Australian Government

Biosecurity Australia

Draft report for the non-regulated analysis of existing policy for apples from New Zealand

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Cover image: Royal Gala apple in a Nelson orchard, New Zealand. Biosecurity Australia.

Submissions

This draft report has been issued to give all interested parties an opportunity to comment and draw attention to any scientific, technical, or other gaps in the data, misinterpretations and errors. Any comments should be submitted to Biosecurity Australia within the comment period stated in the related Biosecurity Australia Advice on the Biosecurity Australia website. The draft report will then be revised as necessary to take account of the comments received and a final report will be released at a later date.

Comments on the draft report should be submitted to:

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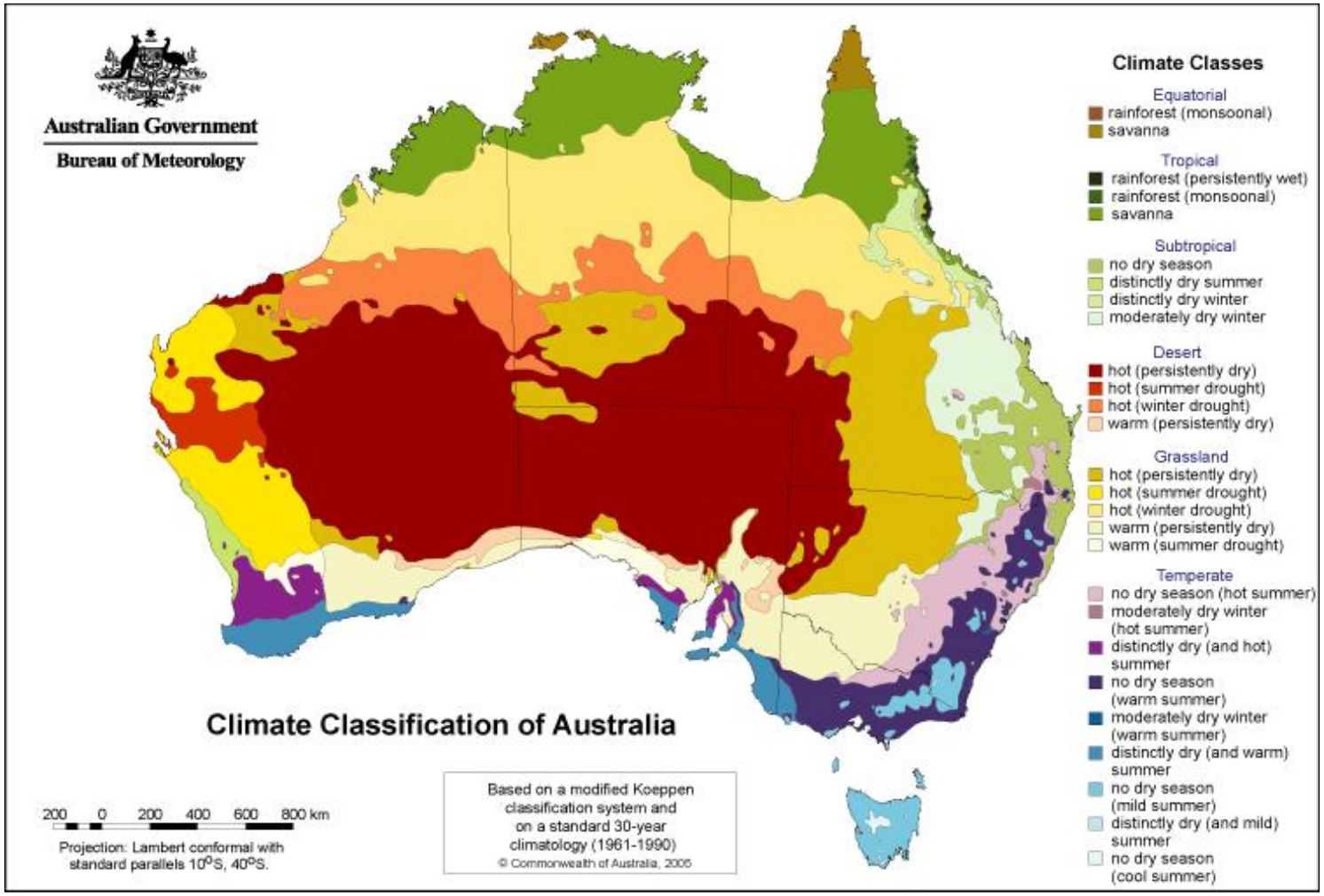

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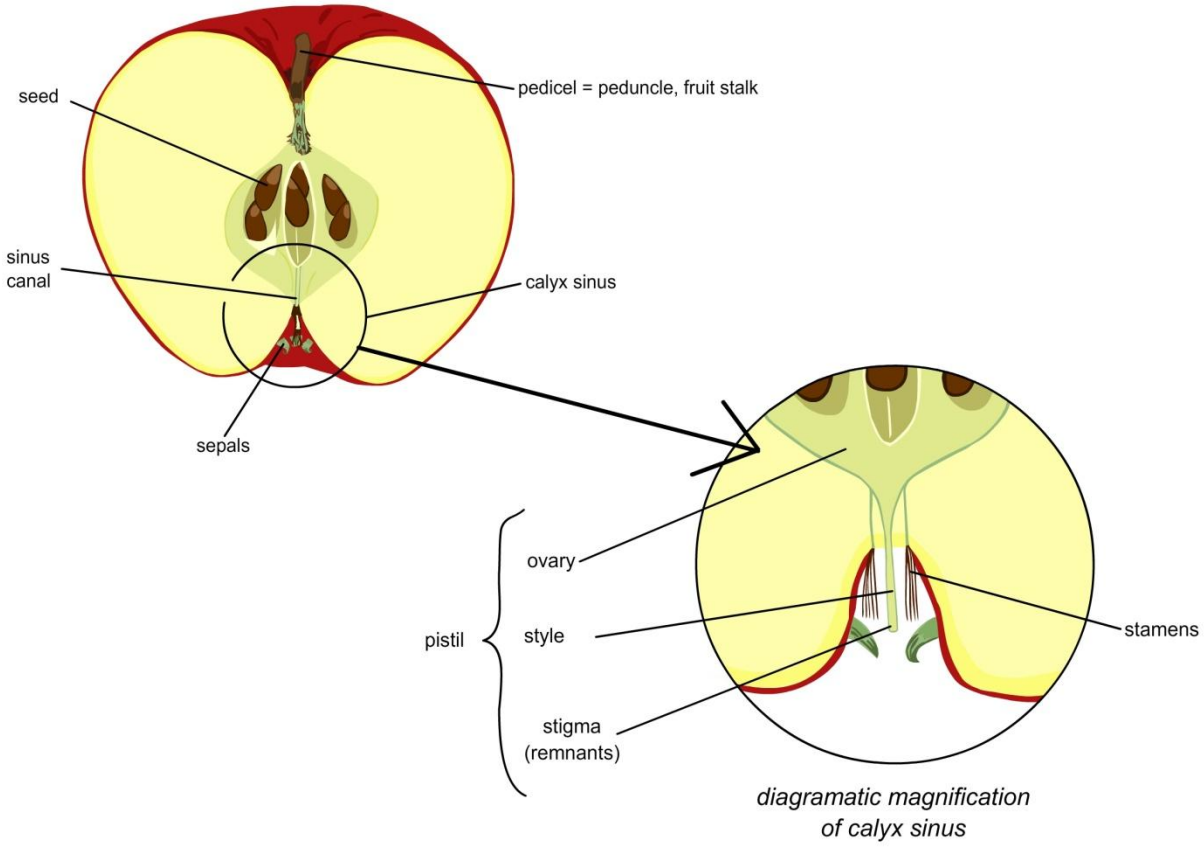

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Acronyms and abbreviations

Term or abbreviation	Definition
ABS	Australian Bureau of Statistics
ACERA	Australian Centre of Excellence for Risk Analysis
ACT	Australian Capital Territory
ALOP	Appropriate level of protection
ALPP	Areas of low pest prevalence
APAL	Apple and Pear Australia Limited
APHIS	Animal and Plant Health Inspection Service
APPD	Australian Plant Pest Database (Plant Health Australia)
AQIS	Australian Quarantine and Inspection Service
BA	Biosecurity Australia
BAA	Biosecurity Australia Advice
BSG	Biosecurity Service Group
CABI	CAB International, Wallingford, UK
CMI	Commonwealth Mycological Institute
CSIRO	Commonwealth Science and Industry Research Organisation
CT	Concentration time
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
DAFWA	Department of Agriculture and Food, Western Australia (formerly DAWA: Department of Agriculture, Western Australia)
DPIW	Department of Primary Industries and Water, Tasmania
EP	Existing policy
EPPO	European and Mediterranean Plant Protection Organization
FAO	Food and Agriculture Organization of the United Nations
FAS	The Foreign Agriculture Service in the United States Department of Agriculture
IDM	Integrated Disease Management
IPC	International Phytosanitary Certificate
IPM	Integrated Pest Management
IPPC	International Plant Protection Convention
IRA	Import Risk Analysis
IRAAP	Import Risk Analysis Appeals Panel
ISPM	International Standard for Phytosanitary Measures
MAFNZ	Ministry of Agriculture and Forestry New Zealand
MOU	Memorandum of Understanding
NASS	The National Agricultural Statistics Service in the United States Department of Agriculture
NPPO	National Plant Protection Organization
NSW	New South Wales
NT	Northern Territory
OEPP	Organisation européenne et méditerranéenne pour la protection des plantes
PIAPH	Product Integrity, Animal and Plant Health Division
PIMC	Primary Industries Ministerial Council

PRA	Pest Risk Analysis
Qld	Queensland
SA	South Australia
SPS	Sanitary and phytosanitary
Tas.	Tasmania
Vic.	Victoria
WA	Western Australia
WAFGA	Western Australia Fruit Growers' Association
WTO	World Trade Organisation

Abbreviations of units

Term or abbreviation	Definition
ºC	degree Celsius
g	gram
h	hour
ha	hectare
kg	kilogram
km	kilometre
L	litre
ml	millilitre
m	metre
m^3	cubic metre
mg	milligram
mm	millimetre
ppm	parts per million
µL	Microlitre
MPa	Mega Pascals

Summary

This non-regulated analysis of existing policy reassesses the quarantine risks posed by three pests associated with the importation of apples from New Zealand: fire blight (caused by the bacterium *Erwinia amylovora*), European canker (caused by the fungi *Neonectria ditissima*), and apple leaf curling midge (*Dasineura mali*). The analysis is being undertaken to consider the three pests in order to meet Australia's WTO obligations and the requirements of the *Quarantine Act 1908* and relevant sub-ordinate legislation.

The draft report proposes that the current import conditions for apple fruit from New Zealand be amended and that the importation of apples be permitted, subject to a range of quarantine conditions.

In November 2006 the *Final import risk analysis report for apples from New Zealand* (final IRA report) was published. On 26 March 2007 the Director of Animal and Plant Quarantine determined the policy to permit import of apples from New Zealand, subject to application of the quarantine measures specified in the final IRA report. New Zealand challenged the measures for fire blight, European canker and apple leaf curling midge, through the Dispute Settlement Body of the World Trade Organization (WTO), claiming that the measures were inconsistent with Australia's international obligations under the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement).

A Panel was formed and, on 9 August 2010, ruled that Australia's phytosanitary measures for New Zealand apples were not justified. Australia notified its intention to appeal the Panel's decision and the Appellate Body reported on 29 November 2010, reaffirming the Panel's rulings that Australia's phytosanitary measures for New Zealand apples are not justified. There are no further avenues for appeal. As a member of the WTO, Australia is obliged to implement the independent reports of the Panel and Appellate Body.

This draft report takes into account the pre-harvest, harvest and post-harvest practices described as being standard commercial practice for the production of apples for export in New Zealand. Also considered is new scientific information that was not available when the 2006 final IRA report was completed.

The draft report concludes that when the New Zealand apple industry's standard commercial practices for production of export grade fruit are taken into account, the unrestricted risk for all three pests assessed achieves Australia's appropriate level of protection (ALOP). Therefore, no additional quarantine measures are recommended, though New Zealand will need to ensure that the standard commercial practices detailed in this review are met for export consignments. These practices include:

- Application of the integrated fruit production system, or an equivalent, to manage pests and diseases in orchard
- Testing to ensure that only mature fruit is exported to Australia
- Maintenance of sanitary conditions in dump tank water
- High pressure water washing and brushing of fruit in the packing house
- A minimum 600 fruit sample from each lot of fruit packed is inspected and found free of quarantine pests for Australia.

In addition to the three pests considered in this draft report, the final IRA report in 2006 recommended quarantine measures for a further nine quarantine pests. Of those nine pests, five leafrollers were assessed as quarantine pests for all of Australia, while two mealybugs, codling moth, and apple scab (caused by *Venturia inaequalis*) were assessed as quarantine pests only for Western Australia. However, apple scab is now considered to be present in Western Australia and is no longer a quarantine pest requiring measures. The measures recommended for those remaining pests must also be applied to export consignments and included:

- A 600 fruit sample from each lot of fruit inspected and found free of quarantine pests for Australia (for leafrollers and mealybugs). New Zealand's standard commercial practice is recognised as meeting this requirement
- Establishment of pest free areas, or areas of low pest prevalence for codling moth, or fumigation with methyl bromide. This measure is only required for lots destined for Western Australia

This draft report contains details of the risk assessments for the quarantine pests and the proposed quarantine measures in order to allow interested parties to provide comments and submissions to Biosecurity Australia within the 60 day consultation period.

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[1] 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 pest risk analysis (PRA) process is an important part of Australia's biosecurity policies. It enables the Australian Government to formally consider the risks that could be associated with proposals to import new products into Australia. If the risks are found to exceed Australia's appropriate level of protection (ALOP), risk management measures are proposed to reduce the risks to an acceptable level. But, if it is not possible to reduce the risks to an acceptable level, then no trade will be allowed.

Successive Australian Governments have maintained a conservative, but not a zero-risk, approach to the management of biosecurity risks. This approach is expressed in terms of Australia's ALOP, which reflects community expectations through government policy and is currently described as providing a high level of protection aimed at reducing risk to a very low level, but not to zero.

Australia's PRAs are undertaken by Biosecurity Australia using technical and scientific experts in relevant fields, and involves consultation with stakeholders at various stages during the process. Biosecurity Australia provides recommendations for animal and plant quarantine policy to Australia's Director of Animal and Plant Quarantine (the Secretary of the Australian Department of Agriculture, Fisheries and Forestry). The Director, or delegate, is responsible for determining whether or not an importation can be permitted under the *Quarantine Act 1908*, and if so, under what conditions. The Australian Quarantine and Inspection Service (AQIS) is responsible for implementing appropriate risk management measures.

More information about Australia's biosecurity framework is provided in Appendix C of this report and in the *Import Risk Analysis Handbook 2011* located on the Biosecurity Australia website www.biosecurityaustralia.gov.au.

[1] A pest is any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (FAO 2009).

1.2 This pest risk analysis

1.2.1 Background

Following the release of the *Final import risk analysis report for apples from New Zealand* in November 2006, the Director of Animal and Plant Quarantine determined a policy for the importation of apples from New Zealand. That determination, made on 26 March 2007, permitted imports of apples subject to the *Quarantine Act 1908* and the application of the quarantine measures as specified in the *Final import risk analysis report for apples from New Zealand* (2006 final IRA report).

On 31 August 2007, New Zealand requested consultations with Australia through the World Trade Organization (WTO), claiming that the quarantine measures relating to *Erwinia amylovora* (the cause of fire blight of apples), *Neonectria ditissima* (the cause of European canker), and *Dasineura mali* (apple leaf curling midge) were inconsistent with Australia's obligations under the Sanitary and Phytosanitary Agreement (SPS Agreement). Subsequently, following a request from New Zealand, the WTO Dispute Settlement Body established a Panel to examine New Zealand's claims. The Panel's findings, as modified by the Appellate Body, were that Australia's import risk analysis that recommended quarantine measures for New Zealand apples was not sufficiently supported by scientific evidence and did not fully take into account standard commercial practices in New Zealand. The recommended quarantine measures were therefore inconsistent with Australia's obligations under the SPS Agreement. The Dispute Settlement Body formally adopted the reports of the Appellate Body and the Panel report as modified by the Appellate Body on 17 December 2010.

In response to that finding the Government announced that a science-based review of the import risk analysis for New Zealand apples would be conducted by Biosecurity Australia. The review was to consider the three pests at dispute to meet Australia's WTO obligations and the requirements of the *Quarantine Act 1908* and relevant sub-ordinate legislation.

1.2.2 Scope

The scope of the PRA is to re-assess the quarantine risks and measures associated with three of the pests considered in the 2006 final IRA report; *Erwinia amylovora*, *Neonectria ditissima*, and *Dasineura mali*. The quarantine measures required for those three pests were the subject of the WTO dispute.

Other quarantine pests were identified in the 2006 final IRA report, but as the measures required for those pests were not included in the WTO dispute they are not re-assessed here. The quarantine requirements recommended in the 2006 final IRA report and determined by the Director of Animal and Plant Quarantine in March 2007 therefore remain current for those pests.

1.2.3 Existing policy

International policy

Import policy exists for Fuji apples from Japan (AQIS 1998a). An IRA on apples from New Zealand has been completed (BA 2006). No apples have been imported into Australia under

these policies. Import policy also exists for apples from China (BA 2010) and imports first arrived in Australia in early 2011.

Import policies also exist for Korean pears from Korea (AQIS 1999), ya pears and Asian pears from China's provinces of Hebei, Shandong and Shaanxi (AQIS 1998b), and fragrant pears from Xinjiang Uygur Autonomous Region (BA 2005).

The import requirements for these commodities can be accessed at AQIS Import Conditions database http://www.aqis.gov.au/icon.

