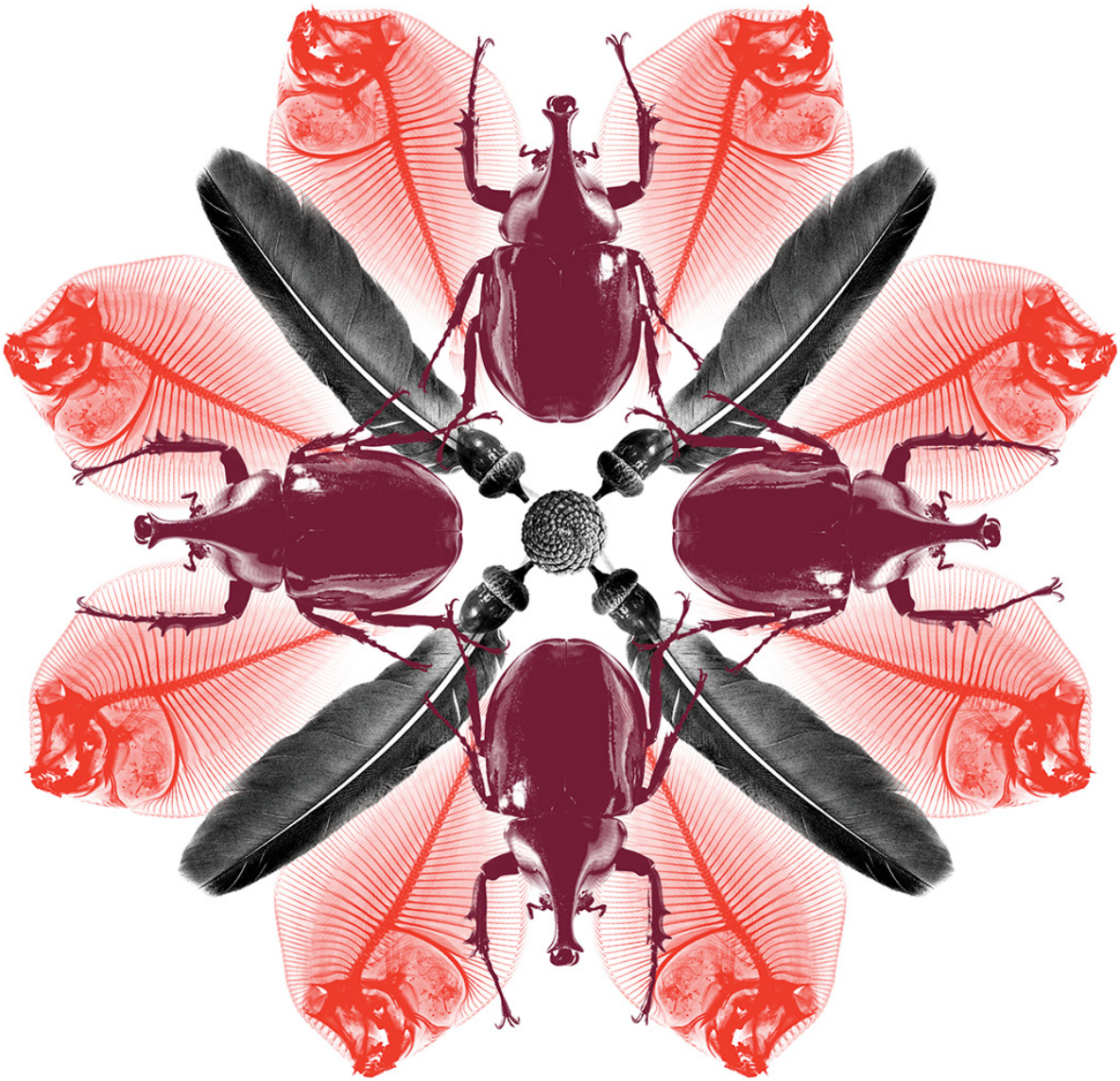
Australian Government
Department of Agriculture and Water Resources

Final pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops

September 2017



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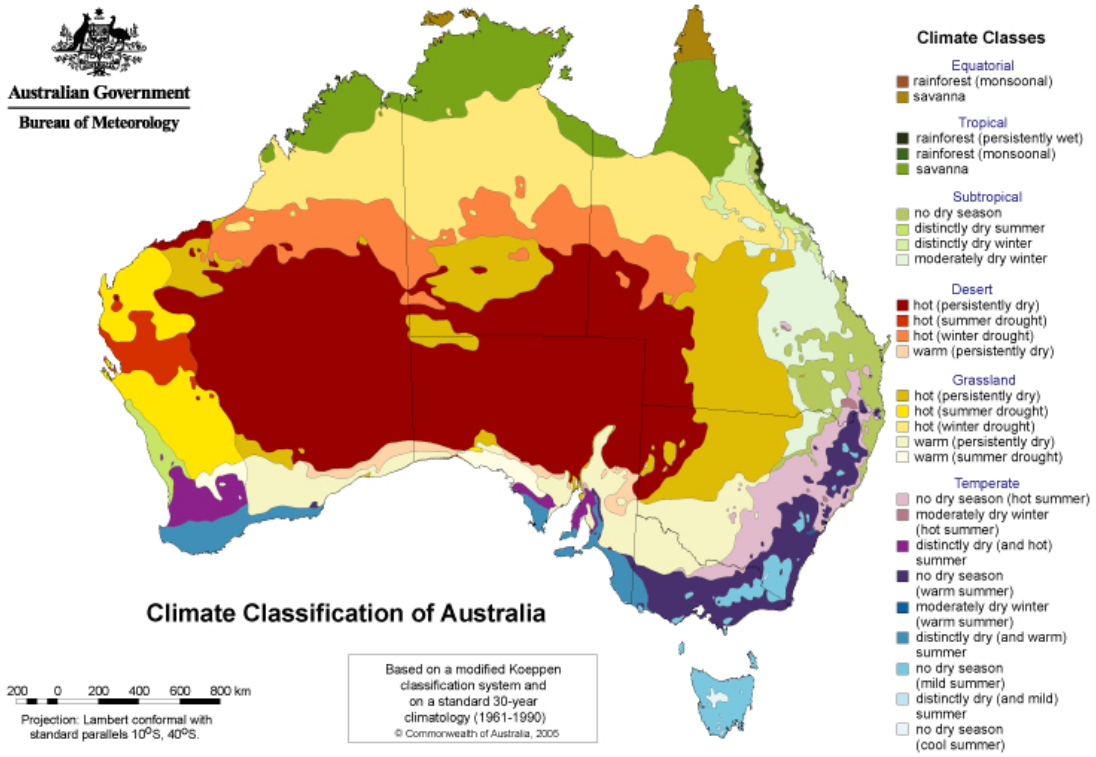

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Acronyms and abbreviations

Term or abbreviation	Definition
ACT	Australian Capital Territory
ALOP	Appropriate level of protection
BA	Biosecurity Advice
BICON	Australia's Biosecurity Import Conditions System
BIRA	Biosecurity Import Risk Analysis
'*Ca.* L. solanacearum'	'*Candidatus* Liberibacter solanacearum'
FAO	Food and Agriculture Organization of the United Nations
IIGB	Interim Inspector-General of Biosecurity
IPC	International Phytosanitary Certificate
IPPC	International Plant Protection Convention
ISPM	International Standard for Phytosanitary Measures
NSW	New South Wales
NPPO	National Plant Protection Organisation
NT	Northern Territory
PCR	Polymerase Chain Reaction
PRA	Pest risk analysis
Qld	Queensland
SA	South Australia
SEM	Scanning Electron Microscopy
SPS Agreement	WTO agreement on the Application of Sanitary and Phytosanitary Measures
Tas.	Tasmania
TEM	Transmission Electron Microscopy
the department	The Australian Government Department of Agriculture and Water Resources
Vic.	Victoria
WA	Western Australia
WTO	World Trade Organization

Summary

The Department of Agriculture and Water Resources initiated this pest risk analysis (PRA) in response to the introduction of emergency measures against '*Candidatus* Liberibacter solanacearum' ('*Ca*. L. solanacearum') infecting apiaceous crops, including carrot (*Daucus carota*) and celery/celeriac (*Apium graveolens*). This bacterium is not known to occur in Australia and is reported to cause serious damage to the carrot and celery industries in Europe. Australia introduced emergency measures on apiaceous host propagative material in August 2014 to manage the risk of introduction of '*Ca*. L. solanacearum' into Australia.

The International Plant Protection Convention (IPPC) and the 'World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures' (SPS Agreement) requires that any phytosanitary measures applied against the introduction of new pests must be technically justified. The IPPC's International Standards for Phytosanitary Measures (ISPM) No. 1 states that countries may take appropriate emergency action on a pest posing a potential threat to its territories; however, it requires that the action be evaluated as soon as possible to justify the continuance of the action. This PRA meets Australia's international obligations to review the emergency phytosanitary measures on '*Ca*. L. solanacearum' associated with apiaceous crops.

The department considers that the current emergency measures are adequate to mitigate the risk posed by '*Ca*. L. solanacearum' associated with apiaceous crops. These emergency measures are recommended to become the standard conditions to import apiaceous host propagative material into Australia, with some minor amendments.

Since the publication of the Draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops, new findings suggested that this bacterium has expanded its natural host range within the Apiaceae family. It was detected in seed lots of carrot in Italy (2016) and Israel (2017), parsley seed in the UK (2016), parsnip seed (2016) and celery/celeriac seed (2017).

Most recently, '*Candidatus* Liberibacter solanacearum' has been detected in plants of two other apiaceous crops: chervil and fennel in France (2017) and in imported fennel seed in New Zealand (2017). The detection of CaLsol in fennel seed has raised concerns that this bacterium may also be seed-borne in chervil. Based on the new available information, the department has made the following significant changes to the draft PRA:

- The inclusion of mandatory off-shore or on-shore Polymerase Chain Reaction (PCR) testing or hot water treatment for celery/celeriac, chervil, fennel, parsley and parsnip seed; AND if the testing or treatment is conducted off-shore, a Phytosanitary Certificate with the additional declaration that the mandatory testing or treatment has been conducted in accordance with Australia's requirements.
- The inclusion of mandatory off-shore or on-shore PCR testing for chervil, fennel and parsley tissue cultures; AND if the testing or treatment is conducted off-shore, a Phytosanitary Certificate with the additional declaration that the mandatory treatment or testing has been conducted in accordance with Australia's requirements.

- The inclusion of mandatory growth of chervil, fennel and parsley tissue cultures not tested off-shore in a closed government post-entry quarantine (PEQ) facility for disease screening; AND mandatory on-shore PCR testing for freedom from '*Ca.* L. solanacearum'.

In addition, the department has also made several minor changes following consideration of stakeholder comments on the Draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops. However, these changes have no impact on the recommended risk management measures.

The recommended import conditions for apiaceous crops are summarised below.

Seeds for sowing (carrot, celery/celeriac, chervil, fennel, parsley and parsnip): mandatory off-shore or on-shore PCR testing or hot water treatment (50 °C for 20 minutes); AND if the testing or treatment is conducted off-shore, a Phytosanitary Certificate with the additional declaration that the mandatory treatment or testing has been conducted in accordance with Australia's requirements.

Tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) off-shore option: mandatory off-shore PCR testing; AND a Phytosanitary Certificate with the additional declaration that the testing has been conducted in accordance with Australia's requirements.

Tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) on-shore option: mandatory growth in a closed government post-entry quarantine (PEQ) facility for disease screening; AND mandatory on-shore PCR testing for freedom from '*Ca*. L. solanacearum'.

The department considers that the recommended risk management measures will be adequate to mitigate the risks posed by '*Ca*. L. solanacearum' associated with apiaceous crops.

1 Introduction

1.1 Australia's biosecurity policy framework

Australia's biosecurity policies aim to protect Australia against the risks that may arise from exotic pests entering, establishing and spreading in Australia, thereby threatening Australia's unique flora and fauna, as well as those agricultural industries that are relatively free from serious pests.

The risk analysis process is an important part of Australia's biosecurity policies. It enables the Australian Government to formally consider the level of biosecurity risk that may be associated with proposals to import goods into Australia. If the biosecurity risks do not achieve the appropriate level of protection (ALOP) for Australia, risk management measures are proposed to reduce the risks to an acceptable level. If the risks cannot be reduced to an acceptable level, the goods will not be imported into Australia until suitable measures are identified.

Successive Australian Governments have maintained a stringent, but not a zero risk, approach to the management of biosecurity risks. This approach is expressed in terms of the ALOP for Australia, which is defined in the *Biosecurity Act 2015* as providing a high level of protection aimed at reducing risk to a very low level, but not to zero.

Australia's risk analyses are undertaken by the Australian Government Department of Agriculture and Water Resources (the department) using technical and scientific experts in relevant fields, and involve consultation with stakeholders at various stages during the process.

Risk analyses may take the form of a biosecurity import risk analysis (BIRA) or a non-regulated risk analysis (such as a scientific review of existing policy and import conditions, pest-specific assessments, weed risk assessments, biological control agent assessments or scientific advice).

Further information about Australia's biosecurity framework is provided in the *Biosecurity Import Risk Analysis Guidelines 2016* located on the Australian Government Department of Agriculture and Water Resources website.

1.2 This risk analysis

The department undertook this pest risk analysis (PRA) to meet Australia's obligations under the International Plant Protection Convention (IPPC) and International Standards for Phytosanitary Measures (ISPM) No. 1 (FAO 2016a) to review the emergency phytosanitary measures introduced to manage the risk of '*Candidatus* Liberibacter solanacearum' ('*Ca*. L. solanacearum') associated with specific apiaceous crops entering Australia through legal pathways.

In August 2014, Australia introduced emergency measures for seed (carrot) and tissue culture (carrot, celery) imports and notified trading partners of the emergency measures through a World Trade Organization Sanitary and Phytosanitary (WTO SPS) notification (G/SPS/N/AUS/345). The IPPC and the WTO Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement), require that any measure against the introduction and spread of new pests must be justified by a science-based assessment, such as a PRA, to justify the continuance of the measures. The IPPC's ISPM No. 1 (FAO 2016a) states that 'countries may take appropriate emergency action on a pest posing a potential threat to its territories; however, it requires that the action be evaluated as soon as possible to justify the

continuance of the action'. The department published a 'Draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops in December 2015 to provide justification for the introduction of emergency measures (G/SPS/N/AUS/377). As several new hosts of this bacterium were reported after the publication of the draft PRA, these newly identified hosts have been included in this final PRA.

1.2.1 Background

The association of '*Ca*. L. solanacearum' with carrot crops was first reported in 2010 in Finland (Munyaneza et al. 2010b) and since then the bacterium has spread to several carrot growing areas in Europe (Haapalainen 2014) and North Africa (Tahzima et al. 2014), and celery growing regions of Spain (Teresani et al. 2014a) and Austria (EPPO 2015). The confirmation of the seed-borne nature and seed transmission of '*Ca*. L. solanacearum' in carrot (Bertolini et al. 2015) was a new phytosanitary situation.

'*Candidatus* Liberibacter solanacearum' associated with apiaceous crops

2010 Finland: Carrot plants with symptoms resembling those of carrot psyllid (*Trioza apicalis*) damage were observed in fields in southern Finland. Molecular tests indicated that '*Ca*. L. solanacearum' was present in the infected plants (Munyaneza et al. 2010b).

2012 Norway: '*Ca.* L. solanacearum' was detected in carrot crops in four provinces (Munyaneza et al. 2012b). The carrot psyllid, *Trioza apicalis*, was found to be associated with '*Ca*. L. solanacearum' in Norway (Munyaneza et al. 2012b).

Sweden: '*Ca.* L. solanacearum' was detected in carrot crops in the Halland province (Munyaneza et al. 2012a). The carrot psyllid, *Trioza apicalis*, was found to be associated with '*Ca*. L. solanacearum' in Sweden (Munyaneza et al. 2012a).

Spain: '*Ca.* L. solanacearum' was detected in carrot crops from mainland Spain in Alicante, Albacete and Valencia (Alfaro-Fernández et al. 2012a) and the Canary Islands (Alfaro-Fernández et al. 2012b). The psyllid, *Bactericera trigonica*, was found to be associated with '*Ca.* L. solanacearum' in carrot crops in the Canary Islands and mainland Spain (Alfaro-Fernández et al. 2012a; Alfaro-Fernández et al. 2012b; EPPO 2012).

2014 Spain: '*Ca.* L. solanacearum' was detected in celery crops in Villena (Alicante, Spain) (Teresani et al. 2014b).

The seed-borne nature and seed to seedling transmission of '*Ca*. L. solanacearum' was confirmed in carrot seeds (Bertolini et al. 2015).

France: '*Ca.* L. solanacearum' was detected in carrot crops in central France (Loiseau et al. 2014).

Morocco: '*Ca.* L. solanacearum' was detected in carrot crops (Tahzima et al. 2014). This was the first report of '*Ca*. L. solanacearum' in Africa. The psyllid vector has not been identified in carrot crops in Morocco.

2015 Austria: '*Ca.* L. solanacearum' was detected in carrot and celery crops (EPPO 2015). Infected plants were destroyed and the bacterium in Austria is declared as transient, actionable and under surveillance.

Germany: '*Ca.* L. solanacearum' was detected in carrot crops in Lower Saxony (Munyaneza et al. 2015). The carrot psyllid, *Trioza apicalis*, was found to be associated with '*Ca.* L. solanacearum' in carrot in Germany (Munyaneza et al. 2015).

Spain: '*Ca.* L. solanacearum*'* was detected in parsnip crops (Cambra et al. 2015).

2016 Italy: '*Ca.* L. solanacearum' was detected in carrot seeds sold in Italy (Ilardi, Di Nicola & Tavazza 2016).

UK: '*Ca.* L. solanacearum' was detected in parsley seeds sold in the UK (Monger & Jeffries 2016). '*Candidatus* Liberibacter solanacearum' was detected in parsnip seed (Monger & Jeffries 2016).

2017 '*Candidatus* Liberibacter solanacearum' was detected in celery/celeriac seed (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January).

Israel: '*Ca.* L. solanacearum' was detected in carrot crops in Northern and Southern Israel (EPPO 2017). The psyllid, *Bactericera trigonica*, was found to be associated with '*Ca.* L. solanacearum' in carrot in Israel (EPPO 2017).

Morocco: '*Ca.* L. solanacearum' in carrot was found to be associated with the psyllid, *Bactericera trigonica* in Morocco (Tahzima et al. 2017).

Spain: '*Ca.* L. solanacearum' was detected in parsley and parsnip crops (Alfaro-Fernández, Hernández-Llopis & Font 2017).

France: '*Ca.* L. solanacearum' was detected in carrot, celery, chervil, fennel, parsley and parsnip crops (Hajri et al. 2017).

New Zealand: introduced emergency measures after detection of '*Ca.* L. solanacearum' in imported seed. The emergency measures require mandatory PCR seed testing using 10,000 seed or hot water treatment (50 ^{o}C for at least 30 minutes). These specific requirements will apply to all species of *Anthriscus, Apium, Daucus, Foeniculum, Pastinaca* and *Petroselinum* (G/SPS/N/NZL/557)

1.2.2 Scope

The scope of this risk analysis includes:

- assessing the risk of introducing '*Ca*. L. solanacearum' associated with apiaceous crop propagative material (seeds and tissue cultures) from all sources
- reviewing and evaluating the existing risk management measures including emergency measures
- recommending additional risk management measures where appropriate.

This PRA does not assess the risk of introducing '*Ca*. L. solanacearum' in infected psyllids because psyllids are not associated with the propagative material pathway.

This PRA is limited to recommending appropriate risk management measures to address the risk of introducing '*Ca*. L. solanacearum' associated with apiaceous propagative material into Australia. It is the importer's responsibility to ensure compliance with the requirements of all other regulatory and advisory bodies associated with importing commodities into Australia. These include the Australian Department of Immigration and Border Protection, Therapeutic Goods Administration, Australian Pesticides and Veterinary Medicines Authority, Department of the Environment, and state and territory departments of agriculture.

1.2.3 Existing import conditions

International import conditions

Prior to the introduction of emergency measures, propagative material of apiaceous crops (seeds and tissue cultures) from all sources was permitted entry into Australia without any specific disease testing.

In October 2014, Australia introduced emergency measures for imports of carrot (seeds and tissue cultures) and celery (tissue cultures) due to the identified quarantine risk of introducing '*Ca*. L. solanacearum' in imported carrot and celery propagative material.

Since the introduction of the emergency measures, '*Ca*. L. solanacearum' has been detected on the seeds of celery/celeriac, parsley and parsnip. In March 2017, Australia amended emergency measures to include the seeds and tissue cultures of these additional apiaceous hosts. More recently, the bacterium has been detected in imported fennel seed in New Zealand (2017). The detection of CaLsol in fennel seed has raised concerns that this bacterium may also be seed-borne in chervil. Therefore, based on the new available information, the department has extended the mandatory off-shore or on-shore Polymerase Chain Reaction (PCR) testing, or hot water treatment to both chervil and fennel seed.

Domestic arrangements

The Australian Government is responsible for regulating the movement of goods such as plants and plant products into and out of Australia. However, the state and territory governments are responsible for plant health controls within their individual jurisdictions. Legislation relating to resource management or plant health may be used by state and territory government agencies to control interstate movement of plants and their products. Once plants and plant products have been cleared by Australian Government biosecurity officers, they may be subject to interstate movement conditions. It is the importer's responsibility to identify, and ensure compliance with all requirements.

1.2.4 Consultation

The department consulted stakeholders through the public release of a draft report for comment. The 'Draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops' was released for a 45 day stakeholder consultation period on 11 December 2015. All submissions were carefully considered and, where relevant, changes were made to the final report. A summary of major stakeholder comments and how they were considered is contained in Appendix A of this report.

The department worked closely with industry stakeholders during the development of the emergency measures to minimise any trade and crop production disruption. Prior to introducing

emergency measures against '*Ca*. L. solanacearum', the department consulted with the seed industry including AUSVEG, the Australian Seed Federation (ASF) and representatives of domestic and international seed companies.

16 June 2014	The department held a teleconference with industry to discuss implications of the published evidence that '*Ca*. L. solanacearum' is seed-borne and seed-transmissible in carrot. The department stated that, based on the current information, future carrot seed imports from all sources would be regulated and that it intended to introduce the regulatory measures within four to six weeks.
10 July 2014	The department held a teleconference with industry to discuss the intention of implementing emergency measures for '*Ca*. L. solanacearum' on imported carrot seeds. The department stated that, based on the current information, future carrot seed imports from all sources would be regulated and that it intended to introduce the regulatory measures within four to six weeks.
5 August 2014	The department held a teleconference with industry to discuss the proposed emergency measures for future imports of carrot (seed, tissue culture) and celery (tissue culture) from all sources.
21 August 2014	Australia notified trading partners of the upcoming emergency measures through a WTO SPS notification (G/SPS/N/AUS/345), advising that the measures would take effect from 20 October 2014.
22 August 2014	The department individually notified National Plant Protection Organisations (NPPOs) of the main trading partners affected by the emergency measures, including Belgium, France, Germany, Italy, Japan, the Republic of Korea, Malaysia, the Netherlands, New Zealand, Singapore, the United Arab Emirates, the United Kingdom and the United States of America.
25 August 2014	The department published a BICON alert advising importers of the planned emergency measures for carrot (seed, tissue culture) and celery (tissue culture), to take effect from 20 October 2014.
20 October 2014	Australia's emergency measures came into force for imports of carrot (seed, tissue culture) and celery (tissue culture) from all sources. The department published a BICON alert advising importers of the commencement of the emergency measures for carrot (seed, tissue culture) and celery (tissue culture). The BICON alert included details on a transition period for carrot seeds in transit. The department advised industry representatives that the import conditions for carrot seed had been updated in BICON.
21 January 2015	The department published a BICON alert advising importers that carrot seeds require an Import Permit.

27 August 2015	The department provided an update on the progress of the '*Ca*. L. solanacearum' draft PRA at the ASF Annual Conference held in Toowoomba, Australia.
11 December 2015	The department released the 'Draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops' for a 45 day stakeholder comment period (G/SPS/N/AUS/377).
8 March 2017	The department held a teleconference with industry and discussed the proposed amendments of existing emergency measures (G/SPS/N/AUS/345) to include additional apiaceous hosts.
16 March 2017	Australia notified trading partners of the amendments of emergency measures through a WTO SPS notification (G/SPS/N/AUS/345/Add.2), advising the extension of existing measures to the seeds and tissue cultures of additional apiaceous hosts.

