions is highly unlikely to be selected for export to New Zealand.
    - *Phyllosticta citricarpa* can cause small (0.5–2 mm in diameter) lesions on small twigs, most often in lemon plants (*C. limon*) (IPPC 2014).
    - Twig lesions are round and slightly sunken with a brown to black margin and a grey to light brown centre (IPPC 2014). Pycnidia may occasionally be present in the centre of the lesions (IPPC 2014). The lesions are confined to discrete spots on twigs (Tran et al. 2017).
    - Such lesions are likely to be visible, particularly once leaves are removed from the budwood.
- *Phyllosticta citricarpa* has been detected in and cultured from citrus twigs and branches without visible symptoms:
    - A recent study investigated the prevalence of *P. citricarpa* in young *C. sinensis* shoots and *C. sinensis* branches of different ages (de Oliveira Silva et al. 2017). *Phyllosticta citricarpa* was isolated at a very low frequency (0.8%) from older branches but not from young shoots or young branches. The study authors concluded that fungi had not yet had an opportunity to colonise these younger tissues, as neither *P. citricarpa,* nor other fungal species were recovered (de Oliveira Silva et al. 2017). Dead branches also yielded no *P. citricarpa*, but in this case, it is likely that the fungus was outgrown by other faster-growing fungi such as *Colletotrichum* and *Penicillium* species (de Oliveira Silva et al. 2017).
    - In inoculation experiments, young branches were colonised by *P. citrocarpa*, and the pathogen could be recovered 45 days after inoculation with no visibly detectable lesions or fruiting body formation on the inoculated tissue (de Oliveira Silva et al. 2017). However, at 90 and 135 days, the pathogen was not recovered from the inoculated branches, and lesions or reproductive structures were not observed at any stage.
    - In this study, *P. citricarpa* DNA was not detected by culture independent PCR of DNA extracts from shoots or branches of any age, which de Oliveira Silva et al. (2017) surmised was due to a low concentration of the pathogen in samples.
    - *Phyllosticta citricarpa* has been isolated/detected by PCR-based techniques from citrus twigs (Meyer et al. 2012). However, the age of the twigs in this study was not given. In addition, a positive PCR test result does not necessarily prove that there are viable fungal spores, hyphae or mycelium present.
- EFSA (2014) notes that citrus plants for planting have been assumed to be a very important potential pathway for the entry of *P. citricarpa* into new areas, because aerial parts of budwood, scions, rootstocks and nursery plants of citrus species may be infected with

P. citricarpa without, or with very few, symptoms and citrus plants are normally propagated vegetatively by grafting onto rootstocks.
- EFSA (2014) considered it likely that there will be a high prevalence of *P. citricarpa* in citrus planting material for propagation purposes if citrus nurseries are located near citrus orchards infected by the pathogen.
- However, EFSA (2014) found no data on the prevalence of *P. citricarpa* in citrus nurseries in countries where the pathogen is currently distributed and no authenticated records of *P. citricarpa* introductions into new areas through plants for planting.
- EFSA (2014) considered that *P. citricarpa* is most likely to be associated with plants for planting as mycelium in latently infected leaves.
- Therefore, along with visual inspection to remove budwood with visible *P. citricarpa* lesions, removal of the leaves to meet the commodity description reduces the likelihood of *P. citricarpa* entering New Zealand associated with citrus budwood to low. However, there is high uncertainty in this conclusion, because the frequency of asymptomatic *P. citricarpa* infections of shoots and branches in natural infection is not well defined.

The minimum requirements are unlikely to further reduce the likelihood of entry, assuming that *P. citricarpa* can (rarely) colonise budwood in latent infections without causing visible symptoms within one growing season.

- Visual inspection of budwood and the mother plants is likely to detect symptomatic material, but not asymptomatic infection.
- Apart from lemons, lesions of *P. citricarpa* on leaves are rare especially in young healthy plants (Kotzé 1981; EFSA 2014). Citrus plants will produce leaves in post entry quarantine but will not fruit, which reduces the likelihood of *P. citricarpa* infections being detected.
- EFSA (2014) considered that it is highly likely that infected citrus plant propagation material will be asymptomatic, since citrus black spot symptoms do not generally appear on trees until they are over 10 years old, and *P. citricarpa* has been known to remain latent for even longer periods.
- If *P. citricarpa* was latent in citrus budwood at the time of entry, symptoms may not develop during one growing season in post entry quarantine, as plants would be young, well maintained and grown under conditions that enhance growth.

Given that asymptomatic *P. citricarpa* infections of shoots and branches may be extremely rare or may not occur in natural infection, there is high uncertainty around the likelihood of *P. citricarpa* entering New Zealand associated with leafless *Citrus* budwood. At present, there is insufficient evidence to be certain whether asymptomatic *P. citricarpa* infections of twigs and branches are very rare or if fungal mycelium in early infections is present in very low amounts. The fungus is seldom detected by culture-based or PCR-based techniques. Nevertheless, it is highly likely that if budwood containing latent *P. citricarpa* mycelium is imported*,* the infections will escape detection during phytosanitary inspection and one growing season in post-entry quarantine.

5.7.5 Risk assessment: likelihood of establishment and spread

Given the arguments and evidence below, the likelihood of *P. citricarpa* establishing in New Zealand is considered high, with low uncertainty.

The suitability of the New Zealand environment for *P. 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 7** and the CMI for each country/state is given in **Table 12.** Climate is highly unlikely to limit the establishment of *P. citrocarpa*, because it is reported from many areas with very similar climates to New Zealand including Uruguay, regions of Brazil (e.g. Rio Grande do Sul and Santa

Catarina), Australia (e.g. New South Wales and Victoria), and the eastern provinces of South Africa (e.g. Eastern Cape, Kwa Zulu Natal and Mpumalanga).

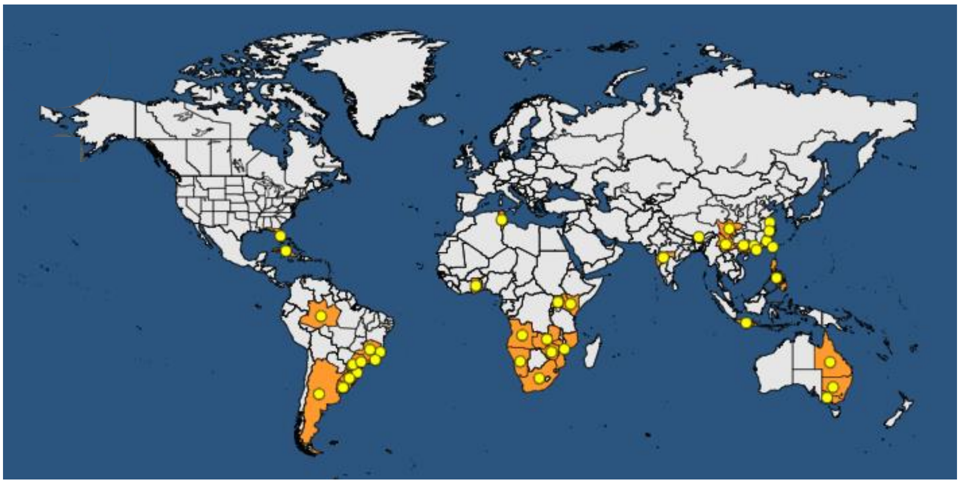

Figure 7: Distribution of *P. citricarpa* (orange shaded areas and yellow dots indicate countries where *P. citricarpa* has been reported) (EPPO 2020)

Table 12: Distribution of *P. citricarpa* (EPPO 2020a)
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 (Philips 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**

Region	Country	State/Province (if recorded)	CMI range (Philips et al. 2018).
		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 –1**

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 (**Table 13**) especially lemons and sweet oranges (Kotzé 1981)
- In New Zealand, 783 hectares are planted in commercial oranges, 556 ha in mandarins, 25 ha in lemons and 15 ha in grapefruit (Plant and Food Research 2019). Citrus is commercially produced in both the North Island and the South Island, with most commercial production taking place in the North Island (Section 2.4.1). Citrus trees are commonly grown in domestic gardens.

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:

- In Australia, South Africa and South America (Argentina, Brazil) ascospores (sexual spores) formed in pseudothecia in leaf litter from citrus trees are the major source of inoculum to spread the pathogen (Reis et al. 2006; Tran et al. 2017).
    - Release of ascospores from leaf litter 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).
    - Once released, ascospores are spread by wind currents to leaves, twigs and young fruit of citrus (Kotzé 1981).
    - Ascospore release in Argentina and South Africa peaks in December–January. In Brazil, the peak is January–February (Reis et al. 2006). Ascospores are infectious at temperatures between 15°C and 29.5°C and require 15–38 hours of wetness (Reis et al. 2006; EPPO 2020b).
    - Most citrus plants in New Zealand set fruit in November (late spring/early summer) (Brown 2001), although some citrus trees in New Zealand produce fruit through 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.
- Ascospores require two mating types to be present. 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).
    - Conidia of *P. citricarpa* are produced in pycnidia in lesions on infected fruit, leaves and branches and can be spread by watersplash and windblown rain (Kotzé 1981; EFSA 2014; Tran et al. 2017).
    - *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). Evidence from Florida suggests that *P. citricarpa* can establish and spread in an area via dispersal of conidia even if only one mating type is present, as has apparently happened in Florida (Tran et al. 2017, 2020; Hendricks et al. 2020). However, the situation in Florida (with no sexual stage) is currently unique.
- As most commercial citrus fruit sets in November (Brown 2001), 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 (Section 2.4.1). These conditions are likely to favour infection of young fruit with *P. citricarpa* ascospores or conidia.

- *Phyllosticta citricarpa* has established and spread to new areas in other parts of the world.
    - In Nabeul, Tunisia (an area with a CMI of 0.7 with the whole of New Zealand), symptoms were first observed on lemon and orange fruit in March and April 2019 (Boughalleb-M'Hamdi et al. 2020). Following this discovery, plants with symptomatic fruit were observed in 69 out of 339 lemon and orange orchards surveyed from June to September 2019 (Boughalleb-M'Hamdi et al. 2020).
    - *Phyllosticta citricarpa* was first reported on sweet orange trees in a grove in Florida, USA in 2010 (Schubert et al. 2012), and by July 2019, the quarantine zone encompassed 1160.32 km^2 in the Lee, Charlotte, Collier, Hendry and Polk counties (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).

5.7.6 Risk assessment: impacts to New Zealand

Given the arguments and evidence below, the introduction of *P. citricarpa* is considered likely to cause moderate economic impacts for New Zealand, but high economic impacts for the citrus industry, with low uncertainty.

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

- *Phyllosticta citricarpa* causes black spot lesions on citrus fruit (**Figure 8**).
    - The most common symptom is shallow lesions known as hard spots, which are 3–10 mm in diameter, with a grey to tan centre and a dark brown to black margin (IPPC, 2014). Pycnidia commonly form in the centre of hard spots (Miles et al. 2019).
    - Lesions range in size from small freckle spots and false melanoses to virulent spots (sunken irregular red to brown or colourless lesions that form late in the season on heavily affected mature fruit) (IPPC 2014). Virulent spots grow rapidly, can cover two thirds of the fruit within 4–5 days and can cause premature fruit drop (IPPC 2014);
    - In Brazil and Florida, interaction between the fungus and spider mites can result in cracks in the skin (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).

Figure 8: Lesions on citrus fruit caused by *P. citricarpa.* From left to right: Citrus black spot lesions (Florida Division of Plant Industry Archive 2008); hard spot on orange, with pycnidia visible in the middle of the lesions (Cesar Calderon 2006); cracked spot lesions on Valencia orange (P. Barkley 2004).