Domestic arrangements

The Commonwealth Government is responsible for regulating the movement of plants and plant products in and out of Australia. However, the state and territory governments are responsible for plant health controls within Australia. Legislation relating to resource management or plant health may be used by state or territory government agencies to control interstate movement of plants or their products.

1.2.4 Contaminating pests

In addition to the pests of apples from New Zealand that are assessed in this PRA, and those identified in the 2006 final IRA report, there are other organisms that may arrive with the imported commodity. These organisms could include pests of other crops or predators and parasitoids of other arthropods. Biosecurity Australia considers these organisms to be contaminating pests that could pose sanitary and phytosanitary risks. These risks are addressed by existing operational procedures.

1.2.5 Consultation

On 7 December 2010, Biosecurity Australia Advice (BAA) 2010/38 informed stakeholders of the formal commencement of a non-regulated analysis of existing policy for the importation of apples from New Zealand (a review).

1.2.6 Next steps

This draft report gives stakeholders the opportunity to comment and draw attention to any scientific, technical, or relevant other gaps in the data, misinterpretations and errors.

Biosecurity Australia will consider submissions received on the draft report and may consult informally with stakeholders. Biosecurity Australia will revise the report as appropriate. Biosecurity Australia will then prepare a final report, taking into account stakeholder comments.

The report will be distributed to registered stakeholders and the documents will be placed on the Biosecurity Australia website.

The Director of Animal and Plant Quarantine will then make a determination. The determination provides a policy framework for decisions on whether or not to grant an import permit and any conditions that may be attached to a permit.

A policy determination represents the completion of the process.

The Director of Animal and Plant Quarantine notifies AQIS and Biosecurity Australia of the policy determination. In turn, Biosecurity Australia notifies the proposer and registered

stakeholders, and the Department of Agriculture, Fisheries and Forestry notifies the WTO Secretariat, of the determination. The determination will also be placed on the Biosecurity Australia website.

2 Method for pest risk analysis

This section sets out the method used for the pest risk analysis (PRA) in this report. Biosecurity Australia has conducted this PRA in accordance with the International Standards for Phytosanitary Measures (ISPMs), including ISPM 2: *Framework for Pest Risk Analysis* (FAO 2007) and ISPM 11: *Pest Risk Analysis for Quarantine Pests, including analysis of environmental risks and living modified organisms* (FAO 2004) 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 a pest should be regulated and the strength of any phytosanitary measures to be taken against it' (FAO 2009). A pest is 'any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products' (FAO 2009).

Quarantine risk consists of two major components: the probability 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, AQIS 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 spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests' (FAO 2009).

A glossary of the terms used is provided at the back of this report.

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

2.1 Stage 1: Initiation

Initiation identifies the pest(s) and pathway(s) that are of quarantine concern and should be considered for risk analysis in relation to the identified PRA area.

Part C of the 2006 *Final import risk analysis report for apples from New Zealand* listed the pests and diseases with the potential to be associated with exported apples produced using commercial production and packing procedures. The entries from that table for *E. amylovora, N. ditissima,* and *D. mali* are reproduced in this review in Appendix A.

For this PRA, the 'PRA area' is defined as Australia. None of the three pests considered are present in any part of Australia.

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 likelihood of associated potential economic consequences' (FAO 2009).

In this PRA, pest risk assessment was divided into the following interrelated processes:

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, as defined in ISPM 5: *Glossary of phytosanitary terms* (FAO 2009).

The pests identified in Stage 1 were categorised using the following primary elements to identify the quarantine pests for the commodity being assessed:

- 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

The results of pest categorisation for the pests considered in this PRA are set out in columns 4 – 7 in Appendix A and are as they were presented in the2006 *Final import risk analysis report for apples from New Zealand*. The steps in the categorisation process are considered sequentially, with the assessment terminating with a 'Yes' in column 4 or the first 'No' in columns 5 or 6. The quarantine pests identified during pest categorisation were carried forward for pest risk assessment and are listed in Table 4.1.

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 2004). A summary of this process is given below, followed by a description of the qualitative methodology used in this PRA.

Probability of entry

The probability of entry describes the probability 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. It is based on pathway scenarios depicting necessary steps in the sourcing of the commodity for export, its processing, transport and storage, its use in Australia and the generation and disposal of waste. In particular, the ability of the pest to survive is considered for each of these various stages.

The probability of entry estimates for the quarantine pests for a commodity are based on the use of the existing commercial production, packaging and shipping practices of the exporting country. Details of the existing commercial production practices for the commodity are set out in Section 3. These practices are taken into consideration by Biosecurity Australia when estimating the probability of entry.

For the purpose of considering the probability of entry, Biosecurity Australia divides this step of this stage of the PRA into two components:

Probability of importation: the probability that a pest will arrive in Australia when a given commodity is imported.

Probability of distribution: the probability 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 considered in the probability of importation 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
- 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 life cycle 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 (e.g. refrigeration) applied to consignments during transport and storage in the country of origin, and during transport to Australia

Factors considered in the probability of distribution include:

- commercial procedures (e.g. 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 (e.g. for planting, processing or consumption)
- risks from by-products and waste

Probability of establishment

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO 2004). In order to estimate the probability of establishment of a pest, reliable biological information (lifecycle, host range, epidemiology, survival, etc.) 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 probability of establishment.

Factors considered in the probability of establishment in the PRA area 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

Probability of spread

Spread is defined as 'the expansion of the geographical distribution of a pest within an area' (FAO 2004). The probability 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 probability 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 probability of spread.

Factors considered in the probability of spread 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 qualitative likelihoods for the probability of entry, establishment and spread

In its qualitative PRAs, Biosecurity Australia uses the term 'likelihood' for the descriptors it uses for its estimates of probability of entry, establishment and spread. Qualitative 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 2.1). Descriptive definitions for these descriptors are given in Table 2.1. The standardised likelihood descriptors provide guidance to the risk analyst and promote consistency between different risk analyses.

Table 2.1 Nomenclature for qualitative likelihoods

Likelihood	Descriptive definition
High	The event would be very likely to occur
Moderate	The event would occur with an even probability
Low	The event would be unlikely to occur
Very low	The event would be very unlikely to occur
Extremely low	The event would be extremely unlikely to occur
Negligible	The event would almost certainly not occur

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 2.2). 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.

For example, if the probability of importation is assigned a likelihood of 'low' and the probability of distribution is assigned a likelihood of 'moderate', then they are combined to give a likelihood of 'low' for the probability of entry. The likelihood for the probability of entry is then combined with the likelihood assigned to the probability of establishment (e.g. 'high') to give a likelihood for the probability of entry and establishment of 'low'. The likelihood for the probability of entry and establishment is then combined with the likelihood assigned to the probability of spread (e.g. 'very low') to give the overall likelihood for the probability of entry, establishment and spread of 'very low'. A working example is provided below;

P [importation] x *P* [distribution] = *P* [**entry**] e.g. **low x moderate = low**

P [entry] x *P* [establishment] = *P* [**EE**] e.g. **low x high = low**

P [**EE**] x [spread] = ***P* [EES]** e.g. **low x very low = very low**

Table 2.2 Matrix of rules for combining qualitative 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

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.

Biosecurity Australia normally considers the likelihood of entry on the basis of the estimated volume of one year's trade. This is a convenient value for the analysis that is relatively easy to estimate and allows for expert consideration of seasonal variations in pest presence, incidence and behaviour to be taken into account. The consideration of the likelihood of entry, establishment and spread and subsequent consequences takes into account events that might happen over a number of years even though only one year's volume of trade is being considered. This difference reflects biological and ecological facts, for example where a pest or disease may establish in the year of import but spread may take many years.

The use of a one year volume of trade has been taken into account when setting up the matrix that is used to estimate the risk and therefore any policy based on this analysis does not simply apply to one year of trade. Policy decisions that are based on Biosecurity Australia's method that uses the estimated volume of one year's trade are consistent with Australia's policy on appropriate level of protection and meet the Australian Government's requirement for ongoing quarantine protection.

Based on an analysis presented by the Australian Bureau of Agricultural and Resource Economics (ABARE 2006), the 2006 final IRA report estimated a volume of trade that could

range from 50 million apples to 400 million apples, which correspond to a range of 2.5–20 per cent of the average Australian apple fruit production and 5–40 per cent of the Australian domestic fresh apple fruit production. However, in the 2006 analysis, emphasis was given to the lower end of that range. In the absence of an existing trade it is difficult to estimate the volume of apples that might be imported in any given year from New Zealand. For this review, the volume of trade has been estimated as up to 20 per cent of the domestic fresh apple fruit market.

2.2.3 Assessment of potential consequences

The objective of the consequence assessment is to provide a structured and transparent analysis of the likely 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 2009) and ISPM 11 (FAO 2004).

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, etc
- 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)[2] using Table 2.3[3]. For example, a consequence with a magnitude of 'significant' at the 'district' level will have a consequence impact score of D.

Table 2.3 Decision rules for determining the consequence impact score based on the magnitude of consequences at four geographic scales

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

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 2.4). These rules are mutually exclusive, and are assessed in numerical order until one applies.

[2] In earlier qualitative IRAs, 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-F has 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 2.4 were adjusted accordingly.

[3] The decision rules for determining the consequence impact score are presented in a simpler form in Table 2.3 from earlier IRAs, to make the table easier to use. The outcome of the decision rules is the same as the previous table and makes no difference to the final impact score.

Table 2.4 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 above assessments 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 2.5) to combine the estimates of the probability of entry, establishment and spread and the overall consequences of pest establishment and spread. Therefore, risk is the product of likelihood and consequence.

When interpreting the risk estimation matrix, note the descriptors for each axis are similar (e.g. 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 2.5 Risk estimation matrix

Likelihood 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

Consequences of pest entry, establishment and spread

2.2.5 Australia's appropriate level of protection (ALOP)

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. Australia's ALOP, which reflects community expectations through government policy, is currently expressed as providing 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 2.5 marked 'very low risk' represents Australia's ALOP.

2.3 Stage 3: Pest risk management

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

The conclusions from pest risk assessments are used to decide whether risk management is required and if so, the appropriate measures to be used. Where the unrestricted risk estimate exceeds Australia's ALOP, 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 Australia's ALOP. The effectiveness of any proposed phytosanitary measure (or combination of measures) is evaluated, using the same approach as used to evaluate the unrestricted risk, to ensure it reduces the restricted risk for the relevant pest or pests to meet Australia's ALOP.

ISPM 11 (FAO 2004) provides details on the identification and selection of appropriate risk management options and notes that the choice of measures should be based on their effectiveness in reducing the probability of entry of the pest.

Examples given of measures commonly applied to traded commodities include:

- options for consignments – e.g., inspection or testing for freedom from pests, prohibition of parts of the host, a pre-entry or post-entry quarantine system, specified conditions on preparation of the consignment, specified treatment of the consignment, restrictions on end-use, distribution and periods of entry of the commodity
- options preventing or reducing infestation in the crop – e.g., treatment of the crop, restriction on the composition of a consignment so it is composed of plants belonging to resistant or less susceptible species, harvesting of plants at a certain age or specified time of the year, production in a certification scheme
- options ensuring that the area, place or site of production or crop is free from the pest – e.g., pest-free area, pest-free place of production or pest-free production site
- options for other types of pathways – e.g., consider natural spread, measures for human travellers and their baggage, cleaning or disinfestation of contaminated machinery
- options within the importing country – e.g., surveillance and eradication programs
- prohibition of commodities – if no satisfactory measure can be found

Risk management measures are identified for each quarantine pest where the risk exceeds Australia's ALOP. These are presented in the 'Pest Risk Management' section of this report.

3 New Zealand's commercial production practices for apples

This chapter provides information on the pre-harvest, harvest and post-harvest practices of the New Zealand apple industry for the production of fresh apple fruit for export. The practices described in this section are considered to be standard practice for all export apple production and Biosecurity Australia has taken them into consideration when estimating the unrestricted risk of pests that may be associated with the import of this commodity.

While general information on New Zealand apple production is provided, the focus is on those practices relevant to the three pests that this review considers: fire blight, European canker, and apple leaf curling midge.

Figure 3-1 Map of New Zealand[4]

3.1 Climate in production areas[5]

Apple production in New Zealand occurs on both the north and south islands, with two main production districts accounting for nearly 90 per cent of the total plantings. The first and most significant of the production districts is Hawke's Bay, which includes the adjacent cities of

[4] Map from http://www.newzealand.com/travel/images/maps/bloggers/newzealandmap_large_en.jpg

[5] Climate descriptions are taken from http://www.niwa.co.nz/education-and-training/schools/resources/climate/overview

Napier and Hastings. Hawke's Bay is located on the east coast of the north island at a latitude of 39.5°S, placing it slightly south of Melbourne, Victoria.

The second major production district is around Nelson located at the northern end of New Zealand's south island at a latitude of 41.3°S. Nelson is at a latitude similar to Devonport, Tasmania.

The third production district of note is Central Otago, located in the southern central region of New Zealand's south island and includes the cities of Alexandra, Clyde, Cromwell and Queenstown. At a latitude of around 45°S, the district is slightly further south than the southernmost parts of Tasmania.

New Zealand has a wide range of climatic conditions, from warm subtropical conditions in the northernmost areas of the north island, to cool temperate conditions at the southernmost areas of the south island. Severe alpine conditions also occur in the mountainous areas of the southern island.

The two largest production areas, Hawke's Bay and Nelson are located close to the coast and therefore do not experience extreme temperatures, the proximity of the Southern Ocean moderating the climatic conditions. Hawke's Bay is sheltered by mountains to the west and experiences warm, dry summers. Summer daytime temperatures reach 28°C, but rarely exceed 32°C. Winter is mild to cool.

Nelson has similar summer conditions, also being dry, though with temperatures reaching 26°C and only occasionally exceeding 30°C. Winters are colder than in Hawke's Bay, but are still regarded as mild.

In contrast, the Central Otago region, being further inland to the other regions experiences more severe winter conditions. Winter temperatures are very cold with frequent frosts and with daytime temperatures rarely exceeding 11°C. The Central Otago region receives only around one-third the total rainfall experienced in Nelson and Hawke's Bay.

The graphs presented below provide an indication of average daily maximum and minimum temperatures, as well as average rainfall for four sites in New Zealand where apples are grown. While only a small proportion of export apples are grown there, the Waikato district, represented by Hamilton, is included because it provides an indication of the climatic conditions in the north of the island. Substantial research into apple production has also been undertaken there. The graphs indicate the similar summer temperatures in all of these regions, though also highlight the comparatively cold winters experienced in the Central Otago region. The annual rainfall, based on a 30-year average is 360mm for the Central Otago, 803mm for Hawke's Bay, 970mm for Nelson, and 1190mm for the Waikato.

For comparison, the annual rainfall based on a 30-year average in major apple production regions in Australia is 779mm for Stanthorpe, 967mm for Batlow, 454mm for Goulburn Valley, 1008mm for the Adelaide hills, 887mm for Huon Valley and 899mm for Donnybrook. Graphs are also presented for major apple production regions in Australia (Figures 3-2 to 3-11).

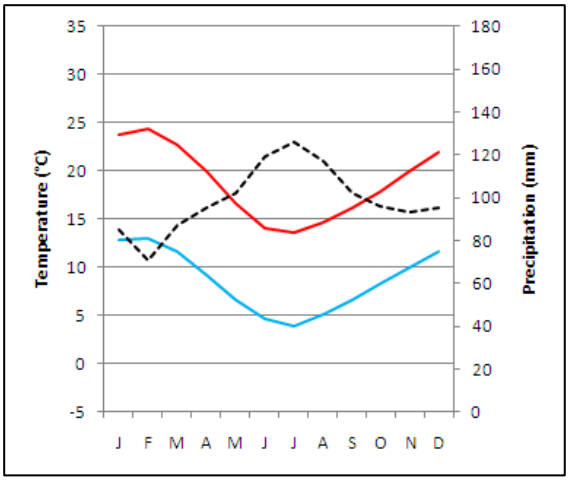


Figure 3-2 Maximum and minimum temperatures and mean monthly rainfall for Hamilton (Waikato) 1971–2000[6]

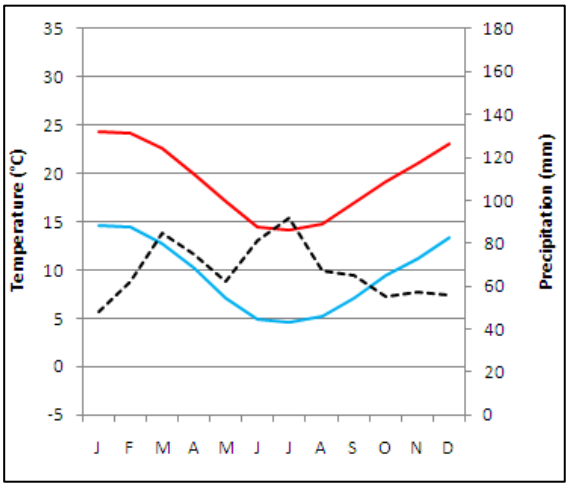
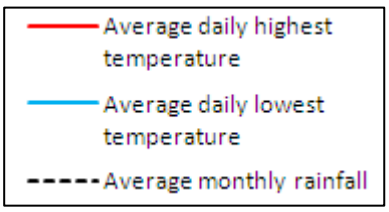


Figure 3-3 Maximum and minimum temperatures and mean monthly rainfall for Napier (Hawke's Bay) 1971–2000[6]