2 Method for pest risk analysis

This chapter sets out the method used for the pest risk analysis (PRA) in this report. The Australian Government Department of Agriculture and Water Resources has conducted this PRA in accordance with the International Standards for Phytosanitary Measures (ISPMs), including ISPM 2: *Framework for pest risk analysis* (FAO 2016b) and ISPM 11: *Pest risk analysis for quarantine pests* (FAO 2016f) that have been developed under the SPS Agreement (WTO 1995).

A PRA is 'the process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it' (FAO 2016d). A pest is 'any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products' (FAO 2016d).

Biosecurity risk consists of two major components: the likelihood of a pest entering, establishing and spreading in Australia from imports; and the consequences should this happen. These two components are combined to give an overall estimate of the risk.

Unrestricted risk is estimated taking into account the existing commercial production practices of the exporting country and that, on arrival in Australia, the department will verify that the consignment received is as described on the commercial documents and its integrity has been maintained.

Restricted risk is estimated with phytosanitary measure(s) applied. A phytosanitary measure is 'any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests' (FAO 2016d).

A glossary of the terms used in the risk analysis is provided at the end of this report.

The PRAs are conducted in the following three consecutive stages: initiation, pest risk assessment and pest risk management.

2.1 Stage 1 Initiation

The initiation of a risk analysis involves identifying the pest(s) and pathway(s) that should be considered for risk analysis in relation to the identified PRA area. According to ISPM No. 2 (FAO 2016b), a PRA process may be initiated as a result of:

- identification of a pathway that presents a potential pest risk (a means of pest introduction or spread);
- identification of a pest that may require phytosanitary measures (a pest may have been detected or intercepted, a request made to import it or it may have been reported elsewhere);
- review or revision of existing phytosanitary policies and priorities; or
- identification of an organism not previously known to be a pest.

Australia introduced emergency measures in October 2014, in response to reports of '*Ca*. L. solanacearum' being associated with apiaceous crops (carrot, celery) and being seed-borne in carrot (Bertolini et al. 2015). In accordance with ISPM No. 2 (FAO 2016b) this PRA was initiated by the department as a basis for a review and possible revision of the emergency measures introduced by Australia for importation of carrot (seed, tissue cultures) and celery (tissue

cultures) for propagation in Australia. In Australia, '*Ca*. L. solanacearum' associated with apiaceous crops (carrot and celery/celeriac) has been regulated as a quarantine pest since October 2014.

For this PRA, the 'PRA area' is defined as Australia for '*Ca*. L. solanacearum' associated with apiaceous crops.

2.2 Stage 2 Pest risk assessment

A pest risk assessment (for quarantine pests) is the 'evaluation of the probability of the introduction and spread of a pest and of the magnitude of the associated potential economic consequences' (FAO 2016d).

The following three, consecutive steps were used in pest risk assessment:

2.2.1 Pest categorisation

Pest categorisation identifies which of the pests with the potential to be on the commodity are quarantine pests for Australia and require pest risk assessment. A 'quarantine pest' is a pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (FAO 2016d).

The process of a pest categorisation is summarised by ISPM No. 11 (FAO 2016f) as a screening procedure based on the following criteria:

- identity of the pest
- presence or absence in the PRA area
- regulatory status
- potential for establishment and spread in the PRA area
- potential for economic consequences (including environmental consequences) in the PRA area.

2.2.2 Assessment of the probability of entry, establishment and spread

Details of how to assess the 'probability of entry', 'probability of establishment' and 'probability of spread' of a pest are given in ISPM 11 (FAO 2016f). The SPS Agreement (WTO 1995) uses the term likelihood rather than probability for these estimates. In qualitative PRAs, the department uses the term 'likelihood' for the descriptors it uses for its estimates of likelihood of entry, establishment and spread. The use of the term 'probability' is limited to the direct quotation of ISPM definitions.

A summary of this process is given below, followed by a description of the qualitative methodology used in this risk analysis.

Likelihood of entry

The likelihood of entry describes the likelihood that a quarantine pest will enter Australia as a result of trade in a given commodity, be distributed in a viable state in the PRA area and subsequently be transferred to a host. Assessing the likelihood of entry requires an analysis of each of the pathways with which a pest may be associated, from its origin to its distribution in the PRA area.

For the purpose of considering the likelihood of entry, the department divides this step into two components:

- **Likelihood of importation**—the likelihood that a pest will arrive in Australia when a given commodity is imported.
- **Likelihood of distribution**— the likelihood that the pest will be distributed, as a result of the processing, sale or disposal of the commodity, in the PRA area and subsequently transfer to a susceptible part of a host.

Factors to be considered in the likelihood of importation may include:

- distribution and incidence of the pest in the source area
- occurrence of the pest in a life-stage that would be associated with the commodity
- mode of trade (for example, bulk, packed)
- volume and frequency of movement of the commodity along each pathway
- seasonal timing of imports
- pest management, cultural and commercial procedures applied at the place of origin
- speed of transport and conditions of storage compared with the duration of the lifecycle of the pest
- vulnerability of the life-stages of the pest during transport or storage
- incidence of the pest likely to be associated with a consignment
- commercial procedures (for example, refrigeration) applied to consignments during transport and storage in the country of origin, and during transport to Australia.

Factors to be considered in the likelihood of distribution may include:

- commercial procedures (for example, refrigeration) applied to consignments during distribution in Australia
- dispersal mechanisms of the pest, including vectors, to allow movement from the pathway to a host
- whether the imported commodity is to be sent to a few or many destination points in the PRA area
- proximity of entry, transit and destination points to hosts
- time of year at which import takes place
- intended use of the commodity (for example, for planting, processing or consumption)
- risks from by-products and waste.

Likelihood of establishment

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO 2016d). In order to estimate the likelihood of establishment of a pest, reliable biological information (for example, lifecycle, host range, epidemiology, and survival) is obtained from the areas where the pest currently occurs. The situation in the PRA area can then be compared with that in the areas where it currently occurs and expert judgement used to assess the likelihood of establishment.

Factors to be considered in the likelihood of establishment in the PRA area may include:

- availability of hosts, alternative hosts and vectors
- suitability of the environment
- reproductive strategy and potential for adaptation
- minimum population needed for establishment
- cultural practices and control measures.

Likelihood of spread

Spread is defined as 'the expansion of the geographical distribution of a pest within an area' (FAO 2016d). The likelihood of spread considers the factors relevant to the movement of the pest, after establishment on a host plant or plants, to other susceptible host plants of the same or different species in other areas. In order to estimate the likelihood of spread of the pest, reliable biological information is obtained from areas where the pest currently occurs. The situation in the PRA area is then carefully compared with that in the areas where the pest currently occurs and expert judgement used to assess the likelihood of spread.

Factors to be considered in the likelihood of spread may include:

- suitability of the natural and/or managed environment for natural spread of the pest
- presence of natural barriers
- potential for movement with commodities, conveyances or by vectors
- intended use of the commodity
- potential vectors of the pest in the PRA area
- potential natural enemies of the pest in the PRA area.

Assigning likelihoods for entry, establishment and spread

Likelihoods are assigned to each step of entry, establishment and spread. Six descriptors are used: high; moderate; low; very low; extremely low; and negligible (Table 1). Descriptive definitions for these descriptors and their indicative probability ranges are given in Table 1. The indicative probability ranges are only provided to illustrate the boundaries of the descriptors and are not used beyond this purpose in qualitative PRAs. These indicative probability ranges provide guidance to the risk analyst and promote consistency between different pest risk assessments.

Table 1 Nomenclature of likelihoods

Likelihood	Descriptive definition	Indicative range
High	The event would be very likely to occur	0.7 < to ≤ 1
Moderate	The event would occur with an even likelihood	0.3 < to ≤ 0.7
Low	The event would be unlikely to occur	0.05 < to ≤ 0.3
Very low	The event would be very unlikely to occur	0.001 < to ≤ 0.05
Extremely low	The event would be extremely unlikely to occur	0.000001 < to ≤ 0.001
Negligible	The event would almost certainly not occur	0 < to ≤ 0.000001

Combining likelihoods

The likelihood of entry is determined by combining the likelihood that the pest will be imported into the PRA area and the likelihood that the pest will be distributed within the PRA area, using a matrix of rules (Table 2). This matrix is then used to combine the likelihood of entry and the likelihood of establishment, and the likelihood of entry and establishment is then combined with the likelihood of spread to determine the overall likelihood of entry, establishment and spread.

Table 2 Matrix of rules for combining likelihoods

	High	Moderate	Low	Very low	Extremely low	Negligible
High	High	Moderate	Low	Very low	Extremely low	Negligible
Moderate		Low	Low	Very low	Extremely low	Negligible
Low			Very low	Very low	Extremely low	Negligible
Very low				Extremely low	Extremely low	Negligible
Extremely low					Negligible	Negligible
Negligible						Negligible

For example, if the likelihood of importation is assigned a descriptor of 'low' and the likelihood of distribution is assigned a descriptor of 'moderate', then they are combined to give a likelihood of 'low' for entry. The likelihood for entry is then combined with the likelihood assigned for establishment of 'high' to give a likelihood for entry and establishment of 'low'. The likelihood for entry and establishment is then combined with the likelihood assigned for spread of 'very low' to give the overall likelihood for entry, establishment and spread of 'very low'. This can be summarised as:

importation x distribution = entry [E] **low x moderate = low**

entry x establishment = [EE] **low x high = low**

[EE] x spread = [EES] **low x very low = very low**

Time and volume of trade

One factor affecting the likelihood of entry is the volume and duration of trade. If all other conditions remain the same, the overall likelihood of entry will increase as time passes and the overall volume of trade increases.

The department normally considers the likelihood of entry on the basis of the estimated volume of one year's trade. However, in case of a high risk propagative commodity, the volume of trade is restricted to certain numbers. Therefore, other factors listed in ISPM No. 11 (FAO 2016f) may not be relevant to propagative material of a high risk commodity.

2.2.3 Assessment of potential consequences

The objective of the consequence assessment is to provide a structured and transparent analysis of the potential consequences if the pests or disease agents were to enter, establish and spread in Australia. The assessment considers direct and indirect pest effects and their economic and environmental consequences. The requirements for assessing potential consequences are given in Article 5.3 of the SPS Agreement (WTO 1995), ISPM 5 (FAO 2016d) and ISPM No. 11 (FAO 2016f).

Direct pest effects are considered in the context of the effects on:

- plant life or health
- other aspects of the environment.

Indirect pest effects are considered in the context of the effects on:

- eradication, control
- domestic trade
- international trade
- environment.

For each of these six criteria, the consequences were estimated over four geographic levels, defined as:

Local—an aggregate of households or enterprises (a rural community, a town or a local government area).

District—a geographically or geopolitically associated collection of aggregates (generally a recognised section of a state or territory, such as 'Far North Queensland').

Regional—a geographically or geopolitically associated collection of districts in a geographic area (generally a state or territory, although there may be exceptions with larger states such as Western Australia).

National—Australia wide (Australian mainland states and territories and Tasmania).

For each criterion, the magnitude of the potential consequence at each of these levels was described using four categories, defined as:

Indiscernible—pest impact unlikely to be noticeable.

Minor significance—expected to lead to a minor increase in mortality/morbidity of hosts or a minor decrease in production but not expected to threaten the economic viability of production. Expected to decrease the value of non-commercial criteria but not threaten the criterion's intrinsic value. Effects would generally be reversible.

Significant—expected to threaten the economic viability of production through a moderate increase in mortality/morbidity of hosts, or a moderate decrease in production. Expected to significantly diminish or threaten the intrinsic value of non-commercial criteria. Effects may not be reversible.

Major significance—expected to threaten the economic viability through a large increase in mortality/morbidity of hosts, or a large decrease in production. Expected to severely or irreversibly damage the intrinsic 'value' of non-commercial criteria.

The estimates of the magnitude of the potential consequences over the four geographic levels were translated into a qualitative impact score (A-G) using Table 3. For example, a consequence with a magnitude of 'significant' at the 'district' level will have a consequence impact score of D.

Table 3 Decision rules for determining the consequence impact score based on the magnitude of consequences at four geographic scales

	Geographic scale			
Magnitude	Local	District	Region	Nation
Indiscernible	A	A	A	A
Minor significance	B	C	D	E
Significant	C	D	E	F
Major significance	D	E	F	G

Note: In earlier qualitative PRAs, the scale for the impact scores went from A to F and did not explicitly allow for the rating 'indiscernible' at all four levels. This combination might be applicable for some criteria. In this report, the impact scale of A to F has been changed to become B-G and a new lowest category A ('indiscernible' at all four levels) was added. The rules for combining impacts in Table 4 were adjusted accordingly.

The overall consequence for each pest is achieved by combining the qualitative impact scores (A–G) for each direct and indirect consequence using a series of decision rules (Table 4). These rules are mutually exclusive, and are assessed in numerical order until one applies.

Table 4 Decision rules for determining the overall consequence rating for each pest

Rule	The impact scores for consequences of direct and indirect criteria	Overall consequence rating
1	Any criterion has an impact of 'G'; or more than one criterion has an impact of 'F'; or a single criterion has an impact of 'F' and each remaining criterion an 'E'.	Extreme
2	A single criterion has an impact of 'F'; or all criteria have an impact of 'E'.	High
3	One or more criteria have an impact of 'E'; or all criteria have an impact of 'D'.	Moderate
4	One or more criteria have an impact of 'D'; or all criteria have an impact of 'C'.	Low
5	One or more criteria have an impact of 'C'; or all criteria have an impact of 'B'.	Very Low
6	One or more but not all criteria have an impact of 'B', and all remaining criteria have an impact of 'A'.	Negligible

2.2.4 Estimation of the unrestricted risk

Once the assessment of the likelihood of entry, establishment and spread and for potential consequences are completed, the unrestricted risk can be determined for each pest or groups of pests. This is determined by using a risk estimation matrix (Table 5) to combine the estimates of the likelihood of entry, establishment and spread and the overall consequences of pest establishment and spread. Therefore, risk is the combination of likelihood and consequence.

When interpreting the risk estimation matrix, note the descriptors for each axis are similar (for example, low, moderate, high) but the vertical axis refers to likelihood and the horizontal axis refers to consequences. Accordingly, a 'low' likelihood combined with 'high' consequences, is not the same as a 'high' likelihood combined with 'low' consequences—the matrix is not symmetrical. For example, the former combination would give an unrestricted risk rating of 'moderate', whereas, the latter would be rated as a 'low' unrestricted risk.

Table 5 Risk estimation matrix

Likelihood of pest entry, establishment and spread	Consequences of pest entry, establishment and spread					
	Negligible	Very low	Low	Moderate	High	Extreme
High	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Moderate	Negligible risk	Very low risk	Low risk	Moderate risk	High risk	Extreme risk
Low	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk	High risk
Very low	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk	Moderate risk
Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk	Low risk
Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Very low risk

2.2.5 The appropriate level of protection (ALOP) for Australia

The SPS Agreement defines the concept of an 'appropriate level of sanitary or phytosanitary protection (ALOP)' as the level of protection deemed appropriate by the WTO Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory.

Like many other countries, Australia expresses its ALOP in qualitative terms. The ALOP for Australia, which in defined in the *Biosecurity Act 2015,* is a high level of sanitary or phytosanitary protection aimed at reducing risk to a very low level, but not to zero. The band of cells in Table 5 marked 'very low risk' represents the acceptable ALOP threshold for Australia.

2.3 Stage 3 Pest risk management

Pest risk management describes the process of identifying and implementing phytosanitary measures to manage risks to achieve the ALOP for Australia, while ensuring that any negative effects on trade are minimised.

The conclusions from the pest risk assessment process are used to decide whether risk management is required and if so, the appropriate measures to be used. Where the unrestricted risk estimate does not achieve the ALOP for Australia, risk management measures are required to reduce this risk to a very low level. The guiding principle for risk management is to manage risk to achieve the ALOP for Australia. The effectiveness of any proposed phytosanitary measures (or combination of measures) is evaluated, using the same approach as used to evaluate the unrestricted risk, to ensure the restricted risk for the relevant pest or pests achieves the ALOP for Australia.

Examples of risk management measures which may be applied to propagative material consignments include:

- Import from pest free areas only (ISPM No. 4, 10)—the establishment and use of a pest free area by a National Plant Protection Organisation (NPPO) provides for the export of plants from the exporting country to the importing country without the need for the application of additional phytosanitary measures when certain requirements are met.

- Testing for freedom from regulated pests—this is a practical measure for pests which do not produce visible symptoms on plants.
- Inspection and certification (ISPM No. 7, 12, 23)—the exporting country may be asked to inspect the shipment and certify that the shipment is free from regulated pests before export.
- Pre-entry or post-entry quarantine—the importing country may define certain control conditions, inspection and possible treatment of shipments upon their entry into the country. Pre- or post-entry quarantine of dormant cuttings, seeds and tissue cultures (*in vitro* plantlets) can help avoid the introduction of new viruses or other pathogens into the importing countries.
- Removal of the pest from the consignment by treatment or other methods—the importing country may specify chemical or physical treatments that must be applied to the consignment before it may be imported.
- Prohibition of commodities—the importing country may prohibit the commodity if no satisfactory measure can be found.

In some cases, more than one risk management measure may be required in order to reduce the pest risk to an acceptable level.

3 The pathogen

This chapter details information on '*Candidatus* Liberibacter solanacearum' ('*Ca.* L. solanacearum') that is relevant to the pest risk assessment. The genus '*Candidatus* Liberibacter' ('*Ca*. L.') [Rhizobiales: Rhizobiaceae] is composed of gram-negative bacteria belonging to the alpha subdivision of the proteobacteria (Bové 2006; Jagoueix, Bové & Garnier 1996). '*Ca*. L.' species are fastidious, phloem-limited and infect a variety of agriculturally important crops (Haapalainen 2014). These bacteria have thin cell walls that allow them to pass through the narrow sieve pores and survive within the phloem vascular system of a plant (da Graca 2008). These bacteria are naturally transmitted between plants by psyllid insects, which feed on plant phloem sap (Janse 2012).

3.1 '*Candidatus* Liberibacter' species

The genus '*Candidatus* Liberibacter' contains seven species that differ in their natural host range, vector specificity and environmental tolerances (Bertolini et al. 2015; Bové 2006; Haapalainen 2014; Lopes & Frare 2008; Monger & Jeffries 2016; Munyaneza 2012; Teresani et al. 2014b). Characteristics of these species are summarized in Table 6.

Table 6 Characteristics of '*Candidatus* Liberibacter' species

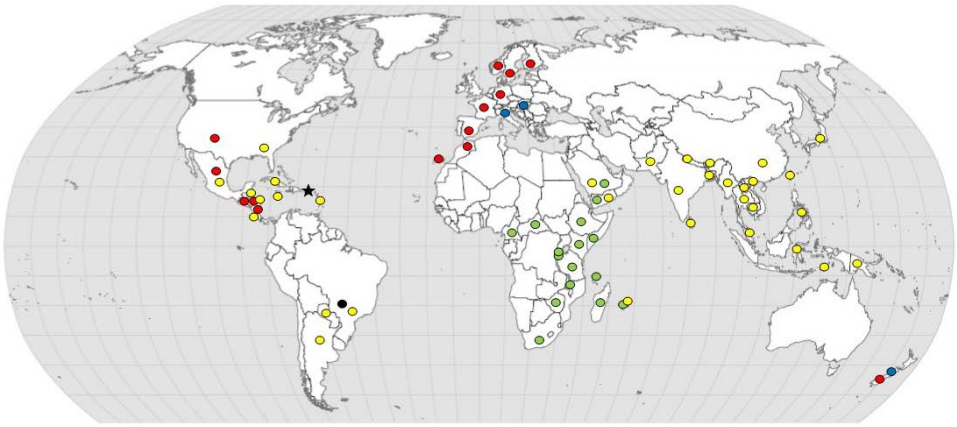
'*Ca.* Liberibacter' species	Natural host plant (*Ca*. L. spp)	Psyllid vector	Temperature sensitivity
'*Ca.* L. africanus'	Rutaceae (Bové 2006)	*Trioza erytreae* (Del Guercio)	Heat sensitive (Bové et al. 1974)
'*Ca.* L. americanus'	Rutaceae (Bové 2006)	*Diaphorina citri* Kuwayama	Heat sensitive (Lopes et al. 2009)
'*Ca.* L. asiaticus'	Rutaceae (Bové 2006)	*Diaphorina citri* Kuwayama	Heat tolerant (Bové 2006)
'*Ca*. L. crescens'	Caricaceae (Leonard et al. 2012)		
'*Ca.* L. europaeus'	Rosacae (Camerota et al. 2012); Fabaceae (Thompson et al. 2013)	*Cacopsylla pyri* (L.)	Heat sensitive (Haapalainen 2014)
'*Ca.* L. solanacearum'	Solanaceae (Hansen et al. 2008; Munyaneza 2012); Apiaceae (Bertolini et al. 2015; Monger & Jeffries 2016; Teresani et al. 2014b)	*Bactericera cockerelli* (Sulc); *Trioza* (Dyspersa) *apicalis* Förster *Bactericera trigonica* Hodkinson	Heat sensitive (Munyaneza 2012)
'*Ca.* L. brunswickensis'	Not known	*Acizzia solanicola* Kent & Taylor	

'*Candidatus* Liberibacter' species affecting solanaceous crops were confirmed in New Zealand in 2008 (Liefting et al. 2009a) and later the pathogen associated with 'Zebra chip' disease in potatoes was identified as a '*Ca*. L.' species (Abad et al. 2009; Liefting et al. 2009a). Molecular studies confirmed that the American isolates of '*Ca*. L.' represented the same species found in New Zealand and the name '*Ca*. L. solanacearum' was suggested (Abad et al. 2009; Liefting et al. 2009b). The same bacterial pathogen was also associated with diseases of tomato and pepper in Mexico (Munyaneza et al. 2009) and tobacco plants in Honduras (Aguilar et al. 2013). This bacterium has also been reported in a number of solanaceous weed species (Wen et al. 2009). In

all of these cases, the bacterium was transmitted by the tomato potato psyllid (*Bactericera cockerelli*).

'*Candidatus* Liberibacter solanacearum' affecting apiaceous crops has been reported from Europe (Alfaro-Fernández, Hernández-Llopis & Font 2017; Haapalainen 2014; Hajri et al. 2017; Munyaneza et al. 2010b, a) and northern Africa (Tahzima et al. 2014). The bacterium is transmitted by the psyllids *Bactericera trigonica* (Alfaro-Fernández et al. 2012b; EPPO 2017; Tahzima et al. 2017) and *Trioza apicalis* (Munyaneza et al. 2010b; Munyaneza et al. 2015). The geographical distribution of plant-associated '*Ca*. L.' species is presented in Map 3.

Map 3 Global occurrence of '*Candidatus* Liberibacter' species



Source: (Haapalainen 2014): '*Ca*. L. africanus' (green), '*Ca*. L. americanus' (black), '*Ca*. L. asiaticus' (yellow), '*Ca*. L. crescens' (black star), '*Ca*. L. europaeus' (blue), '*Ca*. L. solanacearum' (red)

'*Candidatus* Liberibacter' species are obligate parasites of plants and psyllids and are only able to multiply inside their hosts. '*Ca.* L.' species enter the plant host as the psyllid feeds on phloem and in turn enter the insect during feeding, making their way from the gut to the haemolymph and then to the salivary glands for transport to the next host (Aubert 2008). In the plant host, '*Ca*. L.' species move with the phloem in the sieve tubes throughout the whole plant, including the roots.

'*Candidatus* Liberibacter' species and the psyllid vectors are suspected of adapting to new host plant species, following changes in vegetation and environmental factors (Haapalainen 2014). Native wild plants may have developed some resistance or tolerance to '*Ca*. L.' species (Albrecht & Bowman 2012; Korsten et al. 1996). These wild plants carry low levels of bacteria without producing disease symptoms (Albrecht & Bowman 2012; Korsten et al. 1996). However, cultivated hosts, such as citrus, potato, carrot and celery plants, can be severely affected by '*Ca*. L.' infections and may be relatively new hosts for these pathogens. Epidemics involving different plants, psyllids and '*Ca*. L.' species are now emerging in different countries on several continents (Haapalainen 2014).