Phyllosticta citricarpa has been reported to cause severe damage and production loss of citrus in areas with a 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 which 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).
- In China*, 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 given that susceptible citrus varieties such as sweet oranges and lemons are commonly grown.

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 citrus plot in São Paulo, Brazil, that was not treated with fungicide during the susceptible period of fruit development, the mature fruit showed 100% incidence of citrus black spot (Baldassari et al. 2006).
- In Queensland, São Paulo and Florida, regular applications of fungicide throughout the period when fruit are susceptible are necessary to prevent fruit from being infected (Lanza et al. 2018; Hendricks et al. 2020; 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 NZ$80 million per year through export restrictions, fungicide applications and fruit damage (Hort Innovation 2018).

Citrus is economically important in New Zealand (Table 3, Section 2.6.2).

- *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 citrus sales was NZ$58.5 million (Plant and Food Research 2019).

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*[40]. Infected citrus fruit could not be exported 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).

There is low uncertainty in this conclusion, because 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. Evidence from other countries suggests that there will be ongoing costs to manage the disease. 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.

Given the arguments and evidence below, the introduction of *P. citricarpa* is considered likely to cause low sociocultural impacts in New Zealand, 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.

Given the arguments and evidence below, the introduction of *P. citricarpa* is considered likely to cause very low environmental impacts in New Zealand is likely, with low uncertainty. However, there may be some indirect impacts 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. In São Paulo fungicide applications at intervals through the production period are used 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*) (Allan Herbarium 2020), it seems likely that environmental impacts would be low.
- There is low uncertainty in this conclusion. Although 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), records on hosts outside the Rutaceae family are doubtful and presumably refer to *Phyllosticta capitalensis* or *Guignardia mangiferae* (Glienke et al. 2011; Farr and Rossman 2020).

Given the arguments and evidence below, the introduction of *P. citricarpa* is considered likely to cause very low human health impacts in New Zealand, with low uncertainty.

- *Phyllosticta citricarpa* is a plant pathogen, and no evidence was found of effects on human or animal health.

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[40] 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*).

- However, there is potential for indirect impacts on human health due to increased use of fungicides for pathogen control.

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5.8 *Plenodomus tracheiphilus* (mal secco disease of citrus)

Plenodomus tracheiphilus is a mitosporic (asexual) fungal pathogen that causes mal secco, a highly destructive vascular disease of *Citrus* (especially lemon) and related genera. The disease lowers fruit yield, resulting from a reduction in canopy volume due to twig death, and eventually kills affected trees (Migheli et al. 2009).

Taxonomy
Scientific name: *Plenodomus tracheiphilus* (Petri) Gruyter, Aveskamp & Verkley
Order/family: Pleosporales/Leptosphaericeae
Other scientific names: *Phoma tracheiphila*; *Bakerophoma tracheiphila*; *Deuterophoma tracheiphila*
Common name: mal secco, mal secco of citrus, citrus mal secco, citrus wilt, mal secco disease of citrus, dieback of citrus, wilt of citrus (EFSA 2014; EPPO 2020)

General information on the biology of *P. tracheiphilus*
Plenodomus tracheiphilus only reproduces asexually, and no sexual stage (teleomorph) of this fungus has been identified (Perrotta and Graniti 1988; Migheli et al. 2009; EFSA 2014). The asexual fruiting bodies (pycnidia) usually develop on withered twigs as raised black spots within lead-grey or ash-grey areas and produce infective conidia (pycnoconidia). Phialides on ‘free’ mycelial hyphae growing in the xylem, on wounded plant tissues and exposed wood surfaces of the tree or in debris also produce conidia (phialoconidia) (Perrotta and Graniti 1988). Dispersal of conidia from pycnidia and exposed phialides to other parts of the same plant or to a new host occurs mainly by rain (especially windblown rain), but conidia can also be dispersed by overhead irrigation, wind, birds, insects and farm tools, etc. (Migheli et al. 2009; Nigro et al. 2011). The conidia infect host tissue (leaves, twigs, branches, roots) via wounds/injuries caused by cultivation practices, hail and frost, insect/bird feeding and other means, and eventually reach the xylem vessels. Infection of the host and disease development is favoured by warm, humid conditions (14–28°C and 65–90% relative humidity), with 20–25°C being the optimum temperature range for mycelial growth of the fungus and symptom expression, and 30°C stopping fungal growth inside the host (Perrotta and Graniti 1988).

5.8.1 Summary of conclusions

- *Plenodomus tracheiphilus* meets the criteria to be a quarantine pest for New Zealand.
- The association of *Plenodomus tracheiphilus* with leafless citrus budwood (especially lemon, *Citrus limon*) is considered strong, with low uncertainty**.**
- The likelihood of *Plenodomus tracheiphilus* entering New Zealand associated with leafless *Citrus* budwood is considered low, with low uncertainty.
- The likelihood of *Plenodomus tracheiphilus* establishing in New Zealand is considered high, with low uncertainty.
- The introduction of *Plenodomus tracheiphilus* is considered likely to cause low economic impacts for New Zealand (but impacts in citrus, specifically lemon production is likely high), with moderate uncertainty.
- The introduction of *Plenodomus tracheiphilus* is considered likely to cause moderate sociocultural impacts in New Zealand, with low uncertainty.
- The introduction of *Plenodomus tracheiphilus* is considered likely to cause negligible environmental impacts in New Zealand, with low uncertainty.
- The introduction of *Plenodomus tracheiphilus* is considered likely to cause negligible human health impacts in New Zealand, with low uncertainty.
- *Plenodomus tracheiphilus* may be considered for additional measures on citrus budwood.

5.8.2 Hazard identification: regulatory status

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

Criteria for being a regulated quarantine pest relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand), and the pest is of potential importance (able to establish and cause harm[41]).

Plenodomus tracheiphilus is not known to be present in New Zealand.

- *Plenodomus tracheiphilus* is not listed in NZFungi2 (2020) or PPIN (2020).
- *Plenodomus tracheiphilus* (listed as *Phoma tracheiphila*, synonyms: *Bakerophoma tracheiphila*, *Deuterophoma tracheiphila*) is a regulated pest for New Zealand (ONZPR 2020; BRAD 2020).

Plenodomus tracheiphilus has the potential to establish in New Zealand:

- *Plenodomus tracheiphilus* is present in Africa: Algeria, Egypt, Libya, Tunisia; Asia: Armenia, Iraq, Israel, Lebanon, Republic of Georgia, Syria, Turkey, Yemen; Europe: Albania, Cyprus, France, Greece, Italy, Spain, Russia (CPC 2019; EPPO 2020).
- Based on a climate match index (CMI) developed by Phillips et al. (2018), some of the above countries (or regions within) have high climate similarity (CMI ≥0.7) to New Zealand, including areas where citrus is grown: Albania (0.8–0.9); Algeria (0.3–0.8); Armenia (0.7–0.8); France (0.8–0.9); Georgia (0.7–0.9); Greece (0.7–0.9), Italy (0.8–0.9); Lebanon (0.7–0.8); Turkey (0.7–0.9); Spain (0.8–0.9).
- Lemon (*C. limon*), which is the most susceptible host of *P. tracheiphilus*, is commercially grown across 257 ha in the warmer northern parts of New Zealand (Plant and Food Research 2019), as well as in home gardens across the country.
- Following establishment, long-distance spread of the pathogen between orchards and regions is likely to occur mainly through the distribution of infected material (budwood or whole plants) for planting (Nigro et al. 2011; CPC 2019; EPPO 2020).

Plenodomus tracheiphilus has the potential to cause economic and sociocultural consequences.

- *Plenodomus tracheiphilus* is the most destructive fungal pathogen of lemons (*C. limon*) in the Mediterranean region and can affect 100% of trees in an orchard of a susceptible lemon cultivar (Perrotta and Graniti 1988, cited in Migheli et al. 2009; Nigro et al. 2011; EFSA 2014).
- The pathogen reduces the quantity and quality of lemon production and kills infected plants, thus limiting the use of susceptible species and cultivars, some of which produce better quality fruit than less susceptible cultivars (Migheli et al. 2009; Nigro et al. 2011; EPPO 2020).
- Lemons have cultural value in New Zealand, as fruit from home gardens is commonly shared with family, friends and colleagues.

5.8.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of *Plenodomus tracheiphilus* with leafless *Citrus* budwood (especially *C. limon*) is rated as strong, with low uncertainty.

Plenodomus tracheiphilus is reported from citrus, especially lemons.

- Almost all citrus species are susceptible to *P. tracheiphilus* by inoculation, but lemon (*Citrus limon*) is the main host, and the only species in which economic damage has been widely reported (Raimondo et al. 2007; Migheli et al. 2009; Nigro et al. 2011; EFSA 2014; Ben-Hamo et al. 2020).
- Other *Citrus* species and related genera in the Rutaceae family are listed as either minor or incidental hosts, although CPC (2019) includes citron (*C. medica*) and bergamot (*C. bergamia*) as main hosts (**Table 14**).

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[41] 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".

Table 14: List of *P. tracheiphilus* hosts (from EPPO 2020 and CPC 2019)

Scientific name	Common name	Host Status (EPPO 2020)	Host status (CPC 2019)
C. limon	Lemon	Major	Main
C. aurantiifolia	Mexican/key lime	Minor	Other
C. aurantium	Sour orange	Minor	Other
C. bergamia	Bergamot	Minor	Main
C. jambhiri	Rough lemon	Minor	Other
C. medica	Citron	Minor	Main
C. deliciosa	Tangerine	Incidental	Not listed
C. paradisi	Grapefruit	Incidental	Other
C. reticulata	Mandarin	Incidental	Other
C. sinensis	Sweet orange	Incidental	Other
C. unshiu	Satsuma mandarin	Not listed	Other
C. latifolia	Tahiti lime	Not listed	Other
C. nobilis	Tangor	Not listed	Other
C. limonia	Mandarin lime	Not listed	Other
C. macrophylla	Alemow	Not listed	Other
C. volkameriana	Volkamer lemon	Incidental	Not listed
C. myrtifolia	Myrtle-leaved orange	Minor	Not listed
Citroncirus		Minor	Not listed
Fortunella	Kumquat	Minor	Other
Poncirus trifoliata	Trifoliate orange	Minor	Other
× *Citrofortunella microcarpa*	Calamansi/Philippine lemon	Minor	Other

Plenodomus tracheiphilus is a systemic pathogen, and conidia and mycelia are likely to be present in young twigs and stems of infected plants:

- The pathogen infects host tissues (leaves, branches, twigs and roots) through wounds/injuries, and invades the lumen of the xylem where it spreads systemically; being transported in the xylem sap (Perrotta and Graniti 1988).
- Systemic infection due to the presence of conidia and mycelia in the xylem means that most parts of the tree are able to carry the fungus (Perrotta and Graniti 1988).

5.8.4 Risk assessment: likelihood of entry

Given the arguments and evidence below, the likelihood of *Plenodomus tracheiphilus* entering New Zealand associated with leafless *Citrus* budwood is low, with low uncertainty.

- *Plenodomus tracheiphilus* has a strong association with budwood of *Citrus*: Although almost all citrus species are susceptible when artificially inoculated, field observations show that lemon (*C. limon*) is the most susceptible citrus species (Migheli et al. 2009; Nigro et al. 2011; EFSA 2014; CPC 2019; EPPO 2020).
- CPC (2019) considers citron (*Citrus medica*) and bergamot (*C. bergamia*) susceptible varieties, but there is little supporting field evidence.
- The pathogen is systemic. However, mycelial growth is inhibited inside the host during hot periods (>30°C) (Perrotta and Graniti 1988), and trees that are only recently infected in these conditions may appear healthy while harbouring conidia and mycelia systemically (Migheli et al. 1981).
- *Plenodomus tracheiphilus* has been detected by PCR in twigs collected from naturally infected asymptomatic plants (Balmas et al. 2005).
- Based on the last two points above, there is the potential for some contaminated material to be collected as budwood.