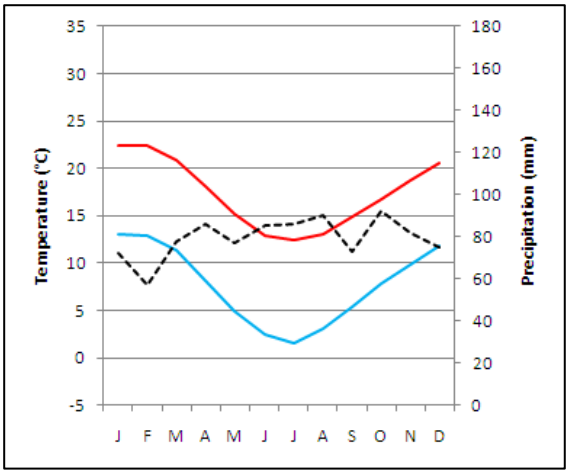


Figure 3-4 Maximum and minimum temperatures and mean monthly rainfall for Nelson 1971–2000[6]

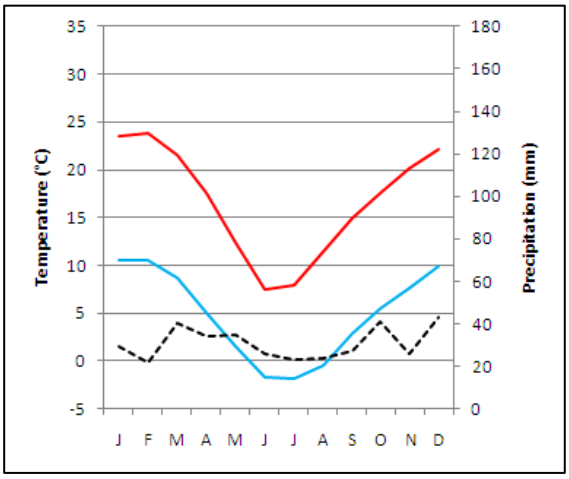


Figure 3-5 Maximum and minimum temperatures and mean monthly rainfall for Alexandra (Central Otago) 1971–2000[6]

[6] Climate data from National Institute of Water and Atmospheric Research. http://www.niwa.co.nz/education-and-training/schools/resources/climate

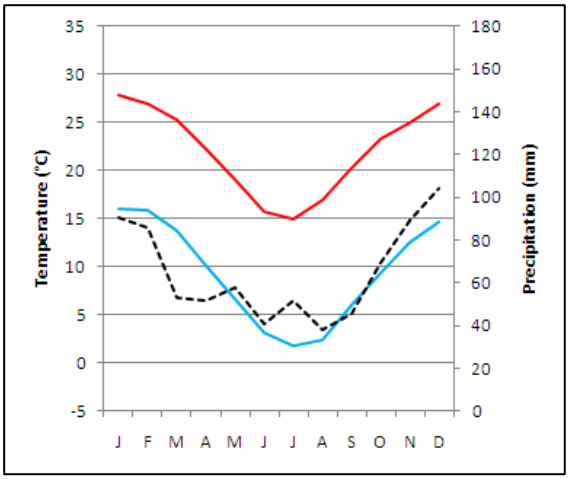


Figure 3-6 Maximum and minimum temperatures and mean monthly rainfall for Stanthorpe, Qld. 1981–2010[7]

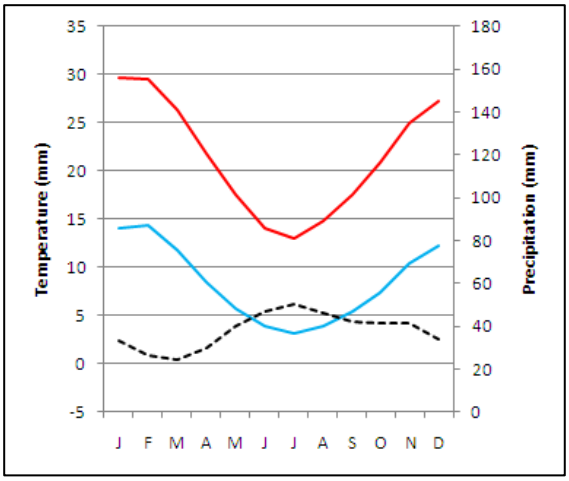


Figure 3-8 Maximum and minimum temperatures and mean monthly rainfall for Tatura, Vic. (Goulburn Valley) 1981–2010[7]

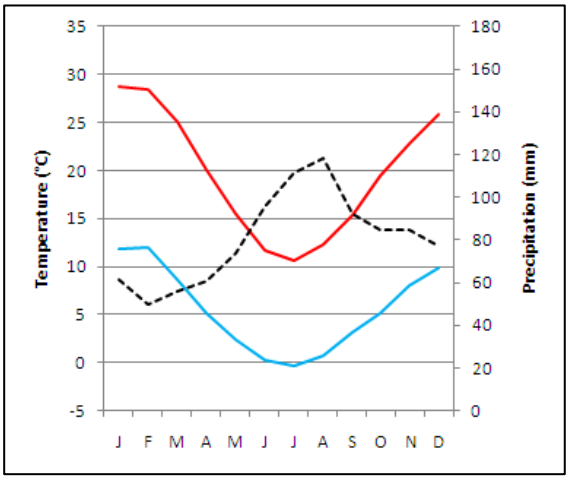
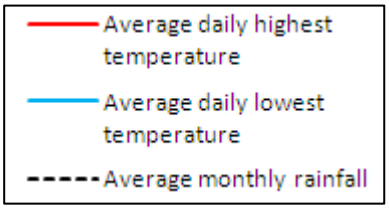


Figure 3-7 Maximum and minimum temperatures and mean monthly rainfall for Batlow[8], NSW 1971–2000[7]



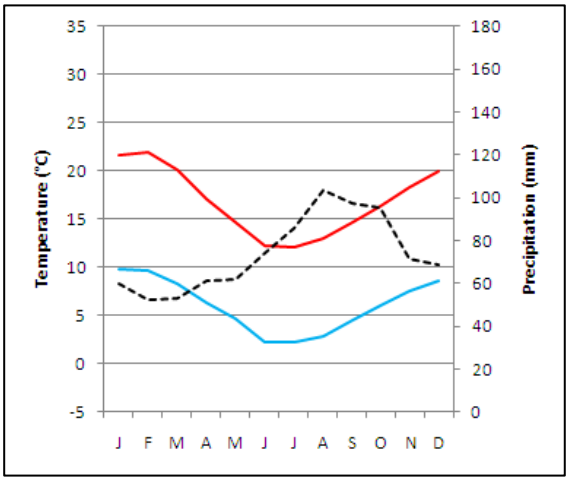


Figure 3-9 Maximum and minimum temperatures and mean monthly rainfall for Geeveson, Tas. (Huon Valley) 1981–2010[7]

[7] Climate data from Bureau of Meteorology http://www.bom.gov.au/climate/data/index.shtml?bookmark=200

[8] Batlow data taken from Tumbarumba weather station

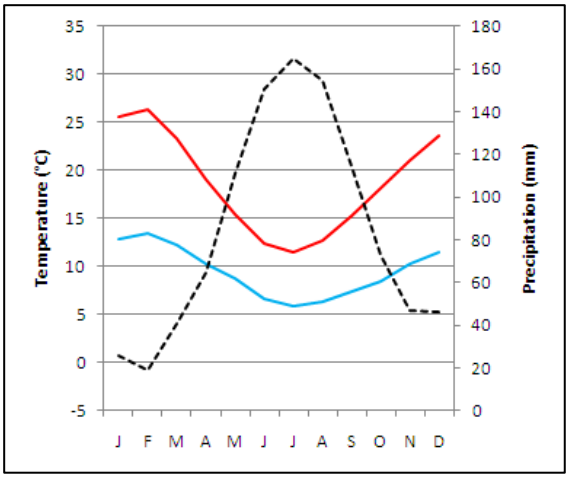


Figure 3-10 Maximum and minimum temperatures and mean monthly rainfall for Lenswood, SA (Adelaide Hills) 1981–2010[7]

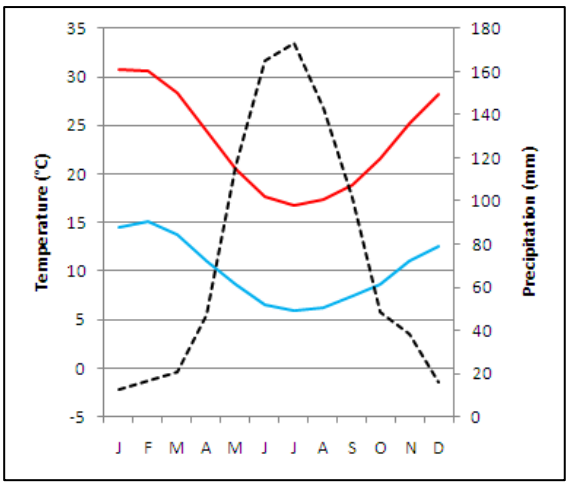
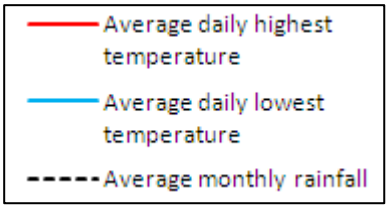


Figure 3-11 Maximum and minimum temperatures and mean monthly rainfall for Donnybrook WA 1981–2010[7]



3.2 Pre-harvest

3.2.1 Orchard layout

For registration and trace back purposes, apple orchards can be divided into a number of smaller units. These include the orchard, the production site and variety/orchard blocks.

An orchard is defined as the total planting in a single location and has its boundary defined by the registered owner/grower. An orchard is covered by a single Registered Property Identification Number (RPIN). Depending on size, orchards may be divided into a number of production sites. Division into production sites are for administrative and pest management purposes.

Most orchards, if not all, grow a number of different varieties of apples and may have multiple plantings of a particular variety in different areas within the orchard. Within an orchard, each continuous planting of a single variety of apple is defined as an orchard block or variety block. Fruit being packed in a packing house, fruit can be traced back to a specific orchard block and in some cases specific rows within that orchard block.

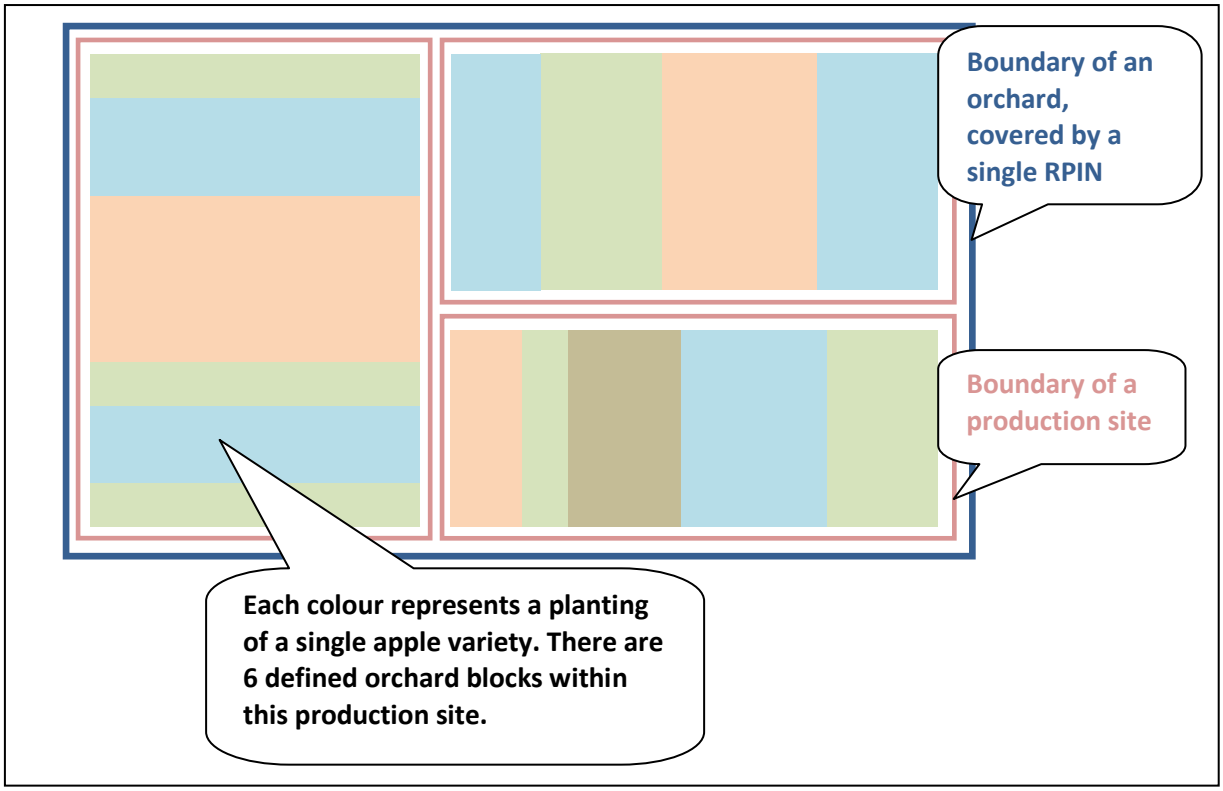


Figure 3-12 Representation of divisions within an orchard

3.2.2 Cultivars

In 2010 there was 9 061 hectares of apple and pear production in New Zealand, with 60 per cent of this in the Hawke's Bay district and 28 per cent in the Nelson district (Pipfruit NZ 2010). The Central Otago region is also noted for apple production, but includes only 4 per

cent of New Zealand's total number of hectares under production. This is a slight increase over the total planted area of 8 896 hectares in 2009.

While a range of apple varieties are available in New Zealand, the varieties with the greatest planted area in 2010 were Royal Gala (27 per cent), Braeburn (21 per cent), Jazz™ (11 per cent), and Fuji (11 per cent). Other varieties include Cox, Cripps Pink (Pink Lady), Granny Smith, Pacific Beauty™, Pacific Queen™, and Pacific Rose™ (Pipfruit NZ 2010). Pear orchards make up only a relatively small proportion of the total pipfruit production, with 431 hectares reported in 2010.

3.2.3 Cultivation practices

Commercial apple plantings in New Zealand are typically grown on grafted rootstock. The use of grafted rootstocks, particularly clonal rootstocks, is preferred as it allows for control over tree size, ripening of fruit and may also confer resistance to certain pests and diseases. While a range of rootstocks are available, the New Zealand industry indicated that the M9 variety is most commonly used for new plantings (BSG 2011). M9 rootstock produces a small tree around 3–4 metres high which bears large fruit, comes into commercial production within three years from planting and is considered fully grown in five to six years. Plantings of apple trees on M9 rootstock have a between tree spacing of one metre and a between row spacing of three metres. M9 rootstock or another dwarfing variety is preferred due to the moderate growth habit and shorter trees which assist with pest management, spray application and harvesting.

Canopy management varies between orchards, dependent largely on age, though most trees are pruned and trained to keep most growth parallel to the row. Branches are trained into a mostly horizontal position to encourage fruit bearing over vegetative growth. While the canopies are open, reflective sheets on the orchard floor are used for up to two weeks prior to harvest to promote full fruit colouring.

Orchard irrigation is most commonly delivered by drip irrigation (BSG 2011). Overhead sprinklers are not commonly used in New Zealand apple orchards, their use being mostly limited in use to the Central Otago Region. Use of overhead irrigation in other regions is avoided due to the potential to result in problems with apple scab (caused by *Venturia inaequalis*) early in the season (MAFNZ 2011). Where used, overhead sprinklers can assist in managing the potential for frost damage.

According to the Pipfruit Industry Statistical Annual the 2009 export production was 302 075 tonnes from 8 484 hectares, or an export yield of around 35 tonnes per hectare across all varieties of apples. In addition to this there was an export yield of 5 421 tonnes of pears from 412 hectares (Pipfruit NZ 2010). Export yield does not include fruit for the domestic market, or for processing and juicing facilities. The World Apple and Pear Association reported a total 2009 New Zealand production of 466 000 tonnes (WAPA 2010), or around 54 tonnes per hectare. However, these figures are inferred values from export volumes and average pack-out (MAFNZ 2011). Significantly higher yields are reported in a number of the orchards visited in March 2011, with yields of 75–100 tonnes per hectare expected from recently established orchards (BSG 2011).

3.2.4 Pest management

In 1996, the Integrated Fruit Production program was first introduced for New Zealand pipfruit. In subsequent years it was rapidly adopted by the apple and pear industry with 100

per cent adoption for export grown fruit reported by 2001 (Wiltshire 2003). The IFP program has been further developed with the Apple Futures program (Pipfruit NZ 2008a) with an emphasis on managing chemical residues to the lowest levels possible. In 2010, 87 per cent of total planted area was managed under IFP (including Apple Futures), 11 per cent as organic; while only 2 per cent of the total planted area produced solely for the domestic market (Pipfruit NZ 2010).

While the IFP program is proprietary information that covers all aspects of pipfruit production in New Zealand, it contains information that is relevant to the management of the pests and diseases considered in this review. Those key aspects of the IFP program are outlined below.

Fire blight management

In New Zealand, management of fire blight focuses on reducing inoculum levels through cultural practices in the orchard and use of chemical or biological controls during the most susceptible infection period, blossom time. The decision to apply chemical or biological control measures is supported by a computer model based warning system that considers temperatures, wetness periods and fire blight prevalence in the surrounding area. The model operated by Pipfruit New Zealand is available to registered growers through the Pipfruit New Zealand website and is derived from the Maryblyt and Cougarblyt models developed in the USA and adapted for New Zealand conditions.

The risk period for infection by *E. amylovora* in New Zealand is during blossom. Unlike some other regions of the world, New Zealand's apple growing areas do not experience severe frosts later in the season that can cause cracking of branches that provide opportunity for secondary infections. The risk factors for fire blight infections are:

- Open flowers are present with stigmas and petals intact
- 110 degree hours greater than 18.3°C have accumulated after the first bloom
- Dew or at least 0.25mm or rain on the day of infection has occurred; or at least 3mm rain on the previous day
- An average daily temperature of 15.6°C

When considered in light of potential inoculum levels, fire blight symptoms in orchard, in adjacent orchards, and in the district, growers are provided guidance on whether sprays are required. The final decision on whether control sprays will be applied is made by orchard managers.