Environmental factors including temperature and relative humidity have a significant effect on the development and distribution of Liberibacter species (Bové 2013; Bové et al. 1974; Bové 2006; Lopes et al. 2009; Munyaneza et al. 2012a; Pietersen et al. 2010). '*Ca.* L. africanus' and '*Ca.* L. americanus' have been described as heat sensitive, whereas '*Ca*. L. asiaticus' has been described as heat tolerant (Bové 2013; Bové et al. 1974; Lopes et al. 2009; Pietersen et al. 2010).

Under controlled environments, temperatures below 17 °C slow the development of '*Ca*. L. solanacearum' and zebra chip disease symptoms, and temperatures above 32 °C are also detrimental to this bacterium (Munyaneza et al. 2012a). Therefore, similarly to '*Ca*. L. africanus' and '*Ca*. L. americanus', *'Ca*. L. solanacearum' appears heat sensitive (Munyaneza et al. 2012a). This pathogen sensitivity to heat may explain the geographical distribution of these different Liberibacter species and their insect vectors as well as the diseases they cause in different parts of the world. '*Ca.* L. brunswickensis' detected in eggplant psyllid (*Acizzia solanicola*') is not associated with any plant disease in Australia (Morris et al. 2017).

3.2 '*Candidatus* Liberibacter solanacearum'

'*Candidatus* Liberibacter solanacearum' (synonym: '*Candidatus* Liberibacter psyllaurous') associated with solanaceous crops was identified in 2008 in New Zealand (Liefting, Perez-Egusquiza & Clover 2008; Liefting et al. 2009b) and the USA (Hansen et al. 2008). Later the bacterium was detected in Central America, North America (Haapalainen 2014; Nelson, Fisher & Munyaneza 2011) and Norfolk Island (NIQS 2014). The bacterium was documented for the first time outside solanaceous crops in Europe in carrot crops in Finland (Munyaneza et al. 2010b, a). The bacterium was then reported in carrot crops in several other European countries, including Norway (Munyaneza et al. 2012a), Sweden (Munyaneza et al. 2012b), Germany (Munyaneza et al. 2015) and Austria (EPPO 2015). Subsequently, '*Ca.* L. solanacearum' was detected in carrot crops in several countries within the Mediterranean region, including France (Loiseau et al. 2014); Spain (Alfaro-Fernández et al. 2012a; EPPO 2012; Teresani et al. 2014b), the Canary Islands (Alfaro-Fernández et al. 2012b), and Italy (Ilardi, Di Nicola & Tavazza 2016). '*Ca.* L. solanacearum' was reported for the first time on the African continent in carrot crops in Morocco (Tahzima et al. 2014). '*Ca.* L. solanacearum' was also reported to occur on celery in Austria (EPPO 2015), and celery/celeriac, parsley and parsnip in Spain (Alfaro-Fernández, Hernández-Llopis & Font 2017; Cambra et al. 2015; Teresani et al. 2014b). Recently, this bacterium was reported to also occur on chervil and fennel in France (Hajri et al. 2017).

'*Candidatus* Liberibacter solanacearum' was demonstrated to be transmitted through carrot seeds (Bertolini et al. 2015), although this result has not been reproduced by other authors (Loiseau et al. 2017a; Loiseau et al. 2017b). Since 2016, the bacterium has been detected in carrot seed in Italy (Ilardi, Di Nicola & Tavazza 2016), parsley and parsnip seed (Monger & Jeffries 2016), and celery/celeriac seed (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January) . Commercially available seed of caraway (*Carum carvi*), coriander (*Coriandrum sativum*), cumin (*Cuminum cyminum*), dill (*Anethum graveolens*) and fennel (*Foeniculum vulgare*) were tested for '*Ca.* L. solanacearum' in the UK and the bacterium was not detected in the seed of these commodities. However, more recently, the bacterium was detected in imported fennel seed in New Zealand. The detection of CaLsol in fennel seed has raised concerns that this bacterium may also be seed-borne in chervil.

3.2.1 Haplotypes of '*Ca*. L. solanacearum'

Isolates of '*Ca*. L. solanacearum' from different geographical areas have been characterised into five haplotypes using molecular techniques (Nelson, Fisher & Munyaneza 2011; Nelson et al. 2012). '*Ca.* L. solanacearum' isolates from North and Central America represent haplotypes A and B, and infect solanaceous plants (Nelson, Fisher & Munyaneza 2011; Nelson et al. 2012). Haplotype A has been found primarily from Honduras and Guatemala, through to western Mexico, Arizona and California, and in New Zealand (Nelson, Fisher & Munyaneza 2011).

Haplotype B is currently found from eastern Mexico, northwards through Texas, to south central Washington (Nelson, Fisher & Munyaneza 2011). These haplotypes show some range overlap in Texas, Kansas and Nebraska (Nelson, Fisher & Munyaneza 2011).

Haplotype C was first described in carrots (Nelson, Fisher & Munyaneza 2011) and is present in Finland, Norway, Sweden and Germany (Nelson et al. 2012). Haplotype D is also associated with carrots (Nelson et al. 2012) and is present in Spain, the Canary Islands, Morocco and France (Hajri et al. 2017; Teresani et al. 2015). Haplotype E was described in Spain associated with both carrot and celery crops (Teresani et al. 2014b) and is also in France, Morocco and Israel (EPPO 2017; Ilardi, Di Nicola & Tavazza 2016; Teresani et al. 2015). Haplotypes D and E were detected in parsley seed (Monger & Jeffries 2016) and parsley and parsnip crops (Alfaro-Fernández, Hernández-Llopis & Font 2017). Additionally, a haplotype closely related to haplotype D and E has been detected in Italy (Ilardi, Di Nicola & Tavazza 2016). The vectors, hosts and distribution of known haplotypes of '*Ca*. L. solanacearum' are summarised in Table 7.

Table 7 '*Candidatus* Liberibacter solanacearum' haplotypes, vectors, natural hosts and distribution

'*Ca*. L. solanacearum'	Psyllid host/vector	Natural hosts	Distribution*
Haplotype A	*Bactericera cockerelli*	Solanaceae family	North and Central America, New Zealand, Norfolk Island#
Haplotype B	*Bactericera cockerelli*	Solanaceae family	North and Central America
Haplotype C	*Trioza* (*Dyspersa*) *apicalis*	Apiaceae family (carrot)	Finland, Germany, Norway, Sweden
Haplotype D	*Bactericera trigonica*	Apiaceae family (carrot, parsley, parsnip)	Spain (mainland and Canary Islands), Morocco, Israel, Italy, France
Haplotype E	*Bactericera trigonica*	Apiaceae family (carrot, celery/celeriac, chervil, fennel, parsley, parsnip)	Spain (mainland), France, Morocco

* This table only lists countries where the '*Ca*. L. solanacearum' haplotype has been confirmed. For example, this bacterium is reported to occur in carrot and celery in Austria; however, the associated haplotype/s are unknown.

Australian External Territory

3.2.2 Symptoms of '*Ca.* L. solanacearum'

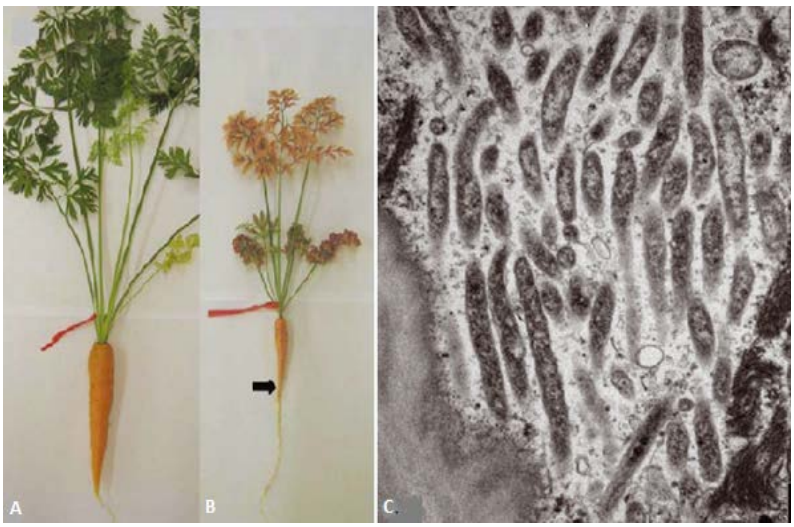
Within infected plants '*Ca.* Liberibacter' cells are present in but limited to the phloem; once a plant has become infected, the bacterium can move throughout the plant. Symptoms caused by '*Ca*. L.' species are not constant over time or between locations, and can vary with season, host, pathogen species and environmental conditions. For example, potato and tomato plants infected with '*Ca*. L. solanacearum' can become severely diseased, whereas pepper and eggplant do not develop severe symptoms (Lin & Gudmestad 2013).

Symptoms caused by '*Ca.* L. solanacearum' in carrot

Symptoms caused by '*Ca*. L. solanacearum' in carrot plants include leaf yellowing, bronze or red leaf discolouration, reduced size of the main root and lateral root proliferation (Munyaneza et al. 2011)(Figure 1B). Shoot proliferation is also seen in haplotype D and E infected carrots in Spain and Morocco (Bertolini et al. 2015; Tahzima et al. 2014). In contrast, haplotype C does not induce shoot proliferation but causes discolouration of the carrot leaves (Nissinen et al. 2014; Wang et al. 2017). Other symptoms include stunting and proliferation of dwarfed shoots, bushy tops and a dense hairy growth of secondary roots (Loiseau et al. 2014). The number of leaves

showing discolouration symptoms and the root weight reduction are positively correlated with the titre of '*Ca*. L. solanacearum' in the plant (Nissinen et al. 2014). Infected plants show collapsed phloem cells and phloem tubes densely colonised by bacteria (Figure 1C).

Figure 1 Symptoms caused by '*Ca*. L. solanacearum' in carrot: (A) healthy carrot; (B) infected carrot showing discoloured leaves and reduced root volume; (C) bacterial cells in a sieve tube element of an infected carrot root



Republished with permission of (Haapalainen 2014)

Symptoms caused by '*Ca.* L. solanacearum' in celery

Celery plants infected with '*Ca*. L. solanacearum' haplotype E show an abnormal number of shoots, curling of stems and yellowing (Figure 2A–D) (Teresani et al. 2014b).

Figure 2 Symptoms caused by '*Ca*. L. solanacearum' in celery: (A) infected celery (left) healthy celery (right); (B) infected celery showing abnormal shoot proliferation; (C) curling of stems; (D) mild symptoms in plant

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'*Candidatus* Liberibacter solanacearum' also infects parsley and parsnip under field conditions (Alfaro-Fernández, Hernández-Llopis & Font 2017). Infected parsnip crops show stunting and proliferation of secondary roots with early root senescence, yellowing and proliferation of the leaves. Parsley infected by '*Ca*. L. solanacearum' shows yellowing, proliferation and reddening of leaves (Alfaro-Fernández, Hernández-Llopis & Font 2017).

3.2.3 Transmission of '*Ca.* L. solanacearum'

'*Candidatus* Liberibacter solanacearum' is transmitted through vegetative propagation and naturally by several psyllid species (Teresani et al. 2014b). Recently, seed transmission has been demonstrated in carrot (Bertolini et al. 2015) although this result has not be reproduced by other authers (Loiseau et al. 2017a; Loiseau et al. 2017b). '*Candidatus* Liberibacter solanacearum' is not known to be mechanically or environmentally transmitted (e.g. by wind dispersal or rain splash).

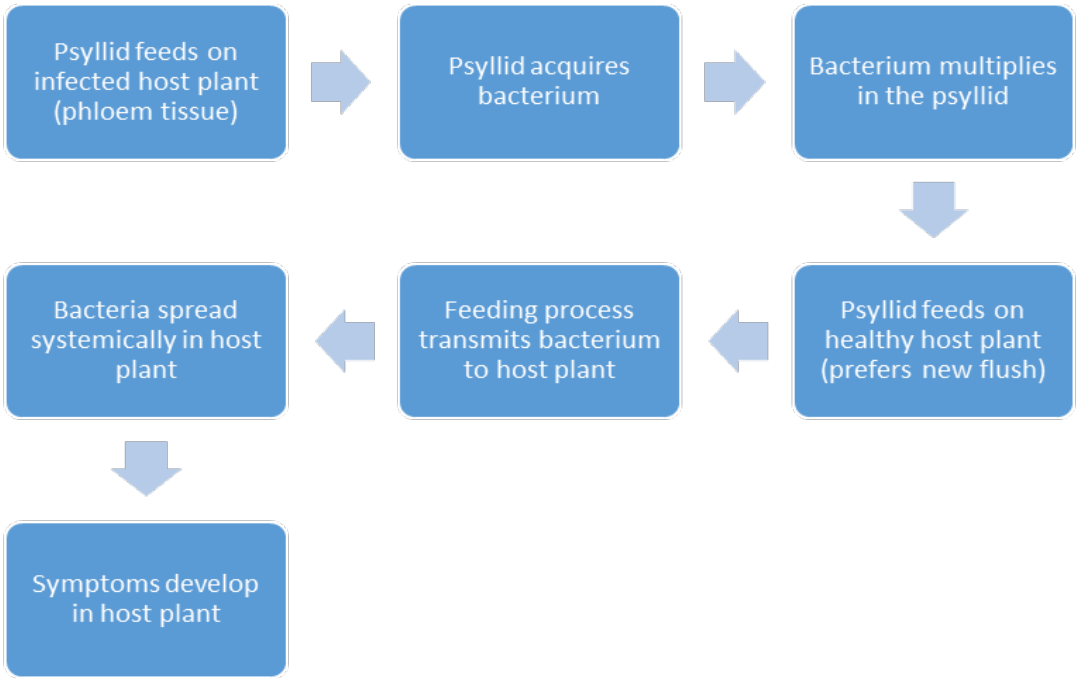
Psyllid transmission

Psyllids are pests in their own right due to their phytophagous (sap-sucking) behavior, in addition to being vectors of '*Ca*. L.' species (Nehlin, Palterova & Borg-Karlson 1994; Nissinen et al. 2007). The leaves of psyllid-infested plants appear chlorotic or discoloured, galled and a heavy infestation can lead to premature senescence and plant death. The psyllid-feeding symptoms in plants are referred to as 'psyllid yellows' (Sengoda et al. 2010).

Psyllids can travel globally and extend their distribution rapidly, because they are capable of long distance spread through active flight, wind-assisted dispersal and through storms and hurricanes (Barkley & Beattie 2008; Bové 2006; Gottwald, da Graca & Bassanezi 2007; Tsai 2006). One of the best examples of global psyllid movement is the Asian citrus psyllid *Diaphorina citri*. It has been in South America for many years and has spread to Central America and the Caribbean (Boykin et al. 2012; Department of Agriculture 2011).

Psyllids acquire '*Ca*. L.' species through feeding on infected hosts (Bové 2006; Gottwald, da Graca & Bassanezi 2007). Once the psyllids have acquired the bacterium from an infected host, they transmit the bacterium in a persistent manner (Teresani et al. 2015). The psyllid acquires the bacterium within two hours of feeding (Munyaneza 2010), the bacterium then multiplies within the psyllid and transmission occurs within three days (Nissinen et al. 2014). The symptoms of leaf discolouration in carrot become visible within 1–1.5 months (Nissinen et al. 2007; Nissinen et al. 2012). The process of transmission of the bacterium by psyllid vectors is presented schematically in Figure 3.

Figure 3 Transmission of '*Ca.* L. solanacearum' through psyllids



The total number of eggs laid by a mated female psyllid can range from one hundred to one thousand (Hodkinson 2009) and there can be several generations per year. Consequently, psyllid populations can grow very rapidly if no control measures are taken.

'*Candidatus* Liberibacter solanacearum' associated with solanaceous crops has been detected in the psyllid, *Bactericera cockerelli* (Nelson, Fisher & Munyaneza 2011). '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops has been detected in *B. nigricornis, B. tremblayi, B. trigonica* and *Trioza apicalis* (Alfaro-Fernández et al. 2012b; Nelson et al. 2012; Teresani et al. 2015; Teresani et al. 2014b), therefore, all these psyllids are potential vectors of the bacterium (Teresani et al. 2015). However, only *T. apicalis* (Munyaneza et al. 2010b) and *B. trigonica* (Alfaro-Fernández et al. 2012b) have been demonstrated to be able to transmit '*Ca*. L. solanacearum' associated with apiaceous crops.

Seed Transmission

'*Candidatus* Liberibacter solanacearum' has been detected in/on seed of carrot (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January), parsley and parsnip (Monger & Jeffries 2016) and seed transmission has been reported (Bertolini et al. 2015). Other studies have not replicated this result (Loiseau et al. 2017a; Loiseau et al. 2017b). The bacterium is reported to be borne internally in the seed and in the phloem and sieve tubes of the seed coat (Bertolini et al. 2015).

3.2.4 Psyllid vectors and carriers of '*Ca.* L. solanacearum' in apiaceous crops

The psyllid vectors and carriers of '*Ca.* L. solanacearum' associated with apiaceous crops are part of the psyllid family Triozidae (Table 8).

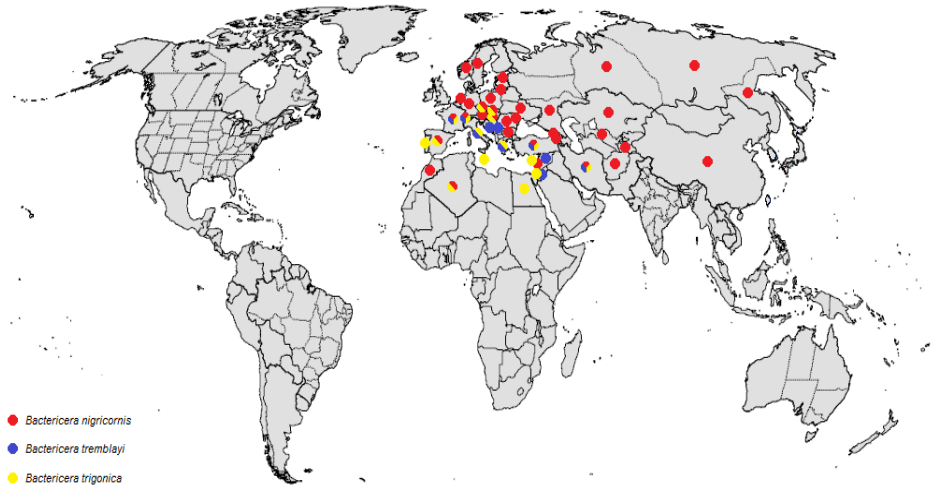
Table 8 Known vectors and carriers of '*Ca.* L. solanacearum' associated with apiaceous crops

Vector/carrier	'*Candidatus* Liberibacter solanacearum'
Known vectors	
Bactericera trigonica Hodkinson [Hemiptera: Triozidae]	'*Ca.* L. solanacearum' (haplotype D, E) (Alfaro-Fernández et al. 2012b)
Trioza apicalis Förster [Hemiptera: Triozidae] (synonym: *Dyspersa apicalis* Förster)	'*Ca.* L. solanacearum' (haplotype C) (Munyaneza et al. 2010b)
Known carriers	
Bactericera nigricornis Förster [Hemiptera: Triozidae] (synonyms: *Eubactericera nigricornis* (Förster); *Bactericera brassicae* (Vasil'ev); *Trioza actericera brassicae* (Vasil'ev); *Trioza nigricornis* Förster	'*Ca.* L. solanacearum' (haplotype D, E) (Teresani et al. 2015)
Bactericera tremblayi (Wagner) [Hemiptera: Triozidae] (synonym: *Trioza tremblayi* Wagner)	'*Ca.* L. solanacearum' (haplotype D, E) (Teresani et al. 2015)

'*Bactericera nigricornis* group'

Bactericera nigricornis, *B. tremblayi* and *B. trigonica* are morphologically similar psyllid species that belong to the '*Bactericera nigricornis* group' (Hodkinson 1981). Members of this group are polyphagous, show overlapping areas of distribution and are widely distributed in the Mediterranean region (Alfaro-Fernández et al. 2012b; Haapalainen 2014; Ouvrard & Burckhardt 2012; Teresani et al. 2015);Map 4).

Map 4 Distribution of '*Bactericera nigricornis* group'



Source: Ouvrard (2015)

The species within the '*B. nigricornis* group' are multivoltine (Hodkinson 2009) and overwinter as adults (Burckhardt & Lauterer 1997; Lauterer 1991). *Bactericera nigricornis, B. tremblayi* and *B. trigonica* are found in carrot and celery fields in Spain (Alfaro-Fernández et al. 2012a; Font et al. 2010; Teresani et al. 2015). '*Candidatus* Liberibacter solanacearum' has been detected in all these psyllid species and therefore these psyllids are potential vectors of the bacterium (Teresani et al. 2015). It is suspected that more psyllid species may be vectors of '*Ca*. L. solanacearum' (Teresani et al. 2015). Overlapping host ranges would provide opportunity for

other members of the '*B. nigricornis* group' that feed on carrot to acquire the '*Ca*. L. solanacearum' pathogen (Teresani et al. 2015).

Bactericera nigricornis

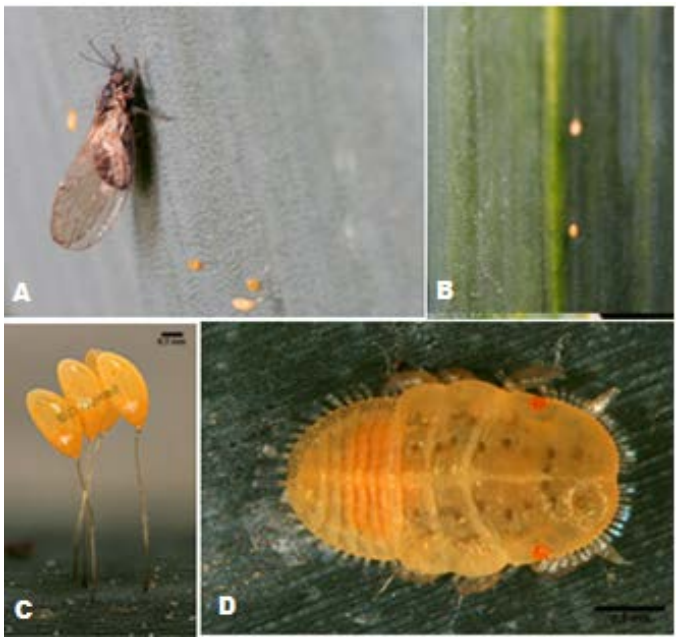
The origin of *Bactericera nigricornis* (synonym: *Trioza nigricornis*) is unknown, but it was described from Germany ((Foerster 1848), cited in (Hodkinson 1981)) and has subsequently been recorded throughout Europe, Asia Minor, North Africa and from as far east as Siberia (Hodkinson 1981). Earlier studies demonstrated that *B. nigricornis* is highly polyphagous, feeding and developing on carrot, parsley, potato, beet, brassicas, onion and radish in addition to a variety of weed species in a number of families (Hodkinson 1981). In Sweden, *B. nigricornis* was reported to breed on *Brassica* species, and adults were reported to occur, but not breed, on carrot ((Lundblad 1929), cited in (Hodkinson 1981)). In contrast, in Germany this psyllid was reported to breed on carrot and parsley, while beetroot and Jimson weed (*Datura stramonium*) were alternative hosts ((Bey 1931), cited in (Hodkinson 1981)). Subsequently, potato and *Brassica* species were listed as the main hosts of this psyllid in Germany ((Heinze & Profft 1939), cited in (Hodkinson 1981)), Sweden and the Netherlands (Hodkinson 1981).

Bactericera nigricornis is a major pest of potatoes in Iran (Fathi 2011). Females lay eggs on the lower surface of potato leaves; after hatching, the nymphs feed on plant sap and excrete large amounts of honeydew (Fathi & Nouri-Ganbalani 2008). Field observations in Iran indicate that in potato fields infested with *B. nigricornis*, yield is decreased and a striped pattern of necrosis develops in the potato tuber cross-section (Fathi 2011). These symptoms resemble those that develop in tubers of potato infested with *B. cockerelli* (Fathi & Nouri-Ganbalani 2008). However, there is currently no information on the presence of '*Ca*. L. solanacearum' or *B. cockerelli* in Iran. *Bactericera nigricornis* may transmit '*Ca*. L. solanacearum' in infested potatoes, but no study has investigated this possibility (Fathi 2011). '*Candidatus* Liberibacter solanacearum' has been detected in *B. nigricornis* collected from carrot and celery fields in Spain (Teresani et al. 2015), however, there is no information available on the transmission of '*Ca* L. solanacearum' through *B. nigricornis*.