However:

- It is unlikely that plants from areas with high levels of mal secco disease or severely infected plants with obvious symptoms will be used to produce commercial budwood material.

- Material infected with *P. tracheiphilus* is unlikely to be included if budwood is collected in spring when symptoms are clearly visible. The disease first appears as shoot and interveinal leaf chlorosis, followed by dieback of twigs and branches (Migheli et al. 2009; Nigro et al. 2011; EFSA 2014; CPC 2019).
- In addition, when the wood of infected twigs, branches or trunks is cut or stripped of bark, a characteristic salmon-pink or orange-red discolouration of the wood may be seen; this internal symptom is associated with gum production within the xylem vessels (Perrotta and Graniti 1988).

Minimum requirements reduce the likelihood of entry by a high degree, with low uncertainty. Although symptoms may not always be obvious prior to export, they are likely to be detected during one growing season in post-entry quarantine.

- Warm moist conditions are conducive to infection of the host and disease development; conidia germinate at temperatures between 5°C and 30°C, with 20–25°C being the range for optimum growth of mycelium within the host (Perrotta and Graniti 1988; Migheli et al. 2009; Nigro et al. 2011).
- Although temperature regulation is not a general requirement in Level 3A post-entry quarantine facilities, temperature and other conditions (e.g. humidity) must be adequate for the plants to grow through a full growing season. This will likely include temperatures within the range (14–28°C) suitable for the fungus to grow and express symptoms. Average summer temperatures across most of New Zealand’s North Island, for example, range from 18–21°C (NIWA 2020).
- Disease symptoms first appear on new growth as shoot and interveinal leaf chlorosis, followed by dieback of twigs and branches, with leaves falling off while their petioles remain attached to the twigs/branches (Migheli et al. 2009; Nigro et al. 2011). The growth of sprouts from the base of the affected branches and growth of suckers from the rootstock are also very common responses of host plants to infection (Migheli et al. 2009; Nigro et al. 2011).
- In a laboratory experiment in which seedlings of sour orange (*C. aurantium*) were inoculated with *P. tracheiphilus* and incubated at 25°C, leaf chlorosis was evident 5–7 days post inoculation, and by day 25, the chlorosis covered ~30% of leaf surface area (Raimondo et al. 2007). The leaf blade was shed between 45 and 55 days after inoculation, and the petiole was shed some days later. At leaf blade shedding, ~45% of the leaf surface area was still green with no visible symptoms of damage. Also, the expanded ‘wings’ of the petiole were green and visually healthy (Raimondo et al. 2007).
- Perrotta and Graniti (1988) also reported that on sour orange seedlings artificially infected with *P. tracheiphilus*, pycnidia (which appear as black spots within lead-grey or ash-grey areas on affected twigs) were more abundant at a mean temperature of 10.5°C (range 3–19°C) than at 20–22°C, and optimum differentiation and development of pycnidia *in vitro* occurs between 10°C and 15°C.
- Based on the above evidence, it is very likely that plants grafted with *P. tracheiphilus*-infected budwood and grown in a Level 3A post-entry quarantine facility will show visible symptoms.

If *P. tracheiphilus* produces symptoms in Level 3A post-entry quarantine, the conidia produced during the growing season are likely to be contained.

- The conidia of *P. tracheiphilus* are non-motile and rely mainly on passive dispersal by watersplash, windblown rain, insects, birds, etc. to infect new host plant tissues (Perrotta and Graniti 1988).
- Isolation of *P. tracheiphila* from air samples in Italy (Balmas et al. 2005) suggests that conidia may be airborne, but airborne conidia may have limited mobility; the fungus spread only a short distance (15–20 m) from an inoculum source, although distance of spread may be increased by the prevailing wind direction (Laviola and Scarito 1989, cited in Nigro et al. 2011).
- On the other hand, Tuttobene (1994) (cited in Nigro et al. (2011)) explains that the short distance travelled by *P. tracheiphila* pycnoconidia indicates that these conidia do not behave as other airborne disseminated conidia, which tallies with the notion that they are immersed in mucilage and are, therefore, mainly disseminated by rain-splash or irrigation.

- It is unlikely there will be strong winds in a Level 3A post-entry quarantine facility, and, as such, the likelihood that airborne spores of *P. tracheiphila* will escape is very low, even though these facilities do not have measures to contain airborne fungal spores (MPI 2019).
- If *P. tracheiphilus* spores escape from the facility via wind action, they are not likely to land on a suitable host, unless a citrus orchard is located close to the post-entry quarantine facility, which is very unlikely.
- Other measures in place within Level 3A glasshouses (including protective clothing, handwashing) (MPI 2019) further reduce the likelihood of any conidia leaving the glasshouse due to human activity and, potentially, transferring to a suitable host.

Uncertainty:
Uncertainty, with respect to entry, is mainly due to the slight possibility that spores produced in post-entry quarantine may become airborne and escape into the environment, although this, and subsequent exposure to host plants, is unlikely.

5.8.5 Risk assessment: likelihood of establishment and spread

Given the arguments and evidence below, the likelihood of *Plenodomus tracheiphilus* establishing in New Zealand is considered high, with low uncertainty.

Environmental conditions (climate and host availability) in New Zealand, and the biology of the pathogen make establishment likely.

- *Plenodomus tracheiphilus* occurs in <u>Africa</u>: Algeria, Egypt, Libya, Tunisia; <u>Asia</u>: Armenia, Iraq, Israel, Lebanon, Republic of Georgia, Syria, Turkey, Yemen; and <u>Europe</u>: Albania, Cyprus, France, Greece, Italy, Spain, Russia (CPC 2019; EPPO 2020).
- Based on a climate match index (CMI) developed by Phillips et al. (2018), some of the above countries (or regions within) have a sufficiently similar climate (CMI ≥0.7) to New Zealand, including to areas in New Zealand where citrus is grown: Albania (0.8–0.9); Algeria (some parts have 0.7–0.8); Armenia (0.7–0.8); France: Corsica (0.8–0.9); France (0.9); Georgia (0.7–0.9); Greece (0.7–0.9); Lebanon (0.7–0.8); Turkey (0.7–0.9); Italy: Sardinia (0.8–0.9), Sicily (0.7–0.8); Spain (0.8–0.9).
- Average summer temperatures of 18–21°C, and average annual temperatures of 10–16°C in New Zealand's citrus-growing areas (NIWA 2020) are adequate for survival of the fungus, because the conidia (spores) germinate at temperatures between 5°C and 30°C, with optimum mycelial growth within the host occurring between 20–25°C (Migheli et al. 2009; Nigro et al. 2011).
- Lemon (*C. limon*), which is the most susceptible host of *P. tracheiphilus*, is commercially grown on about 260 hectares in the warmer northern parts of New Zealand's North Island (Plant and Food Research 2019) and is the most common citrus variety in home gardens across the country.

Once established, the pathogen is likely to spread.

- Short-range (within orchard) spread of *P. tracheiphilus* is very likely to occur via conidia, dispersed mainly by water (rain splash, windblown rain, overhead irrigation). Conidia may also be carried by birds and insects or on contaminated tools such as pruning shears (Migheli et al. 2009; Nigro et al. 2011).
- The primary sources of inoculum are conidia from pycnidia that develop mainly on young shoots of diseased plants at relatively low temperatures in late autumn and winter (Nigro et al. 2011). Phialoconidia, which are produced quickly and abundantly by hyphae on wounded infected shoots, are responsible for the epidemic explosion of infections after hailstorms and/or heavy rain with strong wind during late summer to early autumn, when there are no pycnoconidia able to germinate (Perrotta and Graniti 1988; Migheli et al. 2009; Nigro et al. 2011).
- Infected twigs and branches can remain infectious for several weeks, and fungal propagules can survive within plant debris in orchard soil for up to a year (De Cicco et al. 1987 cited in Migheli et al. 2009). The fungus can survive long term in the vascular tissues of citrus plants, because citrus is a perennial host (Nigro et al. 2011).

- Long-distance spread of the pathogen between orchards and regions is likely to occur mainly through the distribution of infected budwood or whole plants for planting (Nigro et al. 2011; CPC 2019; EPPO 2020).

5.8.6 Risk assessment: impacts to New Zealand

Given the arguments and evidence below, the introduction of *Plenodomus tracheiphilus* is likely to cause low economic impacts for New Zealand (but its impact on commercial lemon production and export is likely to be high), with moderate uncertainty.

- In the Mediterranean region, *P. tracheiphilus* is the most destructive fungal pathogen of lemons (*C. limon*) and can affect 100% of trees in an orchard of a susceptible lemon cultivar (Perrotta and Graniti 1988; Nigro et al. 2011; CPC 2019).
- Further, *P. tracheiphilus* is likely to affect exports of New Zealand lemons due to phytosanitary measures that will be required, given that the pathogen is a quarantine pest for several regional plant protection services that cover many countries, i.e. the European and Mediterranean Plant Protection Organization (EPPO), the Asia and Pacific Plant Protection Commission (APPPC), the Caribbean Plant Protection Commission (CPPC), the Comité de Sanidad Vegetal del Cono Sur (COSAVE), the Inter-African Phytosanitary Council (IAPSC), the North American Plant Protection Organization (NAPPO) and the Pacific Plant Protection Organisation (PPPO), and national plant protection organisations (Nigro et al. 2011; EPPO 2020).
- By attacking the vascular system, which leads to dieback and eventual death of affected plants, mal secco disease reduces the quantity and quality of lemon production and limits the use of susceptible cultivars that produce better quality lemons than less susceptible cultivars (Migheli et al. 2009; Nigro et al. 2011; EFSA 2014; CPC 2019; EPPO 2020).
- A rapidly fatal form of the disease, described as “mal fulminante”, is apparently due to root or stem infections that quickly invade the functional xylem, causing a rapid wilting of branches or the whole tree (Perotta and Graniti 1988; Migheli et al. 2009; Nigro et al 2011; EFSA 2014).
- Given its high susceptibility to the pathogen, lemon is citrus crop most likely to be affected if mal secco establishes in New Zealand. Lemons had a domestic sales value of NZ$12 million in 2018/2019 and an export (free-on-board) sales value of NZ$9.8 million in 2019 (Plant and Food Research 2019).
- The optimum temperature range for disease development is 20–25°C. Hence, in the Mediterranean region, mal secco disease progresses rapidly in the spring and autumn and slows down in the summer when high temperatures (≥30°C) inhibit the growth of the fungus and invasion of the hosts’ vascular system (Perrotta and Graniti 1988; Migheli et al. 2009; Nigro et al. 2011; Ben-Hamo et al. 2020).
- In contrast to the Mediterranean region, disease severity could remain moderate-to-high throughout summer in New Zealand’s main citrus production areas where the average summer temperature range is 18–21°C (NIWA 2020), and not high enough (i.e. less than 30°C) to inhibit the pathogen’s growth and its invasion of the host vascular system (Perrotta and Graniti 1988; Migheli et al. 2009; Nigro et al. 2011; Ben-Hamo et al. 2020).
- Additional production costs will be incurred for control measures, which mainly comprise of cultural practices such as pruning and burning of infected branches or whole plants (Migheli et al. 2009; EFSA 2014; CPC 2019; EPPO 2020).
- Economic impact may be mitigated by the fact that trifoliate orange (*Poncirus trifoliata*), the most widely used rootstock in New Zealand commercial citrus (Currie and Harty 2001), is reported to be resistant/tolerant to *P. tracheiphilus* (Perrotta and Graniti 1988; CPC 2019). However, the extent to which trifoliate rootstock would reduce severity of the disease on commercial lemon cultivars in New Zealand (e.g. Yen Ben) is uncertain, because there are no data on the susceptibility of New Zealand scion cultivars to the pathogen.
- *Plenodomus tracheiphilus* has not been reported as causing economic damage in other citrus varieties (CPC 2019; EPPO 2020).