For chemical control, the antibiotic streptomycin is registered for use. Sprays are applied during high risk climatic conditions when blossoms are present. Orchard managers aim to apply the spray 12–24 hours prior to a rain event to allow time for it to dry and also ensure the application is made late in the day as it is degraded by ultraviolet light. According to orchard managers streptomycin use is limited due to chemical residue restrictions imposed by markets such as Europe (BSG 2011).

Alternatively, the biological control *Pantoea agglomerans* (synonym *Erwinia herbicola*) (known as Blossom Bless) is available to orchard managers. Blossom Bless is a commonly occurring bacterium that can be sprayed onto susceptible tissue where it competes for infection sites, reducing the opportunity for *E. amylovora* to infect the tissue. Usage of Blossom Bless is varied, though multiple applications are common. Depending on the risk posed by fire blight, Blossom Bless may be applied at 10 per cent, 50 per cent, and 80 per cent blossom, the effect being cumulative.

Finally, bud break promoters are used in some orchards to accelerate the budding process and reduce the period of time that susceptible host tissue is present on the tree. The mild conditions in New Zealand can result in blooms being present on trees for a number of weeks. Budding promoters can reduce this period to around one week.

Frequent inspection of orchards is recommended by the Pipfruit IFP manual, which is consistent with recommendations made around the world. Inspections are targeted to find distinctive blight symptoms or "shepherd's crooks" on terminal shoots. It is recommended that symptomatic shoots or branches are pruned out, with the cut to be made 45–60cm below the symptoms. This should be augmented with removal of any symptomatic tissues during winter pruning, along with removal or monitoring of alternative host material in the area surrounding the orchard.

Overhead irrigation is not recommended and is rarely used outside the Central Otago district. When used, overhead sprinklers are a management tool for frost protection, therefore being used when conditions are unfavourable for *E. amylovora* infection.

Data from the 2009–10 season indicates that of all registered apple production blocks in New Zealand, 3.3 per cent received at least one streptomycin spray and 5.0 per cent received at least one Blossom Bless spray. Note, however, that these may include blocks that utilised both control measures and that sprays are applied based on estimates of potential infection not actual infections.

During a verification visit in March 2011, officials from the Biosecurity Services Group had the opportunity to discuss the recommendations of the Pipfruit IFP program with orchard owners, orchard managers, and pest control consultants in both the Hawke's Bay and Nelson districts. The only variation to the measures as described above was the pruning of symptomatic tissue. Some orchard managers stated their experience that immediate pruning of 'shepherd's crooks' was not necessary in their orchards where the incidence of symptomatic tissue was extremely low (BSG 2011). Those orchards were observed to have only the occasional fire blight strike and were producing high yields of commercial quality fruit.

In considering those orchards where either a low incidence of fire blight symptoms were observed or which had a history of some fire blight infection, orchard managers described a "severe" incidence as an average of around one strike per tree. During the verification visit some trees were observed as having multiple strikes, though the adjacent trees were seen to have either one strike or no strikes. No bacterial oozes were observed on any of the blighted limbs.

European canker management

According to the Pipfruit IFP manual, European canker is only considered a problem in high rainfall areas such as Auckland and Waikato. It may occasionally also pose problems in Gisborne and Nelson. Spread of European canker is attributed to introduced nursery stock as well as localised spread from neighbouring infected trees.

Control for European canker focuses on removal of any visible cankers during the winter pruning period when the symptoms are most easily observed. Removal is through pruning, ensuring that cuts are at least 10cm below the lowest observed canker to ensure that any infected wood is removed. Pruning cuts are then recommended to be covered with a sealing paint that includes an antifungal agent, carbendazim. It is then recommended that any infected material be removed from the orchard and burned.

Antifungal chemicals used for other more economically concerning pathogens are also considered effective against European canker and contribute to the general control in orchard. These include sprays to manage black spot (*Venturia inaequalis*, apple scab) and powdery mildew (*Podosphaera* sp.).

During site visits in March 2011, orchard managers in the Nelson region reported that European canker was known from the region, but uncommon in orchards. For example, only a single tree on a 40 hectare property had been identified with symptoms during the last 5 years and the infection was traced back to the introduced nursery stock. At a second orchard in Nelson, it was reported that symptoms could be found if one were to look hard enough for long enough.

Apple leaf curling midge management

Under the IFP program, specific monitoring and control programs for apple leaf curling midge are only recommended for blocks of young trees and trees that have recently been grafted. Both of these situations can provide the young, vigorous growth that adult apple leaf curling midge lay eggs onto and on which the developing larvae feed.

For orchards that have recently been planted, or newly grafted, sampling of 40 actively growing shoots from late November through to early December is recommended, with foliar application of diazinon if more than 50 per cent of the shoots are infested with eggs.

Monitoring should subsequently occur in January and February, also sampling 40 leaves with the action threshold again being reached of more than 50 per cent of the sampled leaves are infested with eggs.

In blocks of mature trees that are producing fruit, the parasitoid *Platygaster demades* (Hymenoptera: Platygastridae) and predator *Sejanus albisignata* (Hemiptera: Miridae) are considered effective in controlling apple leaf curling midge, provided that broad-spectrum insecticides have not been applied. Further, while insecticides such as diazinon are recommended as a foliar spray, application precludes fruit from entering a number of export markets due to chemical residue requirements. The IFP program does not recommend any specific monitoring program for apple leaf curling midge in producing blocks with mature trees. During the March 2011 visit, orchard managers explained that apple leaf curling midge is not an issue in mature trees as they don't produce the required fresh growth for apple leaf curling midge throughout the season. Some orchards are now monitoring soil moisture to minimise vegetative growth during the season to maximise fruit production and quality.

3.3 Harvesting and handling procedures

The apple harvest season in New Zealand can commence from early February with varieties like Pacific Beauty™ and Royal Gala. The season extends until mid-late April with varieties like Cripps Pink (Pink Lady), Braeburn, and Fuji (Pipfruit NZ 2008c).

Prior to harvest, maturity is monitored by sampling twenty fruit per variety per block from the orchard and subjecting them to a series of tests: starch pattern index; background and foreground colour; fruit penetrometer; and soluble sugars (brix). The results of these laboratory tests indicate that fruit is either ready for harvest, or recommended to be re-tested after a nominated period of time (BSG 2011). This testing establishes whether the conversion of fruit starches to sugars has commenced, whether fruit sugars exceed a certain level, and

whether fruit colour has developed sufficiently to meet market specifications. Harvesting will not commence until the maturity levels have reached a minimum level.

Due to the prolonged blossom period for apples in New Zealand, fruit can mature over a period of time and when harvest commences, it is common for a first pick to target only those fruit showing higher colour levels and therefore the appropriate level of maturity. Other fruit will be left to finish ripening and 'colouring up' for another 4–7 days before a second pick is undertaken. This process may be repeated as and if necessary and some orchards this season where onto their fourth pick.

Apples are hand-picked, with some assistance from either portable ladders or motorised 'cherry pickers' to reach higher branches. In-field, pickers grade out fruit with obvious signs of unacceptable damage, including cuts, bruises and tractor damage. Further, evidence of specific pests can be recorded on field bins to alert packing houses to any pest issues that may limit access to specific markets.

After harvesting into picker bags, fruit is transferred to field bins that hold approximately 400kg of fruit. Bins are consolidated at the orchard before being transported to the packing house. Each bin has an attached record that identifies the supplier, grower, orchard, variety, orchard block and picker that facilitates trace-back.

3.4 Post-harvest

3.4.1 Packing house

Apples will not be accepted by packinghouses unless spray diary clearance has been received from the Independent Verification Agency (IVA). At the point of receival, apples at all packing houses are sampled for maturity. As for pre-harvest testing, this includes starch pattern index, background and foreground colour, fruit penetrometer, and soluble sugars (brix). At this point, maturity of fruit is further defined into storage grades depending on how far fruit starch mobilisation has progressed.

The important test for establishing fruit maturity is the starch pattern index test. For the test, a random sample of apple fruit from bins are taken, sliced in half and the exposed apple flesh sprayed with an iodine solution. The presence of starch is indicated by a blue–black colour on the fruit where iodine has reacted with starches. Unripe fruit, where high levels of starch are present, develop an even dark colour across the entire fruit surface. As fruit reach maturity, starches are converted into sugars and instead of an even dark colour a distinctive pattern will develop on the cut surface of the fruit (Reid *et al.* 1982). As maturity progresses, the amount of colour reduces.

Fruit may then be processed immediately or sent into cold store for later processing, depending on fruit volumes and market demands. Having already tested maturity and colour of fruit, packing houses have a clear indication of market suitability of fruit prior to packing.

The first stage of fruit processing is the water dump where fruit are removed from bins into water which is circulated to move fruit towards the packing line. The second step is the movement of fruit into the high pressure washing stage. Here fruit move onto beds of brushed rollers that continually move fruit while they are subjected to a high pressure spray, the combined brushing and spraying removing contaminants and leaf material. During the March 2011 verification visit, it was observed that each apple was subject to the high pressure spray for between 30 and 60 seconds whilst being continually turned due to the counter rotating

rollers. This exposed all surfaces of the fruit to the high pressure spray. Any contaminating material was seen to be blown past the brushed rollers, away from the fruit.

Subsequently, apples are then passed back into a water bath (which is separate from the dump tank), or directly onto rollers and conveyors that take them into the packing house.

All packing houses observed during the verification visit utilised Nylate® as a post harvest sanitiser. In water, Nylate® breaks down to two biocidal agents, hypochlorus acid and hypobromus acid. In some cases, the Nylate® was applied in the dump tank, in other cases after the high pressure washing. In all cases, application of Nylate® was monitored, automatically or at specific times, for both concentration and pH.

Grading and sorting of apples was observed to follow a number of different practices. In some cases, the first stage was hand sorting of apples as they entered the packing house to remove apples with damage or other symptoms that would make them not suitable for market. Fruit was then directed to electro-optical grading equipment to determine fruit colour, size and weight before being directed to specific packing lines.

Alternatively, some packing houses have more advanced grading equipment that allows both grading and defect detection. In that case, removal of damaged apples still occurred prior to grading, though less staff were involved as the machinery was responsible for detecting minor defects that would otherwise have been removed by packing house staff.

After grading, all packing houses were observed to utilise a conveyor system that carried apples to the appropriate packing line where apples were "dropped" onto the appropriate packer's table.

Apples that do not meet specification were consigned to either processing/juicing or to the domestic market. Those apples directed to the domestic market were observed to still be free of damage and rots, but were affected by symptoms of black spot (apple scab), russetting, or other quality parameters.

The most common form of packaging for apples is the 18kg carton which contains four or five layers of apples each on top of a moulded cardboard insert. The number of apples and exact weight depends on the size being packed, with between 95 and 150 apples being common. Each carton includes a lid. Also observed were single layer cardboard boxes, without lid, each containing around 40 fruit and weighting 6.5kg. Both of these forms of packaging are palletised for transport.

Packaging of apples in bulk bins, while not considered a large part of the market, does occur. Bulk bins are utilised where receiving markets specifically prefer to re-pack on arrival, with packing into small "clamshells" each with six fruit being an example of such packaging (BSG 2011). For the 2009–10 season, only 0.19 per cent of fruit was exported in bulk bins, and only to the UK and France (MAFNZ 2011).

During the packing process, phytosanitary and quality control inspections were undertaken by trained staff and monitored by an Independent Verification Agency. In some cases packing machinery was configured to randomly drop apples, at a specified rate and including all sizes, for quality control and phytosanitary inspection on a separate line. In other lines, these samples were taken as random boxes of packed apples. Any detection of pests or grading issues were recorded, and any symptoms of possible infestation examined further through fruit cutting.

Any outcomes from the quality control and phytosanitary inspections apply to the entire processing lot of apples on the packing line at that point in time.

3.4.2 Storage

After packing, palletised boxes of apples were moved to cold stores pending the building of an export consignment and subsequent export. As described by packing house staff, cold storage of boxed apples rarely exceed a few weeks.

Primarily, long term cold storage of apples occurs pre-processing and packing, with apples being stored in the bins they were harvested into. However, in some circumstances and for some markets storage in packed 18kg cartons may occur for up to a three month period. Apples stored for extended period of time are reinspected and/or tested for flesh firmness, sugar levels and any evidence of post-harvest degradation to ensure that the fruit still meets phytosanitary standards of the importing country and the quality standards expected by the importer (MAFNZ 2011).

Finally, some extended storage of pre-graded apples occurs for specific markets. In such cases apples that are of a specific size or colour to suit a particular market will be stored in bulk bins at the end of a packing line. The bins are then returned to cold storage with the packing house having knowledge of the exact size and quality. When required for market, such fruit is then returned to the packing line for packing into boxes. In effect this is a pre-sizing operation, modified to suit the packing lines in specific export packing facilities.

3.4.3 Export procedures

As export phytosanitary inspections are typically conducted as part of the packing house processes, apples are ready for export as soon as packed. Computer records determine which market any consignment is eligible for and are also the basis for phytosanitary certification by the New Zealand Ministry of Agriculture and Forestry.

In some cases an end point inspection will be conducted on a consignment rather than as an "in-line" process as part of the packing line process. In those cases the phytosanitary inspection required by the importing country is conducted by consignment by grower lot.

3.5 Production and export statistics

In the 2009 season, New Zealand is reported to have a total apple production of 466 000 tonnes (WAPA 2010). Of this, the Pipfruit Industry Statistical Annual 2009 reported a 2009 export apple production of 302 705 tonnes, an approximately 16 per cent increase over the 2008 season (Pipfruit NZ 2010). The remainder, or around 35% of the crop, was available for domestic consumption or processing.

New Zealand apple producers are heavily export focussed. Important markets include the United Kingdom, the United States of America, the Netherlands, Belgium, Taiwan, and Hong Kong. Each of those markets imported over 10 000 tonnes of New Zealand apples in 2009 (Pipfruit NZ 2010).

Considered by growing region, approximately 66 per cent of the export fruit came from the Hawke's Bay district, 28 per cent from the Nelson district, and 3 per cent from the Otago district, these figures corresponding closely to the acreages in these regions.

Consistent with the planted acreage per variety, Royal Gala and Braeburn are exported in the most volume, with Royal Gala having the greatest export production in the Hawke's Bay district and Braeburn in the Nelson district. Fuji and Jazz are the next two varieties exported in the greatest volume (Table 3.1). Individually, other varieties of apples each make up less than 5 per cent of the total export volume.

Table 3.1 Export volume and percentages of each variety of fruit for exports from New Zealands three main apple production regions (Pipfruit NZ 2010)

	Hawke's Bay	Nelson	Central Otago
Braeburn	29.3%	41.3%	17.0%
Fuji	11.8%	2.8%	7.1%
Jazz	3.8%	14.3%	5.4%
Royal Gala	39.1%	27.2%	26.4%
Total apple exports (tonnes)	202 138	80 485	10 081

3.5.1 Export season

New Zealand's primary export markets are in the Northern Hemisphere and include the United States of America, the Netherlands, Belgium, Germany, Taiwan, Hong Kong, Thailand, and the United Arab Emirates (Pipfruit NZ 2010). New Zealand fruit is supplied into these markets to meet counter seasonal demand.

Apple exports begin almost immediately with the first harvest of apples in February and continue in significant volumes until around July (MAFNZ 2011). Apples can be stored for long periods and growers and packers have the option to hold apples in cold store immediately after harvest, or after packing processes until required on the market. The start of the season is principally defined by the availability of the New Zealand harvest, while the end of the season is determined by the first availability of apple produced in the northern hemisphere.

While most exports to the Australian market would likely occur between late February and late August, it is possible that New Zealand apples could arrive in Australia all year round. However, it is understood that the majority of large cool store facilities in New Zealand do not operate all year round, with most produce having been exported prior to the southern hemisphere's spring (BSG 2011). Ultimately, economic factors and market access opportunities will determine the market window for New Zealand apple exports to Australia. This review considers the bulk of exports from February until August, with only lower volumes potentially entering Australia after August.

4 Pest risk assessments for quarantine pests

Pest risk assessments are presented in this section for the three pests considered by this review: fire blight, European canker and apple leaf curling midge. Pest risk assessment has been undertaken to determine whether the risk posed by a pest exceeds Australia's ALOP and thus whether phytosanitary measures are required to manage the risk.

According to the 2006 *Final Import Risk Analysis Report for Apples from New Zealand* (BA 2006), fire blight, European canker, and apple leaf curling midge are all absent from Australia and have the potential to establish, spread, and cause economic consequences. These three pests therefore meet the definition of a quarantine pest. Further, all three of these pests are present in New Zealand and have the potential to be associated with imported apple fruit. Pest risk assessment for these three pests is therefore justified. The entries from Part C of the 2006 *Final Import Risk Analysis Report for Apples from New Zealand* that determined these three organisms as potential quarantine pests has been included in Appendix A of this review.

All three of these pests are considered to be absent from all of Australia. Therefore, these assessments are applicable to all of Australia.