Bactericera tremblayi

Bactericera tremblayi (synonym: *Trioza tremblayi*) was described on onion in Italy (Tremblay 1965a, b; Wagner 1961). The psyllid was reported to breed on *Brassica* species, *Capsella bursa-pastori*, *Capsicum* species, *Chenopodium* species and *Stellaria media* (Tremblay 1965a, b). Oviposition did not occur on small, hairy potato plants but some eggs (Figure 4B) and nymphs (Figure 4D) were found on a larger potato plant. Therefore, this psyllid appears to be polyphagous and share several common host-plants with *B. nigricornis*. The distribution of *B. tremblayi* has subsequently been extended to Bosnia-Herzegovina, Bulgaria, France, Greece, Iran, Jordan, Serbia, Spain and Turkey (Ouvrard & Burckhardt 2012). Some authors have continued to apply the name *B. nigricornis* to a species breeding on wild onions (*Allium* species) in Mongolia and Caucasus (Loginova 1968, 1970).

Figure 4 *Bactericera tremblayi*: (A) adult; (B) small elongated eggs; (C) eggs on stalk; and (D) nymphs



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In France, high populations of *B. tremblayi* have been reported to cause previously unrecognized symptoms on *Allium porri* (Ouvrard & Burckhardt 2012). Symptoms include longitudinal yellow stripes on the cylinder, bursting of bundled leaf sheaths and root growth between the burst sheaths. The aerial tip of the green leaves wither, the colour changes from bluish-green to dark shiny green and eventually the plant may die (Ouvrard & Burckhardt 2012). These symptoms could suggest that the psyllid may be vectoring a pathogen, however, no such pathogen has been identified (Ouvrard & Burckhardt 2012). '*Candidatus* Liberibacter solanacearum' has been detected in *B. tremblayi* collected from carrot and celery fields in Spain (Teresani et al. 2015), however, there is no information available on the transmission of '*Ca.* L. solanacearum' by *B. tremblayi*.

Bactericera trigonica

Bactericera trigonica was described from carrot in Portugal, nasturtium in Iran and other vegetables in Cyprus (Hodkinson 1981). *B. trigonica* feeds on carrots and related plants, and the adults overwinter on evergreen shrubs (Hodkinson 2009). *B. trigonica* has two or three generations per year (Hodkinson 1981, 2009) (Figure 5A).

Figure 5 *Bactericera trigonica*: (A) adult; (B) small elongated eggs; (C) eggs on stalk; (D) nymphs; (E) adult

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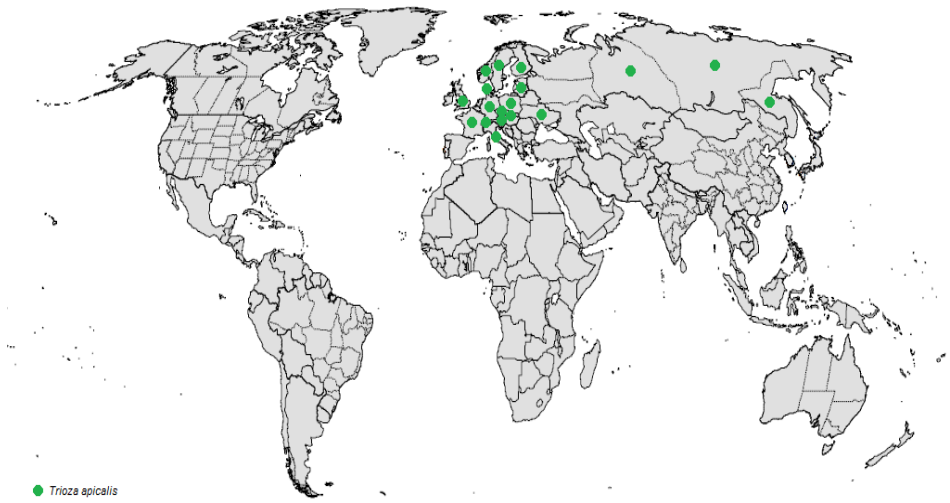
Bactericera trigonica has been reported from Algeria, Cyprus, Czech Republic, Egypt, France, Greece, Hungary, Iran, Israel, Italy, Malta, Portugal, Slovakia, Spain, Switzerland, Turkey (Ouvrard 2015) and Morocco (Tahzima et al. 2017). A large population of *B. trigonica* was noted in carrot fields showing symptoms of leaf curling, yellow, bronze, and purple discolouration of leaves, stunting of shoots and tap roots, and proliferation of secondary roots (Alfaro-Fernández et al. 2012a; Alfaro-Fernández et al. 2012b). '*Candidatus* Liberibacter solanacearum' was detected in both carrots and *B. trigonica*, providing the first report of this pathogen associated with *B. trigonica* (Alfaro-Fernández et al. 2012b).

Trioza apicalis

Trioza apicalis (synonym: *Dyspersa apicalis*) was described from Germany ((Foerster 1848), cited in (Láska 2011)). The psyllid slowly expanded its range and reached continental Denmark in about 1912 ((Rostrup 1921), cited in (Láska 2011)), then expanded from Denmark to neighbouring countries including Latvia, Sweden and Norway. *Trioza apicalis* was reported in Czechoslovakia in 1936 ((Baudyš 1936), cited in (Láska 2011)). *Trioza apicalis* is associated with carrot in Scandinavia, Finland and other parts of northern and central Europe, and it now also occurs in the wider areas of Eurasia from Great Britain to Mongolia (Hodkinson 1984; Láska 2011) (Map 5).

Map 5 Distribution of *Trioza apicalis*



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Trioza apicalis has only one generation per year (Kristoffersen & Anderbrant 2007). Eggs are laid in the leaf tissue (Figure 6B) during summer, and embryonic development takes 12 to 14 days on average under field conditions (Láska 1974). The total development time (including eggs) under field conditions (at a mean temperature of 17 °C) takes a median of 54 days (Láska 1974).

Figure 6 *Trioza apicalis*: (A) adult; (B) female on a carrot leaf; (C) small elongated eggs; (D) nymphs

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The feeding activity of *T. apicalis* causes curling of the youngest leaves (Figure 7). The first record of curling of carrot leaves dates back to 1896, however, the cause of this damage was identified in 1908 as due to feeding activity of *Trioza viridula* (Rostrup 1921), cited in (Láska 2011). Subsequently, similar damage on carrot was reported on the Danish island of Sjalland

(Rostrup 1921), cited in (Láska 2011), Germany (Krumrey & Wendland 1973) and Switzerland (Burckhardt & Freuler 2000; Fischer & Terrettaz 2002).

Figure 7 Leaf curling caused by *Trioza apicalis*

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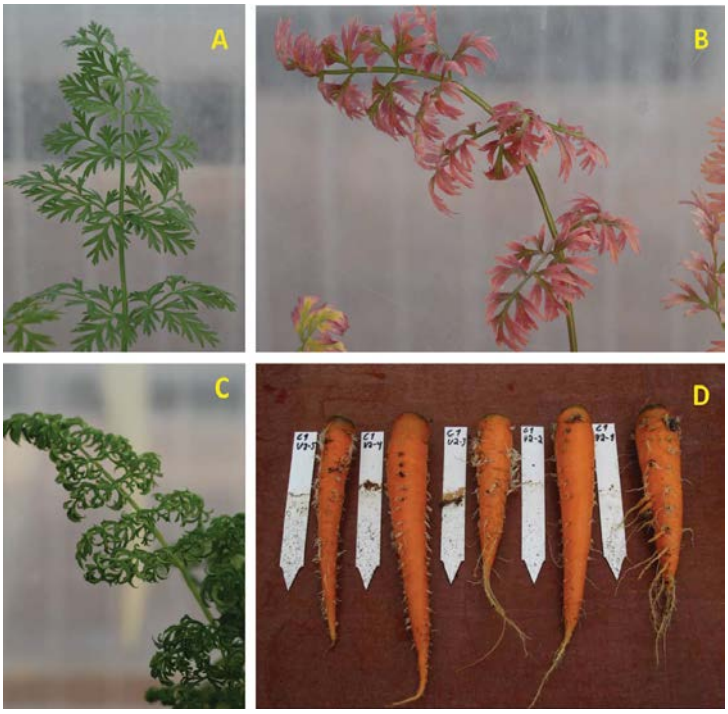
In addition to leaf curling, *T. apicalis* feeding damage includes yellowish, bronze and purplish discolouration of leaves; stunting of the shoots and roots; and proliferation of secondary roots (Markkula, Laurema & Tiittanen 1976; Nehlin, Palterova & Borg-Karlson 1994; Nissinen et al. 2007) (Figure 8).

Figure 8 Symptoms developed on carrot after psyllid exposure: (A) healthy leaf; (B) leaf showing discolouration; (C) damage without discolouration; (D) proliferation of secondary roots



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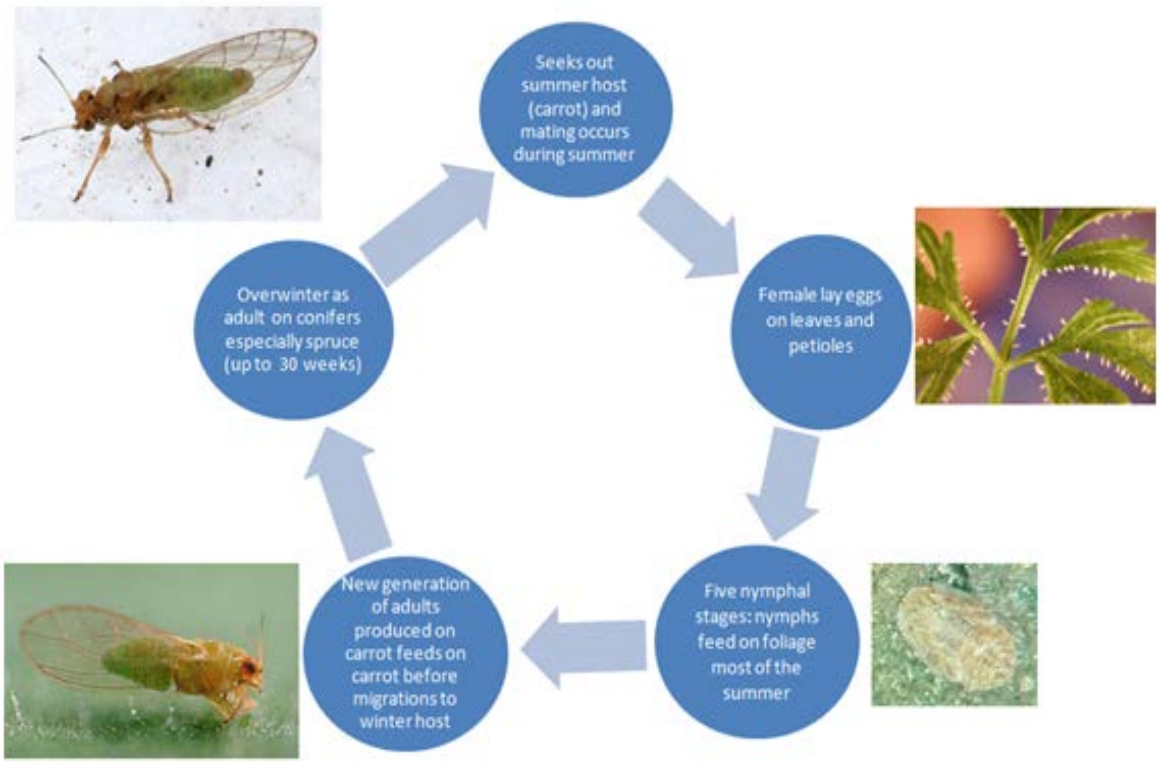
Symptoms caused in carrot were considered to be a result of toxins injected by the psyllid during feeding activities (Markkula, Laurema & Tiittanen 1976; Nehlin, Palterova & Borg-Karlson 1994). However, no toxin was identified from extractions of psyllid salivary glands and salivary secretions (Markkula & Laurema 1971). Further studies demonstrated that the short

feeding period of *T. apicalis* could result in the development of severe symptoms in carrots that usually appeared about one month after insect removal (Nissinen et al. 2007). These studies suggested that plant pathogens could be involved in this *T. apicalis*-induced disorder (Nissinen et al. 2007). Subsequent studies discovered that '*Ca*. L. solanacearum' is associated with both the psyllid and the carrot plant (Munyaneza et al. 2010b, a).

The life cycle of *T. apicalis* begins with mating between fertile adults on summer host plants (Kristoffersen & Anderbrant 2007) on which adult females lay eggs on the leaves. After egg hatching, nymphs develop through five instar stages, before becoming adults (Figure 9). The time needed for development from eggs to mature adults varies in length depending on temperature (Hodkinson 2009). The reproductive biology of *T. apicalis* psyllids is closely tied to the availability of the new leaf flush for egg laying and subsequent development of nymphs. As these leaves mature, they become unsuitable for psyllid development and the psyllids seek out new breeding sites (Hodkinson 2009). Depending on the season and climatic conditions, the newly emerged adults either fly to new summer host plants to reproduce, or migrate to overwintering hosts (Kristoffersen & Anderbrant 2007). The period spent overwintering on shelter plants usually matches the period when the summer host is dormant or unfavourable for psyllid development. The adult carrot psyllids leave their overwintering host in late spring or early summer, usually at the time when the main summer host is emerging. Photoperiod plays a role in the migration between winter and summer hosts (Valterova, Nehlin & BorgKarlson 1997). In addition, changes in the concentration of secondary metabolites in the winter host could affect the timing of the migration of carrot psyllids (Nissinen et al. 2007).

Figure 9 Life cycle of *Trioza apicalis*



4 Pest risk assessments for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops

This risk assessment was initiated to fulfil Australia's obligations under the IPPC and ISPM No. 1 (FAO 2016a) to review the emergency phytosanitary measures that Australia introduced in October 2014 and to justify their continuance or amendments. Australia introduced emergency measures after the confirmation of the seed-borne nature and seed transmission of '*Candidatus* Liberibacter solanacearum' in carrot (Bertolini et al. 2015). '*Candidatus* Liberibacter solanacearum' associated with apiaceous is identified as a quarantine pest for Australia because it:

- is not present in Australia;
- has the potential to be associated with the pathways of seeds and tissue cultures of apiaceous crops;
- has the potential to establish and spread in Australia; and
- has the potential to cause significant economic consequences in Australia.

In the context of this PRA, seeds and tissue cultures of apiaceous host crops (*Anthriscus cerefolium, Apium graveolens, Daucus carota, Foeniculum vulgare, Pastinaca sativa* and *Petroselinum crispum*) are potential pathways (Table 9) through which '*Ca*. L. solanacearum' may enter Australia.

Table 9 Potential pathways by which '*Ca.* L. solanacearum' may enter Australia

Host name	Potential pathways	Reference	Seed-borne
Anthriscus cerefolium (chervil)	Tissue culture	(Hajri et al. 2017)	Not known*
Apium graveolens (celery/celeriac)	Tissue culture, seed	(EPPO 2015; Teresani et al. 2014a)	Yes (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January)
Daucus carota (carrot)	Tissue culture, seed	(Munyaneza et al. 2010b, a)	Yes (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016)
Foeniculum vulgare (fennel)	Tissue culture, seed	(Hajri et al. 2017)	Yes (Ministry for Primary Industries 2017)
Pastinaca sativa (parsnip)	Tissue culture, seed	(Cambra et al. 2015)	Yes (Monger & Jeffries 2016)
Petroselinum crispum (parsley)	Tissue culture, seed	(Monger & Jeffries 2016)	Yes (Monger & Jeffries 2016)

*Although there is no published evidence that the bacterium is seed-borne in chervil, the detection in fennel seed has raised concerns that this bacterium may also be seed-borne in chervil.

4.1 '*Candidatus* Liberibacter solanacearum'

Three haplotypes of '*Ca*. L. solanacearum' (C, D & E) have been identified as associated with propagative material of apiaceous crops (carrot, celery/celeriac, chervil, fennel, parsley and parsnip). Therefore, this risk assessment focuses on apiaceous propagative material (seeds and tissue cultures) as potential pathways for the introduction of '*Ca*. L. solanacearum' haplotypes associated with apiaceous crops.

The probability of entry has been considered individually for each pathway, as the pathway by which '*Ca*. L. solanacearum' haplotypes might enter Australia may have a significant effect on the unrestricted risk estimate.

The probability of establishment and spread, and the assessment of potential consequences, are considered to be independent of the pathway of entry. Instead, they are influenced by post-border issues, such as the susceptibility of hosts, the availability of hosts and the suitability of the environment in Australia for '*Ca*. L. solanacearum' (haplotypes C, D & E). Therefore, the probabilities of establishment and spread, and the economic consequences of '*Ca*. L. solanacearum' have been assessed only once.

4.1.1 Likelihood of entry

The likelihood of entry is considered in two parts, the likelihood of importation and the likelihood of distribution, which consider pre-border and post-border issues, respectively. The likelihood of entry is divided for assessment purposes into the likelihood of importation (the likelihood that the '*Ca*. L. solanacearum' will arrive when apiaceous crop seeds for sowing and tissue cultures are imported) and the likelihood of distribution (the likelihood that '*Ca*. L. solanacearum' associated with apiaceous crop seeds for sowing and tissue cultures will be viable and be transferred to suitable host).

Pathway one: Seeds for sowing

Seed pathogens have evolved many different types of associations with their hosts. These associations range from passive hitchhiking on seed coats to infecting embryonic tissue (Elmer 2001).

Likelihood of importation

The likelihood that '*Ca*. L. solanacearum' will be imported with trade in carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds for sowing is assessed as high.

This is because '*Ca*. L. solanacearum' is seed-borne and likely to remain viable during transport and storage. In addition, Australia imports a large volume of apiaceous seeds for sowing each year for planting.

Association of the pest with the pathway

It is highly likely that '*Ca*. L. solanacearum' is associated with the pathway.

- '*Candidatus* Liberibacter solanacearum' is seed-borne in carrot (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January), fennel (Ministry for Primary Industries 2017); parsley and parsnip (Monger & Jeffries 2016). The bacterium is borne internally in the seed, in the phloem and sieve tubes of the seed coat (Bertolini et al. 2015). Therefore, this bacterium is associated with the carrot, celery/celeriac, parsley and parsnip seed pathway.
- Global trade and the associated movement of carrot seeds across borders may have introduced '*Ca*. L. solanacearum' into new areas (Bertolini et al. 2015). Therefore, the movement of infected carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds may be a significant pathway for the introduction of this pathogen into new areas.
- A low incidence of '*Ca*. L. solanacearum' in the field may enhance its chances of escaping detection. If the level of infection is very low and symptomatic plants are randomly

scattered in the field, the infection may go undetected at the time of harvest. Therefore, seed infected with '*Ca*. L. solanacearum' could be imported into Australia.

- '*Candidatus* Liberibacter solanacearum' was detected in carrot seed lots from 2010 to 2014 (Bertolini et al. 2015), indicating that the bacterium is persistantly present in seeds and is therefore consistently associated with the pathway. More recently, '*Ca*. L. solanacearum' was detected in parsley seed commercially available in retail shops in the UK (Monger & Jeffries 2016), also indicating that '*Ca*. L. solanacearum' could be imported into Australia.
- In early 2016, '*Ca*. L. solanacearum' was detected in imported carrot seed in Australia during on-arrival mandatory testing, indicating that '*Ca.* L. solanacearum' is associated with the pathway.
- Large volumes of apiaceous seeds are imported into Australia each year for planting. '*Candidatus* Liberibacter solanacearum' is borne internally in the seed, in the phloem and sieve tubes of the seed coat (Bertolini et al. 2015). It is highly likely that '*Ca*. L. solanacearum' will not be detected during on-arrival inspection. Therefore, '*Ca*. L. solanacearum' is likely to have repeated opportunity for entry into Australia through the importation of seed.

Ability of the pest to survive transport and storage

It is highly likely that '*Ca*. L. solanacearum' will survive storage and transport.

- '*Candidatus* Liberibacter solanacearum' is very likely to survive during transport and storage since the primary conditions for survival are fulfilled by the presence of the live host material and associated environmental conditions. Carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds are packaged and shipped to areas conducive to their survival. The handling of carrot, celery/celeriac, parsley and parsnip seeds is unlikely to be detrimental to the survival of this pathogen.
- Transport and storage of propagative material is conducted at low temperatures and these conditions are not expected to affect the viability of '*Ca*. L. solanacearum'. Therefore, '*Ca*. L. solanacearum' is likely to survive transport and storage.
- The transportation of carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds from the country of origin to Australia may take several days. '*Candidatus* Liberibacter solanacearum' was detected in early 2016 in imported carrot seed in Australia, indicating that '*Ca*. L. solanacearum' is able to persist during transport from the country of origin to Australia.
- '*Candidatus* Liberibacter solanacearum' is found within carrot, celery/celeriac, chervil, fennel, parsley and parsnip seed. It is unlikely to be dislodged during standard harvesting, handling and shipping operations. Therefore, '*Ca*. L. solanacearum' associated with carrot, celery/celeriac, parsley and parsnip seeds is likely to persist during transport and storage.

Ability of the pest to survive existing pest management procedures

It is highly likely that '*Ca*. L. solanacearum' will survive existing pest management procedures.

- Currently, there are few effective control strategies for the protection of host crops against natural infections of '*Ca*. L. solanacearum'.
- '*Candidatus* Liberibacter' species are typically managed by chemical control of vector populations and the removal of the inoculum source. Crops may also be cultivated under insect-proof facilities to exclude vectors.

- The use of '*Ca*. L. solanacearum'-free carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds and management of psyllid vectors are critical factors in managing '*Ca*. L. solanacearum' in apiaceous crops.
- Plant protection measures are mostly taken against the psyllids. Measures against psyllids have been implemented everywhere that the psyllid and the psyllid/bacterium combination are present, in order to keep damage under a threshold level. Treatments against the insect vector reduce the incidence of damage but do not completely suppress the bacterium. In some years in northern Europe, carrots cannot be grown without the application of insecticides. For example, insecticide treatment is an economic necessity in Norway, Sweden, Denmark, Latvia and Switzerland (Láska 2011).

Likelihood of distribution

The likelihood that '*Ca*. L. solanacearum' will be distributed across Australia in a viable state on imported seed for sowing and subsequently be transferred from the imported seed to a suitable host is assessed as high.

This is because apiaceous seeds for sowing are commercially distributed throughout Australia, and seed to seedling transmission has been reported for '*Ca*. L. solanacearum'. This transmission mechanism provides the means by which this pathogen becomes exposed to a new host plant such as new seedlings. In addition, '*Ca*. L. solanacearum' was detected in imported carrot seed during on-arrival testing in Australia in early 2016, providing further evidence that this bacterium can enter Australia through the trade of vegetable seeds. If infected seeds had been used for sowing, the bacterium could have been distributed across Australia.

Distribution of the imported commodity in the PRA area

It is highly likely that imported apiaceous crop seed will be distributed across Australia.

- It is highly likely that imported apiaceous crop seeds for commercial sale will be sold in vegetable growing areas in Australia. The imported seed for sowing will be distributed through commercial and retail outlets to multiple destinations throughout Australia. Following retail sale, any infected imported seed will be planted in suitable habitats throughout Australia.
- The distribution of infected seeds commercially through seed companies may facilitate the distribution of '*Ca*. L. solanacearum' in Australia. Asymptomatic plants that develop from infected seeds may also be overlooked and sold to commercial users and households.
- Association with carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds provides the opportunity for '*Ca*. L. solanacearum' to be distributed through the trade of carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds across Australia. Its ability to survive on or in seeds acts to ensure its viability on route to and during distribution across Australia.
- '*Candidatus* Liberibacter solanacearum' is likely to survive transportation and storage within Australia. Carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds are likely to be transported, stored and maintained in appropriate conditions for seed survival. Thus, transport and storage conditions within Australia are unlikely to have any impact on the survival of '*Ca*. L. solanacearum' in imported seeds.

Ability of the pest to move from the pathway to a suitable host

It is highly likely that '*Ca*. L. solanacearum' will be transferred to a suitable host.