Given the arguments and evidence below, the introduction of *Plenodomus tracheiphilus* is considered likely to cause moderate sociocultural impacts in New Zealand, with low uncertainty.

- Lemon trees are widely grown in home gardens across New Zealand, and lemons are commonly shared with friends, families and colleagues. The spread of mal secco disease to home gardens is, therefore, likely to cause sociocultural impacts.
- Other citrus varieties grown in home gardens, e.g. oranges and mandarins, are not likely to be affected. The pathogen has only been reported causing damage/losses in lemons (CPC 2019; EPPO 2020).

Given the arguments and evidence below, *the introduction of Plenodomus tracheiphilus* is likely to cause negligible to very low environmental impacts in New Zealand, with low uncertainty.

- *Plenodomus tracheiphilus* is mainly reported as a pathogen of *Citrus*, with occasional reports from *Poncirus* and *Fortunella*, but there are no native species of these genera in New Zealand that could be affected.

Given the arguments and evidence below, the introduction of *Plenodomus tracheiphilus* is likely to cause negligible human health impacts in New Zealand, with low uncertainty.

- *Plenodomus tracheiphilus* is not known to cause any disease or health conditions in humans.

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6 Pest risk assessment: Viruses

6.1 Citrus leprosis viruses

Citrus leprosis is a non-systemic disease caused by several viruses that are spread by species of *Brevipalpus* mites. Local necrotic lesions form on the surface of citrus leaves, stems and fruit at the feeding sites of mites that carry the viruses. Severe disease can result in extensive crop loss and tree debilitation.

Taxonomy
Notes: Although the viruses that cause citrus leprosis are from two taxonomic orders, they have some important features in common: the production of non-systemic lesions on citrus and transmission by tenuipalpid false spider mites in the genus *Brevipalpus* (EFSA 2017).

There are two forms of citrus leprosis: the cytoplasmic form (CL-C) where the virus particles replicate in the cytoplasm of infected host cells, and the nuclear form (CL-N) where they replicate in the nucleus (Cook et al. 2019).

CL-C is caused by three viruses from two genera, *Cilevirus* and *Higrevirus*, in the family *Kitaviridae*: *Citrus leprosis virus C* (CiLV-C), *Citrus leprosis virus C2* (CiLV-C2) and *Hibiscus green spot virus 2* (HGSV-2).

CL-N is caused by three viruses from the one genus, *Dichorhavirus*, but in a different family (*Rhabdoviridae*) and order (*Mononegarivales*) from the CL-C viruses: *Orchid fleck dichorhavirus* (OFV), *Citrus leprosis N dichorhavirus* (CiLV-N) and *Citrus chlorotic spot dichorhavirus* (CiCSV).

Scientific name: *Citrus leprosis virus C*
Order/family/genus: *Martellivirales*/*Kitaviridae*/*Cilevirus*
Other scientific names: Citrus leprosis virus
Abbreviation: CiLV-C
Notes: CiLV-C is the most widespread and best studied of the viruses associated with citrus leprosis disease (Bastianel et al. 2010). Its geographic range appears to be confined to the Americas. Sweet orange (*Citrus sinensis*) is the most susceptible host while other citrus species are affected to varying degrees with many more recently considered resistant or asymptomatic to leprosis (Chagas 2000; Bastianel et al. 2010).

Scientific name: *Citrus leprosis virus C2*
Order/family/genus: *Martellivirales*/*Kitaviridae*/*Cilevirus*
Abbreviation: CiLV-C2
Notes: CiLV-C2 has been identified in sweet orange (*C. sinensis*) in several citrus-growing areas in Colombia. It was recognised as a distinct virus from CiLV-C after tests for the latter failed on symptomatic material (Roy et al. 2013a).

Scientific name: *Hibiscus green spot virus 2*
Order/family/genus: *Martellivirales*/*Kitaviridae*/*Higrevirus*
Abbreviation: HGSV-2
Notes: HGSV-2 was first found in Hawaii in association with mild citrus leprosis-like symptoms in Volkamerian lemon (*Citrus volkameriana*) and nearby symptomatic *Hibiscus arnottianus* plants (Melzer et al. 2012). Surveys have shown that its host range includes mandarin (*C. reticulata*), navel orange (*C. sinensis*) and *Hibiscus tiliaceus* (Roy et al. 2015a).

Scientific name: *Orchid fleck dichorhavirus* [citrus strain]
Order/family/genus: *Mononegarivales*/*Rhabdoviridae*/*Dichorhavirus*
Other scientific names: *Orchid fleck virus* (OFV), citrus strain of *Orchid fleck virus*, *Citrus necrotic spot virus*, *Citrus leprosis virus N*
Abbreviations: OFV, CiNSV
Notes: OFV has been identified in citrus in association with citrus leprosis (Roy et al. 2020). The associated isolates were earlier known as *Citrus leprosis virus N* (reported from Brazil, Colombia, Mexico and Panama) (Roy et al. 2013b; Roy et al. 2015a) and *Citrus necrotic spot virus* (reported from Mexico) (Cruz-Jaramillo et al. 2014) but have since been reclassified as variants of OFV (Afonso et al. 2016). OFV naturally infects several *Citrus* spp. (Table 2).

Symptoms typical for citrus leprosis have been observed on Valencia and navel oranges (*C. sinensis*) in South Africa (Cook et al. 2019). Phylogenetic analyses show that the associated virus is a variant of

OFV that is more closely related to orchid isolates than to isolates from citrus. This is the first confirmed report of CL-N outside the Americas (Cook et al. 2019).

Scientific name: *Citrus leprosis N dichorhavirus*
Order/family/genus: *Mononegarivales/Rhabdoviridae/Dichorhavirus*
Other scientific names: Citrus leprosis virus N, Citrus leprosis virus N *sensu novo*
Abbreviation: CiLV-N, CiLV-N sensu novo
Notes: CiLV-N is a dichorhavirus recorded from sweet orange (*Citrus* × *sinensis*) in Brazil (Ramos-Gonzalez et al. 2017). This species was referred to as *Citrus leprosis virus N* sensu novo (CiLV-N sensu novo) by EFSA (2017) to avoid confusion with dichorhavirus isolates found in citrus in Mexico and Colombia, which are now considered citrus strains of OFV.

Scientific name: *Citrus chlorotic spot dichorhavirus*
Order/family/genus: *Mononegarivales*/*Rhabdoviridae*/*Dichorhavirus*
Other scientific names: Citrus chlorotic spot virus
Abbreviation: CiCSV
Notes: Observation of local chlorotic spots resembling early lesions of citrus leprosis in leaves of sweet orange (*Citrus sinensis*) in Teresina, State of Piaui, northeastern Brazil in 2017 led to the identification of CiCSV (Chabi-Jesus et al. 2018). The virus has also been detected in chlorotic lesions of beach hibiscus (*Hibiscus tileaceus*).

This assessment addresses the six viruses known to cause CL. The current import health standard (IHS) for citrus nursery stock requires specific tests for CiLV-C on imported budwood in post-entry quarantine (PEQ). However, CiLV-C is assessed here so that the risk can be considered for a lower level of PEQ than stipulated in the IHS. In addition, CiLV-C is the best known and most widespread of the citrus leprosis viruses, and there is more information available about this virus than there is about the other viruses, which are assumed to have similar biology.
Given that some of these viruses have only recently been discovered and described, there is some uncertainty about whether there are other viruses not yet discovered that may have similar biology and cause citrus leprosis symptoms in citrus.

6.1.1 Summary of conclusions

- The citrus leprosis viruses meet the criteria to be quarantine pests for New Zealand.
- The association of the six citrus leprosis viruses with leafless *Citrus* spp. budwood is considered high, with low uncertainty.
- The likelihood of any one of the six citrus leprosis viruses entering New Zealand associated with leafless *Citrus* spp. budwood is considered very low, with moderate uncertainty.
- The likelihood of any one of the citrus leprosis viruses establishing in New Zealand is considered moderate, with high uncertainty.
- The introduction of any one of the citrus leprosis viruses is considered likely to cause low to moderate economic impacts for New Zealand (but may be high for citrus growers), with high uncertainty.
- The introduction of any one of the citrus leprosis viruses is considered likely to cause low social impacts in New Zealand, with high uncertainty.
- The introduction of any one of the citrus leprosis viruses is considered likely to cause very low environmental impacts in New Zealand, with high uncertainty.
- The introduction of any one of the citrus leprosis viruses is considered likely to cause negligible human health impacts, with low uncertainty.
- *Citrus leprosis virus C, Citrus leprosis virus C2, Hibiscus green spot virus 2, Orchid fleck dichorhavirus* [citrus strain], *Citrus leprosis N dichorhavirus* and *Citrus chlorotic spot dichorhavirus* may be considered for additional measures on citrus budwood.

6.1.2 Hazard identification: regulatory status

Given the arguments and evidence below, *Citrus leprosis virus C*, *Citrus leprosis virus C2*, *Hibiscus green spot virus 2*, *Orchid fleck dichorhavirus* [citrus strain], *Citrus leprosis N dichorhavirus* and *Citrus chlorotic spot dichorhavirus* meet the criteria to be quarantine pests for New Zealand.

Criteria for being a regulated quarantine pest relevant to this assessment are: the pest is not present in the pest risk assessment area (New Zealand), and the pest is of potential importance (able to establish and cause harm[42]).

The six citrus leprosis viruses are not known to be present in New Zealand.

- *Citrus leprosis virus C* is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015) or PPIN (2020). The quarantine status of *Citrus leprosis virus C* in New Zealand is 'regulated', and it is listed in ONZPR (2020) as Citrus leprosis virus (syn. citrus leprosis, citrus leprosis disease, citrus leprosis rhabdovius, leprosis rhabdovirus).
- *Citrus leprosis virus C2* is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015), or PPIN (2020). The quarantine status of *Citrus leprosis virus C2* in New Zealand is currently unassessed, and it is not listed in BRAD or ONZPR.
- *Hibiscus green spot virus 2* is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015) or PPIN (2020). The quarantine status of *Hibiscus green spot virus 2* in New Zealand is currently unassessed, and it is not listed in BRAD or ONZPR.
- *Orchid fleck dichorhavirus* [citrus strain] is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015), or PPIN (2020). The quarantine status of *Orchid fleck dichorovirus* in New Zealand is currently unassessed. It is not listed in ONZPR, but it is listed in BRAD (as Orchid fleck virus).
- *Citrus leprosis N dichorhavirus* is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015), or PPIN (2020). The quarantine status of *Citrus leprosis N dichorhavirus* in New Zealand is currently unassessed, and it is not listed in BRAD or ONZPR.
- *Citrus chlorotic spot dichorhavirus* is not known to occur in New Zealand. It is not recorded in Veerakone et al. (2015), or PPIN (2020). The quarantine status of *Citrus chlorotic spot dichorhavirus* in New Zealand is currently unassessed, and it is not listed in BRAD or ONZPR.

The six citrus leprosis viruses have the potential to establish and spread in New Zealand.