Table 4.1 Quarantine pests for apple fruit from New Zealand considered in this risk analysis

Pest	Common name
DOMAIN BACTERIA	
Fire blight (Enterobacteriales: Enterobacteriaceae)	
Erwinia amylovora (Burrill 1882) Winslow *et al.* 1920 emend. Hauben *et al.* 1998	Fire blight
DOMAIN EUKARYA	
Apple leaf curling midge (Diptera: Cecidomyiidae)	
Dasineura mali (Kieffer 1904)	Apple leaf curling midge
European canker (Hypocreales: Nectriaceae)	
Neonectria ditissima (Tul. & C. Tul.) Samuels & Rossman	European canker

4.1 Fire blight

Fire blight, caused by the bacterium *Erwinia amylovora* has been reported from 46 countries including New Zealand (van der Zwet 2006). Fire blight-like symptoms were detected on cotoneaster in the Royal Botanic Gardens Melbourne in April 1997, and diagnostic tests confirmed that the causal organism was *E. amylovora* (Rodoni *et al.* 1999). National surveys conducted for three years following the detection of *E. amylovora* have confirmed the absence of the disease in Australia (Rodoni *et al.* 1999). The mode of introduction of fire blight into the Royal Botanic Gardens Melbourne is unknown.

Fire blight is the most serious bacterial disease affecting *Malus* spp. (apple), *Pyrus* spp. (pear), *Cydonia* spp. (quince), *Eriobotrya japonica* (loquat), and amenity hosts including *Crataegus* spp. (hawthorn), *Cotoneaster* spp. (cotoneaster) and *Pyracantha* spp. (firethorn).

The pathogen overwinters almost exclusively in the previous season's cankers (Beer and Norelli 1977) and the primary inoculum is produced mostly as bacterial ooze on the surface of cankers. The disease cycle begins when cankers on infected hosts ooze bacteria (Brooks 1926), but non-oozing cankers can also harbour bacteria (Miller and Schroth 1972). Primary and secondary inocula can also originate from wild, amenity, household and garden plants. The pathogen enters the host through natural openings (for example, stomata or nectaries) or wounds (such as those caused by pruning or hail). Insects, wind, rain and pruning tools are the main methods of spreading primary inoculum of *E. amylovora*. Bees are the primary agents for secondary spread of inoculum from infested flowers to newly opened ones (Thomson 2000).

Erwinia amylovora infects flowers, young leaves, stems and immature fruits. Flowers are highly susceptible to infection by *E. amylovora* (Keil and van der Zwet 1972a), with bacterial populations occurring almost exclusively on stigmas and reaching 10^6 to 10^7 colony forming units (cfu) per flower (Thomson, 2000). Infection occurs when bacteria, spread by rain or dew, enters the nectaries. Often the first symptoms, accompanied by ooze, are seen on the outer surface of the receptacle of fruitlets and the stalks (Beer 1990).

Infection of succulent vegetative tissues often produces a characteristic shepherd's-crook symptom. This is accompanied or followed by a discolouration of the stem and attached leaves as well as the exudation of ooze. Leaves are rarely infected, but prone to infection after hail damage (Beer, 1990). Multiplication of *E. amylovora* could not be demonstrated on leaf surfaces, and bacteria died within a few hours when exposed to solar radiation or high humidity levels (Maas Geesteranus and de Vries 1984).

Infected immature fruits differ in appearance depending on when they are infected. Immature fruit infected with *E. amylovora* often shrivel and remain attached to trees through winter, but do not show any signs of oozing. Fruit infected as a result of progressive infection of branches are less shrivelled and discoloured. Those fruit infected following injury by hail or insects often develop red, brown or black lesions and may exude ooze (Beer, 1990). Epiphytic colonisation of the stigmatic surfaces of flowers by *E. amylovora* may result in bacteria persisting in low numbers on the dry flower parts subsumed into the calyx-end of the fruit where they are known to persist for some time (Hale *et al.* 1987; Sholberg *et al.* 1988).

4.1.1 Probability of entry

Probability of importation

The likelihood that *Erwinia amylovora* will arrive in Australia with the trade in fresh apples for consumption from New Zealand is: **MODERATE**.

Association of the pest with the crop

- *Erwinia amylovora* is known to infect host vegetation including immature fruit (Beer 1990; Norelli *et al.* 2003).
- Fire blight, caused by *E. amylovora*, is endemic in New Zealand (Cunningham, 1925; Wilson, 1970; Reid, 1930). The disease is more common in regions on the North Island (particularly Hawke's Bay, where 66 % of export fruit is produced (Pipfruit NZ 2010), than it is in the cooler areas on the South Island. The lower disease incidence in areas of the South Island is due mainly to lower temperatures during flowering (Hale and Clark, 1990).
- Prior to the implementation of the integrated fruit production program (IFP), the proportion of designated export areas (DEAs) withdrawn from the export program to Japan because of the presence of fire blight symptoms caused by *E. amylovora*, either within orchards and/or buffer zones (0.5km) after three inspections in the 1994–95 growing season, was 58.8% in Hawke's Bay, 63.1% in Nelson, 48.8% in Blenheim and 24.5% in Canterbury. In the 1995–96 season the DEA rejection rate was 56.1% in Nelson and 16.1% in Blenheim, while during the 1996–97 season, it was 12.2% in Blenheim (New Zealand Government, 2000). This indicates that fire blight caused by *E. amylovora* was widespread in New Zealand during the 1990's.
- Japan has a significant pome fruit industry (Apple University 2010) and as a result of negotiations since the Japan-USA apple dispute at the WTO, New Zealand now has access to the Japan market without specific risk management measures for fire blight (Japan Apple Regulations 2007).
- Since the adoption of the IFP program, symptoms of fire blight have become less common and growers do not consider it to be an important disease limiting production (BSG 2011).
- For example, a key strategy of the IFP program to control fire blight is the application of sprays to prevent blossom infection based on a predictive model (refer to section 3.2.3 for more detail on IFP). The number of blocks in New Zealand that applied sprays (streptomycin or Blossom Bless) to control fire blight infection of blossoms was 9.4%, 10.7%, 11.7% and 8.3% in the seasons of 2006/07, 2007/08, 2008/09 and 2009/10 respectively (BSG 2011). These figures include blocks that sprayed both streptomycin and Blossom Bless and therefore include some double counting (MAFNZ 2011). In addition, the application of sprays only indicates that climatic conditions present a high risk for potential infection events, not actual the actual level of infection.
- The predictive model takes account of the presence of fire blight near an orchard. Therefore, the application of sprays for fire blight provides indirect evidence for the prevalence of the disease. Even if compliance with the model recommendations is only 50%, any orchard infection rates is likely to be well below the levels recorded in the 1990's prior to the implementation of the IFP program.
- The incidence of fire blight from year to year mainly depends on spring seasonal conditions (APPS 2009). *Erwinia amylovora* requires suitable climatic conditions, warm temperatures and high humidity, to produce inoculum and cause infection (Brooks 1926; Beer and Ogenorth 1976; Mills 1955).
- The effective management of pests (including fire blight) since the introduction of the IFP program is likely to have contributed to productivity gains. Since 1997, before the start of the IFP program, to 2009, productivity (tonnes/ha) of export quality apple varieties has increased on average by 80% (Wilton 2010). Even for newer varieties, such as Jazz™, that

have an extended flowering period and are considered more susceptible to fire blight (BSG 2011), productivity has more than doubled from 2005 to 2009 (Wilton 2010).

- There has been no reported severe outbreak of fire blight since 1998 even though computer models predict infective events each year in New Zealand as evidenced by the continued use of sprays to manage fire blight. It is most likely the level of *E. amylovora* infection in commercial orchards, as reported from the 1990's, is lower as a result of the full adoption of the IFP program and in particular the targeted management of fire blight and improved prediction methods.

Association of the pest with the commodity pathway–calyx infestation

- *Erwinia amylovora* is known to infest blossoms and mature fruit (Hale *et al.* 1987; Norelli *et al.* 2003).
- The proportion of fruit carrying *E. amylovora* over a 100-day period from immature fruitlet stage to harvest, from a severely infected orchard with 75 infections per tree has been studied using selective media to detect bacteria (Hale *et al.* 1987). This work, based on a logistic plot of the data, showed from an initial infestation level of 53% of fruitlets, by harvest, 3.5% of fruit were infested, a 93% proportional decrease.
- *Erwinia amylovora* predominantly colonise flowers (Thomson, 1986; Thomson, 2000) and only relatively low bacterial numbers have been recorded on dried remnant flower parts subsumed into the calyx sinus of mature fruit (Hale *et al.* 1987; Sholberg *et al.* 1988; Temple *et al.* 2007). All the available literature shows that the highest bacterial population occurs on the stigma of flowers under suitable environmental conditions. Thereafter the population of bacteria in remnant flower parts declines as they subsume into the calyx cavity of fruit. Although it is acknowledged that conditions vary from season to season and between orchards, the 93% proportional decrease provides a guide to the reduction in calyx infestation that may be expected as fruit matures.
- Hale and Clark (1990) reported calyx infestation in apple fruitlets sampled from a number of New Zealand orchards with fire blight symptoms, on apple or alternative hosts in the orchard, averaged 7.4% based on a sample of over 6000 fruitlets. If a 93% decrease in the level of infestation is applied, the final expected rate of calyx infestation in mature fruit would be 0.5%. For orchards without fire blight symptoms, no *E. amylovora* bacteria were detected from a sample of 4000 fruit (Clark *et al.* 1993) (Note: Hale and Clark (1990) report 3200 fruitlets tested, but this was an error). The DNA hybridisation technique used for these assays was sensitive enough to detect 100 cells of *E. amylovora* in calyces of apples (Hale and Clark, 1990).
- In a later study, over 60 000 fruitlets were sampled from 10 orchards over four years and no *E. amylovora* bacteria could be detected from orchards without fire blight symptoms (Clark *et al.* 1993). In one year, fire blight symptoms were detected in three orchards and 0.48% of fruitlets were infested. If the 93% decrease proportional decrease is applied, 0.03% of fruit would likely be infested at harvest.
- Previously, it had been reported that 14.7% of fruitlets from a single orchard without fire blight symptoms at blossom had infested calyces based on information presented in a data table in Clark *et al.* (1993). However, the results section of the paper states that the particular orchard was found to have fire blight symptoms during surveys later in the season.
- In New Zealand *E. amylovora* has been isolated from calyces of less than 1% of mature fruit using a direct plating method from a severely infected (75 infections per tree) orchard (Hale *et al.* 1987), and 2% of fruit immediately after harvest from orchards with an

average level of fire blight symptoms (Hale and Taylor, 1999). This is consistent with the above data using the 93% proportional decrease.

- McManus and Jones (1995) reported the presence of *E. amylovora* in 75% of calyces of mature fruit taken from symptomless trees in a severely infected orchard, using a nested PCR test capable of detecting less than one bacterial cell. These authors also showed that 27% of fruit tested positive using a less-sensitive PCR-dot-blot hybridization test with a lower detection limit of approximately 20 bacteria. The latter method is less prone to false positives than nested PCR (McManus and Jones 1995). However, the DNA techniques used could not distinguish live bacterial cells from dead cells according to the information provided by McManus (AQIS 1998a). McManus suggested that it is possible that the DNA of *E. amylovora* detected was from dead bacteria. Therefore, this data would not provide an accurate estimation of calyx infestation rates by *E. amylovora*.
- *Erwinia amylovora* was not isolated by direct plating of washings of the calyx-end or main portion of fruit (1400) harvested from lightly infected trees (1 to 2 infections per tree) or fruit (300) harvested from fire blight-free orchards and cool-stored for several months in New Zealand (Hale *et al.* 1987).
- In other experiments conducted in New Zealand, *E. amylovora* was not detected at harvest, either in the calyces or on the surfaces of 173 mature fruit sampled within 5 cm of inoculum sites approximately four months after artificial inoculation. Although a few isolates produced slight hybridisation with the DNA probe, none were confirmed as *E. amylovora*, based on tests using selective media or PCR (Hale *et al.* 1996).
- *Erwinia amylovora* was not detected in calyces of 150 mature apple fruit harvested from orchards without fire blight symptoms in New Zealand. In this study macerated calyx tissues were assayed using a sensitive PCR technique (Hale and Taylor 1999).
- A DNA hybridisation method did not detect *E. amylovora* in calyces of 750 mature apples harvested from within 20 cm of inoculated flower clusters, in a season not conducive to infection or spread of fire blight in New Zealand (Clark *et al.* 1993).
- Based on the data discussed above from the 1980's to 1990's in New Zealand, which was prior to the implementation of the IFP program, in the order of 0–3.5%, apples picked from orchards with fire blight symptoms could be infested with viable bacteria. The highest values of this range come from apples harvested from severely infested orchards. In orchards without fire blight symptoms, no bacteria could be detected from large numbers of fruit sampled from many orchards over several years.
- Fruit for export is produced by the industry prescribed IFP program or organic production methods. Fruit enters export packing houses once compliance with the IFP program spray recommendations has been confirmed following examination of the growers spray diary by auditing organisations independent of the industry (MAFNZ 2011).
- In West Virginia, USA, *E. amylovora* was recovered from calyces of 5% of immature fruit harvested from a healthy orchard, located 30 km from infected orchards but when severe fire blight symptoms were in the area (van der Zwet *et al.* 1990). Applying the 93% proportional reduction to the above 5% figure, 0.4% of mature fruit may contain *E. amylovora* in the calyces.
- In Ontario, Canada, *E. amylovora* was not isolated from tissues of the stem-end and calyx-end of 60 mature fruit harvested from severely infected apple trees (Dueck 1974a).
- In British Columbia, Canada, Sholberg *et al.* (1988) isolated epiphytic *E. amylovora* bacteria on naturally contaminated, blemish-free and apparently healthy apple fruit

collected at harvest from an orchard severely infected by fire blight from a season considered exceptional for the disease following hail damage. The apple trees in the experimental site were either adjacent to or interplanted with pear trees, which were severely infected by fire blight. The pathogen was isolated using bulked samples of three fruit, which would have recorded a positive result even if one fruit was contaminated. Therefore the true infestation rate was between 33–100%. This study did not distinguish between surface and calyx infested bacteria.

- Ceroni *et al.* (2004) artificially inoculated pear fruit by placing 30µL of a bacterial suspension (10^8 cfu mL^{-1}) in the calyx cavity (ca. 3 x 10^6 cfu) and followed survival in cold storage. Bacterial numbers in the calyx were detected using PCR (101.8 cfu per calyx on day 0) decreased exponentially, but small numbers survived up to 101 days. These numbers were 0.7, 0, 1.5, 0, and 3.7 cfu per calyx respectively, by day 73, 80, 87, 94 and 101.
- The bacterial numbers in the calyx of mature fruit under natural conditions would be much lower than what Ceroni *et al.* (2004) observed by placing a high dose directly in the calyx of the harvested fruit. The observation by Ceroni *et al.* (2004) that longer survival is possible only in the calyx of pears is in agreement with that of Hale *et al.* (1987) where, in the small numbers of apple fruit carrying bacteria at maturity, detections were almost always in the calyx.
- Roberts *et al.* (1998) reviewed the literature concerning the presence of *E. amylovora* on apple fruit in Canada, USA and New Zealand, and provided an average value of 4.9% infestation for apples from orchards with active fire blight, and an average value of 0.35% infestation for apples drawn from orchards where there was no consideration of fire blight status.
- A later publication revised this estimate down based on new evidence and clarification or correction of previously misinterpreted data present in the literature (Roberts and Sawyer 2008). This later work now reports no *E. amylovora* were detected in apple fruit from orchards without fire blight symptoms and 1.3% of apple fruit are infested from orchards with fire blight symptoms. Many apple fruit samples from orchards with symptoms detected no *E. amylovora* (Roberts and Sawyer 2008).
- More recently, Ordax *et al.* (2010b) reported no *E. amylovora* could be detected from 100 apples immediately after harvest from a severely infected fire blight orchard. Sensitive detection methods were employed that could detect < 1 cfu/ml of calyx extract and would have detected live or dead bacteria including those in a viable but non-culturable (VBNC) state.
- In the USA, numbers of bacteria on blossoms of apple and pear inoculated with *E. amylovora* bacteria decline to very low levels in the calyx of the subsequent mature fruit. An average of 7 cfu of *E. amylovora* was recorded from 3.3% of the pear fruit sampled over two years. In apples, no fire blight could be detected at harvest (Temple *et al.* 2007).
- In a sample of commercial pear orchards, where disease incidence is typically higher than on apples (Agrios 1997; Paulin 2010a), of the orchards sampled, 27% had fire blight symptoms and only 1 fruit of 5600 sampled at harvest had *E. amylovora* with 32 cfu detected (Temple *et al.* 2007).
- In West Virginia, 5% of immature fruit sampled from a symptomless orchard were infested and between 1–50 cfu where detected in the calyx (van der Zwet *et al.* 1990). As previously shown by many studies, this incidence and level of infestation will decline

through time (Hale *et al.* 1987; Sholberg *et al.* 1988; Hale and Taylor 1999; van der Zwet *et al.* 1990).

- In West Virginia USA, van der Zwet *et al.* (1990) isolated *E. amylovora* populations exceeding 1000 cfu per fruit from calyces of mature apples taken from a blight-free orchard when severe fire blight was present in the area during that year. However, it has been later confirmed by the senior author of that study that the apples sampled were immature (WTO 2003).
- The highest reported population of *E. amylovora* on mature apple fruit harvested from an orchard was recorded in Canada (Sholberg *et al.* 1988). This work reported the isolation of an average of $10^{3.3}$ cfu per mL of viable *E. amylovora,* from surface and calyx infested bacteria, from a bulked sample of three harvested mature fruit which were infested naturally. This infestation equates to approximately 700 cfu per individual infested fruit. The fruit in this study were sampled from apple trees next to severely infected pear trees from an exceptional year for fire blight, including hailstorms. This is the highest level of bacteria recorded from naturally infested mature apple fruit.