- '*Candidatus* Liberibacter solanacearum' in imported infected seed for sowing is already associated with a suitable host that will be planted and grown under favourable conditions, and thus will have no requirement to move from the import pathway (seed) to a suitable host.
- The '*Ca.* L. solanacearum' bacterium is seed-borne (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016; Monger & Jeffries 2016) and seed transmissible (Bertolini et al. 2015). The bacterium has been shown to be transmitted from seed to the resultant seedling (Bertolini et al. 2015). Although this result has not been reproduced by other authers (Loiseau et al. 2017a; Loiseau et al. 2017b), no research findings can exclude seed as a transmission pathway.This transmission mechanism provides the means by which this bacterium becomes exposed to a new host plant, namely the new seedling.
- If an infected seed results in an infected seedling within a field, '*Ca*. L. solanacearum' would require a vector to transfer to other suitable hosts within a field. In the absence of a vector, '*Ca*. L. solanacearum' could only persist through multiple generations of seed to seedling transmission.
- '*Candidatus* Liberibacter solanacearum' is associated with carrot, celery/celeriac (Munyaneza et al. 2010b; Teresani et al. 2014b), chervil, fennel (Hajri et al. 2017), parsnip (Alfaro-Fernández, Hernández-Llopis & Font 2017), parsley (Alfaro-Fernández, Hernández-Llopis & Font 2017; Monger & Jeffries 2016). These host crops are widely distributed throughout Australia, with many residential and semi-rural properties in the metropolitan area growing vegetables in domestic backyards. However, in the absence of psyllid vectors, the bacterium is unlikely to move from the point of entry to these available hosts.
- The haplotypes of '*Ca.* L. solanacearum' associated with apiaceous crops are vector specific and are vectored naturally by *Bactericera trigonica* and *Trioza apicalis* (Haapalainen 2014). These vectors are not present in Australia.
- Other species of psyllids including *Bactericera nigricornis, B. tremblayi*, *Cacopsylla* species, *Ctenarytaina* species, *Psylla* species and *Trioza urticae* have been recorded on apiaceous crops, where this bacterium is present (Teresani et al. 2015). However, the bacterium has been detected only in *Bactericera nigricornis* and *B. tremblayi,* and was not detected in those other species (Teresani et al. 2015). This vector specificity suggests it is unlikely that Australian native psyllids would be able to transfer '*Ca*. L. solanacearum' from infected plants to healthy plants in the field.
- Australian native *Cacopsylla* species, *Ctenarytaina* species and *Trioza* species feed on non-apiaceous hosts including Myrtaceae, Euphorbiaceae and Asteraceae (DEWHA 2009).

Pathway two: Tissue cultures

'*Candidatus* Liberibacter solanacearum' infects phloem, therefore, once a plant has become infected, the bacterium can move throughout the plant. Consequently, carrot, celery/celeriac, chervil, fennel, parsley and parsnip tissue cultures could provide a pathway for '*Ca*. L. solanacearum'.

Likelihood of importation

The likelihood that '*Ca*. L. solanacearum' will be imported with trade in tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) for propagation is assessed as high.

This is because '*Ca*. L. solanacearum' is associated with whole plants from which such cultures are derived, the likelihood that '*Ca*. L. solanacearum' will remain viable during tissue culture

transport and storage, and the large volumes of apiaceous tissue cultures imported into Australia each year.

Association of the pest with the pathway

It is highly likely that '*Ca*. L. solanacearum' is associated with the pathway.

- '*Candidatus* Liberibacter solanacearum' is distributed systemically in all parts of an infected plant, and is found in the phloem of leaflets, petioles, stems, crowns and roots (Nissinen et al. 2014). Carrot, celery/celeriac, chervil, fennel, parsley and parsnip plants infected with '*Ca*. L. solanacearum' may be symptomless (Hajri et al. 2017; Monger & Jeffries 2016; Teresani et al. 2014b), which could also contribute to the introduction of the bacterium into tissue cultures.
- The presence of the bacterium in the phloem allows it to avoid the natural defences of the plant, which other pathogens encounter when they infect foliar and intercellular spaces (Kim et al. 2009). Therefore, this bacterium is associated with the tissue culture pathway.

Ability of the pest to survive transport and storage

It is highly likely that '*Ca*. L. solanacearum' will survive storage and transport.

- '*Candidatus* Liberibacter solanacearum' is very likely to survive during transport and storage since the primary conditions for survival are fulfilled by the presence of the live host material (tissue cultures) and associated environmental conditions. Tissue cultures are packaged and shipped to facilities that promote their survival. The handling of tissue cultures is unlikely to be detrimental to the survival of this pathogen.
- Transport and storage of propagative material is conducted at low temperatures and these conditions are not expected to affect the viability of '*Ca*. L. solanacearum'. Therefore, '*Ca*. L. solanacearum' is likely to survive transport and storage.
- '*Candidatus* Liberibacter solanacearum' could be associated with tissue cultures of carrot, celery/celeriac, chervil, fennel, parsley and parsnip and would be unlikely to be lost during standard culturing, handling and shipping operations. Therefore, '*Ca*. L. solanacearum' associated with carrot, celery/celeriac, chervil, fennel, parsley and parsnip tissue cultures would be likely to survive during transport and continued culture.

Likelihood of distribution

The likelihood that imported '*Ca*. L. solanacearum' will be distributed across Australia in a viable state in tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) for propagation and be transferred from these tissue cultures to a suitable host is assessed as high.

This is because imported tissue cultures of carrot, celery/celeriac, chervil, fennel, parsley and parsnip for planting are commercially distributed across Australia and the bacterium is able to transmit to the resultant new plant.

Distribution of the imported commodity in the PRA area

It is highly likely that imported tissue cultures will be distributed throughout Australia.

- It is highly likely that imported tissue cultures for commercial sale will be sold in multiple destinations throughout Australia. Therefore, the bacterium will also be distributed across Australia.

- Distribution of infected tissue cultures through propagation houses may facilitate the distribution of '*Ca*. L. solanacearum' throughout Australia. Asymptomatic plants that develop from infected tissue cultures may be overlooked and sold to commercial users and households.
- Tissue cultures are likely to be transported, stored and maintained in appropriate conditions for their survival. Thus, transport and storage conditions within Australia are unlikely to have any impact on the survival of '*Ca*. L. solanacearum' in imported tissue cultures.
- Association with carrot, celery/celeriac, chervil, fennel, parsley and parsnip tissue cultures provides the opportunity for '*Ca*. L. solanacearum' to enter Australia. The ability of '*Ca*. L. solanacearum' to survive within propagative material acts to ensure its viability on route to and during distribution to propagation houses across Australia.

Ability of the pest to move from the pathway to a suitable host

It is highly likely that '*Ca*. L. solanacearum' will be transferred to a suitable host, in the form of a regenerated plant.

- '*Candidatus* Liberibacter solanacearum' arriving in Australia with imported infected tissue cultures is already present within a suitable host that will be used for further propagation in propagation houses. Therefore, the bacterium is not required to move from the pathway to a suitable host.
- Tissue cultures are imported specifically for the purpose of propagation and infected tissue cultures are therefore likely to be further propagated in propagation houses at multiple locations throughout Australia. The distribution of infected tissue cultures commercially will assist in the distribution of '*Ca*. L. solanacearum'.
- If infected tissue culture results in an infected seedling within a propagation house, '*Ca*. L. solanacearum' would require a vector to transfer to other suitable hosts. In the absence of a vector, '*Ca*. L. solanacearum' could only persist through multiple generations of seed to seedling transmission.
- '*Candidatus* Liberibacter solanacearum' is associated with carrot, celery/celeriac (Munyaneza et al. 2010b; Teresani et al. 2014b), chervil, fennel (Hajri et al. 2017), parsnip (Alfaro-Fernández, Hernández-Llopis & Font 2017), parsley (Alfaro-Fernández, Hernández-Llopis & Font 2017; Monger & Jeffries 2016). These host crops are widely distributed throughout Australia with many residential and semi-rural properties in the metropolitan area growing vegetables in the backyard. However, in the absence of psyllid vectors, the bacterium is unlikely to move from the point of entry to these available hosts.
- '*Candidatus* Liberibacter solanacearum' is vector specific and is vectored naturally by *Bactericera trigonica* and *Trioza apicalis* (Haapalainen 2014). These specific vectors are not present in Australia.
- Other species of psyllids including *Bactericera nigricornis, B. tremblayi*, *Cacopsylla* species, *Ctenarytaina* species, *Psylla* species and *Trioza urticae* have been recorded on apiaceous crops where this bacterium is present (Teresani et al. 2015). However, the bacterium was detected only in *Bactericera nigricornis* and *B. tremblayi*, and was not detected in the other species (Teresani et al. 2015). This vector specificity suggests it is unlikely that Australian native psyllids would be able to transfer '*Ca*. L. solanacearum' from infected plants to healthy plants within the field.
- Australian native *Cacopsylla* species, *Ctenarytaina* species and *Trioza* species feed on non-apiaceous hosts including Myrtaceae, Euphorbiaceae and Asteraceae (DEWHA 2009).

Overall likelihood of entry

The likelihoods of importation and distribution '*Ca*. L. solanacearum' are combined to give an overall likelihood of entry using the matrix rules for combining likelihoods (Table 2). The overall likelihood of entry that '*Ca*. L. solanacearum' will be imported into Australia on different pathways and be transferred to a suitable host is set out in Table 10.

Table 10 Overall likelihood of entry of *'Ca.* L. solanacearum' on different pathways

Pathway	Likelihood of importation	Likelihood of distribution	Overall likelihood of entry
Seeds for sowing	High	High	High
Tissue cultures	High	High	High

4.1.2 Likelihood of establishment

The likelihood of establishment of '*Ca*. L. solanacearum' within Australia will depend upon the availability of a host, suitable climate, reproductive strategy and method of pest survival. Based on a comparison of factors that affect pest survival and reproduction in the source and destination areas, the likelihood of establishment on imported propagative material (seeds and tissue cultures) is assessed as high.

This is because of the extensive planting of apiaceous crops in Australia, the deliberate introduction and establishment of plants grown from imported propagative material for cultivation, the transmission of the bacterium from infected propagative material to seedlings, wide distribution of suitable hosts, and broad availability of suitable climates in Australia.

Availability of suitable hosts, alternative hosts and vectors in the PRA area

It is highly likely that '*Ca*. L. solanacearum' will establish in Australia because of broad availability of host plant species.

- The infecting '*Ca*. L. solanacearum' is already associated with host propagative material, giving it a distinct advantage for establishment in Australia. Therefore, importation and distribution of host propagative material through commercial and retail outlets provides '*Ca*. L. solanacearum' with the means to establish in multiple apiaceous vegetable and herb growing areas across Australia.
- Although '*Ca*. L. solanacearum' is specific to apiaceous crops, these crops are widely cultivated throughout Australia, with many residential and semi-rural properties in the metropolitan areas growing vegetables and herbs in their backyards.
- Seeds and tissue cultures are intended for ongoing propagation and are deliberately introduced, distributed and aided to establish. This material will enter and then be maintained in a suitable habitat, potentially in substantial numbers and for an indefinite period. Therefore, the introduction and establishment of plants from imported seeds and tissue cultures establishes those pathogens associated with the propagative material.
- The latent period of infection before visible symptoms appear may result in non-detection of '*Ca*. L. solanacearum', therefore, '*Ca*. L. solanacearum' will have ample time to establish in new areas. In seed to seedling transmission studies, visible symptoms may appear after 60 days (Bertolini et al. 2015).
- *'Candidatus* Liberibacter solanacearum' is systemic in the host plant and is seed-borne in carrot (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January), parsley and

parsnip (Monger & Jeffries 2016); it can multiply and move in the phloem of the host plant. For '*Ca*. L. solanacearum' to transfer from an infected plant to a new host, a vector would have to be present in the PRA area, acquire the bacterium by feeding on the infected plant and transmit the bacterium to a new host plant.

- Apiaceae-infecting haplotypes of '*Ca.* L. solanacearum' are vector specific and are vectored naturally by *Bactericera trigonica* and *Trioza apicalis* (Haapalainen 2014). These vectors are not present in Australia.
- Other species of psyllids including *Bactericera nigricornis, B. tremblayi*, *Cacopsylla* species, *Ctenarytaina* species, *Psylla* species and *Trioza urticae* have been recorded on apiaceous crops where this bacterium is present (Teresani et al. 2015). However, the bacterium was detected only in *Bactericera nigricornis* and *B. tremblayi* and was not detected in the other species (Teresani et al. 2015). This vector specificity suggests it is unlikely that Australian native psyllids would be able to transfer '*Ca*. L. solanacearum' from infected plants to healthy plants within the field.
- Australian native *Cacopsylla* species, *Ctenarytaina* species and *Trioza* species feed on non-apiaceous hosts including Myrtaceae, Euphorbiaceae and Asteraceae (DEWHA 2009).

Suitability of the environment

It is highly likely that '*Ca*. L. solanacearum' will establish in Australia because of suitable climatic conditions.

- *'Candidatus* Liberibacter solanacearum' is established overseas in areas with a wide range of climatic conditions. The current reported distribution of '*Ca.* L. solanacearum' suggests an ability to establish in new environments. There are similar climatic regions in parts of Australia that would be suitable for the establishment of '*Ca.* L. solanacearum'.
- Extensive cultivation of imported apiaceous propagative material potentially infested/infected with '*Ca.* L. solanacearum' and seed to seedling transmission will help establish this bacterium in apiaceous vegetable and herb growing areas in Australia. As host plant material is likely to be maintained in places with similar climates to the area of production, climatic conditions are expected to favour '*Ca.* L. solanacearum' establishment.
- *'Candidatus* Liberibacter solanacearum' is heat sensitive (Munyaneza 2012), therefore, its establishment is likely to be restricted to the temperate southern regions of Australia and it is less likely to establish and/or persist in the tropical northern regions of Australia.

The potential for adaptation of the pest

'*Candidatus* Liberibacter solanacearum' has potential for adaptation.

- The haplotypes of '*Ca*. L. solanacearum' associated with apiaceous crops have established under various climatic conditions (scandinavian countries and Mediterranean climates) (Alfaro-Fernández et al. 2012a; Alfaro-Fernández et al. 2012b; Ilardi, Di Nicola & Tavazza 2016; Monger & Jeffries 2016; Munyaneza 2010; Tahzima et al. 2014; Tahzima et al. 2017) indicating the potential of this bacterium for adaptation.

The reproductive strategy and survival of the pest

'*Candidatus* Liberibacter solanacearum' has a suitable reproductive strategy for establishment in Australia.

- '*Candidatus* Liberibacter' species are obligate parasites of plants and psyllids (Haapalainen 2014). '*Ca.* L. solanacearum' multiplies and survives in the phloem of infected host plants and in its psyllid vectors, including *B. trigonica* (Teresani et al. 2015) and *T. apicalis*

(Munyaneza et al. 2010a). '*Ca.* L. solanacearum' is reliant on infected host plants for survival and is likely to survive as long as the infected plant material survives.

- The survival and multiplication of this bacterium within its host is influenced by temperature. '*Ca.* L. solanacearum' is heat sensitive to contant temperature above 30 °C, but has established across a wide range of climates (Munyaneza 2012).
- On carrot, celery/celeriac, chervil, fennel, parsley and parsnip plants, the infection may be maintained as long as new carrot, celery/celeriac, chervil, fennel, parsley and parsnip seeds are produced from the line originating from the infected imported seeds and tissue cultures. In the absence of a suitable vector, it is likely that these cases will not lead to long term establishment, but they could lead to transient '*Ca*. L. solanacearum' populations.

4.1.3 Likelihood of spread

The likelihood of spread describes the likelihood that '*Ca*. L. solanacearum', once entered Australia on apiaceous crop propagative material (seeds and tissue cultures) and become established, will spread from the point of introduction to new areas. Based on a comparison of factors relevant to the expansion of the geographic distribution of '*Ca*. L. solanacearum' in the source and destination areas, the likelihood is assessed as low in the absence of suitable psyllid vectors, and as high if suitable vectors are present.

This assessment is based on the suitability of the natural and managed environments for natural spread, the ability of '*Ca*. L. solanacearum' to survive for long periods of time on seeds, and the known role of seed in the spread of pathogens globally. However, for vector-transmitted pathogens, the likelihood of spread differs, depending on the presence of suitable vectors.

The suitability of the natural or managed environment for natural spread

The environment in Australia is suitable for natural spread of '*Ca*. L. solanacearum'.

- '*Candidatus* Liberibacter solanacearum' was first discovered in a carrot crop in Finland (Munyaneza et al. 2010b) and since then has been detected in Norway (Munyaneza et al. 2012b), Sweden (Munyaneza et al. 2012b), Spain (Alfaro-Fernández et al. 2012a), France (Loiseau et al. 2014), Morocco (Tahzima et al. 2014), Austria (EPPO 2015), Germany (Munyaneza et al. 2015), Italy (Ilardi, Di Nicola & Tavazza 2016) and UK (Monger & Jeffries 2016). The current distribution suggests that the bacterium may be more widely distributed than previously reported (Loiseau et al. 2014). However, it is not present everywhere the vector is present (Teulon et al. 2009). There are similarities in the natural and urban environments of these areas to those in Australia, which suggests that '*Ca*. L. solanacearum' could survive and spread in Australia.
- '*Candidatus* Liberibacter solanacearum' can survive for a long period in, or on, contaminated or infected seeds. Consequently, it can be spread over long distances in a viable state through commercial distribution of seeds. During planting, infected seeds may be randomly distributed throughout the crop, which may result in localised areas of establishment and spread within the field.
- Apiaceous vegetables and herbs are grown in various regions of Australia. If imported infected seed is distributed throughout production areas, this will help spread '*Ca*. L. solanacearum' across Australia.
- Natural spread of '*Ca*. L. solanacearum' is dependent on the transmission of the bacterium by seeds and its psyllid vectors (Bertolini et al. 2015). Natural spread may be achieved

through seeds, as this bacterium is seed-borne in carrot, celery/celeriac, parsley and parsnip (Monger & Jeffries 2016) and seed transmissible in carrot (Bertolini et al. 2015).

- On carrot, celery/celeriac, chervil, fennel, parsley and parsnip, the infection may be maintained as long as new seeds are produced from the line originating from the infected imported seeds. It is likely that these cases will not lead to long distance spread, but rather to transient and localised '*Ca*. L. solanacearum' populations.
- '*Candidatus* Liberibacter solanacearum' has been detected in three species of *Bactericera* (*B. nigricornis, B. tremblayi* and *B. trigonica*) and *Trioza apicalis*. However, only *B. trigonica* and *T. apicalis* are known to transmit '*Ca*. L. solanacearum' naturally (Haapalainen 2014). This vector specificity suggests it is unlikely that Australian native psyllids would be able to transmit '*Ca*. L. solanacearum'. In the absence of psyllid vectors, natural long distance spread of '*Ca*. L. solanacearum' is likely to be limited or absent.

Presence of natural barriers

The presence of natural barriers in Australia is unlikely to have any influence on the spread of '*Ca*. L. solanacearum'.

- The transmission of '*Ca*. L. solanacearum' through seeds is an efficient mechanism by which plant pathogens are able to overcome natural barriers. Commercial seed distribution systems would help '*Ca*. L. solanacearum' to overcome natural barriers and establish throughout Australia, providing a high risk for its continued spread post-border.
- A significant natural barrier to the spread of '*Ca*. L. solanacearum' is the absence of suitable known insect vectors of the bacterium in Australia. The natural spread of '*Ca*. L. solanacearum' associated with apiaceous crops is achieved by *B. trigonica* (Bertolini et al. 2015) and *T. apicalis* (Munyaneza et al. 2010a), which are not present in Australia.

Potential for movement with commodities

There is a potential for domestic trade to facilitate the spread of '*Ca*. L. solanacearum'.

- Pathogens carried on seeds have a distinct advantage for long-distance spread that is not available to pathogens that rely exclusively on wind and rain-splash modes of dispersal. Pathogens that are exclusively dispersed by wind or rain are generally limited to short-distance spread, providing a host and suitable environment are present. In contrast, pathogens carried on seeds will continue to spread through human conveyance. The close association of a pathogen with seed increases its chances of survival during storage and transport over potentially long-distances, as well as increasing its likelihood of transferring to a suitable host.
- '*Candidatus* Liberibacter solanacearum' has the potential to spread from its point of introduction to new areas within Australia by human-assisted activities (via trade in propagative material). Carrot, celery/celeriac, chervil, fennel, parsley and parsnip are grown in various regions of Australia. If imported infected propagative material is distributed throughout production areas, this will help spread '*Ca*. L. solanacearum' throughout Australia.
- The increased trade of propagative material between (and within) countries has led to new opportunities for plant pathogens to spread to new areas (Dehnen-Schmutz et al. 2010; Stenlid et al. 2011; Wingfield, Slippers & Wingfield 2010). Infection of carrots with '*Ca*. L. solanacearum' in Austria, Finland, France, Germany, Italy, Morocco, Spain and Sweden (EPPO 2013; Haapalainen 2014; Ilardi, Di Nicola & Tavazza 2016; Munyaneza et al. 2015),

suggests that the movement of carrot seeds might be responsible for the introduction of this bacterium into these countries.

- The bacterium could be spread with the movement and trade of infected seeds and tissue cultures. However, spread of the bacterium by movement of infected planting material will likely result in an isolated infection if a vector is not present in the areas where the material is moved.

Potential natural enemies

- '*Candidatus* Liberibacter' species are not known to have any natural enemies that could hamper their spread. However, certain entomophagous and predatory insects can drastically reduce psyllid populations and thus indirectly prevent an increase of the pathogen population and associated spread where vectors are present (Aubert 1987).

Spread potential if known vectors establish in Australia

The information presented under this heading is only applicable to the assessment of the probability of spread of haplotype C, D and E of '*Ca*. L. solanacearum' in the event that known vectors were to establish in Australia.

- Vector-transmitted pathogens rely on complex interactions between the host, the vector and the pathogen for their spread. In plant pathosystems, the spread of a pathogen is highly dependent on the movement and mobility of the vector (Martini et al. 2015).
- '*Candidatus* Liberibacter solanacearum' is vector specific and is vectored naturally by *Bactericera trigonica* and *Trioza apicalis* (Haapalainen 2014). Other species of psyllids including *Bactericera nigricornis, B. tremblayi*, *Cacopsylla* species, *Ctenarytaina* species, *Psylla* species and *Trioza urticae* have been recorded on apiaceous crops, where this bacterium is present (Teresani et al. 2015). However, the bacterium was detected only in *Bactericera nigricornis* and *B. tremblayi*, and was not detected in the other species (Teresani et al. 2015).
- '*Candidatus* Liberibacter solanacearum' may initially be introduced to new areas on apiaceous crop seed (Bertolini et al. 2015; Monger & Jeffries 2016) and may afterwards be transmitted by different psyllid species in a persistent manner (Teresani et al. 2015). Psyllids acquire the bacterium while feeding on infected plants (Haapalainen 2014). Once the psyllid has acquired the bacterium from infected hosts, the vector is likely to maintain the ability to spread the bacterium in a persistent manner (Teresani et al. 2015).
- Psyllid vectors feeding on infected host plants are likely to acquire and maintain the bacterium (Haapalainen 2014). The natural spread of '*Ca*. L. solanacearum' by its psyllid vectors will depend on the acquisition period, the latency period of the pathogen in the psyllid prior to transmission and the transmission efficiency.

Trioza apicalis

- *Trioza apicalis* has a strong preference for its summer host and selects carrots over other host plants (Nehlin, Paltrova & Borg-Karlson 1996; Rygg 1977). *Trioza apicalis* has one generation per year and overwinters as an adult on conifers, favouring Norway spruce (*Picea abies*) as the winter host (Kristoffersen & Anderbrant 2007). Overwintering adult *T. apicalis* usually start migrating to carrot fields during early summer. They feed and lay eggs on carrot plants during summer (Kristoffersen & Anderbrant 2007). Both the summer and winter hosts of this psyllid are present in Australia.
- The factors triggering the carrot psyllid migration from overwintering hosts to carrots are not known. Terpenes produced in spruce needles may play a role in migration (Schönwitz et

al. 1990). Out of the terpenes, limonene was the most effective repellent of psyllids in carrot fields (Nehlin, Paltrova & Borg-Karlson 1996). Therefore, it has been suggested that that changes in the concentration of secondary metabolites in the winter host plant (that is, Norway spruce) could affect the migration of the carrot psyllid (Nissinen et al. 2007).