- The known geographic distribution of the citrus leprosis viruses include regions that have areas with similar climates to New Zealand (for example, parts of Mexico and Brazil), although there is some uncertainty around the geographic distribution of the more recently discovered viruses.
- There are no ecoclimatic constraints known for the five leprosis-associated viruses that were evaluated by EFSA (2017), except for those affecting their host plants and mite vectors. EFSA (2017) believed the viruses would establish where their *Citrus* hosts and mite vectors are able to develop.
- *Citrus* species, including sweet orange (*C. sinensis*), which is the most susceptible species (Chagas 2000), are grown both commercially and domestically in New Zealand, particularly in warmer northern regions of the country (see sections 2.4 and 2.5).
- The citrus leprosis viruses are naturally transmitted by mites of the genus *Brevipalpus* (Bastianel et al. 2010; Roy et al. 2015a). *Brevipalpus phoenicis* sensu lato, *B. californicus* and *B. obovatus* are recorded as present in New Zealand (NZOR 2020).
- Therefore, suitable host plants and vectors may be present in suitable environmental conditions to support establishment and spread.

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[42] 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 six citrus leprosis viruses have the potential to have impacts of economic and sociocultural value by causing symptoms on citrus in New Zealand.

- Citrus leprosis disease caused by the expression of citrus leprosis viruses has been recorded in regions that have areas with similar climates to New Zealand (for example, parts of Mexico and Brazil).
- Citrus leprosis induces symptoms of localised lesions on foliage, stems and fruit and severe disease can result in extensive crop loss and tree debilitation (Chagas 2000).
- Sweet orange (*C. sinensis*) is the primary species affected, while other citrus species and cultivars show varying levels of susceptibility or resistance (Chagas 2000; EFSA 2017), depending on the citrus leprosis virus species.
- Citrus, including *C. sinensis*, is an important commercial crop for New Zealand and is commonly grown by home gardeners (sections 2.4 and 2.5).

6.1.3 Hazard identification: commodity association

Given the arguments and evidence below, the association of the six citrus leprosis viruses with leafless *Citrus* spp. budwood is considered to be high, with low uncertainty.

Citrus leprosis viruses can be present in young twigs and stems of infected plants.

- Citrus leprosis is characterised by the presence of local lesions on plant parts including twigs and stems (Bastianel et al. 2010).
- Generally, virus particles of citrus leprosis occur mostly in parenchyma cells of the lesion area in affected orange leaves, fruits, or stems (Rodrigues et al. 2003a).

6.1.4 Risk assessment: likelihood of entry

Given the arguments and evidence below, the likelihood of any one of the six citrus leprosis viruses entering New Zealand associated with leafless *Citrus* spp. budwood is considered to be very low, with moderate uncertainty.

The citrus leprosis viruses have a strong association with leafless *Citrus* budwood, because these viruses cause lesions on twigs and stems.

- Particles of the citrus leprosis viruses occur in the parenchyma cells of the lesion area in affected plant tissues and do not become systemic (see the above section 6.1.3 Hazard identification: commodity association). EFSA (2017) makes the following points:
    - Contrary 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. 2015a). These viruses are only able to move locally, from an infected cell to immediately neighbouring cells.
    - One of the consequences of this peculiar infection biology is that plant tissues away from an infection site are considered free of infection and propagation using this material should result in virus-free progeny plants.
- CiLV-C has been recorded as causing natural infection from many *Citrus* spp. (**Table 15**). The most susceptible host is sweet orange (*Citrus sinensis*), which is severely damaged; other citrus species and varieties, such as mandarins (*C. reticulata*) and their hybrids, are susceptible to varying degrees with some showing high levels of resistance (Chagas 2000; Bastianel et al. 2006 a, b; Bastianel et al. 2008; EFSA 2017). According to Bastianel et al. (2006a), lemons [*Citrus limon* (L.) Osbeck], limes [*C. aurantifolia* (Christmann) Swingle], grapefruit [*C. paradisi* (McFad.) Hooker] and some tangors (hybrids between sweet oranges and mandarins) exhibit variable levels of resistance to the virus, with lemons and limes being considered immune to leprosis. Fewer citrus hosts are known for the other citrus leprosis viruses, the most having been recorded for the citrus strain of OFV, which includes lemons (*C.* × *limon*), limes (*C. aurantiifolia*) and grapefruit (*C.* × *paradisi*), among others (**Table 15**). Host ranges for the viruses will be determined to some extent by the host ranges of their mite vectors.

Table 15: Host range (natural infections only) for five viruses causing leprosis, taken from Table 5 in EFSA (2017).

	Viruses causing citrus leprosis disease					**Reference**
	CiLV-C	**CiLV-C2**	**HGSV-2**	**OFV – citrus strains**	**CiLV-N**	
Rutaceous host plants						
Citrus sinensis	X	X		X	X	Ramos-Gonzalez et al. (2017)
Citrus aurantium	X			X		Roy et al. (2015a, b)
Citrus jambhiri	X					Roy et al. (2015a, b)
Citrus medica	X					Roy et al. (2015a, b)
Citrus reshni	X			X		Roy et al. (2015a, b)
Citrus reticulata × *C. sinensis*	X			X		Roy et al. (2015a, b)
Citrus sinensis × *Poncirus trifoliata*	X					Roy et al. (2015a, b)
Citrus × *paradisi*				X		Roy et al. (2015a, b)
C. × *limon*				X		Roy et al. (2015a, b)
C. aurantifolia				X		Roy et al. (2015a, b)
C. limetta				X		Roy et al. (2015a, b)
C. × *latifolia*				X		Roy et al. (2015a, b)
Citrus volkameriana	X		X			Roy et al. (2015a, b); Melzer et al. (2012)
C. reticulata	X					Bastianel et al. (2008)
C. deliciosa	X					Bastianel et al. (2008)
C. suhuiensis	X					Bastianel et al. (2008)
C. clementina × *C. reticulata*	X					Bastianel et al. (2008)
C. clementina × (*C. reticulata* × *C. paradisi*)	X					Bastianel et al. (2008)
C. sinensis × *C. reticulata*	X					Bastianel et al. (2008)
C. latifolia	X					Lovisolo et al. (2000)
C. limon	X					Lovisolo et al. (2000)
C. sinensis × *Poncirus trifoliata*	X					Lovisolo et al. (2000)
Swinglea glutinosa	X	X		X		Leon et al. (2008)
Non-rutaceous host plants						
Commelina benghalensis	X					Leon et al. (2008)
Dieffenbachia sp.		X		X		Roy et al. (2015b)
Hibiscus arnottianus			X			Melzer et al. (2012)

- The likelihood of material being taken from citrus plants with lesions is low, as there would be a preference for healthy looking material for export as budwood. However, lesions can be found in crevices of plants so could be overlooked on imported budwood.
- Symptoms of infection have been recorded taking from 17 to 60 days to develop after mite transmission with most symptoms appearing between 21 and 30 days (Chiavegato and Salibe 1984), so there is potential for material to be selected and imported into post-entry quarantine before symptoms develop.
- The citrus leprosis viruses are transmitted by *Brevipalpus* spp. mites (this has not yet been confirmed for HGSV-2 but seems likely) (Childers et al. 2003; Rodrigues and Childers 2013; Roy et al. 2015a; EFSA 2017). Mites can be found in crevices in branches, shoots, buds. However, this association with the commodity is weaker than for lesions caused by citrus leprosis viruses.
- Citrus leprosis disease and the known citrus leprosis viruses have been reported almost entirely from North, Central and South America (**Table 16**). CiLV-C is the most widely distributed of the citrus leprosis viruses and occurs in many countries from Mexico to Argentina, including many of the provinces in Brazil (**Table 16**). The more recently discovered

virus species have been reported in locations within this range, but records are not nearly as widespread as for CiLV-C. A recent report of an orchid strain of OFV causing citrus leprosis symptoms on *Citrus sinensis* in South Africa (Cook et al. 2019) is the first confirmed record of a citrus leprosis virus outside the Americas. Therefore, the restricted geographic distribution means material is unlikely to be sourced from infected regions for these species.

Table 16: Geographic distribution of *Citrus leprosis virus* sensu lato. Citrus leprosis is associated with at least five distinct virus species. The distribution below shows countries where disease symptoms have been observed (EPPO (2020) https://gd.eppo.int/taxon/CILV00)

Region	Country (State/Province)
Africa	South Africa
North America	Mexico, USA (Hawaii)
Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama
South America	Argentina, Bolivia, Brazil (Acre, Amazonas, Bahia, Ceara, Distriti Federal, Espírito Santo, Goiás, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraná, Piauí, Rio de Janeiro, Rio Grande do Sul, Rondônia, Roraima, Santa Catarina, São Paulo, Sergipe, Tocantins), Colombia, Paraguay, Uruguay, Venezuela

- However, there is potential for discovery of more viruses that can cause citrus leprosis or for the distribution to be wider than reported (as shown by the recent South Africa finding).
- There is a low likelihood that symptomatic infected plants would be used to produce budwood material. The symptoms show as non-systemic lesions on the plant surface so are likely to be detected visually. However, a very small lesion at an early stage of development (or recently following mite transmission) might go undetected on some parts of the budwood. Therefore, there is the potential for some contaminated material to be used for budwood for export.

The minimum requirements reduce the likelihood of entry to very low with low uncertainty, because the viruses cause visibly detectable surface lesions and imported budwood would be treated with acaricides.

- It is assumed that healthy looking budwood without obvious signs of disease would be selected for export.
- Visual inspections are likely to detect both disease lesions and *Brevipalpus* mites.
- Imported citrus budwood would be treated with acaricides either prior or upon entry to post-entry quarantine (IHS 155.02.06), which would be expected to kill any associated mites (for cuttings from non-approved facilities in any country).
- Because symptoms of infection have been recorded taking from 17 to 60 days to develop after mite transmission, with most symptoms appearing between 21 and 30 days (Chiavegato and Salibe 1984), there is potential for infected material to initially appear healthy and then develop symptoms during the post-entry quarantine period.
- The virus would not spread from lesions in the absence of the vector mites, because the virus particles are found in and immediately around lesions, only move locally from infected to neighbouring cells and are unable to systemically invade *Citrus* (Bastianel et al. 2010; Roy et al. 2015a). Virus lesions are associated with *Brevipalpus* mites' feeding sites. Mites acquire the virus by feeding on the infected tissues and are thought to remain infective for their lifetime (Bastianel et al. 2010; Tassi et al. 2017). There is no evidence the virus can be passed on from parent to offspring (Tassi et al. 2017).
- Therefore, the viruses are not likely spread around plant material in post-entry quarantine undetected, because both lesions and mites are likely to be detected during regular inspections and handling of material.

However, if citrus leprosis viruses produced surface lesions on citrus nursery stock in post-entry quarantine, there is a very low likelihood the virus would not be contained in level 3A.

- Citrus leprosis viruses are transmitted by or associated with mites in the genus *Brevipalpus*: *B. phoenicis* sensu lato (s.l.) (Geijskes), *B. californicus* s.l. Banks, and *B. obovatus* Donnadieu (Childers et al. 2003; Rodrigues and Childers 2013; Roy et al. 2015a). The following *Brevipalpus* species have been recorded in New Zealand (*B. phoenicis* s.l., *B. californicus* and

B. obovatus) (NZOR 2020; Berry and Fan 2012; Collyer 1973; Manson 1967). It is also likely that *B. phoenicis* sensu stricto (s.s.) is present in New Zealand (Beard et al. 2015).