Association of the pest with the commodity pathway–infection

- McLarty (1924; 1925; 1926) isolated viable *E. amylovora* from apples that had been artificially inoculated on the tree when they were immature, allowed to mature and then held in storage for several months. This demonstrated that *E. amylovora* could withstand the physiological changes in fruit as it matured.
- Goodman (1954) recovered viable *E. amylovora* from the tissues directly beneath the skin of several apples that were retained on the trees until February (late winter). These trees had been severely affected by fire blight during the previous growing season. The report also stated that the fruit had moist flesh, indicating that they were not mummified and therefore supporting the conclusion that they had developed normally.
- The recovery of endophytic populations of *E. amylovora* from developing fruit harvested (in summer) within 15 cm of blighted shoots but not from 60 cm to 200 cm has been reported (van der Zwet *et al.* 1990). These authors also recovered viable *E. amylovora* from internal tissues of one maturing apple fruit out of a sample of 160 harvested in July and August (summer) from apparently symptomless trees of four cultivars.
- When mature apples were artificially inoculated with *E. amylovora*, the bacterium dispersed into the fruit pulp with a concomitant increase in the bacterial population, at room temperature, two weeks after inoculation, without producing any fire blight symptoms. However, the pathogen population did not change during further storage over a period of five weeks (Jock *et al.* 2005).
- Azegami *et al.* (2006) experimentally demonstrated systemic movement from the stem into fruit. These authors examined the invasion and colonization of mature apple fruit by depositing *E. amylovora* inoculum concentrations, ranging from 5–10µl drops in most instances at 10^4–10^7 cfu/ml, on cut surfaces of pedicels of fruit, wounds on the shoulder and the calyx of fruit, fruit bearing twigs with attached fruit and cut fruit flesh (mesocarp). The authors showed that under these conditions the pathogen can invade mature and immature apple fruit. It was shown to spread vertically and horizontally and colonise along vascular bundles, increasing its population. It was reported to spread up to the calyx end and the flesh just under the exocarp within 3–4 days after inoculation. Irrespective of fruit maturity the population increased and survived 2–4 weeks or more at 25 ºC. Bacteria were able to migrate rapidly within twigs and reach the abscission layers between fruit-bearing twigs and the fruit stem. These experiments were done under high inoculum

pressure on freshly cut surfaces and the authors considered that such invasions may not occur under field conditions.

- Tsukamoto *et al.* (2005) examined the infection frequency of mature apple fruit inoculated with 10µl drops containing 10^5 and 10^4 cfu of *E. amylovora* on each of the freshly cut pedicels and enclosed in plastic boxes at 25 ºC. The results showed that *E. amylovora* infected mature fruit latently and that it remained viable after 6 months of storage at 5 ºC in most of the inoculated fruit. The authors suggested that latently infected mature fruit could transmit the disease over long distances. However, this phenomenon has not been demonstrated using naturally infected fruit in orchards. Azegami *et al.* (2006) examined the invasion of apple fruit after approximately 10^5 cfu *E. amylovora* was used to inoculate fruit bearing twigs in potted plants raised outdoors but placed in a greenhouse before inoculation. These authors isolated *E. amylovora* from 3%–5% of symptomless fruit whose fruit-bearing twigs had been inoculated indicating that the pathogen can move through the abscission layer and invade the fruit during fruit maturation. The authors concluded that the possibility cannot be excluded that *E. amylovora* can invade apple fruit through fruit-bearing twigs in late summer to yield mature symptomless fruit.
- However, the inoculation experiments of Tsukamoto *et al.* (2005) and Azegami *et al.* (2004; 2006) that report fruit infection were criticised because of their highly artificial nature and they do not support fruit infection under field conditions (Paulin 2010a). There is not sufficient information to support infection of mature apple fruit (Deckers 2010).
- *Erwinia amylovora* was isolated from internal tissues of fruit harvested from blighted orchards in Utah, USA (van der Zwet *et al.* 1990). These authors recovered 1 to 300 colonies of *E. amylovora* from internal tissues. However, a statement, provided to the WTO Japan–USA apple dispute by two of the four authors of this report more than 10 years after the work was published, indicated that the internally contaminated fruit harvested for testing was immature (WTO 2003).
- In Canada, mature apples were infected only when high inoculum doses were injected into the cortex of fruit and bacteria remained viable as long as the fruit was physiologically active (Dueck 1974a).
- Tests conducted to examine the presence of bacteria within ovules and seeds of a range of plant species identified *E. amylovora* as one of the bacterial species (Mundt and Hinkle 1976). The authors have not linked the different species of bacteria obtained to the different plant species tested, but apple and crab-apple were the only Rosaceae species tested and it is possible that the detection of *E. amylovora* is from the seeds of these species. The tested seeds were surface-sterilised, indicating that the bacterium was present inside the seed. However, this work has been criticised as the methods employed do not confirm the presence of *E. amylovora* (Paulin 2010a).
- In the USA, *E. amylovora* was not isolated from any whole or split apple seeds tested (van der Zwet *et al.* 1990).
- *Escherichia coli* and *E. amylovora* belong to the family Enterobacteriaceae and *E. coli* could be considered an analogue for *E. amylovora*. Studies conducted on *E. coli* report artificial inoculations using very high inoculum doses on injured fruit (Buchanan *et al.* 1999; Burnett *et al.* 2000). These conditions do not reflect the situation that exists naturally in orchards. Therefore, strict comparison or extrapolation of results relating to the behaviour of *E. amylovora* may not be applicable.
- *Erwinia amylovora* can occur in the xylem vessels (Bogs *et al.* 1998; Vanneste and Eden-Green 2000), phloem (Lewis and Goodman 1965) and cortical parenchyma (Eden-Green

and Billing 1974) of symptomless plants. The persistence of *E. amylovora* in xylem vessels seems to be limited, possibly because the salts and water contained within lack elements required for rapid bacterial multiplication (Gowda and Goodman 1970; Momol *et al.* 1998), but still indicates that *E. amylovora* is able to migrate in symptomless plants (Momol *et al.* 1998).

- Bacteria tend to aggregate and disrupt the water flow (Sjulin and Beer 1977), which causes leakage of the vessels and extrusion of bacteria into the parenchyma. Rapid multiplication of *E. amylovora* occurs when bacteria escape from the xylem vessels into intercellular spaces of the cortical parenchyma, resulting in symptom development (Vanneste and Eden-Green, 2000). Sudden outbreaks of fire blight without any evidence of inoculum have been attributed to this phenomenon (Thomson 2000).
- A recent review of the evidence supports the view that *E. amylovora* can occur in xylem vessels (Billing 2011). It is further stated that *E. amylovora* can multiply in the xylem and may survive latently for many years, expressing symptoms once the xylem vessel is damaged and bacteria are released into the parenchyma (Billing 2011).
- If bacteria were to occur in the vascular tissue in the tree there is no reason to assume that they would not find their way into fruits. However, the paucity of evidence of endophytic infection in mature fruit suggests that if endophytic infection does take place in fruit it must be a rare event.
- *Erwinia amylovora* was not recovered from aqueous sonicates or core tissues of 1555 mature symptomless apples harvested from blighted trees of seven apple cultivars that were cold-stored. The sonication–membrane filtration technique was able to detect as few as 19 cfu and its sensitivity exceeds that for an immunofluorescent assay using monoclonal antibodies (Roberts *et al.* 1989).
- A Japanese–US study tested 30 900 mature apple fruit from two sites in Washington State, USA, harvested between 0 to 300 metres from a source of fire blight inoculum. The fruit was analysed for internal populations of *E. amylovora* after harvest. Bacteria were not detected in any of 900 fruit (sourced from fire blight-infected apple trees or directly adjacent to blighted pear trees) using isolation methods, with this result confirmed by PCR tests (Roberts 2002). Of the 30,000 fruit placed in cold storage, none developed external symptoms. Further, no internal symptoms were detected in any of the 1500 fruit that were sliced open. Of these, 500 were streaked onto plates with selective media, but *E. amylovora* was not recovered (Roberts 2002).
- *Erwinia amylovora* could not be isolated from internal tissue of symptomless fruit harvested from blighted trees, where approximately 20% of the wood on the trees from which apples were harvested had symptoms of fire blight (Dueck, 1974a).
- It has been argued that fruit can be internally infected without showing symptoms, but if this were to occur many fruit would have developed a rot, and there is no evidence for this in commercial trade of apples.
- It is considered there are no reports of true infection in mature apples under natural conditions as they are resistant to infection (Paulin 2010a). Even if fruit are artificially inoculated, they do not develop symptoms of fire blight because the bacteria do not readily multiply in the mature fruit due to an absence of the required carbohydrate source (Deckers 2010; Paulin 2010a).

- In the absence of any new evidence to support fruit infection in mature apple fruit, the likelihood of fruit infection occurring under natural conditions is considered to be negligible.

Ability of the pest to survive adverse conditions–viable but non-culturable state

- Studies conducted by Biosca *et al.* (2004) and Ordax *et al.* (2004; 2006) indicate that *E. amylovora* can enter into a viable but non culturable (VBNC) state. Another study, using an attenuated strain of *E. amylovora* which had lost its pathogenic ability, confirmed that *E. amylovora* can enter into a VBNC state (Sly *et al.* 2006). This phenomenon may contribute to an underestimation of the pathogen numbers when culture methods for detection of *E. amylovora* bacteria. However, DNA detection techniques, such as PCR, rely on genetic material in the bacteria and would detect VBNC bacteria as well as dead and lysed cells and would not result in an under-estimation of *E. amylovora*.
- *E. amylovora* can be induced to enter into a VBNC state by nutrient starvation (Biosca *et al.* 2004) or by the presence of copper (Ordax *et al.* 2004). *E. amylovora* is able to survive and remain infective for six months in sterile irrigation water (Biosca *et al.* 2004) and the culturability and pathogenicity of copper-induced VBNC *E. amylovora* (Ordax *et al.* 2004) can be restored under sterile conditions.
- The studies of Biosca *et al.* (2004) and Ordax *et al.* (2004; 2006) were conducted under artificial conditions (sterile mineral medium and sterile water microcosms) with high inoculum doses. These conditions differ significantly from those present on apple trees under natural conditions. Application of copper during apple's dormant growth periods and at flowering to reduce *E. amylovora* populations in apple orchards could induce this pathogen to enter into a VBNC state. Ordax *et al.* (2004) have shown a 10^6 reduction in the bacterial population, including bacteria considered to be in the VBNC state, 70 days after exposure to copper. Given the low numbers of bacteria likely to be present on apples if copper is applied, these results suggest no culturable bacteria are likely to be present at fruit maturity.
- According to the information presented by several authors (Rahman *et al.* 1996; Ericsson *et al.* 2000; Bogosian and Bourneuf 2001; van Overbeek *et al.* 2004) the significance of VBNC in relation to bacterial survival is not yet clearly established. The few studies on *E. amylovora* show that only a small proportion of the cells appear to enter a VBNC state. One study (Sly *et al.* 2006) was unable to demonstrate recovery of cells to a culturable state suggesting that the VBNC state may be an irreversible stage towards cell death.
- The VBNC hypothesis has frequently generated sharp debate and some proponents argue that this condition may be a physiological condition prior to cell death (Bogosian and Bourneuf 2001; McDougald *et al.* 1998).
- No field studies have been undertaken to verify the claim that sudden appearance of fire blight in apple orchards is due to resuscitation of copper-induced VBNC cells. Ordax *et al.* (2006) have suggested that further studies on the interaction of copper with *E. amylovora* and the VBNC state are needed to better understand the life cycle of this pathogen and to optimize the fire blight control strategies.
- A recent study has confirmed that *E. amylovora* can enter a VBNC state in the calyx of apple fruit in response to copper and then infect receptive host tissue after periods of 7–28 days post calyx inoculation under favourable laboratory conditions (Ordax *et al.* 2009). The level of infection recorded in this experiment was low and the culturing of *E. amylovora* from infected tissue was several orders of magnitude lower than bacteria that had not entered the VBNC state.

- For VBNC to be a risk pathway, bacteria would need to enter the VBNC state in the orchard and would need to resuscitate before, or during, an infection event in Australia for infection to occur. Copper is known to induce the VBNC state in the laboratory, but it is not generally applied at flowering because of plant phytotoxicity (APPS 2009) and there is still no evidence to confirm resuscitation can occur under natural conditions (Paulin 2010a).

Ability of the pest to survive adverse conditions–Exopolysaccharides and biofilms

- Bacteria occur either as independent single cells (planktonic) or as complex multicellular communities attached to surfaces embedded in exopolysaccharides (EPS) which account for approximately 90% of the enveloping matrix polymers. Biofilm formation is widespread among enterobacterial species (Charkowski *et al.* 2005). These communities adhere to living or abiotic surfaces, typically at a liquid–solid interface (Hall-Stoodley *et al.* 2004).
- The matrix in which microbes in a biofilm are embedded can protect them from ultraviolet (UV) exposure, metal toxicity, acid exposure, dehydration and salinity, phagocytosis, antibiotics, and antimicrobial agents (Hall-Stoodley *et al.* 2004; Sapers 2001; Ryu and Beuchat 2005). In addition, EPS are thought to play a role in protecting the bacterial cell against desiccation, in adhesion to solid surfaces and also in cellular recognition (Allison 1998). Therefore, EPS can provide a physical barrier to protect cells against environmental stresses, in addition to being involved in cell adhesion and biofilm formation (Weiner *et al.* 1995; Stoodley *et al.* 2002; Harrison *et al.* 2005).
- Biofilms can also form on the surfaces of containers used for harvesting, transporting, and displaying foods at retail level (Costerton *et al.* 1987) and on food surfaces (Carmichael *et al.* 1999). Biofilms may exist in uncleaned dump tanks and grading equipment in apple packing houses. However, it is unlikely that biofilms in dump tanks and on grading equipment will involve large numbers of *E. amylovora*, given the conditions that would be present, including low levels of nutrients, the presence of many other bacterial species and the poor epiphytic ability of *E. amylovora*.
- Even if bacteria in biofilms are sloughed off surfaces in dump tanks from time to time, the bacteria are unlikely to attach to fruit because fruit are held in dump tanks for only a very short time. Bacteria that may be superficially attached to fruit leaving the dump tank would be washed off by the high-volume high-pressure water wash systems installed in all New Zealand export packing houses (MAFNZ 2011).
- The most important EPS of *E. amylovora* is amylovoran, which form loose capsules around the bacterial cells and are an important virulence factor (Bellemann and Geider 1992). *E. amylovora* also secretes levansucrase for extracellular levan formation in the presence of sucrose (Geider 2000; 2006). In addition, it produces glucan, which helps in stabilisation of the cell structure (Smith *et al.* 1995). Capsulated bacteria protected by an amylovoran coat survive better under dry conditions as it prevents the loss of residual water (Geider 2000).
- Under laboratory conditions, the EPS of *E. amylovora* (amylovoran and levan) can be used as carbon sources by the bacteria during periods of starvation (Ordax *et al.* 2010a). The utilisation of EPS may assist in the survival of *E. amylovora* during periods of starvation and this factor would be taken into account during the many studies of *E. amylovora* survival in the calyx.
- It has been reported that copper ions increase the level of the EPS amylovoran (Bereswill *et al.* 1998) and that these ions are accumulated on the surface of *E. amylovora* cells

(Zhang *et al.* 2000). Moreover, it is known that bacterial EPS have a cation-binding capacity (Gutnick and Bach 2000). *E. amylovora* in biofilms are over 250 times more resistant to quaternary ammonium compounds than the same bacteria in suspension (Marques *et al.* 2005).

- It is thought that EPS contribute to the survival of *E. amylovora* and therefore allows fire blight to establish and spread (Bennett and Billing 1978). There is no specific evidence concerning the role of biofilms and EPS on the survival of low bacterial numbers in calyces but if EPS did support survival in calyces then this factor would already be accounted for by the bacterial numbers that have been detected on mature healthy apples.
- More recently it has been shown that EPS contributes to the formation of biofilms and plays an important role in the pathogenesis and disease development of *E. amylovora* in plants (Koczan *et al.* 2009; Lee *et al.* 2010).
- However, biofilms are normally formed in the presence of significant nutrient levels at a liquid–solid interface. These are quite different conditions to those present in the calyx or on the surface of apple fruit where the availability of nutrients would be very low and the occurrence of free water would be quite rare. Under these conditions it is unlikely that *E. amylovora* could develop a significant biofilm. This is in contrast to active cankers or pear slices where nutrient levels are high and water is freely available, resulting in the copious production of slime that could contribute to biofilm production and bacterial survival.

Ability of the pest to survive adverse conditions–Quorum sensing

- Quorum sensing describes a mechanism of bacterial cell-to-cell communication which allows bacteria to assess their local population density and/or physical confinement via secretion and detection of signal molecules (von Bodman *et al.* 2003). Quorum sensing, also called autoinduction, is a bacterial defence mechanism known to be associated with biofilm formation (Harrison *et al.* 2005).
- Quorum sensing is also a mechanism by which bacteria can respond to cell density and regulate the expression of specialised gene sets which is regulated by the production of a signal molecule called an autoinducer. Genetic and phenotypic evidence for the existence of quorum sensing in *E. amylovora* was described by Venturi *et al.* (2004) and Molina *et al.* (2005, 2006).
- Quorum sensing may serve as a defence mechanism against antibiotics (Harrison *et al.* 2005). It is noted that relevant studies on survival dynamics of *E. amylovora* reported in this review already take account of quorum sensing.

Ability of the pest to survive adverse conditions–sigma factor

- Sigma factors are regulators of bacterial transcription that can control the expression of specific proteins. Sigma factors can be activated in response to different environmental conditions and could play a role that enhances the survival of *E. amylovora* during periods of stress.
- The sigma factor σ^S, encoded by the gene *rpoS* (RNA polymerase, sigma S), regulates expression of a number of genes that serve to maintain viability of bacteria during periods of starvation and environmental stress (Kolter *et al.* 1993). However, Anderson *et al.* (1998) demonstrated that expression of *rpoS* plays no role in the survival of *E. amylovora* during overwintering in mature tissue.
- The sigma factor plays a role in biofilm formation (Prigent-Combaret 2001), during periods of nutrient limitation (Zambrano and Kolter 1996) and as a regulator required for

virulence (Barak *et al.* 2005). But the role of sigma factor in *E. amylovora* is not yet fully investigated. There is no specific information relevant to survival on apple fruit. However, if sigma factor enhances the survival of bacteria, then it would also have already been taken into account when considering the bacterial numbers present in mature apple fruit.