- Psyllids are highly effective dispersers over both short and long distances, although in almost all cases dispersal is wind assisted. The maximum distance that the carrot psyllid can fly is not known (Kristoffersen & Anderbrant 2007). However, *Trioza apicalis* is known to move up to one kilometre to shelter plants to overwinter (Kristoffersen & Anderbrant 2007).
- There are several species of *Trioza* in Australia including *T. banksiae, T. barrettae, T. euginae, T. kentae, T. malloticola, T. oleariae, T. pallida, T. percyae, T. tricornuta* and *T. tristaniae* (DEWHA 2009). Australian *Trioza* species feed on non-apiaceous hosts including Myrtaceae, Euphorbiaceae and Asteraceae (DEWHA 2009).

Bactericera trigonica

- The presence of psyllid vectors, including *B. trigonica*, can increase the presence of '*Ca*. L. solanacearum' in carrot fields from two per cent to close to 100 per cent after six months of cultivation (Bertolini et al. 2015).
- The '*B. nigricornis* group' (Hodkinson 1981), of which *B. trigonica* is a member, has polyphagous habits and overlapping areas of distribution, and is- widely distributed in the Mediterranean region (Ouvrard 2015). The '*B. nigricornis* group' feeds on a variety of herbaceous plants, including beet, cabbage, carrot, onion, parsley, potato (Burckhardt & Lauterer 1997) and celery (Alfaro-Fernández et al. 2012a; Bertolini et al. 2015).
- The '*B. nigricornis* group' is composed of multivoltine species, having two or three generations per year, which feed on carrots and other herbaceous crops (Hodkinson 2009). Eggs are laid on the host foliage and the entire duration of the lifecycle is four to five weeks; but this varies considerably depending on the hosts and temperatures. The adults overwinter in evergreen shrubs (Hodkinson 2009). Short development times and high rates of oviposition allow populations to increase explosively under optimal conditions (Liu & Trumble 2004).
- *Bactericera tremblayi* is associated with Mediterranean climates; however, *B. nigricornis* and *B. trigonica*, which are also found in these regions, are associated with more temperate climates (Teresani et al. 2015). Suitable climates are present in parts of Australia, which is likely to assist in the spread of these vectors.
- The spread of the bacterium in the presence of the vector can be dramatic. For example, in the presence of *B. trigonica*, '*Ca*. L. solanacearum' spread across an entire carrot field to infect 100 per cent of the crop (Bertolini et al. 2015). Therefore, in the presence of the vector, the bacterium can spread locally very quickly.
- *Bactericera* species feed and reproduce on a wide variety of hosts including carrot, celery and potato, whereas *T. apicalis* preferentially feed and breed on carrot, coriander and caraway (Valterova, Nehlin & BorgKarlson 1997). These hosts are widespread in commercial, natural and urban environments of Australia. This makes it increasingly likely that the vectors would spread '*Ca*. L. solanacearum' to suitable hosts, if introduced to Australia.
- Temperature and humidity may affect both the absolute distribution and the relative breeding success of a psyllid species across its range (Hodkinson 2009). Overlapping host

ranges would provide ample opportunity for *B. nigricornis* (which can feed on carrot and celery) to acquire '*Ca*. L. solanacearum' and spread it to healthy hosts.

Spread potential in the absence of known vectors

The absence of known vectors from Australia is likely to significantly limit the spread of '*Ca*. L. solanacearum'.

- In the absence of known vectors, the most likely means of spread of '*Ca*. L. solanacearum' would be through the movement of infected planting material (seeds and tissue cultures). If infected planting material is used it will spread the bacterium to non-infested areas within Australia.
- '*Candidatus* Liberibacter solanacearum' is vector specific and is vectored naturally by *Bactericera trigonica* and *Trioza apicalis* (Haapalainen 2014). These specific vectors are not present in Australia.

4.1.4 Overall likelihood of entry, establishment and spread

The overall likelihood of entry, establishment and spread is determined by combining the likelihoods of entry, of establishment and of spread using the matrix of rules shown in Table 2.

- The overall likelihood that '*Ca*. L. solanacearum' will enter Australia on seed and tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip), be distributed in a viable state to susceptible hosts, establish in that area and subsequently spread within Australia is set out in Table 11.
  - Association with the seed, transmission of this bacterium from infected propagative material to the resultant seedling, and the detection of this bacterium in host crops in a wide range of climates supports a likelihood estimate for entry and establishment of 'high'; and
  - The ability of the bacterium to quickly spread within the entire crop in the presence of a vector would support a likelihood estimate for spread of 'high'. However, in the absence of the psyllid vectors the spread of the bacterium transmission would only be through the movement of infected planting material (seeds and tissue cultures) and will be limited to the infected plant within a field and the inability of the bacterium to spread independently supports a likelihood for spread of 'low'.

Table 11 Overall likelihood of entry, establishment and spread of '*Ca.* L. solanacearum' on different pathways

Pathway	Likelihood of			Overall likelihood of entry, establishment and spread
	Entry	Establishment	Spread	
Seeds for sowing	High	High	High (low)*	High (low)*
Tissue cultures	High	High	High (low)*	High (low)*

* Ratings in parenthesis are in the absence of known vectors in Australia

4.1.5 Consequences

The potential consequences of the introduction and spread of '*Ca*. L. solanacearum' associated with apiaceous crops in Australia have been estimated according to the methods described in Table 3. The overall estimated consequences of introduction and spread of '*Ca*. L. solanacearum' in Australia, is 'moderate'.

Criterion	Estimate and rationale
Direct	
Plant life or health	E—Significant at the regional level '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) has a direct impact on plant life or health of significance at the regional level, which has an impact score of 'E'. This is because the impact would be expected to threaten economic viability through a decrease in production of infected crops at the regional level. *'Ca.* L. solanacearum' associated with apiaceous crops causes yellows decline and vegetative disorders in carrots (Munyaneza et al. 2010b, a) and vegetative disorders in celery/celeriac (Teresani et al. 2014b). The bacterium/vector complex has caused serious damage to the carrot and celery industry in Europe, where it can cause up to 100 per cent crop loss (EPPO 2013) without management. • Symptoms caused by '*Ca*. L. solanacearum' in carrot plants include leaf yellowing, bronze or red leaf discolouration, reduced size of the main root and lateral root proliferation (Munyaneza et al. 2011). Other symptoms include stunting, proliferation of dwarfed shoots with bushy tops and a dense hairy growth of secondary roots (Loiseau et al. 2014). • Symptoms caused by '*Ca*. L. solanacearum' in celery/celeriac include an abnormal amount of shoots, curling of stems and yellowing (Teresani et al. 2014b). The economic impact on plant life or health may depend on the extent of symptom expression on carrot and celery/celeriac. In addition to the yield, the quality of the crop is also affected, with a reduced amount of sugars and increased amounts of phenolic compounds in the root resulting in a bitter taste (Nissinen et al. 2012; Seljåsen et al. 2013). Vegetative disorders associated with '*Ca*. L. solanacearum' in carrot producing areas in Spain have caused economic losses in carrot production for the fresh market (Bertolini et al. 2015). • Hosts include carrot, celery/celeriac, chervil, fennel, parsley and parsnip and multiple industries are expected to be impacted significantly at the regional level.
Other aspects of the environment	A—Indiscernible at the local level The direct impact of '*Ca*. L. solanacearum' on other aspects of the environment would be indiscernible at the local, district, regional and national levels, which has an impact score of 'A'. '*Candidatus* Liberibacter solanacearum' haplotypes associated with apiaceous crops are unlikely to affect the environment in these ways, as the bacterium is only reported to infect and multiply in carrot, celery/celeriac, chervil, fennel, parsley and parsnip (Cambra et al. 2015; Hajri et al. 2017; Monger & Jeffries 2016; Munyaneza et al. 2010b, a; Teresani et al. 2014a). There are no known direct consequences of this pathogen on other aspects of the environment.
Indirect	
Eradication, control	E—Significant at the regional level The indirect impact of '*Ca*. L. solanacearum' on eradication and control would be of major significance at the district level, significant at the regional level and minor significance at the national level, which has an impact score of 'E'. This is because the impact would be expected to threaten economic viability through a large increase in costs for containment, eradication and control at the regional level. Containment and eradication is costly and would also cause disruption to Australia's agribusiness and associated trades. The combination of human-induced introductions (Bertolini et al. 2015) and potential human-assisted spread (trade in infected seeds and tissue cultures) makes this a difficult pathogen to eradicate. • There are no agri-chemicals available to control '*Ca.* L. solanacearum' in host crops. Control of the psyllid vector would be the key to limiting the spread impact of this pathogen. The use of '*Ca*. L. solanacearum'-free seeds for sowing complemented with psyllid control to prevent transmission of the bacterium may be a feasible method to control the bacterium.

Criterion	Estimate and rationale
	• The reduction of the psyllid population would be critical, as even vectors with poor transmission efficiency may play a role in spreading the bacterium. For example, high abundance of the vector may compensate for poor transmission efficiency. Insecticidal sprays would be required to manage psyllid populations (Fischer & Terrettaz 2002; Láska 1974), which would increase production costs. Growth of host crops in insect-proof facilities could potentially protect crops from this bacterium.
Domestic trade	D—Significant at the district level The indirect impact of '*Ca*. L. solanacearum' on domestic trade would be of major significance at the local level, significant at the district level, and of minor significance at the regional level, which has an impact score of 'D'. This is because the impact would be expected to threaten economic viability through a reduction of trade or loss of domestic markets at the district level. • Biosecurity measures would be enforced to prevent the movement of plant material out of the initial incursion area, which would have significant economic impacts on plant industries and businesses at the district level. • The introduction of '*Ca*. L. solanacearum' to a state or territory would disrupt interstate trade due to the biosecurity restrictions on the domestic movement for host fruit, vegetables, seeds and nursery stock. Interstate restrictions on these commodities could lead to a loss of markets, which would likely require industry adjustment.
International trade	D—Significant at the district level The indirect impact of '*Ca*. L. solanacearum' on international trade would be of major significance at the local level, significant at the district level, and of minor significance at the regional level, which has an impact score of 'D'. This is because the impact would be expected to threaten economic viability through loss of trade and export markets at the district level. • The presence of '*Ca*. L. solanacearum' in Australia would likely result in additional export requirements, such as testing of propagative material (carrot, celery/celeriac, parsley and parsnip) for freedom from '*Ca*. L. solanacearum'. This would add significant costs to nursery stock production in Australia. For example, several countries require country freedom or other certification requirements to address the risk of '*Ca*. L. solanacearum' in imported host commodities. • If '*Ca*. L. solanacearum' became established in Australia, restrictions on Australian exports of carrot, celery/celeriac, parsley and parsnip propagative material would be anticipated. The establishment of '*Ca*. L. solanacearum' in Australia could therefore reduce access to international markets and result in additional phytosanitary requirements that would impose a cost burden.
Environmental and non-commercial	C—Significant at the local level. The impact of '*Ca*. L. solanacearum' on other aspects of the environment would be significant at the local level, minor significance at the district level, and indiscernible at the regional level, which has an impact score of 'C'. • No control measures are available for the bacterium, however, broad-scale chemical treatments directed against known insect vectors may have some indirect impacts on native insects. • In Europe, insecticidal sprays are required to manage psyllid populations, as without sprays, substantial losses have been reported (Fischer & Terrettaz 2002; Láska 1974; Tiilikkala, Ketola & Taivalmaa 1995). Insecticidal sprays used to control psyllid populations may also have some impacts on the environment, including native insects.

Based on the decision rules described in Table 4, that is, where the potential consequences of a pest with respect to one or more criteria have an impact of 'E', the overall consequences are estimated to be moderate.

4.1.6 Unrestricted risk estimate

Unrestricted risk is the result of combining the likelihoods of entry, establishment and spread with the outcome of overall consequences. Likelihoods and consequences are combined using the risk estimation matrix shown in Table 5.

Unrestricted risk estimate for '*Ca.* L. solanacearum' associated with apiaceous crops	
Overall likelihood of entry, establishment and spread	High (low)*
Consequences	Moderate
Unrestricted risk	Moderate (low)*

*Ratings in parenthesis are in the absence of known vectors in Australia

4.1.7 Pest risk conclusion

The unrestricted risk estimate for '*Ca*. L. solanacearum' associated with propagative materials of apiaceous crops does not achieve ALOP for Australia, meaning that risk management measures against this bacterium are required.

5 Pest risk management

'*Candidatus* Liberibacter solanacearum' presents an unrestricted risk that does not achieve the appropriate level of protection (ALOP) for Australia. Therefore, risk management measures are required to reduce the estimated risk to a level of very low and to achieve the ALOP for Australia. The recommended risk management measures are described in this chapter.

5.1 Recommended pest risk management measures

Australia considers that the emergency measures, introduced in October 2014, are adequate to mitigate the risk posed by '*Ca*. L. solanacearum' associated with apiaceous propagative material (seeds and tissue cultures) and will provide an appropriate level of protection for Australia. Since the introduction of the emergency measures, chervil, fennel, parsley and parsnip have been reported as natural hosts of '*Ca*. L. solanacearum'. Therefore, these emergency measures, with some minor amendments, are recommended to become the standard conditions for the importation of seeds (carrot, celery/celeriac, parsley and parsnip) and tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) into Australia. The recommended changes to the emergency measures include an option for small seed lots to be tested off-shore, and an option for tissue cultures to be tested off-shore or on-shore.

5.1.1 Seeds for sowing—carrot, celery/celeriac, chervil, fennel, parsley and parsnip

- **Testing**—mandatory Polymerase Chain Reaction (PCR) testing off-shore or on-shore using 20,000 seeds (or 20 per cent of small seed lots) to verify freedom from '*Candidatus* Liberibacter solanacearum'; OR
- **Heat treatment**—mandatory off-shore or on-shore hot water treatment (50 °C for 20 minutes);

  AND
- **Certification**—seed lots tested or treated off-shore must be accompanied by an official government Phytosanitary Certificate endorsed with the following additional declaration:

  'The consignment of [*botanical name* (*Genus species*)] was tested by Polymerase Chain Reaction (PCR) [*insert laboratory name and report number*] on a sample size of 20,000 seeds (or 20 per cent of small seed lots) and found free from *'Candidatus* Liberbacter solanacearum'.

  OR

  'The consignment of [*botanical name* (*Genus species*)] was treated with hot water at a minimum temperature of 50 °C for at least 20 minutes'.
- **On-arrival inspection**—seed lots must be subject to on-arrival inspection to verify freedom from live insects, soil, disease symptoms, prohibited seeds, other plant material (for example leaf and stem material, fruit pulp and pod material), animal material (for example animal faeces and feathers) and any other extraneous contamination of quarantine concern.

5.1.2 Tissue cultures—carrot, celery/celeriac, chervil, fennel, parsley and parsnip

In addition to recommending the continuance of the current import conditions for tissue cultures produced and tested off-shore, the department recommends an alternative set of conditions for tissue cultures to be tested on-shore.

Tissue cultures (off-shore option)—carrot, celery/celeriac, chervil, fennel, parsley and parsnip

- **Mandatory testing (off-shore)**—imported tissue cultures must be subjected to off-shore PCR testing for freedom from '*Candidatus* Liberibacter solanacearum'.
- **Certification**—tissue cultures tested off-shore must be accompanied by an official government Phytosanitary Certificate endorsed with an additional declaration that the testing has been conducted in accordance with Australia's requirements.
- **On-arrival inspection**—imported tissue cultures must be subjected to on-arrival inspection to verify freedom from live insects, soil, disease symptoms, prohibited seeds, other plant material (for example leaf and stem material, fruit pulp and pod material), animal material (for example animal faeces and feathers) and any other extraneous contamination of quarantine concern.

Tissue cultures (on-shore option)—carrot, celery/celeriac, chervil, fennel, parsley and parsnip

- **On-arrival inspection**—imported tissue cultures must be subjected to on-arrival inspection to verify freedom from live insects, soil, disease symptoms, prohibited seeds, other plant material (for example leaf and stem material, fruit pulp and pod material), animal material (for example animal faeces and feathers) and any other extraneous contamination of quarantine concern.
- **Growth in PEQ with disease screening and testing**—imported tissue cultures must be grown in a closed government PEQ facility until they have reached a sufficient stage of growth for disease screening and testing. PCR testing for *'Candidatus* Liberibacter solanacearum'will assist in the detection of the bacterium in both symptomatic and asymptomatic plants.

The recommended risk management measures for importing apiaceous crop seeds for sowing (carrot, celery/celeriac, parsley and parsnip) and tissue cultures (carrot, celery/celeriac, chervil, fennel, parsley and parsnip) are summarised in Table 12.

Table 12 Risk management measures for the importation of apiaceous crop seeds for sowing and tissue cultures

Recommended risk management measures	Seeds for sowing	Tissue cultures (off-shore option)	Tissue cultures (on-shore option)
Pre-border			
Off-shore PCR testing	Yes*	Yes	No
Off-shore heat treatment	Yes*	No	No
Phytosanitary Certification	Yes* (if testing or treatment conducted off-shore)	Yes	No
Border			
On-arrival inspection	Yes	Yes	Yes
On-shore PCR testing	Yes* (if not tested off-shore)	No	No
On-shore heat treatment	Yes* (if not treated off-shore)	No	No
Post-border			
Growth in PEQ	No	No	Yes

Recommended risk management measures	Seeds for sowing	Tissue cultures (off-shore option)	Tissue cultures (on-shore option)
Disease screening and PCR testing during PEQ	No	No	Yes

* Apiaceous crop seeds for sowing are subject to either mandatory heat treatment or mandatory PCR testing. Heat treatment or PCR testing may be conducted off-shore or on-shore. A Phytosanitary Certificate is only required for consignments that have been subject to off-shore PCR testing or heat treatment.

5.1.3 Consideration of alternative measures

Consistent with the principle of equivalence detailed in ISPM 1 (FAO 2016a) and ISMP 11 (FAO 2016f), the Australian Government Department of Agriculture and Water Resources will consider any alternative measure proposed by a NPPO, providing that it achieves the ALOP for Australia. Evaluation of such measures or treatments will require a technical submission from the NPPO that details the proposed treatment, including data from suitable treatment trials to demonstrate efficacy.

Sourcing seeds and tissue cultures from pest free areas (country freedom)

The establishment and use of a pest free area (PFA) by a NPPO provides assurance that specific pests are not present in a delimited geographic area. The delimitation of a PFA should be relevant to the biology of the pest concerned.

The requirements for establishing pest free areas (PFA) are set out in ISPM 4 (FAO 2016c). This ISPM defines a PFA as 'an area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained'. A PFA may concern all or part of several countries and it is managed by the NPPO of the exporting country. The establishment and use of a PFA by a NPPO allows an exporting country to export plants and other regulated articles to an importing country without having to apply additional phytosanitary measures—if certain requirements are met.

Requirements for a NPPO to establish and maintain a PFA include:

- systems to establish freedom (general surveillance and specific surveys)
- phytosanitary measures to maintain freedom (regulatory actions, routine monitoring, and extension advice to producers)
- checks to verify freedom has been maintained.

NPPOs that propose to use area freedom as a measure for managing risks posed by *'Ca*. L. solanacearum' must provide the Department of Agriculture and Water Resources with an appropriate submission demonstrating area freedom, for its consideration.

Sourcing seeds and tissue cultures from pest-free places of production

Requirements for establishing pest free places of production are set out in ISPM 10 (FAO 2016e). The concept of 'pest freedom' allows exporting countries to provide assurance to importing countries that plants, plant products and other regulated articles are free from a specific pest or pests and meet the phytosanitary requirements of the importing country. Where a defined portion of a place of production is managed as a separate unit and can be maintained pest free, it may be regarded as a pest free production site.

Requirements for a NPPO to establish and maintain a pest free place of production or a pest free production site as a phytosanitary measure include:

- systems to establish pest freedom
- systems to maintain pest freedom
- verification that pest freedom has been attained or maintained
- product identity, consignment integrity and phytosanitary security.

Where necessary, a pest free place of production or a pest free production site must also establish and maintain an appropriate buffer zone.

Administrative activities required to support a pest free place of production or pest free production site include documentation of the system and maintenance of adequate records about the measures taken. Review and audit procedures undertaken by a NPPO are essential to support assurance of pest freedom and for system appraisal. Bilateral agreements or arrangements may also be needed.

NPPOs that propose to use pest-free places of production as a measure for managing risks posed by *'Ca*. L. solanacearum' must provide the Department of Agriculture and Water Resources with an appropriate submission demonstrating pest-free place of production status, for its consideration.

Sourcing seeds produced under systems approach

ISPM 14 (FAO 2016g) provides guidelines on the use of systems approaches to manage pest risk. According to ISPM 14 (FAO 2016g), 'a systems approach requires the integration of different measures, at least two of which act independently, with a cumulative effect' that achieves the appropriate level of protection.

Systems approaches could provide an alternative to relying on a single measure to achieve the ALOP of an importing country—or be used where no single measure is available. Systems approaches are often tailored to specific commodity–pest–origin combinations and may be developed and implemented collaboratively by exporting and importing countries. The importing country selects the appropriate approach after considering technical requirements, minimal impact, transparency, non-discrimination, equivalence and operational feasibility.

NPPOs that propose to use a systems approach as a measure for managing risks posed by *'Ca*. L. solanacearum' must provide the Department of Agriculture and Water Resources with an appropriate submission describing their preferred systems approach and rationale, for its consideration.

5.2 Review of policy

The Department of Agriculture and Water Resources reserves the right to review the import policy and conditions periodically and/or when conditions change (or might have changed).

6 Conclusion

The findings of this pest risk analysis are based on a comprehensive analysis of relevant scientific and other appropriate literature on '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops. '*Candidatus* Liberibacter solanacearum' meets the International Plant Protection Convention (IPPC) definition of a quarantine pest, that is being of 'potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled' (FAO 2016d). The PRA provides technical justification that this bacterium meets the IPPC definition of a quarantine pest, and that the introduction of emergency measures were in accordance with international phytosanitary standards.

The Department of Agriculture and Water Resources considers that the existing emergency measures are adequate to achieve an appropriate level of protection against '*Ca*. L. solanacearum' associated with seed (carrot) and tissue cultures (carrot, and celery/celeriac). More recently, chervil, fennel, parsnip and parsley were reported as natural hosts of '*Ca*. L. solanacearum'; consequently, these emergency measures are extended to include celery/celeriac, chervil, fennel, parsley and parsnip seeds. The existing emergency measures are recommended to become the standard conditions to import carrot, celery/celeriac, chervil, fennel, and parsley and parsnip propagative material into Australia. The recommended minor changes to the emergency measures include the option for small seed lots to be tested off-shore, and the option for tissue cultures to be tested off-shore or on-shore.

Appendix A: Stakeholder comments on the draft PRA

The department circulated the draft pest risk analysis for '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops in December 2015 for stakeholder consultation (G/SPS/N/AUS/377). The department received several written responses from stakeholders, including seed companies, international and domestic seed federations and National Plant Protection Organizations (NPPOs). A summary of responses to issues raised by stakeholders is provided below.

Issues raised by stakeholders in response to the draft PRA

The risk assessment for '*Ca*. L. solanacearum'

The draft PRA is based on literature research independent of other regulators

This PRA was conducted in accordance with the International Standards for Phytosanitary Measures (ISPMs) that have been developed under the 'World Trade Organisation Agreement on the Application of Sanitary and Phytosanitary Measures' (SPS Agreement) (WTO 1995). It is Australia's sovereign right to conduct PRAs independently in order to prevent the introduction of identified quarantine pests (in this case, to prevent the introduction of '*Ca*. L. solanacearum' into Australia). International Standards for Phytosanitary Measures (ISPM) No. 1 requires that countries publish and disseminate phytosanitary requirements, restrictions and prohibitions promptly, and that the rationale for such measures be made available upon request (FAO 2016a). Consistent with the principle of transparency, the department released the draft PRA for consultation to national and international stakeholders to provide comments on all aspects, including phytosanitary measures.