- The mites would be marginally capable of passing though ventilation mesh at Level 3A (stainless steel insect-proof mesh with a maximum aperture of 0.2 mm; MPI 2019), given their body width of less than 0.2 mm (CABI 2020), and would be capable of passing through ventilation mesh at L2 (insect-proof mesh with a maximum aperture of 0.6 mm; MPI 2019). *Brevipalpus* spp. are considered to have poor natural dispersal ability but can be moved longer distances passively by strong wind (Alves et al. 2005) and other 'passive' mechanisms. Mites of other species have been reported at L3A (pers. comm., R Lardner, 2020) but not necessarily entering through ventilation mesh.
- If local New Zealand *Brevipalpus* mites entered post-entry quarantine by passing through ventilation mesh, they could become infected by feeding on lesions on citrus plants. They or their virus-carrying offspring could also escape the post-entry quarantine facility through the same ventilation mesh. Exposure of the virus pathogen to the New Zealand environment may then occur if suitable hosts are present near the post-entry quarantine facility. The three *Brevipalpus* spp. recorded in New Zealand are highly polyphagous. Childers et al. (2003) noted that 928 plant species in 513 genera within 139 families are recorded hosts of one or more of *B. californicus* (316 species), *B. phoenicis* (486 species) and *B. obovatus* (451 species). Many of the reported hosts of *Brevipalpus* spp. worldwide are present in New Zealand. Host records for *B. phoenicis* s.l. in New Zealand include *Citrus limon* × *reticulata*, *Citrus* sp., *Ipomea* sp., orchids, slipper orchid and grass (Berry and Fan 2012). However, the likelihood of this sequence of events, that is, New Zealand mites entering post-entry quarantine through ventilation mesh, picking up the virus from undetected lesions on the plants within, escaping the facility via the ventilation mesh and then reaching and feeding on a suitable host plant for citrus leprosis viruses, is considered very low at level 3A but cannot be ruled out. The likelihood would be higher at level 2 post-entry quarantine, given the greater mesh size and construction of less sturdy material than stainless steel.
- The facility construction and operational procedures implemented in level 3A glasshouses (including regular inspections for pests and diseases, protective clothing and handwashing) (MPI 2019), would reduce the likelihood of infected New Zealand-sourced *Brevipalpus* mites escaping the facility to a very low level.

Several factors contribute to the moderate uncertainty associated with the rating for entry to New Zealand. The distribution and prevalence of the different species of citrus leprosis viruses is unclear, especially as some of the viruses have been discovered very recently. There is also potential for further viruses to be discovered that are non-systemic, transmitted by *Brevipalpus* mites and cause citrus leprosis disease, including in new geographic locations. Citrus leprosis complex has been described as an emerging disease in the Americas (Roy et al. 2015a). There is uncertainty around which *Brevipalpus* spp. are present in New Zealand, given recent changes in taxonomy in the genus (e.g., Beard et al. 2015). There is also uncertainty around their geographic distribution, range of host plants and abundance in New Zealand. Little published research was found in literature searches, and nothing was found to indicate any research effort on managing these species in crops in New Zealand.

6.1.5 Risk assessment: likelihood of establishment and spread

Given the arguments and evidence below, the likelihood of any one of the citrus leprosis viruses establishing in New Zealand is considered to be moderate, with high uncertainty.

- Establishment of any of the citrus leprosis viruses would depend on a combination of several factors: The presence of suitable host plants, the presence of vectors and the suitability of the environment.
- For CiLV-C, a wide range of citrus species have been recorded with natural infections of the virus (see Table 16), with sweet orange (*Citrus sinensis*) being the most significant. In addition, a small number of other plant species, both Rutaceae and non-Rutaceae, have been recorded with natural infections, along with many species of experimentally infected hosts (EFSA 2017). Some species that are known to grow in or around citrus orchards in other countries (e.g. *Hibiscus rosa-sinensis* and *H. tiliaceus*) could support establishment by playing

in a role in the epidemiology of the diseases as a source of virus inoculum and by harbouring populations of mite vectors (EFSA 2017) if present in similar circumstances in New Zealand.

- Citrus is grown both commercially and domestically in New Zealand, especially in the warmer northern regions of the country. Sweet orange and many of the other recorded hosts of CILV-C, both natural and experimental, are present in New Zealand (Allan Herbarium 2020). Therefore, hosts are present but restricted in distribution rather than widely available throughout the country.
- CiLV-C causes non-systemic lesions on the plant surface at the feeding sites of its mite vector. The virus is spread around the plant and to other plants by the feeding activity of the mite. *Brevipalpus phoenicis* s.l., the vector for CiLV-C, has been recorded in New Zealand, including from *Citrus* spp. (Berry and Fan 2012). Recent taxonomic revision has shown that *B. phoenicis* is a complex of cryptic species (Beard et al. 2015). As a result, one of the species in the complex, *B. yothersi*, is now considered the main vector for CiLV-C (Tassi et al. 2017). However, it is difficult to know which of the revised species older records are referring to, and it is not clear if *B. yothersi* is present in New Zealand. In addition, there is little recorded information on the distribution and abundance of *Brevipalpus* spp. mites in New Zealand.
- The mites are unlikely to move actively very far without assistance as they move slowly and prefer to shelter in openings and wounds (EFSA 2017). Passive mechanisms such as cultural practices and the movement of tools, machinery and people are likely to play a role in their dispersal (EFSA 2017). Mites can also be spread passively by wind currents (Alves et al. 2005).
- Some of the countries where CiLV-C occurs have areas with climatic similarity to parts of New Zealand, according to climate match indices (CMI) based on Phillips et al. (2018). For example, cytoplasmic leprosis (assumed to be CiLV-C) is reported widely from Brazil, including the southern and southeastern states (Roy et al. 2015a), which have areas with 0.7–0.9 CMI [for example, Rio Grande do Sul (0.7–0.9 CMI), Santa Catarina (0.7–0.9 CMI), Paraná (0.7–0.8 CMI) and São Paulo (parts with 0.7–0.8 CM)], and is also reported from Uruguay (0.8–0.9 CMI) (Roy et al. 2015a). However, EFSA (2017) concluded that there are no ecoclimatic constraints known for the five leprosis-associated viruses that were evaluated by EFSA except for those affecting their host plants and mite vectors.
- For the other citrus leprosis viruses, there is much less information than for CiLV-C. They are assumed to have a similar or lower likelihood of establishment in New Zealand than CiLV-C, based on the availability of their known hosts and the presence of known vector species. There are much fewer recorded natural hosts for these viruses (**Table 14**) than for CiLV-C, although the citrus strain of OFV has been recorded from several citrus species that CiLV-C has not, as well as *C. sinensis*. The known vectors *B. phoenicis* s.l. and B*. californicus* have been recorded in New Zealand, and *B. phoenicis* s.s. is likely to be present, but it is unknown whether *B. yothersi* is present. The host range of any of the viruses will be determined to some extent by host range of its mite vectors.
- According to EFSA (2017), known or likely vectors for these less common citrus leprosis viruses include:
    - CiLV-C2: reported to be transmitted by *B. yothersi* (used as a synonym of *B. phoenicis* s.l.; Roy et al, 2013a, 2015a);
    - HGSV-2: mite transmission suspected but not confirmed; no tentative vector species yet identified (Melzer et al. 2012; Roy et al. 2015a);
    - CiLV-N: transmitted by *B. phoenicis* s.s. (Ramos-Gonzalez et al. 2017);
    - OFV [citrus strain]: believed to be transmitted by *B. californicus*, based on the mite's association in the field
- For CiCSV, *B. yothersi*, and possibly another species of *Brevipalpus* [temporarily designated *B.* aff. *yothersi*] are likely vectors based on association with infected plants (Chabi-Jesus et al. 2018).

The main factors contributing to the high uncertainty associated with the rating for establishment in New Zealand are in relation to the *Brevipalpus* mite vectors. There is uncertainty around which *Brevipalpus* spp. are present in New Zealand, in part as a result of recent changes in taxonomy in the genus (e.g., Beard et al. 2015). There is also uncertainty around their geographic distribution, range of host plants and abundance in New Zealand. Little published research or records were found in literature searches, and there was nothing to indicate any research effort on managing these species in crops in New Zealand.

6.1.6 Risk assessment: impacts to New Zealand

Given the arguments and evidence below, the introduction of any one of the citrus leprosis viruses is considered likely to cause low to moderate economic impacts for New Zealand (but may be high for citrus growers), with high uncertainty.

- Citrus leprosis disease induces localised lesions on the leaves, stems and fruit (Chagas 2000; Roy et al. 2015b). When infestations of viruliferous mites are high, lesions in the petiole cause severe defoliation, lesions in the peduncle result in intense fruit drop, coalesced necrotic lesions induce twig death, and plants may die within 3 to 5 years (Roy et al. 2015b).
- Citrus leprosis lesions, typically circular necrotic or chlorotic lesions on leaves, fruits and stems, can affect both fruit quality and production levels. The disease can cause a decrease in production through reduction in tree canopy development, premature fruit and leaf drop, and dieback (Bastianel et al. 2010). Lesions on the fruit surface reduce the aesthetic appeal of fruit grown for fresh consumption (EFSA 2017).
- The disease can cause up to 100% yield losses, depending upon the susceptibility of the citrus cultivar and level of control of the mite vector (Rodrigues et al. 2003a). According to Rodrigues et al. (2003a), Fawcett (1907) estimated a loss of 35–75% from prematurely dropped fruit during 1905 and 1906 in Florida with this amount being similar to figures recorded in Brazil for different cultivars (Rodrigues et al. 2003b).
- Citrus leprosis is one of the most economically important diseases of the Brazilian citrus industry. In 2010, Bastianel et al. reported that control of the vector mite costs Brazilian growers around US$800 million every year.
- Sweet orange (*C. sinensis*) is the most affected citrus species with others, such as mandarins (*C. reticulata*) and their hybrids, being susceptible or resistant to varying degrees. CiLV-C has the most extensive list of citrus hosts in comparison with the other viruses. However, with the exception of HGSV-2, they have all been reported from sweet orange (*C. sinensis*), and the citrus strains of OFV have been recorded from some of the citrus considered more resistant to CiLV-C, such as lemon, lime and grapefruit.
- Citrus trees, including oranges, mandarins, lemons, tangelos, limes, and grapefruit, are commonly grown commercial plants in New Zealand (section 2.5.2). Therefore, impacts to these species have the potential to cause consequences of economic significance. Oranges are likely to be most affected, while some other commercially grown species and varieties, such as lemons, may be affected to a much lesser degree or not at all, depending on the virus species.
- The discovery of the presence of any of the citrus leprosis viruses in New Zealand, especially CiLV-C, is likely to have an immediate impact on exports of citrus, because the disease is not known to occur in any of the countries that are export destinations for New Zealand citrus. Response activities, if undertaken, could cost millions of dollars.
- If the citrus leprosis viruses established longer term, then a greater and longer-term effect on the citrus industry could be expected through lowered production, increased management activities, reduced access to or increased requirements for overseas markets where the viruses are absent and increased surveillance activities.
- However, impacts on production (quality and quantity) will depend on where the mite vectors are present, whether the climatic conditions are suitable for the mites to thrive in citrus orchards, and whether mites are already controlled in orchards by acaricides and other activities. Disease flourishes where the mite vectors flourish, as lesions only occur at the feeding sites of virus-carrying mites. Therefore, citrus leprosis would have more impact in orchards where *Brevipalpus* mite vectors are abundant and not managed. If mites are controlled or occur at low levels, then citrus leprosis may not have much impact on production except for the situation of increased requirements for export. Some regions of New Zealand may be more affected than others, depending on the geographic distribution and local abundance of the individual *Brevipalpus* species.
- Acaricides are used in commercial citrus production in New Zealand to control citrus red mite (*Panonychus citri*) (Mooney 2001; Jamieson and Stevens 2009). These are used as required

rather than routinely, as *P. citri* is only a significant pest when the broad-spectrum activity of insecticides targeting other key pests disrupts the activity of its natural enemies. These treatments may offer some level of control of the *Brevipalpus* spp. that can vector citrus leprosis viruses.