Ability of the pest to survive epiphytically

- The role of epiphytic bacteria on the fruit surface may also play a role in the importation of *E. amylovora*. However, according to Leben (1965), Miller (1984) and Thomson (2000), *E. amylovora* is not strictly a leaf surface epiphyte. Miller and Schroth (1972) have indicated that while *E. amylovora* is present on leaves only after blossom infection in the spring and even in severely diseased trees, it is not detected in hot summer months. Manceau *et al.* (1990) concluded that *E. amylovora* did not have epiphytic fitness in its biological cycle under the conditions observed in France.
- Epiphytic populations of *E. amylovora* occur almost exclusively on flowers (Thomson 1986; Hale *et al.* 1996; Hattingh *et al.* 1986) compared with other aerial surfaces. There is some evidence that *E. amylovora* can survive epiphytically on leaves and on the surface and calyx-end of apple fruit harvested from infected orchards (Sholberg *et al.* 1988; van der Zwet *et al.* 1990) or alternative hosts (Momol and Aldwinckle 2000). Miller and Schroth (1972) and Miller and van Diepen (1978) argue that *E. amylovora* is transient on the leaf surface and usually present after blossom infections have occurred in the orchard. Leben (1965) does not consider *E. amylovora* to be a strict epiphyte on the leaf surface.
- In the USA, van der Zwet *et al.* (1990) showed that approximately 4% of apparently non-infested fruit sourced from a symptomless orchard developed fire blight symptoms when wounded on the surface. This indicates that bacteria were present on the external surface of the fruit. However, it was later confirmed by the senior author of that study that the apples sampled were immature (WTO 2003).
- Epiphytic colonies of *E. amylovora* were not detected on calyces or surfaces of fruit (number tested was not specified) of six susceptible cultivars from blighted orchards in West Virginia, USA (van der Zwet *et al.* 1991).
- Maas Geesteranus and de Vries (1984) showed that *E. amylovora* (washed cells) were killed by desiccation within 24 hours, within one to two days when stored at 20 ºC, or within a few hours when exposed to 75% relative humidity or six hours of solar radiation. Similarly Gottwald *et al.* (2002) reported that bacteria in the ooze of a similar disease, citrus canker, die upon exposure to drying and that death is accelerated by exposure to direct sunlight. Norelli (2004) reported that *E. amylovora* detected on apple leaves after rain events in June/July in USA were short-lived.
- McManus and Jones (1995) and Sholberg *et al.* (1988) have shown that leaves are colonised by *E. amylovora*. There is also evidence that hail damage can induce development of fire blight symptoms (Beer 1990).
- Vanneste *et al.* (2004) showed how *E. amylovora* did not survive on apple leaves in the field while strains of two of its biological control agents *Pantoea agglomerans* and *Pseudomonas fluorescens*, known to be non-pathogenic epiphytic bacteria, survived longer.
- Dueck and Morand (1975) studied seasonal changes in the epiphytic population of *E. amylovora* on apples and pear leaves in Ontario, Canada. The highest epiphytic prevalence was observed during July and August but in some seasons extending to September. July is generally regarded as the period of maximum rainfall in Ontario,

whereas most apple varieties are harvested during September and October when, according to their data, epiphytic populations are extremely small.

- Ceroni *et al.* (2004) artificially inoculated pear fruit by immersing the fruit for 15 minutes in a bacterial suspension with 10^8 cfu mL^{-1}. After just one day, no bacteria could be detected on the surface using PCR, indicating that the pear fruit surface is not a favourable environment for bacterial survival.
- Steiner (1998) claims *E. amylovora* is a competent epiphyte. However, this paper provides no supporting data for epiphytic survival of the pathogen. The epiphytic fitness of *E. amylovora* was discussed at the 9th International Workshop on Fire blight and several participants were of the view that *E. amylovora* was a poor epiphyte of the leaf surface (Norelli and Brandl 2006).
- Calzolari *et al.* (1982) examined 104 samples of dormant buds from plants being imported into Italy. They detected *E. amylovora* in only in one sample. While their observation may have some relevance to spread of fire blight through planting material, it is not a clear demonstration of the bacterium's epiphytic survival. Further, the likelihood of transfer of bacteria from such a low percentage of infested buds to a clean fruit during picking would be even lower.
- In attempting to study the latent survival of *E. amylovora* in hibernating shoots, Crepel *et al.* (1996) artificially inoculated shoots by cutting the first unrolled leaf and placing 10µL of a bacterial suspension with 10^8 cfu/mL on the wound (ca. 1×10^6 cfu), resulting in bacteria being detected in 30% of the shoots after winter. The bacteria in this study were most likely not epiphytic and this data cannot be used to demonstrate the presence of epiphytic bacteria under natural conditions.
- Van der Zwet *et al.* (1988) cited references claiming the detection of low numbers of epiphytic bacteria, mostly on blossoms and occasionally on leaves during spring. However, at fruit picking time, the numbers of infested fruit or leaves and the numbers of bacteria present on them are likely to be very small because of adverse conditions.
- Geenen *et al.* (1981) tested blossoms (when present), as well as young shoots and leaves of host plants in protected areas of Belgium between May and September, for epiphytic presence of *E. amylovora* using two serological methods, agglutination and immunofluorescence. These authors claimed much higher detection rates using immunofluorescence. In 1979, the number of positives was four using agglutination methods and 23 using immunofluorescence. In total they detected 3.8% positives in 1979 and 18.7% in 1980, presumably using immunofluorescence. Detection of epiphytic populations of *E. amylovora* are possible only during the blossom period (Geenen *et al.* 1981). In fact, they have detected infections in nurseries and their surroundings and although they were testing the protected areas, the authors wrote that; 'in some cases the infection source was detected in the neighbourhood of a place where epiphytic presence of *E. amylovora* had been found'. Further, as they sampled plants from May to September, it is likely that the positives detected were during blossom time, but no indication is given as to when or in which parts of the plant (blossoms or leaves) the positives were detected.
- As discussed earlier, many authors have reported a rapid decline of epiphytic populations after the blossom period, and bacterial numbers during fruit picking are likely to be extremely small. Calzolari *et al.* (1982) used a range of tests to confirm the identity of the bacteria. Of 19 samples testing positive for immunofluorescence staining, only one was considered to be *E. amylovora* following further tests. That is, 18 out of the 19 samples

that were positive to immunofluorescence staining were actually found to be other bacteria such as *Pseudomonas syringae*.

- Roberts (1980) highlighted some problems with immunofluorescent diagnosis of fire blight because of cross-reactions between *E. amylovora* and other bacteria, even those of different genera. Calzolari *et al.* (1982) says immunofluorescence staining also permits detection of dead cells. The identifications of Geenen *et al.* (1981) above are therefore not definitive as they could have been detecting bacteria other than *E. amylovora*.
- Persson (1999) tested leaves of five different fire blight host plants (in areas where fire blight outbreaks had occurred two years earlier) using fatty acid analysis, identification being considered accurate when similarity indexes exceeded 0.6. Leaves were sampled three times (early June, mid July and late August) during two seasons and each sample consisted of 75 leaves bulked together. *E. amylovora* was detected at one sampling occasion each year. Given the approach by others using a range of methods to confirm the identity of the bacterium (Calzolari *et al.* 1982; Roberts *et al.* 1989), it is not clear whether fatty acid analysis with a similarity index of 0.6 alone is sufficient to confirm the identity of *E. amylovora*.
- Thomson and Gouk (1999) concluded that only transient populations of *E. amylovora* are present on leaves following rain storms with the number of leaves infested declining very quickly after rain storms. Therefore there would only be a limited opportunity for leaves to act as a source of contamination for fruit being harvested.
- Other studies support the ability of *E. amylovora* to survive nutrient-poor conditions (Wei *et al.* 1992; Wei and Beer 1995; Wei *et al.* 2000). These studies propose that certain conditions in the plant apoplast, including low nutrient status, may act as environmental signals triggering the transcription of *hrp* genes that produce the secretion machinery and virulence proteins, which in turn interact with plant cells to give hypersensitive and/or pathogenic reactions. Contact between bacteria and plant cells is critical for the development of this reaction (Kim and Beer 2000). The above studies do not provide any supporting evidence for the ability of *E. amylovora* to survive as an epiphyte or infestation outside the cuticle (the outer limit of the apoplast) and without contact with plant cells.
- In fact, these studies provide indirect evidence for the opposite characteristics observed, namely the poor ability of *E. amylovora* to survive as an epiphyte. Further, even with regard to *hrp* gene expression of *E. amylovora,* whether the apoplast can be considered a low nutrient environment is questionable at it is where *E. amylovora* will normally rapidily multiply. Movement of sugars in the apoplast before phloem loading and after phloem unloading is well established (Taiz and Zeiger 2002), and the ideal conditions present for the bacterium in the apoplast containing sugars may explain why it spreads mostly in the apoplast.
- Burnett *et al.* (2000) and Kenney *et al.* (2001) used confocal scanning laser microscopy to study epiphytic survival of *E. coli* on apple fruit after fruits were rinsed for 15 to 30 minutes in suspensions containing high doses of the bacterium. These authors observed the bacterium attaching to the cuticle, wax plates, clefts, lenticels, etc. However, in spite of strong indications that most pathogenic bacteria do not survive desiccation and exposure to sunlight, the above authors did not examine the presence of bacteria on the artificially inoculated fruit after exposure to such natural environmental conditions. Further, conditions equivalent to rinsing in suspensions with high concentrations of bacteria for 30 minutes will not occur with apples in the field. In addition, the ecological niches of the two bacteria are very different and therefore it is questionable as to whether *E. coli* studies can be directly extended to *E. amylovora*.

- Work conducted by Thomson and Gouk (1999) using the sensitive leaf imprinting technique showed populations of *E. amylovora* were detected on less than 25% of the leaves near infections, but the pathogen was detected on 90% of the leaves during or soon after a rainstorm. These populations declined rapidly with the onset of dry conditions and only 7% of leaves tested positive after two days.
- Experiments conducted by Ockey and Thomson (2006), using a sensitive imprinting technique showed that the mean leaf area covered by *E. amylovora* colonies within 0.3 m of an inoculum source in the orchard increased from nearly zero before rain to 3–24% immediately after rain and declined to almost zero again a day after rain. A similar trend was observed in the laboratory study where the mean leaf area colonised by *E. amylovora* following inoculation declined from 53–75% on the day of the inoculation to 2.5–3% on the day following inoculation.
- Norelli and Brandl (2006) reported that when plants were inoculated with cold bacteria (4 ºC) and incubated at high temperature (35 ºC), *E. amylovora* became established within young leaves via hydathodes and glandular trichomes and rapidly declined on the surface of older leaves. These authors showed that under controlled conditions *E. amylovora* populations rapidly decreased on apple leaves from 10^4 per leaf at constant 24 ºC and high relative humidity (80–95%) within 48 hrs. Low *E. amylovora* populations (10 cfu per leaf) were detected 6 and 14 days after inoculation. Based on confocal microscopy of the leaf surface, these authors reported that there was no evidence that *E. amylovora* multiplied on the leaf surface either at 24 ºC or 35 ºC. Norelli and Brandl (2006) also observed that *E. amylovora* detected on leaves sampled from orchards after rain were short-lived. These observations indicate that mature leaves may have a low population of bacteria which could increase immediately after rain but decline to a very low level soon after the rain event.
- In an experiment using cells from cultured *E. amylovora* and cells in air-dried ooze taken from diseased fruits, apple fruit were inoculated by spraying the suspension of bacteria to runoff with 10^5 to 10^7 cfu per mL (Temple *et al.* 2004; abstract only). Fruit were then sampled periodically for up to 35 days to detect *E. amylovora* (Temple *et al.* 2004). Populations of 10^3 to 10^5 cfu of *E. amylovora* per fruit were recovered from 64% of fruit (n = 420) immediately after spraying. The rate of recovery and population size declined with time, regardless of the method of inoculum production. The recovery of *E. amylovora* declined to 6% and 1% of sampled fruit respectively at 7 and 14 days after inoculation. At 35 days, only 8 cfu of *E. amylovora* were recovered from two of 330 fruit. Fire blight symptoms were not observed on inoculated trees or fruit.
- Later, the work by Temple and colleagues were published as a full text article that comprehensively described the experimental methods. Under field conditions, immature pear or apple fruit on the tree were artificially covered by an inoculum suspension with 10^7 cfu per ml, or calyces infested with inoculum from ooze (10^8–10^9 cfu) (Temple *et al.* 2007). Populations of *E. amylovora* declined by an order of magnitude every three to four days in the first two weeks after inoculation. From a starting population of 1.6×10^7 cfu, by day 56, only one pear fruit of 450 tested positive and had only four cfu (Temple *et al.* 2007). This study confirmed the poor survival and rapid decline of *E. amylovora* bacteria, even from very high levels, on the surface of fruit.
- There is no evidence that *E. amylovora* bacteria would survive on the surface of apple fruit better than on leaves. *Erwinia amylovora* bacteria are susceptible to a range of factors (UV light, heat, desiccation, lack of nutrients, competition) that will quickly result in death. Any contamination by epiphytic bacteria, from vegetative or other source material

would be exposed to the same conditions. It is considered epiphytic bacteria outside the calyx are very unlikely to contribute to the importation of *E. amylovora* into Australia (Paulin 2010a; Deckers 2010).

- Overall, the likelihood that viable epiphytic bacteria occur on the leaves and mature fruit surface (except the calyx) at the time of apple picking is very low and the likelihood of transfer of bacteria to clean fruit during picking and transport would be even lower. Any epiphytic bacteria that do contaminate the fruit surface will only survive for a very short period.

Ability of the pest to survive existing pest management

- All export orchards are registered with Pipfruit NZ Inc and utilise either the Integrated Fruit Production program or a certified organic program. These programs provide guidance for targeted management of fire blight. Measures include the preventative application of sprays during flowering (Blossom Bless only for organic fruit) and the targeted pruning of infected shoots and cankers that limit the prevalence of fire blight in trees. Infected immature fruit do not develop to maturity, show obvious symptoms, and would not be harvested.

Ability of the pest to survive packing, transport and storage conditions

- The pulp temperature of fruit at harvest is relatively high. To lower this pulp temperature, fruit may be subjected to at least a short pre-cooling treatment before it is put through packing house procedures. A survey has shown that 71% of the respondents, responsible for exporting over 90% of the crop, use pre-cooling treatment routinely in the packing house (MAFNZ, 2005a).
- Pre-cooling may affect the survival of *E. amylorvora* as it has been shown that cold conditions increase the mortality of bacteria (see discussion below on cold storage). However, the short period of time fruit are exposed to pre cooling, including higher relative humidity, is unlikely to significantly affect *E. amylovora* present in the calyx.
- Bacteria protected in the calyx are unlikely to be removed in the dump tank, at least in closed calyx varieties.
- Packing houses utilise disinfectants such as chlorine or Tsunami® and, increasingly, Nylate® during water washing procedures and in dump tanks. In 2005, only 53% of pack houses used disinfectants. In 2011, 99% of export fruit produced under the IFP program are disinfected (MAFNZ 2011). The concentration of chlorine used varies between 5 and 50 ppm and peroxyacetic acid (Tsunami®), and bromo-chloro-dimethylhydantoin (Nylate®), as alternatives to chlorine, as per label instructions. Monitoring of disinfectants is done manually at specific times on each day or automatically (MAFNZ 2005a). For fruit produced under organic methods, contributing approximately 8% of exports (Pipfruit NZ 2010), fruit wash tank water is regularly replaced to remove contaminating material (MAFNZ 2011).
- Although, wash water for organic fruit does not contain a sanitiser, exopolysaccharides (EPS) of *E. amylovora* are water soluble (Maas Geesteranus and de vries 1984; Ordax *et al.* 2010a). The main EPS of *E. amylovora* (amylovoran) is an acidic polysaccharide with strong water-binding activity with strong water-binding activity, i.e., it is a typical hydrophilic EPS of the kind found among many Gram-negative bacteria; EPS with these properties form loose slime layers which readily disperse in water (Ayres *et al.* 1979; Politis and Goodman 1980; Belleman *et al*. 1994; Nimtz *et al*. 1996; Pers comm.; Dr Chris Hayward April 2011). For example, 95% of the EPS of *E. amylovora* is removed by a single high speed washing (Ayers *et al.* 1979). EPS protect *E. amylovora* and are known

to promote survival (see section–*Ability of the pest to survive adverse conditions*–*Exopolysaccharides and biofilms*). Any epiphytic *E. amylovora* bacteria will not survive for long (see section– *Ability of the pest to survive epiphytically*) and with reduced levels of EPS, survival is likely to be even shorter.