While conducting this PRA, Australia followed the phytosanitary principles as outlined in ISPM No. 1 (FAO 2016a):

- Sovereignty—the department utilised phytosanitary measures to regulate carrot seed and tissue cultures of carrot and celery/celeriac to prevent the introduction of '*Ca*. L. solanacearum' through these pathways.
- Necessity—the department introduced phytosanitary measures as required to prevent the introduction of '*Ca*. L. solanacearum' through carrot seed (this bacterium has recently been intercepted on imported carrot seed during on-arrival testing in Australia). The absence of phytosanitary measures would have resulted in the risk of introduction of this bacterium into Australia.
- Managed risk—The introduced measures were based on a policy of managed risk (recognising that a risk of introduction for '*Ca*. L. solanacearum' always exists when importing carrot seed for sowing).
- Transparency—the department published the introduced emergency measures through a WTO SPS notification (G/SPS/N/AUS/345) and a draft PRA providing scientific justification for the introduced emergency measures through a WTO SPS notification (G/SPS/N/AUS/377). The publication of the PRA gave an opportunity to all interested parties to provide input into the PRA.
- Technical justification—the department published a PRA providing technical justification for the introduced emergency measures based on an appropriate pest risk analysis.

Some stakeholders questioned the seed-borne nature and seed transmission of '*Ca*. L. solanacearum' in carrot. The department notes the published scientific evidence demonstrating seed association and seed transmission in carrot has been peer-reviewed and published in a reputable scientific journal (Bertolini et al. 2015). Multiple detections in seed produced in France and Spain were reported in that study. The seed-borne nature of this pathogen has subsequently been reported in Italy, where '*Ca*. L. solanacearum' was detected in multiple commercial seed lots of different carrot cultivars (including the cultivars 'Berlicum', 'Nantese', 'Flakèe' and 'Mezza Lunga Nantese') (Ilardi, Di Nicola & Tavazza 2016). Of seven carrot seed lots examined, '*Ca*. L. solanacearum' was detected in all six seed lots except for one lot of the cultivar 'Bolero' (Ilardi, Di Nicola & Tavazza 2016). Furthermore, '*Ca*. L. solanacearum' was detected in imported carrot seed during on-arrival testing in Australia in early 2016, providing further evidence that this bacterium is seed-borne in carrot. If this infected seed had been used for sowing, the bacterium may have established in Australia.

The department notes that '*Ca*. L. solanacearum' is also regulated in carrot seed imports by other NPPOs including Argentina, Chile, Japan and New Zealand.

Risk averse conclusion

Stakeholders have commented that the conclusion of the PRA will adversely affect Australian growers' ability to access new germplasm to stay competitive.

The department considers that the draft PRA provides transparent, scientific justification for the proposed risk management measures. The phytosanitary measures are necessary to protect the Australian apiaceous vegetable industry, which had a gross value of $189 million in 2013/2014. Since the introduction of the emergency measures, the department has intercepted '*Ca*. L. solanacearum' on imported carrot seed consignments from the European Union (EU), as detected through on-arrival PCR testing in Australia. Therefore, the department considers that carrot seed is a demonstrated pathway for this bacterium and that it poses an unacceptable risk to Australia if unregulated.

Since the introduction of phytosanitary measures against '*Ca*. L. solanacearum' a large quantity of carrot seed has still been imported into Australia, demonstrating that the introduced measures have not prevented local industry from sourcing carrot seed from overseas.

Conclusion of this PRA sets a dangerous precedent for other NPPOs to introduce phytosanitary measures

Stakeholders have commented that the conclusion of this PRA sets a dangerous precedent for other NPPOs to implement unilateral and non-harmonised phytosanitary measures where little research data is available.

The department considers that sufficient data is available on the bacterium and the economic losses it causes in Europe, as outlined in the draft PRA, to warrant the measures imposed. The scientific evidence for its association with apiaceous hosts, such as its seed transmission in carrot, is thoroughly examined in the draft PRA. Studies by Bertolini et al. (2015), Ilardi et al. (2016) and Monger & Jeffries (2016), and the detection of this bacterium in imported carrot seed in Australia in early 2016, clearly demonstrate the seed-borne nature of this bacterium. In accordance with ISPM No. 1, countries have the sovereign authority to utilise phytosanitary

measures to prevent the introduction and/or spread of quarantine pests into their country (FAO 2016a).

Phytosanitary measures are not technically justified, are trade restrictive, and should be scientifically based and proportional to the risks

Stakeholders have commented that the phytosanitary measures are not technically justified, are trade restrictive and should be scientifically based and proportional to the risks.

The department considers that the draft PRA provided transparent, scientific justification for the proposed risk management measures. '*Candidatus* Liberibacter solanacearum' associated with apiaceous crops has already caused significant economic consequences in Europe, as detailed in the draft PRA. The scientific evidence for its association with apiaceous hosts, such as its seed transmission in carrot, is thoroughly examined in the draft PRA. Studies by Bertolini et al. (2015), Ilardi et al. (2016) and Monger & Jeffries (2016) and the detection of this bacterium in imported carrot seed in Australia in early 2016, clearly demonstrate the seed-borne nature of this bacterium.

The protocols foreseen do not take into consideration the characteristics of the mentioned seeds

Stakeholders have commented that the protocols foreseen do not take into consideration the characteristics of the mentioned seeds.

The department notes that stakeholders did not provide any details as to what characteristics of the seed needed to be taken into consideration, nor the reason why they need to be taken into consideration, nor was any technical justification provided. '*Ca*. L. solanacearum' is demonstrably seed-borne in carrot (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January), parsley and parsnip (Monger & Jeffries 2016) and the detection of this bacterium during on-arrival mandatory seed testing in Australia in early 2016 clearly validates the ability of the bacterium to remain on seed during transportation over thousands of kilometres. The detection of '*Ca*. L. solanacearum' in imported carrot seed in Australia raises the question of whether this bacterium has a wider geographic distribution than is currently known. If other countries are not using tested seeds then the probability of introduction is high for those countries.

The negative impact of treatment on carrot seed quality and performance

Stakeholders commented that the proposed treatment that is hot water treatment of seed at 50°C for 20 minutes may negatively impact the quality and performance of seeds and in particular may have harmful effects on the germination rate.

The department notes that heat treatment is only one of the risk management options for '*Ca*. L. solanacearum' associated with carrot seed; the department also accepts PCR testing of seeds as an alternative risk management measure.

The draft PRA proposed that carrot seeds should undergo hot water treatment (50°C for 20 minutes), which is a standard procedure to mitigate the risk of bacterial pathogens of carrot seed. As was outlined in the draft PRA, carrot seeds are routinely treated by hot water at 50°C for 20 minutes to control *Alternaria* species, bacterial blight and other bacterial pathogens (Floyd & Melvin-Carter 2005; McGrath 2005). Consequently, carrot seed characteristics have been taken into account in the development of the heat treatment method. The department will

consider alternative treatment options if stakeholders can provide technical justification for their effectiveness against '*Ca*. L. solanacearum' associated with carrot seeds.

Emergency measures based on a study that is scientifically unclear

Some stakeholders considered that the emergency measures introduced by the department are based on a study that is scientifically unclear, that is, there is no evidence that experiments were repeated and the outcome confirmed.

ISPMs No. 1 and 11 require that pest risk management measures be technically justified, but allow for some uncertainty, providing that it is clear where expert judgement has been used. The department considers that the measures are appropriate and based on the best evidence that is currently available.

As detailed in the draft PRA, Australia's proposed measures for carrot seed are primarily based on the recent detection of '*Ca*. L. solanacearum' in several commercial carrot seed lots produced in France and Spain (Bertolini et al. 2015). '*Candidatus* Liberibacter solanacearum' was demonstrated to be seed transmitted in carrots, as shown by the presence of infected seedlings resulting from PCR positive carrot seed lots grown in an insect-proof, P2 level containment greenhouses (Bertolini et al. 2015). Since the release of the draft report, further studies have demonstrated that '*Ca*. L. solanacearum' is seed-borne in carrot (Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January) and parsley and parsnip (Monger & Jeffries 2016).

Since the introduction of the emergency measures, the department has intercepted '*Ca*. L. solanacearum' on imported carrot seed consignments from the EU, as detected through PCR testing. Therefore, the department considers that carrot seed is a demonstrated pathway for this bacterium and poses an unacceptable risk to Australia.

The department notes that there is strong evidence of the association of '*Ca*. L. solanacearum' with seeds of apiaceous species. However, there are conflicting reports on the seed to seedling transmission in apiaceous crops. (Bertolini et al. 2015) demonstrated seed to seedling transmission but other authers failed to reproduce these results (Loiseau et al. 2017a; Loiseau et al. 2017b). Therefore, the department is applying appropriate caution until further information is available.

Association of '*Ca*. L. solanacearum' with carrot seed

Seed-borne nature and seed transmission of '*Ca*. L. solanacearum'

Stakeholders questioned the seed-borne and seed transmission nature of '*Ca*. L. solanacearum' in carrot.

The department considers that the seed-borne nature of '*Ca.* L. solanacearum' in apiaceous crops is well documented (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016), celery/celeriac (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January) parsley and parsnip (Monger & Jeffries 2016). Therefore, there is strong evidence of the association of the '*Ca.* L. solanacearum' with seed of these commodities.

The scientific paper that initially demonstrated seed transmission of '*Ca*. L. solanacearum' in carrot has been peer-reviewed and published in a reputable scientific journal (Bertolini et al. 2015). Multiple detections in seed produced in France and Spain were reported in the study. The

detection in various cultivars indicates that the bacterium is widespread and can persist in the seed for a long time, as the bacterium was tested in seed lots produced in different years (Bertolini et al. 2015). Persistent infection of '*Ca*. L. solanacearum' in seedlings from positive seed lots grown in a P2 level containment (insect-proof) greenhouse were demonstrated in this study. Between 12% and 42% of the seedlings from positive seed lots tested positive for this bacterium (Bertolini et al. 2015). These results demonstrate that '*Ca*. L. solanacearum' is seed-transmitted in carrot.

Loiseau et al. (2017a; 2017b) tried twice to assess the transmission of this bacterium, but both times the authers failed to reproduce the results reported by Bertolini et al. (2015). In their first trial, plants were placed in overwintering conditions from the fourth month, which was quite different from what was done by Bertolini et al. (2015). '*Candidatus* Liberibacter solanacearum' is sensitive to low temperature (Munyaneza et al. 2012a). The overwintering conditions applied to the carrot seedlings may have inhibited the development of the bacterium , which led to the failure of detection this bacterium in seedlings (Loiseau et al. 2017a). Further, in the second trial, despite using the growing conditions described by Bertolini et al. (2015), their study still suggested no bacterial transmission from seed to seedlings (Loiseau et al. 2017b). Although lack of consistent results to prove that '*Ca*. L. solanacearum' is transmitted from seed to seedlings, none of the research findings can exclude seed as a transmission pathway.

Since the publication of Bertolini et al. (2015), this bacterium has also been reported in commercial carrot seeds in Italy (Ilardi, Di Nicola & Tavazza 2016). In early 2016, '*Ca*. L. solanacearum' was detected in imported carrot seed in Australia, which demonstrated the seed-borne nature of this bacterium.

Role of carrot seed in spreading '*Ca*. L. solanacearum'

Stakeholders questioned the role of carrot seed in spreading '*Ca*. L. solanacearum'.

The draft PRA stated that '*Ca*. L. solanacearum' has been recently detected in, rather than spread into, other countries. Seed dispersal by human seems a likely mechanism for the long-distance spread of the pathogen in Europe, which has been found in geographically distant countries; in contrast, relatively short-distance spread would be expected if it is only spread by the psyllid vectors. Australia acknowledges that psyllids are highly effective dispersers over both short and long distances, although in almost all cases, psyllid dispersal is wind assisted. *Trioza apicalis* is known to move up to one kilometre (Kristoffersen & Anderbrant 2007), indicating the carrot psyllid could spread the bacterium from infected plants to relatively distant healthy plants. The maximum distance that the carrot psyllid can fly is not known (Kristoffersen & Anderbrant 2007), however it is unlikely that the bacterium was spread by psyllids carrying it to all of these countries. Therefore, carrot seeds are likely to be the initial source of inoculum in these countries. The recent detection of '*Ca*. L. solanacearum' in imported carrot seed during on-arrival testing in Australia in early 2016 indicates that if this infected seed was grown in Australia, it may have established in Australia's carrot growing areas.

Australian historic imports of carrot seed and absence of '*Candidatus* Liberibacter solanacearum'

Stakeholders have suggested that Australia has been importing carrot seed for sowing for decades from areas where this bacterium is now known to exist. Therefore, the bacterium would have been already introduced into Australia through imports of carrot seed.

The department acknowledges that carrot seed has been imported into Australia for decades without any specific testing. However, '*Ca*. L. solanacearum' has only recently been recognised as seed-borne and seed-transmissible in carrot (Bertolini et al. 2015), which prompted Australia to introduce emergency measures (mandatory testing or heat treatment) to mitigate the risk of accidental introduction. To date there is no evidence that this bacterium has established in Australia as a result of historic trade in carrot seed.

Different haplotypes in Northern and Southern Europe

Stakeholders have suggested that the haplotypes in Northern and Southern Europe are not identical. Therefore, if seed transmission were the main source of spread one would expect there to be a dominant haplotype across areas that share the same seed source.

The observation of field occurence of '*Ca*. L. solanacearum' haplotypes should not be taken as a full reflection of patterns of detection of this bacterium on traded seed. Distribution in the field reflects a complex interaction of factors. Some known and some likely not, which would be expected to include vector distribution and habits, environmental aspects (temperature may be important), crop cultivar susceptibilities etc. Hypothetically 'haplotype C' may have been distributed with seed within northern and central Europe and 'haplotype D, E' with seed from Spain (France) to France (Spain) and Morocco.

Seed testing for '*Ca*. L. solanacearum'

The implementation of a non-validated seed test

Stakeholders have suggested that the department implemented a non-validated PCR test for the detection of '*Ca*. L. solanacearum' in carrot seed. The department considers that the PCR test used for the detection '*Ca*. L. solanacearum' has been peer-reviewed and published in a reputable scientific journal (Bertolini et al. 2015) and has been consistently used to detect '*Ca*. L. solanacearum' in carrot, celery/celeriac and parsnip crops as well as in psyllid vectors (Cambra et al. 2015; Tahzima et al. 2014; Teresani et al. 2015; Teresani et al. 2014b). Monger and Jeffries (2016) used PCR to detect this bacterium in commercially available parsley seed.

Most recently in Australia, '*Ca*. L. solanacearum' was detected in imported carrot seed during on-arrival seed testing using PCR. The detection of '*Ca*. L. solanacearum' in imported carrot seed demonstrates that '*Ca*. L. solanacearum' is seed-borne and that the recommended PCR test is able to detect this bacterium. Therefore, the department considers that the PCR test recommended to detect '*Ca*. L. solanacearum' is appropriate and justified.

Detection and differentiation of dead and live bacterial cells

PCR tests can detect and quantify the bacterial genome, but does not differentiate between live or dead bacterial cells. However, DNA intercalating dyes such as ethidium monoazide (EMA) or propidium monoazide (PMA) have been used to detect and quantify DNA from only live cells (Nocker & Camper 2006; Nocker, Sossa & Camper 2007; Temple et al. 2013; Trivedi et al. 2009). Bertolini et al. (2015) used PMA to quantify live '*Ca*. L. solanacearum' cells in carrot seeds. This study found that the majority (about 95 per cent) of the seeds' bacterial population was dead. However, the live cells (5 per cent) were enough to cause infection in carrot seedlings germinated from infected seeds (Bertolini et al. 2015). Similar results have been reported for '*Ca*. L. asiaticus' (83 per cent dead cells) after treatment with ethidium monoazide (Trivedi et al. 2009). This also suggests that the detection of dead bacterial cells in a sample can be an indication that low levels of live bacterial cells are present. Therefore, the department considers

that it is not necessary to differentiate between live and dead cells when testing for the presence of '*Ca*. L. solanacearum' in seeds.

Higher number of seeds required to verify freedom from '*Ca*. L. solanacearum'

Stakeholders have suggested that the 20,000 seed sample required by Australia is high and that a smaller sample would be sufficient to detect '*Ca*. L. solanacearum' in carrot seed.

It is expected that some infected seed lots will contain very few infected seeds and consist mostly of uninfected seeds. To detect the infected seeds in these lots, substantial seed samples need to be tested. Therefore, tests for seed-borne pathogens are frequently done on samples of 10,000 to 50,000 seeds. For example, testing samples of 30,000 crucifer seeds is the industry standard for detecting *Xanthomonas campestris* pv. *campestris*, and 10,000 to 20,000 carrot seeds is the standard for detecting *Xanthomonas campestris* pv. *carotae* (APHIS 2001; de Boer, Elphinstone & Saddler 2007). Testing samples of 20,000 bean seeds is the standard for detecting *Pseudomonas syringae* pv. *phaseolicola* (Agarwal & Sinclair 1996). A test of 10,000 to 50,000 tomato seeds is routinely used to detect *Clavibacter michiganensis* subsp. *michiganensis* (van Vaerenbergh et al. 2013). A test of 30,000 lettuce seeds is used by other NPPOs to detect *Lettuce mosaic virus* (APHIS 2001). Australian laboratories test tomato and capsicum seeds for viroids using samples of 20,000 seeds.

With a sample size of 20,000 seeds, '*Ca*. L. solanacearum' will be detected with a 99 per cent level of confidence in a large seed lot, if that lot is contaminated with infected seeds at a rate of 0.02 per cent or above. This level of confidence is calculated using the hypergeometric distribution (Whyte 2009) and assuming the diagnostic test is 100 per cent effective at detecting infected seeds.

The department therefore considers that using a 20,000 seed sample to detect a low level of '*Ca*. L. solanacearum' in carrot seeds is considered justified.

Why celery/celeriac or parsnip seed are not tested for '*Ca*. L. solanacearum'

Stakeholders questioned why celery/celeriac or parsnip seed is not tested for '*Ca*. L. solanacearum'.

The department acknowledges that '*Ca*. L. solanacearum' is associated with celery/celeriac and parsnip crops (Cambra et al. 2015; Teresani et al. 2015). ISPM No. 5 defines pathway as 'any means that allow the entry or spread of a pest' (FAO 2016f) and ISPM No. 11 states that to assess the probability of entry, an association of the pest with the import pathway is required (FAO 2016b). In this case, the pathway is defined as seed of celery/celeriac and parsnip. At the time of publication of the draft report there was no published evidence that this bacterium was associated with the seed in these commodities. Therefore, it was not considered to be on the pathway and the department did not implement seed testing for these commodities. However, more recently, this bacterium has been detected in celery/celeriac seed (W. Monger [Science and Advice for Scottish Agriculture] 2017 pers. comm. 9th January), parsley and parsnip seed (Monger & Jeffries 2016). Therefore, seeds of celery/celeriac, parsley and parsnip will also be subject to mandatory testing or treatment.

Psyllid vectors of '*Ca.* L. solanacearum'

Absence of vector for '*Ca.* L. solanacearum' in Australia

The department acknowledges that the known vectors (*Trioza apicalis* and *Bactericera trigonica*) of '*Ca*. L. solanacearum' are not present in Australia. The department is also aware that '*Ca*. L. solanacearum' has been detected in *B. tremblayi* and *B. nigricornis* collected from carrot and celery fields in Spain (Teresani et al. 2015). None of these known or potential vectors are present in Australia. Several species of *Trioza* are described from Australia (Taylor et al. 2011). However, none of these *Trioza* species are found in carrot, celery or parsley crops (Ekman & Tesoriero 2015). Therefore, the PRA has separately assessed the spread of the bacterium with vectors and without vectors. In both cases, the risk exceeded Australia's ALOP; therefore, the risk management measures are justified.

Spread of the bacterium more by the vector than through (carrot) seed

'*Candidatus* Liberibacter solanacearum' is primarily spread by infected carrot seeds (Bertolini et al. 2015) and afterwards spread by different psyllid species in a persistent way (Teresani et al. 2015). The presence of infected plants grown from infected seed, when vectors have been excluded, indicates that seed is a pathway (due to seed to seedling transmission). The detection of '*Ca*. L. solanacearum' in imported carrot seed in Australia clearly demonstrates that seed is the main source for long distance spread of this bacterium. The presence of vectors is relevant to the spread of the bacterium, which is why the PRA has separately assessed the spread of '*Ca*. L. solanacearum' with vectors and without vectors. In both cases, the unrestricted risk does not achieve the ALOP for Australia; therefore, the risk management measures are justified.

Estimation in the absence of known vectors, small size of carrot production and consequences of establishment

Stakeholders questioned the likelihood of establishment and the consequences estimated. Australia considers that the stakeholders' conclusion is not consistent with PRA methodology, as described in the draft PRA under "Method for pest risk analysis" (pp. 17–25). Estimation of consequences is an independent estimate that assumes that the pest has already entered, established and spread in Australia. Once the consequences are estimated, the unrestricted risk estimate is calculated as the product of the consequences and the likelihood of entry establishment and spread.

The department considers that the association of '*Ca*. L. solanacearum' with carrot seed will facilitate the establishment of '*Ca*. L. solanacearum', as the pathogen is already established within a suitable host. This material will enter and then be maintained in a suitable habitat and potentially in substantial numbers. Therefore, the introduction and establishment of plants from imported seed in essence establishes seed-transmitted pathogens like '*Ca*. L. solanacearum'. In the absence of a vector, the bacterium is unlikely to move from infected plants (resulting from imported seeds or tissue cultures) to new host plants. The bacterium is likely to survive as long as its host plant is present. In south-eastern Australia there are no crop free periods for carrots, celery and parsnips as they are grown year-round from seed largely sourced internationally, including Europe. Therefore, the bacterium in infected plants resulting from imported infected seeds or tissue cultures will potentially survive year round and from year to year.

Australian native psyllids as potential vectors of '*Ca*. L. solanacearum'

Stakeholders have requested further information on the role of native psyllids as potential vectors of '*Ca*. L. solanacearum' associated with apiaceous hosts. The list of psyllids identified as

potential vectors of '*Candidatus* Liberibacter' species worldwide indicates that vectors are from two families, namely Psyllidae and Triozidae (Table 2).

Table 2 Potential vectors of '*Candidatus* Liberibacter' species

Vector	'*Candidatus* Liberibacter' species	Host plant family
Arytainilla spartiophila Förster [Hemiptera: Psyllidae]	'*Candidatus* Liberibacter europaeus' (Thompson et al. 2013)	Fabaceae (Thompson et al. 2013)
Bactericera cockerelli (Sulc) [Hemiptera: Triozidae]	'*Candidatus* Liberibacter solanacearum' (haplotype A, B) (Hansen et al. 2008)	Solanaceae(Hansen et al. 2008; Liefting, Perez-Egusquiza & Clover 2008; Munyaneza 2012)
Bactericera trigonica Hodkinson [Hemiptera: Triozidae]	'*Candidatus* Liberibacter solanacearum' (haplotype D, E) (Alfaro-Fernández et al. 2012b)	Apiaceae (Bertolini et al. 2015; Teresani et al. 2014a)
Bactericera nigricornis Förster [Hemiptera: Triozidae]	'*Candidatus* Liberibacter solanacearum' (haplotype D, E) (Teresani et al. 2015)	Apiaceae (Teresani et al. 2015)
Bactericera tremblayi (Wagner) [Hemiptera: Triozidae]	'*Candidatus* Liberibacter solanacearum' (haplotype D, E) (Teresani et al. 2015)	Apiaceae (Teresani et al. 2015)
Cacopsylla pyri L. [Hemiptera: Psyllidae]	'*Candidatus* Liberibacter europaeus' (Raddadi et al. 2011)	Pomaceae (Camerota et al. 2012)
Cacopsylla citrisuga Yang & Li [Hemiptera: Psyllidae]	'*Candidatus* Liberibacter asiaticus' (Cen et al. 2012)	Rutaceae (Cen et al. 2012)
Diaphorina citri Kuwayama [Hemiptera: Psyllidae]	'*Candidatus* Liberibacter americanus' (Bové 2006);'Candidatus Liberibacter asiaticus' (Bové 2006)	Rutaceae (Lopes & Frare 2008)
Trioza (*Dyspersa*) *apicalis* Förster [Hemiptera: Triozidae]	'*Candidatus* Liberibacter solanacearum' (haplotype C) (Munyaneza et al. 2010b)	Apiaceae (Bertolini et al. 2015; Teresani et al. 2014a)
Trioza erytreae (Del Guercio) [Hemiptera: Triozidae]	'*Candidatus* Liberibacter africanus' (Bové 2006)	Rutaceae (Lopes & Frare 2008)

Published data indicate that the majority of Australian native psyllids (93 per cent) belong to the family Psyllidae (Table 3) and are associated with myrtaceous flora (DEWHA 2009). The triozid fauna (Triozidae family) show a high degree of host specificity except for *Trioza* species (Taylor et al. 2013).