The main factors contributing to the high uncertainty associated with the rating for economic impacts in New Zealand are in relation to the *Brevipalpus* mite vectors (as discussed earlier for establishment). There is uncertainty around which *Brevipalpus* spp. are present in New Zealand, in part as a result of recent changes in taxonomy in the genus (e.g., Beard et al. 2015). There is also uncertainty around their geographic distribution, range of host plants and abundance in New Zealand. Little published research or records were found in literature searches, and there was nothing to indicate any research effort on managing these species in crops in New Zealand.

Given the arguments and evidence below, the introduction of any one of the citrus leprosis viruses is considered likely to cause low sociocultural impacts in New Zealand, with high uncertainty.

- The viruses may cause impacts to home gardeners who grow *Citrus* spp. in areas of the country where environmental conditions are suitable for the *Brevipalpus* mite vectors.
- Symptoms of citrus leprosis include non-systemic lesions on fruit, leaves and stems, and potentially the death of branches or trees, depending on the level of feeding activity of virus-carrying mites.

Given the arguments and evidence below, the introduction of any one of the citrus leprosis viruses is considered likely to cause very low environmental impacts in New Zealand, with high uncertainty.

- The recorded natural hosts of the six citrus leprosis viruses are largely *Citrus* species. However, 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*. Neither the *Leionema* nor *Melicope* species are considered threatened (NZPCN 2020).
- There are very few recorded natural infections of plants outside the Rutaceae. For example, 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* (Malvaceae). There are two native (but not endemic) *Hibiscus* species in New Zealand, both of which are considered “threatened, nationally critical” (*H. richardsonii* and *H. diversifolius* subsp. *Diversifolius*) (NZPCN 2020).
- There is uncertainty around the natural host ranges of any of these viruses. However, these would be expected to fall within the host ranges of the *Brevipalpus* mite vectors.
- Impacts on plants would be from non-systemic lesions that develop where virus-carrying mites feed on leaves, stems and fruit. Therefore, the impact would be dependent on the feeding activity and the abundance of virus-carrying mites.
- Three species of *Brevipalpus* mites known to be vectors of viruses that cause citrus leprosis have been reported from New Zealand. However, given the few records of the mites from New Zealand and the complexity of relating current taxonomy to older records, the lack of knowledge of population levels of the mites, especially in the natural environment, and the uncertainty around the natural host range for any of the citrus leprosis viruses, it is difficult to estimate the likely impact of these viruses in New Zealand’s natural environment.

Given the arguments and evidence below, the introduction of any one of the citrus leprosis viruses is considered likely to cause negligible human health impacts, with low uncertainty.

Citrus leprosis viruses are not known to pose risks to human health.

- No evidence was found of any citrus leprosis viruses causing human health issues.

6.1.7 References

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Appendix 1: Summary of taxa excluded at hazard identification

Pest taxon	Rationale for exclusion
Acari (mites)	Due to the conditions in the nursery stock import health standard (MPI Standard 155.02.06), which require whole plants and cuttings to undergo miticide treatment, it is considered that the pathway is managed as well as possible. Furthermore, the post-entry quarantine period and requirements (MPI 2019) (e.g. inspections and insect proof mesh) are likely to detect and contain any mites that survive treatment. Therefore, MPI believes that the minimum requirements manage the risk associated with mites.
Insecta	Due to the conditions in the nursery stock import health standard (MPI Standard 155.02.06), which require whole plants and cuttings to undergo insecticide treatment, it is considered that the pathway is managed as well as possible. Furthermore, the post-entry quarantine period and requirements (MPI 2019) (e.g. inspections and insect proof mesh) are likely to detect and contain any insects that survive treatment. Therefore, MPI believes that the minimum requirements manage the risk associated with insects.
Fungi (Aspergillaceae)	*Aspergillus flavus, A. niger, Penicillium digitatum* and *P. italicum* are reported from citrus fruit but are present in New Zealand (NZFungi2 2020; PPIN 2020). *Penicillium ulaiense* was considered in more depth, because it is recorded as absent from New Zealand (NZFungi2 2020). However, it is not generally reported as a pathogen that affects citrus plants, although it can cause rot of citrus fruit in storage. For example, *P. ulaiense* was commonly isolated from packhouses in the USA but could not be detected at production sites (Holmes et al. 1994). MPI believes that the minimum requirements manage the risks of *P. ulaiense* entering New Zealand associated with citrus budwood, because the imported material must be free from soil and other debris.
Fungi (Botryosphaeriaceae)	*Phyllosticta citricarpa* (*Guignardia citricarpa*) required a full pest risk assessment. Several other *Phyllosticta* spp. were excluded at the hazard identification stage because they are not known to be associated with branches, shoots, stems or twigs of citrus or do not meet the criteria for additional measures. For example: *Phyllosticta citribraziliensis* and *P. paracapitalensis* have only been reported as endophytes from healthy citrus leaves (Glienke et al. 2011; EFSA 2014; Guarnaccia et al. 2017a), and there is no evidence that they are associated with budwood. *Phyllosticta citrimaxima* was isolated from tan spots on the fruit surface of pomelo fruit in Thailand (Wikee et al. 2013). *Phyllosticta paracitricarpa* was isolated from leaf litter of *C. limon* in Greece and fruit spots on *C. limon* and *C. sinensis* in China (Guarnaccia et al. 2017a, 2019). *Phyllosticta citriasiana* causes citrus tan spot on *C. maxima* 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 (*C. grandis/C. maxima*) is the only recorded host of *P. citriasiana* (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. *Phyllosticta citrichinaensis* was isolated from fruit of mandarins (*C. reticulata*), pomelos (*C. maxima*), oranges (*C. sinensis*) and lemons (*C. limon*) (Wang et al. 2012). No significant losses resulted from this pathogen (Wang et al. 2012).
Fungi (Ceratobasidiaceae)	*Rhizoctonia noxia* (synonyms *Corticium koleroga*; *Ceratobasidium noxium; Koleroga noxia Pellicularia koleroga*), the fungus that causes thread blight, has previously been assessed on fresh citrus fruit from Samoa as *C. koleroga* (MAF 2008). *Rhizoctonia noxia* did not meet the criteria for further assessment, because MPI believes that the minimal requirements are likely to manage the risk of the fungus, because infestations of thread blight are highly unlikely to go undetected and infected citrus plants are highly unlikely to be used to produce budwood. • *Rhizoctonia noxia* attacks twigs, fruit and leaves of *Citrus* trees. 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).

Pest taxon	Rationale for exclusion
Fungi (Ceratocystidaceae)	*Ceratocystis fimbriata* already has additional requirements for all known host species, including citrus, in the Nursery Stock import health standard. Therefore, risk assessment for this species was excluded from the scope of this import risk analysis. *Ceratocystis radicicola* has been reported from citrus fruit (Mirzaee et al. 2008), but searches[1] found no evidence of an association with branches, stems or twigs. In pathogenicity tests, the fungus could only enter damaged fruit through wounds or cracks (Mirzaee et al. 2008), suggesting it is an opportunistic fruit rot.
Fungi (Dermateaceae)	*Cryptosporiopsis citricarpa* (synonym *Pseudofabraea citricarpa*) was considered in the hazard identification, because it was recently reported as a destructive leaf spot which was first reported China in 2010 (Zhu et al. 2012). However, it does not meet the criteria for further assessment, because there is no evidence for an association with Citrus budwood. 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). *Cryptosporiopsis citricarpa* was not reported from stems or branches in either case. Searches[43] found only these reports and taxonomic studies referring to Zhu et al. (2012). *Paracercosporidium microsorum* (synonyms *Cercospora microsora, Mycosphaerella microsora, Mycosphaerella millegrana, Passalora microsora*) was added to the initial hazard list, requiring further analysis, because it was historically listed in the citrus nursery stock pest list. However, it did not meet the criteria for further assessment, because literature 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.
Fungi (Diaporthaceae)	In addition to *D. baccae, D. hongkongensis* and *D. novem,* which were assessed in a grouped pest risk assessment, several other *Diaporthe* species have recently been isolated from citrus plants. *Diaporthe arecae, D. biconispora, D. biguttulata, D. citriasiana, D. citrichinensis, D. discoidispora, D. endophytica, D. limonicola, D. melitensis, D. multigutullata, D. ovalispora, D. ovoicicola, D. subclavata, D. unshiuensis* were noted as potential hazards in the hazard identification for this import risk analysis because: • These species are not recorded from New Zealand: NZFungi2 (2020) either records these species as absent or does not have a record of them. They are not recorded in PPIN. • They have the potential to be associated with citrus nursery stock. There is a single recent primary report of each of these species from twigs, branches or stems of citrus, either as endophytes or associated with disease symptoms. • Some of these species have the potential for impacts, because they are reported to cause disease symptoms in citrus or other economically important hosts. • However, like *D. baccae, D. hongkongensis* and *D. novem,* citrus disease associated with these species has only been recently differentiated from disease symptoms caused by *D. citri,* and there are only a few reports of them in the literature. • Searches of Google Scholar and CAB Abstracts and Farr and Rossman (August 2020) on the species name and 'citrus' found only a single report from citrus and, in some cases, molecular taxonomy studies with no further hosts or geographical records. There is insufficient information about *Diaporthe arecae, D. biconispora, D. biguttulata, D. citriasiana, D. citrichinensis, D. discoidispora, D. endophytica, D. limonicola, D. melitensis, D. multigutullata, D. ovalispora, D. ovoicicola, D. subclavata* and *D. unshiuensis* to assess them in more depth at this time, but they may be reconsidered in future if more information becomes available (e.g. from the emerging risks system).
Fungi (Glomerellaceae)	*Colletotrichum abscissum* and *C. limetticola* met the criteria for pest risk assessment (see sections 6.1 and 6.2) A number of other *Colletotrichum* species were considered in more depth at the hazard identification stage. For example: *Colletotrichum queenslandicum* has been reported from leaves of Persian lime (C. latifolia) with anthracnose symptoms on a tree at a residential property in Texas, USA (Kunta et al. 2018). Another recently described species, *C. citri-maximae,* is reported as a symptomless endophyte in the