Table 3 Summary of Australian Triozidae and Psyllidae and their hosts

Scientific name	Hosts
AUSTRALIAN PSYLLIDAE	
Acizzia Froggatt (twenty-two species)	*Acacia* [Fabaceae]; *Albizia* [Mimosaceae]; *Amyema* [Loranthaceae]; *Apophyllum*, *Capparis* [Capparidaceae]; *Calothamnus* [Myrtaceae]; *Solanum* [Solanaceae]; *Dodonaea* [Sapindaceae]; *Grevillea* [Proteaceae]; *Brugmansia*; *Datura*; *Physalis* [Solanaceae]
Agelaeopsylla Taylor (four species)	*Angophora*; *Eucalyptus* [Myrtaceae]
Anoeconeossa Taylor (seventeen species)	*Eucalyptus* [Myrtaceae]
Anomalopsylla sp.	*Geijera* [Rutaceae]
Australopsylla (Froggatt) (four species)	*Eucalyptus* [Myrtaceae]
Blastopsylla Taylor (eight species)	*Eucalyptus*; *Melaleuca* [Myrtaceae]

Scientific name	Hosts
Blepharocosta Taylor (seven species)	*Eucalyptus* [Myrtaceae]
Boreioglycaspis Moore (eight species)	*Lophostemon*; *Melaleuca* [Myrtaceae]
Brinckitia sp.	*Jacksonia* [Fabaceae]
Cacopsylla sp.	*Hymenosporum* [Pittosporaceae]
Cardiaspina Taylor (25 species)	*Eucalyptus* [Myrtaceae]
Colophorina sp.	*Acacia*; *Erythrophleum*; *Gastrolobium*; *Pultenaea* [Fabaceae]
Creiis (Froggatt) (six species)	*Eucalyptus* [Myrtaceae]
Cryptoneossa Taylor (five species)	*Eucalyptus*; *Leptospermum* [Myrtaceae]
Ctenarytaina (Froggatt) (seven species)	*Boronia* [Rutaceae]; *Corymbia*; *Eucalyptus*; *Lophostemon* [Myrtaceae]
Dasypsylla Froggatt (one species)	*Eucalyptus* [Myrtaceae]
Diaphorina (one species)	*Conyza* [Asteraceae]
Eriopsylla Taylor (two species)	*Melaleuca* [Myrtaceae]
Eucalyptolyma Froggatt (three species)	*Angophora*; *Eucalyptus* [Myrtaceae]
Euryconus sp.	*Cassia* [Caesalpiniaceae]
Glycaspis (Glycaspis) Moore (seventy two species)	*Eucalyptus* [Myrtaceae]
Glycaspis (Synglycaspis) Moore (thirty nine species)	*Eucalyptus* [Myrtaceae]
Heteropsylla Crawford (one species)	*Leucaena*; *Mimosa* [Mimosaceae]
Hyalinaspis Taylor (five species)	*Eucalyptus* [Myrtaceae]
Kenmooreana Taylor (three speices)	*Eucalyptus* [Myrtaceae]
Lasiopsylla Froggat (three species)	*Eucalyptus* [Myrtaceae]
Leptospermonastes Taylor (five species)	*Leptospermum*; *Melaleuca* [Myrtaceae]
Phellopsylla (Froggatt) (five species)	*Eucalyptus* [Myrtaceae]
Phyllolyma Taylor (five species)	*Eucalyptus*; *Melaleuca* [Myrtaceae]
Platyobria Taylor (nine species)	*Eucalyptus* [Myrtaceae]
Prosopidopsylla Burckhardt	*Prosopis* [Fabaeceae]
Spondyliaspis (Froggatt) (three species)	*Eucalyptus* [Myrtaceae]
Syncarpiolyma Froggatt (two species)	*Syncarpia* [Myrtaceae]
Trisetipsylla Yang & Li	*Toona* [Meliaceae]
AUSTRALIAN TRIOZIDAE	
Aacanthocnema Tuthill & Taylor (six species)	*Allocasuarina* [Casuarinaceae]
Acanthocasuarina Taylor (six species)	*Allocasuarina* [Casuarinaceae]
Cauarinicola Taylor (four species)	*Casuarina* [Casuarinaceae]
Cerotrioza Crawford (one species)	*Ceratopetalum* [Cunoniaceae]
Leptynoptera Crawford (two species)	*Calophyllum* [Calophyllaceae]
Schedotrioza Tuthill & Taylor (twelve species)	*Eucalyptus* [Myrtaceae]
Trioza Foester (nine species)	*Banksia* [Proteaceae]; *Lophostemon, Syzygium* [Myrtaceae]; *Ficus* [Moraceae]; *Mallotus* [Euphorbiaceae] and *Olearia* [Asteraceae]

Analysis of Table 2 and 3 indicates that members of the following native Australian psyllid genera may be potential vectors of '*Candidatus* Liberibacter' species:

- Members of the native Australian psyllid genus *Cacopsylla* may be considered as potential vectors of '*Ca*. L. solanacearum', since congeneric species *C. pyri* is a vector of '*Ca*. L. europaeus' (Raddadi et al. 2011) and *C. citrisuga* is a potential vector of '*Ca*. L. asiaticus' (Cen et al. 2012);
- Members of the Australian native genus *Diaphorina* may be considered as potential vectors of '*Ca*. L. solanacearum', since congeneric species *D. citri* is a vector of '*Ca*. L. asiaticus' and '*Ca*. L. americanus' (Bové 2006); and
- Members of the native Australian psyllid genus *Trioza* may be considered as potential vectors of '*Ca*. L. solanacearum', since congeneric species *T. erytreae* is a vector of '*Ca*. L. africanus' (Bové 2006).

The department acknowledges that members of *Cacopsylla*, *Diaphorina* and *Trioza* are present in Australia, however these native Australian psyllids are not known to feed on apiaceous crops and are therefore unlikely to vector '*Ca*. L. solanacearum'.

The published evidence indicates that '*Ca*. L. solanacearum' has been detected in three species of *Bactericera* (*B. nigricornis, B. tremblayi* and *B. trigonica*) and *T. apicalis*. However, only *B. trigonica* and *T. apicalis* are known to transmit '*Ca*. L. solanacearum' naturally (Haapalainen 2014). Species of psyllids collected from the carrot, celery and potato crops in areas of Spain where '*Ca*. L. solanacearum' is present include *Trioza urticae, Ctenarytaina* species, *Cacopsylla* species and *Psylla* species (Teresani et al. 2015). '*Ca.* L. solanacearum' has not been detected in these psyllid species (Teresani et al. 2015). This vector specificity suggests it is unlikely that Australian native psyllids will be able to transmit '*Ca*. L. solanacearum'.

Koch's postulates for '*Ca.* L. solanacearum'

Stakeholders questioned whether it is enough to detect the pathogen without visible symptoms without evidence that Koch's postulates have been fulfilled.

The department recognises that a traditional Koch's postulates assessment for this pathogen has not been conclusively fulfilled. Unsuccessful attempts to culture '*Ca.* L.' species (e.g. (Garnett 1985; Ghosh et al. 1971; Munyaneza 2012; Sechler et al. 2009; Sodhi & Dhillion 1973)) led to the realisation that Koch's postulates, in a classical sense, could not be met, owing to the fastidious and unculturable nature of the bacterium. By way of background, Koch's postulates to identify the causative agent of a particular disease include the following four criteria:

1. The organism must be regularly associated with the disease;
2. The organism must be isolated from the diseased host and grown in culture;
3. The disease must be reproduced when a pure culture of the organism is introduced into a healthy, susceptible host; and
4. The same organism must be re-isolated from the experimentally infected host.

Despite the importance of Koch's postulates in the identification of causative microbial agents of disease, there are other relevant considerations. For example, the application of nucleic acid-based methods of microbial identification has made Koch's postulates less critical. Nucleic acid-based methods, such as PCR, are very sensitive and can detect small numbers of microbes, even

if they occur in the absence of disease symptoms. The department recognises that the postulate steps two, three and four cannot be fulfilled for '*Ca*. L.' species, therefore, a number of approaches have been applied to demonstrate the association of this pathogen with the disease (Ariovich & Garnett 1989; Chen, Miyakawa & Matsui 1971; Davis et al. 2008; Hilf et al. 2013; Parker et al. 2014; Sechler et al. 2009). The modified Koch's postulates support the etiological role of '*Ca*. L. solanacearum' in apiaceous crop disease. This bacterium is consistently associated with diseases in carrot and celery (Alfaro-Fernández et al. 2012a; Alfaro-Fernández et al. 2012b; Haapalainen 2014; Munyaneza et al. 2011; Munyaneza et al. 2012a; Munyaneza et al. 2012b). Psyllids have been collected from '*Ca*. L. solanacearum'-infected apiaceous crops and celery fields and have been used to infect healthy hosts (Nelson, Fisher & Munyaneza 2011; Teresani et al. 2015). The bacterium has been detected by PCR in plant hosts and psyllid vectors and the bacterium has been observed in phloem tissue through transmission electron microscopy (TEM). Therefore, Australia considers that a modified Koch's postulates assessment has been fulfilled.

Origin of seed has not been considered as part of the PRA

Stakeholders have commented that seed origin has not been considered as part of this analysis and that to date, '*Ca*. L. solanacearum' has only been detected in Europe, as have the vectors for this bacterium.

The department considered seed origin in detail in Appendix A of the draft PRA. The department notes that this bacterium is also reported to occur in Africa, as reported in the draft PRA. Outbreaks of yellows disease were observed in different regions of Spain, including the Canary Islands (Font et al. 1999). Carrot fields in the Canary Islands were heavily infested with the psyllid *B. trigonica* (Font et al. 1999). Plant symptoms included small leaves with yellowing and reddening discolouration, proliferation of leaves and small roots and deformation, reduction and early senescence of roots (Font et al. 1999). Symptoms observed on carrots in the Canary Islands (Font et al. 1999) were very similar to those often observed in *T. apicalis*–'*Ca*. L.' affected carrots in Finland (Munyaneza et al. 2010b). Symptomatic plants showing yellows disease and *B. trigonica* were both collected from carrot fields in the Canary Islands (Font et al. 1999), but neither were tested for this pathogen, as the presence of this bacterium was not then suspected (Munyaneza et al. 2010b). However, recent studies have detected '*Ca*. L. solanacearum' in carrot crops and *B. trigonica* in the Canary Islands and in other areas of Spain (Alfaro-Fernández et al. 2012a; Teresani et al. 2014b).

'*Candidatus* Liberibacter solanacearum' associated with carrot is reported to be seed-borne (Bertolini et al. 2015; Ilardi, Di Nicola & Tavazza 2016) and seed transmissible (Bertolini et al. 2015). The bacterium was first detected in Finland in 2010 (Munyaneza et al. 2010b) and since then has been reported from Austria (EPPO 2015), France (Loiseau et al. 2014), Germany (Munyaneza et al. 2015), Italy (Ilardi, Di Nicola & Tavazza 2016), Morocco (Tahzima et al. 2014), Norway (Munyaneza 2012), Spain (Alfaro-Fernández et al. 2012a) and Sweden (Munyaneza et al. 2012b). The presence of the bacterium in geographically distant countries indicates that the bacterium is likely to have spread to these areas via carrot seeds. The detection of '*Ca*. L. solanacearum' in imported carrot seed through on-arrival testing in Australia in early 2016 clearly demonstrates the long range dispersal of this bacterium from the source country to thousands of kilometres away to Australia. If the infected seed was not intercepted but instead grown in multiple locations in Australia, the bacterium may have established in Australia.

Vegetable seed production (breeding and multiplication programmes) is generally an international production pathway. This pathway involves multiple steps—breeding parental lines, production of basic seed, production/multiplication, quality control (processing, treatment and packaging) and selling these seeds to growers in many other countries. Therefore, if risk management measures against any designated quarantine pest are not included in this international production pathway, seed-borne pathogens will be introduced.

In 2015, the Interim Inspector-General of Biosecurity (IIGB) audited the effectiveness of the department's biosecurity control in managing risks associated with importation of carrot and tomato seeds into Australia. The IIGB audit highlighted that seed present significant biosecurity risks due to the numerous complex, variable international pathways, including contracted farms in countries where biosecurity might not always be consistent with Australian standards (IIGB 2016). Apiaceous crop seeds are regularly traded internationally and production (breeding, testing, multiplication and counter seasonal multiplication) normally occurs at multiple locations. Global trade in seeds increases the potential for the introduction of new pathogens into uninfested areas. The movement of seeds between countries may result in the unintentional spread of '*Ca*. L. solanacearum', particularly if other countries do not have measures in place to address the risks posed by this bacterium. Therefore, the department has applied risk management measures for apiaceous host (carrot, celery/celeriac, parsley and parsnip) seeds from all countries.

However, if a NPPO wishes to use country freedom or pest free place of production as a measure to manage the risk posed by '*Ca*. L. solanacearum' associated with apiaceous seeds for sowing, it should address the requirements outlined in section 5.1.3 of this PRA.

Glossary

Term or abbreviation	Definition
Additional declaration	A statement that is required by an importing country to be entered on a phytosanitary certificate and which provides specific additional information on a consignment in relation to regulated pests (FAO 2016f).
Appropriate level of protection (ALOP)	The level of protection deemed appropriate by the Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory (WTO 1995).
Appropriate level of protection (ALOP) for Australia	The *Biosecurity Act 2015* defines the appropriate level of protection (or ALOP) for Australia as a high level of sanitary and phytosanitary protection aimed at reducing biosecurity risks to very low, but not to zero.
Area	An officially defined country, part of a country or all or parts of several countries (FAO 2016f).
Area of low pest prevalence	An area, whether all of a country, part of a country, or all parts of several countries, as identified by the competent authorities, in which a specific pest occurs at low levels and which is subject to effective surveillance, control or eradication measures (FAO 2016f).
Arthropod	The largest phylum of animals, including the insects, arachnids and crustaceans.
Asexual reproduction	The development of new individual from a single cell or group of cells in the absence of meiosis.
Australian territory	Australian territory as referenced in the *Biosecurity Act 2015* refers to Australia, Christmas Island and Cocos (Keeling) Islands.
Biosecurity	The prevention of the entry, establishment or spread of unwanted pests and infectious disease agents to protect human, animal or plant health or life, and the environment.
Biosecurity import risk analysis (BIRA)	The *Biosecurity Act 2015* defines a BIRA as an evaluation of the level of biosecurity risk associated with particular goods, or a particular class of goods, that may be imported, or proposed to be imported, into Australian territory, including, if necessary, the identification of conditions that must be met to manage the level of biosecurity risk associated with the goods, or the class of goods, to a level that achieves the ALOP for Australia. The risk analysis process is regulated under legislation.
Biosecurity measures	The *Biosecurity Act 2015* defines biosecurity measures as measures to manage any of the following: biosecurity risk, the risk of contagion of a listed human disease, the risk of listed human diseases entering, emerging, establishing themselves or spreading in Australian territory, and biosecurity emergencies and human biosecurity emergencies.
Biosecurity risk	The *Biosecurity Act 2015* refers to biosecurity risk as the likelihood of a disease or pest entering, establishing or spreading in Australian territory, and the potential for the disease or pest causing harm to human, animal or plant health, the environment, economic or community activities.
Consignment	A quantity of plants, plant products or other articles being moved from one country to another and covered, when required, by a single phytosanitary certificate (a consignment may be composed of one or more commodities or lots) (FAO 2016f).
Control (of a pest)	Suppression, containment or eradication of a pest population (FAO 2016f).
Diapause	Period of suspended development/growth occurring in some insects, in which metabolism is decreased.
Endangered area	An area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss (FAO 2016f).
Endemic	Belonging to, native to, or prevalent in a particular geography, area or environment.
Entry (of a pest)	Movement of a pest into an area where it is not yet present, or present but not

Term or abbreviation	Definition
	widely distributed and being officially controlled (FAO 2016f).
Equivalence (of phytosanitary terms)	The situation where, for a specified pest, different phytosanitary measures achieve a contracting party's appropriate level of protection (FAO 2016f).
Establishment (of a pest)	Perpetuation, for the foreseeable future, of a pest within an area after entry (FAO 2016f).
Food plant	A plant on which adult psyllids feed, but do not breed and do not spend an extended period of time (e.g. diapause or winter season).
Goods	The *Biosecurity Act 2015* defines goods as an animal, a plant (whether moveable or not), a sample or specimen of a disease agent, a pest, mail or any other article, substance or thing (including, but not limited to, any kind of moveable property).
Host	An organism that harbours a parasite, mutual partner, or commensal partner, typically providing nourishment and shelter.
Host range	Species capable, under natural conditions, of sustaining a specific pest or other organism (FAO 2016f).
Import permit	Official document authorising importation of a commodity in accordance with specified phytosanitary import requirements (FAO 2016f).
Infection	The internal 'endophytic' colonisation of a plant, or plant organ, and is generally associated with the development of disease symptoms as the integrity of cells and/or biological processes are disrupted.
Infestation (of a commodity)	Presence in a commodity of a living pest of the plant or plant product concerned. Infestation includes infection (FAO 2016f).
Inspection	Official visual examination of plants, plant products or other regulated articles to determine if pests are present or to determine compliance with phytosanitary regulations (FAO 2016f).
Intended use	Declared purpose for which plants, plant products, or other regulated articles are imported, produced or used (FAO 2016f).
Interception (of a pest)	The detection of a pest during inspection or testing of an imported consignment (FAO 2016f).
International Plant Protection Convention (IPPC)	The IPPC is an international plant health agreement, established in 1952, that aims to protect cultivated and wild plants by preventing the introduction and spread of pests. The IPPC provides an international framework for plant protection that includes developing International Standards for Phytosanitary Measures (ISPMs) for safeguarding plant resources.
International Standard for Phytosanitary Measures (ISPM)	An international standard adopted by the Conference of the Food and Agriculture Organization, the Interim Commission on Phytosanitary Measures or the Commission on Phytosanitary Measures, established under the IPPC (FAO 2016f).
Introduction (of a pest)	The entry of a pest resulting in its establishment (FAO 2016f).
Larva	A juvenile form of animal with indirect development, undergoing metamorphosis (for example, insects or amphibians).
Life cycle	Cyclical progression of stages in the growth and development of an organism (plant, animal, or pathogen) that occur between the appearance and reappearance of the same stage of the organism (Shurtleff & Averre 1997)
Lot	A number of units of a single commodity, identifiable by its homogeneity of composition, origin et cetera, forming part of a consignment (FAO 2016f).
National Plant Protection Organization (NPPO)	Official service established by a government to discharge the functions specified by the IPPC (FAO 2016f).
Non-regulated risk analysis	Refers to the process for conducting a risk analysis that is not regulated under legislation (Biosecurity import risk analysis guidelines 2016).
Nymph	The immature form of some insect species that undergoes incomplete metamorphosis. It is not to be confused with larva, as its overall form is already that of the adult.

Term or abbreviation	Definition
Official control	The active enforcement of mandatory phytosanitary regulations and the application of mandatory phytosanitary procedures with the objective of eradication or containment of quarantine pests or for the management of regulated non-quarantine pests (FAO 2016f).
Overwintering or shelter plant	A plant on which adult psyllids overwinter, and on which they may feed.
Pathogen	A biological agent that can cause disease to its host.
Pathway	Any means that allows the entry or spread of a pest (FAO 2016f).
Pest	Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (FAO 2016f).
Pest categorisation	The process for determining whether a pest has or has not the characteristics of a quarantine pest or those of a regulated non-quarantine pest (FAO 2016f).
Pest free area (PFA)	An area in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained (FAO 2016f).
Pest free place of production	Place of production in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period (FAO 2016f).
Pest free production site	A defined portion of a place of production in which a specific pest does not occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained for a defined period and that is managed as a separate unit in the same way as a pest free place of production (FAO 2016f).
Pest risk analysis (PRA)	The process of evaluating biological or other scientific and economic evidence to determine whether an organism is a pest, whether it should be regulated, and the strength of any phytosanitary measures to be taken against it (FAO 2016f).
Pest risk assessment (for quarantine pests)	Evaluation of the probability of the introduction and spread of a pest and of the magnitude of the associated potential economic consequences (FAO 2016f).
Pest risk assessment (for regulated non-quarantine pests)	Evaluation of the probability that a pest in plants for planting affects the intended use of those plants with an economically unacceptable impact (FAO 2016f).
Pest risk management (for quarantine pests)	Evaluation and selection of options to reduce the risk of introduction and spread of a pest (FAO 2016f).
Pest risk management (for regulated non-quarantine pests)	Evaluation and selection of options to reduce the risk that a pest in plants for planting causes an economically unacceptable impact on the intended use of those plants (FAO 2016f).
Pest status (in an area)	Presence or absence, at the present time, of a pest in an area, including where appropriate its distribution, as officially determined using expert judgement on the basis of current and historical pest records and other information (FAO 2016f).
Phytosanitary certificate	An official paper document or its official electronic equivalent, consistent with the model of certificates of the IPPC, attesting that a consignment meets phytosanitary import requirements (FAO 2016f).
Phytosanitary certification	Use of phytosanitary procedures leading to the issue of a phytosanitary certificate (FAO 2016f).
Phytosanitary measure	Any legislation, regulation or official procedure having the purpose to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests (FAO 2016f). In this risk analysis the term 'phytosanitary measure' and 'risk management measure' may be used interchangeably.
Phytosanitary procedure	Any official method for implementing phytosanitary measures including the performance of inspections, tests, surveillance or treatments in connection with regulated pests (FAO 2016f).
Phytosanitary regulation	Official rule to prevent the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests, including establishment of procedures for phytosanitary certification (FAO 2016f).

Term or abbreviation	Definition
Polyphagous	Feeding on a relatively large number of hosts from different plant family and/or genera.
PRA area	Area in relation to which a pest risk analysis is conducted (FAO 2016f).
Quarantine	Official confinement of regulated articles for observation and research or for further inspection, testing or treatment (FAO 2016f).
Quarantine pest	A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (FAO 2016f).
Regulated article	Any plant, plant product, storage place, packaging, conveyance, container, soil and any other organism, object or material capable of harbouring or spreading pests, deemed to require phytosanitary measures, particularly where international transportation is involved (FAO 2016f).
Regulated non-quarantine pest	A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated within the territory of the importing contracting party (FAO 2016f).
Regulated pest	A quarantine pest or a regulated non-quarantine pest (FAO 2016f).
Restricted risk	Restricted risk is the risk estimate when risk management measures are applied.
Risk analysis	Refers to the technical or scientific process for assessing the level of biosecurity risk associated with the goods, or the class of goods, and if necessary, the identification of conditions that must be met to manage the level of biosecurity risk associated with the goods, or class of goods to a level that achieves the ALOP for Australia.
Risk management measure	Are conditions that must be met to manage the level of biosecurity risk associated with the goods or the class of goods, to a level that achieves the ALOP for Australia. In this risk analysis, the term 'risk management measure' and 'phytosanitary measure' may be used interchangeably.
Spread (of a pest)	Expansion of the geographical distribution of a pest within an area (FAO 2016f).
SPS Agreement	WTO Agreement on the Application of Sanitary and Phytosanitary Measures.
Stakeholders	Government agencies, individuals, community or industry groups or organizations, whether in Australia or overseas, including the proponent/applicant for a specific proposal, who have an interest in the policy issues.
Surveillance	An official process which collects and records data on pest occurrence or absence by surveying, monitoring or other procedures (FAO 2016f).
Systems approach(es)	The integration of different risk management measures, at least two of which act independently, and which cumulatively achieve the appropriate level of protection against regulated pests.
Tissue culture	The products of 'an in vitro technique of cultivating (propagating) cells, tissues, or organs in a sterile synthetic medium' (Shurtleff & Averre 1997); comprising plant cells, tissues or organs, sterile synthetic medium, and the vessel in which cells have been propagated.
Treatment	Official procedure for the killing, inactivation or removal of pests, or for rendering pests infertile or for devitalisation (FAO 2016f).
Unrestricted risk	Unrestricted risk estimates apply in the absence of risk management measures.
Vector	An organism that does not cause disease itself, but which causes infection by conveying pathogens from one host to another.
Viable	Alive, able to germinate or capable of growth.

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