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[43] 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 exclusion
	C. gigasporum complex reported from a study of Colletotrichum species on *C. maxima* fruit imported from China (Douanla-Meli and Unger 2017). Searches on the species name in Google Scholar and CAB Abstracts found no reports of this species from other plant parts and no reports of it causing disease. There is no evidence for an association of *C. queenslandicum* or *C. citri-maximae* with citrus budwood with the leaves removed. A number of *Colletotrichum* species (*Colletotrichum catinaense, C. helleniense, C. hystricis* and *C. limonicola*) were recently reported from surveys as associated with citrus, but there was insufficient information to assess them further: • *Colletotrichum catinaense* was isolated from *C. sinensis* fruit with anthracnose (tear stain) symptoms in Portugal and from *C. reticulata* leaf lesions and *C. aurantiifolia* twigs with wither tip symptoms in Italy (Guarnaccia et al. 2017b). • *Colletotrichum helleniense* was isolated from twigs of *Poncirus trifoliata* with wither tip, as well as lesions on fruit, in Arta, Greece (Guarnaccia et al. 2017b). • *Colletotrichum hystricis* was isolated from leaf lesions on *C. hystrix* in Italy (Guarnaccia et al. 2017b). • *Colletotrichum limonicola* was isolated from leaf lesions of *C. limon* in Malta (Guarnaccia et al. 2017b). Searches using the species name and citrus as search terms in Google Scholar, CAB Abstracts, CABI and Farr and Rossman (August 2020) found no information about the association of these species with citrus beyond the initial report. These species may need to be assessed in future if more information becomes available (e.g. from the emerging risks system).
Fungi (Meliolaceae – sooty blotches)	*Meliola citricola* was assessed on citrus fruit from Samoa (MAF 2008) and so was considered as part of the hazard identification. However, there is no evidence for an association with citrus budwood: • *Meliola citricola* causes unsightly black fungal growth on fruit and leaves of citrus (MAF 2008). Searches on 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 *M. citricola,* and the related species *M. camelliae,* in historic country indexes and lists of fungal species, but no evidence was found for an association with branches, twigs, shoots or stems of citrus.
Fungi (Mycosphaerelleaceae)	A number of *Mycosphaerella* and *Zasmidium* leaf and fruit spot species were considered during the hazard identification process, including: • *Mycosphaerella citri* (synonym *Zasmidium citri*) does not meet the criteria for further assessment because there is no pathway for establishment from leafless citrus budwood (based on information in MAF 2008). *Mycosphaerella citri* causes greasy spot of citrus leaves and greasy spot rind blotch of citrus (MAF 2008). • The CABI datasheet (2020) says it is not transmitted via budwood. • Since *Mycosphaerella citri* overwinters in the soil and sporulates on fallen leaves (MAF 2008), removing the leaves and importing clean, rootless budwood prevents entry and establishment of the pathogen via this pathway. • *Mycosphaerella horii* is also reported to sporulate on decomposing leaves (Ieki 1986). Several other *Mycosphaerella* and *Zasmidium* species are reported to cause leaf and/or fruit spots in citrus but do not meet the criteria for further assessment (e.g. *M. citrigena*, *M. loefgrenii, Z. fructicola*, *Z. fructigenum* and *Z. indonesianum*). • Searches on the species name (Google Scholar, CABI, CAB Abstracts, Farr and Rossman, June 2020) found no detail on life cycle and no evidence for an association with citrus budwood with no leaves. • Since these species are closely related to *M. citri,* the life cycle is likely to be similar. Assuming these other *Mycosphaerella* and *Zasmidium* species overwinter in the soil and sporulate on fallen leaves, removing the leaves and importing clean rootless budwood prevents these pathogens from entering New Zealand and establishing from citrus nursery stock. *Pseudocercospora angolensis* (synonyms: *Cercospora angolensis; Phaeoramularia angolensis*; *Pseudophaeoramularia angolensis*) was considered in some depth during the hazard identification process because this fungus is reported to cause spots and lesions on leaves, fruit and

Pest taxon	Rationale for exclusion
	sometimes stems of all citrus species, including grapefruit, lemon, orange, lime and tangerine (Seif and Hillocks 1993, 1998). However, MPI believes that the biosecurity risks associated with *P. angolensis* are managed by minimum measures. *Pseudocercospora angolensis* is highly unlikely to be associated with healthy citrus budwood, because the fungus only causes stem lesions in severely diseased plants with visible lesions on the leaves: • *Pseudocercospora angolensis* causes spots on leaves which can coalesce, particularly on young leaves, and cause yellowing and early leaf loss. • Stem lesions are not frequent and mostly occur as an extension of lesions on the petiole (Seif and Hillocks 1993). • Occurrence of several such lesions at the stem tip results in dieback; those on other parts of the stem coalesce, become corky, and crack. At the base of the dead stem, there is usually a profuse growth of secondary shoots. In addition, *P. angloensis* is only found in sub-Saharan Africa (not reported from South Africa) and Yemen (EFSA 2017). There are no records of imports of Citrus nursery stock from countries where *P. angolensis* is reported, although trade on these pathways cannot be ruled out in future.
Fungi (Nectriaceae)	Several species in the Nectriaceae were considered during the initial hazard identification stage. Several Fusarium species have recently been isolated from citrus plants but do not meet the criteria for additional measures: • *Fusarium citricola, F. ensiforme, F. salinense, F. sarcochroum, F. siculi* were noted as potential hazards in the hazard identification for this import risk analysis because: ○ These species are not recorded from New Zealand – NZFungi2 (2020) either records these species as absent or does not have a record of them. ○ They have the potential to be associated with citrus nursery stock. There is a single recent primary report of each of these species from twigs, branches or stems of citrus, either as endophytes or associated with disease. ○ Some of these species have the potential for impacts because they are reported to cause disease symptoms in citrus or other economically important hosts. ○ Searches of Google Scholar, CAB Abstracts and Farr and Rossman (August 2020) on the species name and 'citrus' found only a single report from citrus and, in some cases, molecular taxonomy studies with no further hosts or geographical records. ○ There is insufficient information about the association of *F. citricola, F. ensiforme, F. salinense, F. sarcochroum* or *F. siculi* with citrus to assess them in more depth at this time, but they may be reconsidered in future if more information becomes available (e.g. from the emerging risks system). ○ *Fusarium solani* and *F. oxysporum* are reported as citrus root pathogens and are now considered to be a species complexes, however *F. solani* sensu stricto (as its synonym *Nectria haematococca*) and *F. oxysporum* sensu stricto have both been recorded from citrus plants in New Zealand (NZFungi2 2020). *Cylindrocarpon lichenicola* (synonyms include *Fusarium lichenicola* and *Neocosmospora lichenicola*) was reported as a cause of severe post-harvest fruit rot of pomelo in Viet Nam (Amby et al. 2015), but there is no evidence that it is associated with citrus budwood. However, although other citrus species developed rot symptoms in pathogenicity tests (Amby et al. 2015) searches using the search terms '*Cylindrocarpon lichenicola'* or its synonyms and 'citrus' found no other reports of *C. lichenicola* from citrus. *Cylindrocarpon lichenicola* 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. *Neocosmospora euwallaceae* (synonym *Fusarium euwallaceae*) does not meet the criteria for additional measures, because it is a wood rot fungus that colonises beetle galleries and is spread by beetle vectors (Paap et al. 2018). It is therefore highly unlikely to be associated with citrus budwood.

Pest taxon	Rationale for exclusion
Fungi (Pleosporaceae)	A number of *Alternaria* species were considered in more depth at the hazard identification stage but do not meet the criteria for additional measures: • A number of *Alternaria* species are described from *Citrus* but are now considered synonyms of species that are present in New Zealand and have been recorded from Citrus here (e.g. *A. pellucida* is a synonym of *A. alternata*; *A. scorzonerae* is a synonym of *A. linicola*). • *Alternaria limicola,* the cause of the citrus leaf spot disease mancha foliar de los citros, attacks young twigs and leaves, producing small chlorotic spots with raised centres (Timmer et al. 2000). Affected leaves often abscise and twigs may die back (Timmer et al. 2000) • It is uncertain whether *A. limicola* can spread from infected twigs. It produces airborne conidia in leaf lesions (Palm and Civerolo 1994), however, no records were found that reported whether conidia were produced in lesions on twigs. • The risk of *A. limicola* entering New Zealand is likely to be managed by minimum measures because: ○ Disease symptoms develop rapidly, so it is very unlikely that budwood will be sourced from plants infected with *A. limicola.* Palm and Civerolo (1994) describe leaves with both mature and newly formed lesions 5 days after inoculation. Timmer et al. (2000) report that conidia of *A. limicola* germinate within 4 hours and penetrate the tissue within 12 hours, and that *A. limicola* sporulates about 8 days after symptoms develop. *Alternaria limicola* has a very limited geographical distribution. Palm and Civerolo (1994) report the disease from the pacific coast of Mexico, but not elsewhere in Mexico. No reports were found of *A. limicola* from anywhere else in the world.
Fungi (Capnodiaceae and Chaetothyriaceae-sooty moulds)	*Capnodium citri* 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 therefore, the biosecurity risks associated with these species are managed by minimum requirements: *Antennella citrina, Capnodium citri, Capnodium tanakae, Capnophaeum fuliginoides, Chaetothyrium citri, Chaetothyrium javanicum, Chaetothyrium spinigerum, Hypocapnodium japonicum.*
Fungi (Wood, root, butt or rot fungi e.g. Agaricales, Hymenochaetales, Polyporales, many Xylariales)	Fungi that cause root and butt rots of citrus plants and are only reported to be associated with roots and butts were not assessed further. Likewise, wood rots that are only reported from mature woody tissues of citrus plants were not assessed. The risk of these pathogens entering New Zealand is managed by the commodity description, because it is highly unlikely that such fungi will be associated with shoots and new growth from which budwood cuttings are taken. For example: • *Armillaria luteobubalina* and *A. mellea* were assessed in the Prunus import risk analysis. *Armillaria* species are associated with roots and crowns and are sometimes saprophytic but are unlikely to be associated with healthy dormant cuttings with roots removed. • Another root rot, *Pyrrhoderma noxium* (Corner) L.W. Zhou & Y.C. Dai (2018), is on the pest list of the existing import health standard as *Phellinus noxius.* This pathogen was previously assessed by MPI, and the likelihood of it entering New Zealand associated with rootless budwood was assessed as negligible (MPI 2016). • *Ganoderma lucidum* causes white discolouration and white stringy wood rot in the roots and bases of trunks of host plants (CPC 2021). • *Fomitiporia mediterranea* infects citrus trees via pruning wounds, causing white rot decay in trunks and large branches (Elena et al 2006).

* Searches of Google Scholar and CAB Abstracts with the species name and ‘Citrus’ as search terms. In situations where there were hundreds of search results, the first 10 pages of Google Scholar records were scanned for relevant records.

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Appendix 2: Glossary and Abbreviations

Term or abbreviation	Definition
BORIC	Biosecurity Organisms Register for Imported Commodities, a retired MPI database now replaced by ONZPR
BRAD	Biosecurity Risk Analysis Database (MPI database)
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	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	The commodity description defines the form of the commodity that is covered by the IRA, 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.
CPC	Crop Protection Compendium (CABI database)
Disease	A disorder of structure or function in a plant, especially one that affects a specific location and is not simply a direct result of physical injury
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
ERS	Emerging Risk System (MPI workflow)
Exposure	The process of the hazard organism moving from the commodity it arrived on to another host (also called “transfer”)
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.

Term or abbreviation	Definition
Hazard	A hazard is a pest (including arthropods and pathogens) or disease that is not present in the PRA area, e.g. New Zealand (or is present but still represents a biosecurity risk, e.g. is capable of vectoring pathogens not present in the PRA area), has the ability to establish and cause harm in the PRA area and is associated with the entry pathway (commodity/country of origin) under consideration.
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 (FAO 2012)
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
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 IPCC
IHS	Import health standard
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
NPPO	National plant protection organisation, official service established by a government to discharge the functions specified by the IPPC.
NZOR	New Zealand Organisms Register
ONZPR	Official New Zealand Pest Register (MPI database), replacement of BORIC
PEQ	Post-entry quarantine
Pest	Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products
PFA	Pest-free area
PFPP	Pest-free place of production
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

Term or abbreviation	Definition
QuanCargo	New Zealand border transaction database, detailing commercial consignments and interceptions of pests made by quarantine inspection (MPI)
Quarantine pest	A quarantine pest is an organism that is not present in a PRA area, e.g. New Zealand (or is present but still represents a biosecurity risk, e.g. is capable of vectoring pathogens not present in the PRA area) and is capable of establishing and causing harm in the PRA area.
Risk management question/s	Specific question/s that the risk manager needs answered in order to make a decision. They are based on the commodity description and basic measures for that commodity type.
Vector	An organism or object that transfers a pest, parasite, pathogen or disease from one area or host to another.