- In 2005, 93% of packing houses used high pressures washing (MAFNZ 2005a). High pressure washing is now standard practice and is used at 100% of export packing houses (MAFNZ 2011).
- The increased use of high pressure sprays is likely to increase the penetration of disinfectants, when used on non organic fruit, into the protected region of the calyx. Although it is recognised disinfectants will not kill 100% of any remaining bacteria, they would reduce their numbers (Deckers 2010; Paulin 2010a). For organic fruit, it has been reported that high pressure washing can be as effective in removing micro-organisms as 200 ppm chlorine (Bechat 1999). Even low pressure washing can remove approximately 90% of *E. amylovora* on apple fruit (Roberts and Reymond 1989).
- Brushing would not remove bacteria present in the calyx-ends of fruit, as these areas are inaccessible. Even if waxing were to occur, bacteria will survive low-temperature waxing, as the thermal death point of *E. amylovora* ranges from 45 to 50 ºC (van der Zwet and Keil 1979).
- Bacteria infesting the calyx-end of fruit would not be detected during visual inspection.
- Packaging, which aims to minimise moisture loss and maximise heat dissipation, will not reduce the bacterial population in the calyx.
- The ability of *E. amylovora* to survive on mature pear and apple for several weeks after cold storage and in some instances develop symptoms while in storage was reported (Anderson 1952; Dueck 1974a; Nachtigall *et al.* 1985). However, these papers report the use of high inoculum doses injected into the cortex of fruit, which does not reflect natural conditions.
- When mature fruit are inoculated by swabbing calyces of apples with high levels of *E. amylovora* (an average of 10^7 cfu per mL), a level of infestation that is many orders of magnitude higher than naturally infested calyces, the initial population steadily decreased to an undetectable level over a six month period in cold storage (Sholberg *et al.* 1988).
- Hale and Taylor (1999) inoculated mature fruit at the calyx-end with different concentrations of *E. amylovora* ranging from 10 to 10^7 cfu per fruit, and kept them in cool storage (2 ºC ± 0.5 ºC) for 25 days or cool-stored them for 25 days before incubating at room temperature (about 20 ºC) for a further 14 days in the laboratory. The results indicate that after cool storage alone, *E. amylovora* was detected by PCR in 90% and 20% of fruit inoculated with 10^7 cfu and 10^4 cfu respectively, and in less than 8% of fruit inoculated with 10, 10^2 or 10^3 cfu at the end of this 25-day period. It was also reported that after cool storage, *E. amylovora* was isolated only from 75% of fruit inoculated with 10^7 cfu and in 10% of fruit inoculated with 10^4 and 10^5 cfu. However, after cool storage and incubation at room temperature, *E. amylovora* was detected in 35% of fruit inoculated with 10^7 cfu and in 3% of fruit inoculated with 10^5 cfu, but not in fruit inoculated with 10, 10^2,10^3 or 10^4 cfu.
- In another experiment, mature fruit inoculated with the various concentrations of *E. amylovora* were subjected to cool storage alone or alternatively, cool storage and incubation under commercial conditions (see Table 2 of Hale and Taylor (1999)). This data show that after cool storage, *E. amylovora* was detected (by PCR) in 3%, 10%, 28%

and 66% of fruit inoculated with 10, 10^3, 10^5 and 10^7 cfu respectively. *E. amylovora* was isolated from only 7% of fruit inoculated with 10^7 cfu and not from any other fruit (data not shown in table). After cold storage (25 days) and incubation (14 days) *E. amylovora* was detected in 36% of fruit inoculated with 10^7 cfu, 6% of fruit inoculated with 10^5 cfu, but not from any other fruit. *E. amylovora* was isolated from fruit inoculated with 10^5 or 10^7 cfu, but not from any other fruit. These results show that bacterial populations (10^4 cfu or below) on cool-stored fruit incubated at room temperature (about 20 ºC) for 14 days decrease to levels undetectable by the sensitive PCR technique.

- Hale and Taylor (1999) also reported that before cool storage *E. amylovora* was detected by PCR in 2% of fruit sourced from orchards with fire blight symptoms, but not in any fruit after either from cool storage or cool storage and return to ambient temperatures. *E. amylovora* was not isolated from any stored fruit tested. These authors also reported that *E. amylovora* was neither detected nor isolated from fruit harvested from symptomless orchards before or after cool storage.
- Taylor and Hale (2003) inoculated the calyces of the closed-calyx variety Braeburn. These authors showed that bacterial populations in the calyx decreased from 10^6 cfu to 10^2 cfu over a 20-day period and from 10^4 to non-culturable levels after 14 days. These authors also showed that populations of *E. amylovora* in calyces infested with 10^2 cfu decreased to non-culturable levels after 8 days in storage. PCR tests, which would detect the DNA of both live and dead bacteria, detected *E. amylovora* in calyces infested with 10^6 cfu and 10^4 cfu, but not in those with 10^2 cfu after the 20-day cool-storage period.
- Roberts (2002) reported that out of 30,000 apples sampled from trees adjacent to infected trees, then cold-stored for two to three months, and no external symptoms were found. A total of 1500 fruit were also examined for internal symptoms but none were infected. However, *E. amylovora* was not isolated from any of the fruit (900) in the sub-sample examined before storage. Therefore, the absence of bacteria after this period cannot necessarily be attributed to the effects of cold storage. However, this data is useful in regard to studies of the potential for apples to carry *E. amylovora*.
- Mature fruit inoculated with a suspension of 10^7 cfu, less than 100 cfu per fruit could be detected after 4 weeks, and no bacteria could be detected after eight weeks in cold storage using a sensitive detection method that could detect as little as 2 cfu (Temple *et al.* 2007).
- Recent work in Spain has shown that no *E. amylovora* could be detected from 300 mature apples after 10 months in cold store. Sensitive detection methods were employed that could detect < 1 cfu/ml of calyx extract and would have detected live or dead bacteria including those in a viable but non-culturable (VBNC) state (Ordax *et al.* 2010b).
- The studies above show that any *E. amylovora* in the calyx present at harvest will decrease through time while in storage and eventually all apples will be free of viable bacteria. The time required for this to occur is variable, depending on the conditions and starting population, but covers a period from about a week to a maximum of six months. Experiments using apples infested at levels that represent naturally occurring levels of *E. amylovora* in the calyx typically have undetectable levels after a relatively short period of time.
- The longer fruit are held in cold storage in New Zealand, the number of infested fruit and number of *E. amylovora* bacteria per fruit will decline.
- For harvested fruit in long-term storage in New Zealand (either cold storage or controlled atmosphere storage), the continued decline in bacterial numbers will result in the majority, or all, of this fruit being free of viable bacteria.

Conclusion on probability of importation

The information presented indicates that *Erwinia amylovora* is wide spread in New Zealand, and importantly is recorded in the two major apple growing areas of Hawke's Bay and Nelson that jointly produce 93 per cent of the export crop. However, while the pathogen is present in apple growing areas, the majority of orchards are likely to be free of symptoms. There has been no detection of *E. amylovora* bacteria in the calyx of apples sourced from orchards free of fire blight symptoms. In orchards, *E. amylovora* is actively managed through the removal of inoculum sources. In spring, blossom infection is managed through the application of sprays as recommended by a predictive model of infection events.

For *E. amylovora* to be imported into Australia, either fruit would need to harbour an infection by the bacterium, or fruit parts would need to be infested by bacteria. If fruit infection occurs, infected fruit does not mature and will not be harvested. There is no evidence that supports mature fruit infection can occur under natural conditions. With regard to epiphytic (surface) contamination, there is considerable evidence the *E. amylovora* bacteria will not survive. Fruit infection and epiphytic pathways are therefore considered to be of no significance. However, calyx infestation of mature fruit has been well documented. For calyx infestations to occur, seasonal climatic conditions need to be conducive for the production of *E. amylovora* inoculum which can then infest the floral parts that are subsumed into the calyx of the developing fruit. Such calyx infestations are documented to only involve small populations of bacteria. It is well documented that the calyx is an adverse environment for *E. amylovora* because of the lack of nutrients and moisture. The number of infested fruit, and the number of bacteria in those infested fruit, will therefore decline with time.

While any population of *E. amylovora* bacteria would be declining in number, bacterial populations have been reported to survive for a sufficient length of time that would allow importation of some infested apples when considering a significant volume of trade.

In summary, considering a significant volume of trade, the evidence shows that *E. amylovora* has the potential to be associated with fruit from major export areas in New Zealand, but that the proportion of infested fruit will be small and the bacterial populations in low numbers per fruit. Both the infestation rate and bacterial populations will be affected by climate from year to year and by orchard management practices. The evidence supports a rating of 'moderate' for the importation of *E. amylovora*.

Probability of distribution

The likelihood that *E. amylovora* will be distributed in a viable state within Australia with imported fruit and transferred to a suitable host is: **EXTREMELY LOW**.

Distribution of the imported commodity in the PRA area

- Minimal on arrival inspection procedures, that includes checks that the consignment is as described on the phytosanitary certificate would not detect calyx infested fruit.
- Imported fruit will be distributed throughout Australia as wholesalers and retailers are located at multiple locations and would facilitate the distribution of apples potentially infested with *E. amylovora*.
- *Erwinia amylovora* would need to survive transportation and storage within the PRA area. Fruit is typically stored and transported in refrigerated containers maintained at cool temperatures and receival temperatures in the range of 1–10 ºC are required by a major retailer (Woolworths 2010). The storage and transport conditions are likely to continue the decline in bacterial numbers in the calyx (see discussion in importation).

- Once fruit is displayed for retail sale and sold it will be exposed to ambient temperatures. As previously discussed, the decline in bacterial numbers will continue once the fruit is returned to ambient temperatures. For example, bacteria in naturally infested apple calyces that are exposed to cold storage for 25 days and then ambient temperatures decline to undetectable levels in 14 days at 20 ºC using the sensitive PCR detection technique (Hale and Taylor 1999).
- Imported fruit may be packed by orchard wholesalers that would be in close proximity to commercial fruit crops. Orchard wholesaler waste may be dumped at a site within the premises or in landfills close to orchards. Before waste is finally disposed of, it could remain exposed to the elements (for example, in a skip) near the packing house.
- Occasionally workers and visitors could discard apple cores in the orchard itself. The packing of New Zealand fruit from bulk bins and/or the repacking of boxes of New Zealand fruit would bring packing house workers and host trees (apples and pears) into close proximity to both New Zealand apples and apple waste. However, the bacteria in the calyx would then need to move to the new host (see discussion in– *Ability of the pest to move from the pathway to a suitable host* and *Ability of the pest to move from the pathway to a suitable host)*
- However, the export data from New Zealand shows that the majority of fruit exported (99.8% in 2009–10) is in retail-ready boxes or trays that will not require repacking in Australia (MAFNZ 2011). It is likely the majority of fruit will be distributed to retailers, potentially through wholesale markets, without the need for re-packing. Only a small volume would be likely to be re-packed within Australia.

Availability of hosts

- Apples purchased via retail outlets can enter the environment after being purchased by consumers. The majority of the population (and therefore the majority of apple consumption) is in the capital cities significant distances from most commercial apple and pear orchards. However, hosts of *E. amylovora* are present in many home gardens, parks and roadsides in large cities.
- Common hosts of this pathogen include species in the genera where fire blight is the most serious bacterial disease including *Malus* spp. (apple), *Pyrus* spp. (pear), *Cydonia* spp. (quince), *Eriobotrya japonica* (loquat), and amenity hosts including *Crataegus* spp. (hawthorn), *Cotoneaster* spp. (cotoneaster) and *Pyracantha* spp. (firethorn). These hosts all belong to the sub-family Maloideae of the family Rosaceae (CABI, 2005).
- Other host species in the family Rosaceae that are susceptible to infection by *E. amylovora* are *Rosa rugosa* (sub-family Rosoideae) (Vanneste *et al.* 2002) and *Prunus salicina* (sub-family Amygdaloideae) (Mohan and Thomson, 1996). The pathogen also infects raspberry and blackberry (*Rubus* spp.) plants, which belong to the Rosoideae sub-family. Strains isolated from *Rubus* spp. were host-specific and did not infect apple or pear (Starr *et al.* 1951; Ries and Otterbacher 1977; Heimann and Worf 1985).
- The potential for flowers of non-host plants to support epiphytic growth of *E. amylovora* has also been reported (Johnson 2004; Johnson *et al.* 2006). The overlapping of flowering times between apple trees and non-host plants could enhance the chances of pollinators distributing the inoculum during foraging.
- Many suitable hosts are commonly grown in Australia and are present in areas where apples would be sold and consumed. However, host susceptibility of all hosts is variable throughout the year and only some of these host species are highly susceptible to *E. amylovora* and would play a role in the distribution of the pathogen (Paulin 2010a).

- Fruit trees in commercial orchards are planted in high-density monocultures of suitable hosts. Fruit trees and ornamental plants that are hosts of *E. amylovora* may be found in household gardens, although their density would be low. The use of irrigation may create climatic conditions more conducive for infection to household and garden plants.

Risks from by-products and waste

- Although the intended use of fresh fruit is human consumption, waste material would be generated (e.g. overripe and damaged fruit, uneaten portions). Whole or parts of the fruit may be disposed of at multiple locations throughout Australia in compost bins or amongst general household or retail waste.
- Orchard wholesaler waste is disposed of into isolated areas within the orchard itself or in landfills close to the orchard. These disposal sites are surrounded mostly by pome fruit grown as a monoculture and wild and amenity plants are less abundant. Consumers may also occasionally discard fruit waste along roadsides and recreation areas.
- A relatively high proportion of household and retail waste would be managed through regulated refuse collection and disposal services. Managed waste will remove any *E. amylovora* bacteria from the household and environment, reducing the likelihood that susceptible plants will be exposed to this pathogen.
- *E. amylovora* does not produce resting cells or spores (Roberts *et al.* 1998) and it is vulnerable to desiccation (Maas Geesteranus and de Vries 1984) and dry conditions (Jock *et al.* 2005). It is known that exopolysaccharides of *E. amylovora* capsules prevent cells from losing water, which can help bacteria to survive dry environmental conditions (Geider 2000; Jock *et al.* 2002). However, the recorded survival of *E. amylovora* in calyces would take into account the role of EPS.
- Viability of *E. amylovora* is adversely affected by high temperature and low relative humidity (Maas Geesteranus and de Vries 1984). *Erwinia amylovora* cells can survive in the dark for considerable periods, but are killed rapidly when exposed to ultraviolet light/full sunlight (Maas Geesteranus and de Vries 1984).
- The infested calyces of fruit discarded near susceptible hosts could be considered a source of inoculum for infections in new areas.
- However, by the time of disposal to the environment, the majority of the bacteria would no longer be viable, particularly for apples kept in long term cold storage, and those remaining would be in an attenuated state due to adverse conditions of the calyx (lack of nutrients, desiccation, heat etc). The remaining bacteria in the calyx of waste would continue to be exposed to adverse environmental conditions that decrease the number of viable bacteria.
- Waste material should either have an adequate inoculum dose in a viable state or bacteria must multiply to a concentration that could initiate an infection. When cores are discarded into the environment, nutrients released from damaged cells in apple cores could encourage any remaining viable bacteria in the calyx to multiply. The multiplication of *E. amylovora* on apple waste is considered possible (Paulin 2010a) but this has never been observed and there is no evidence to support this can occur. If this were to occur, bacteria that have been subjected to adverse conditions require a long lag phase before growth resumes under favourable conditions (Madigan and Martinko 2006). Even for freshly cultured *E. amylovora* inoculated into host flower nectaries, a lag phase of 6–36 hours is required before rapid growth can occur (Wilson *et al.* 1990).

- The availability of water in fruit waste, as measured by water potential, is an important factor that will affect bacterial growth. Water potential is described by a scale from zero, for pure water, to increasingly negative numbers for water containing dissolved substances (sugars, salts etc). For example, sea water has a water potential of about –3.0 Mega Pascals (MPa) (Salisbury and Ross 1992). Water potential is a measure of the tendency of water to move from one area to another due to osmosis, gravity, mechanical pressure, and matrix effects including surface tension (Salibury and Ross 1992).
- The water potential in fruit waste will affect the ability of *E. amylovora* to utilise nutrients in the waste for growth. It has been shown in live host plants, fire blight disease resistance increases as moisture content and water potential decreases (Shaw 1934; van der Zwet and Keil 1979). Disease infection and severity is linked to bacterial growth (van der Zwet and Keil 1979; Agrios 1997).
- In more recent work, fire blight disease incidence and severity in susceptible tissue of crab apple approached zero at water potentials of –3.0 MPa and was zero at −4.0 MPa (Pusey 2000). Maximum disease incidence and severity occurred at water potentials above –2.0 MPa, and disease severity continued to increase above –1.0 MPa (Pusey 2000).
- In an additional experiment, fire blight incidence and severity in susceptible apple tissue was zero at –2.77 MPa (Pusey 2000).
- Apple leaves have a water potential of –0.5 MPa at full turgor before sunrise and this can decrease to –1.5 MPa during the day or –2.0 MPa in water stressed plants (Mpelasoka 2001). 'Braeburn' apples, sampled at commercial harvest in New Zealand, have a water potential of about –1.4 MPa and an osmotic potential of –2.0 MPa (Mpelasoka 2001). Osmotic potential will equal water potential when the pressure of the solution is zero.
- Apples stored at 0°C can lose about 3% of their weight over 12–17 weeks and the majority of this is due to water loss through the apple skin (Mpelasoka 2000; Zegbe *et al.* 2008; Maguire *et al.* 2001). At ambient temperatures of 20°C, the rate of weight loss increased to about 5% in 18 days (Zegbe *et al.* 2008). Small increases in solute concentration, such as from water loss, result in large decreases in water potential (see figure 3-6 p54, Salisbury and Ross 1992).
- In addition to water loss, commercial fruit are harvested when fruit starch has started to mobilise. The conversion of starch to sugars in the fruit will continue post harvest (Mills *et al.* 1996) that is likely to increase solute concentration, further decreasing water potential in the fruit. A study has shown that the water potential of several varieties of apple fruit decreased by 10–20% over an eight day period when kept at conditions that approximate retail sale conditions (20°C) (Dobrzañski *et al.* 2000).
- In dry conditions, it is likely discarded apple waste will continue to lose moisture rapidly, promoted by the loss of fruit skin integrity, to levels well below that recorded in living tissue and significantly decreasing the water potential and therefore the availability of water for bacterial growth. The decrease in water potential affecting bacteria in the calyx would also be relevant for any bacteria that may occur in the flesh of the fruit if fruit infection was a pathway of concern.
- In wet conditions, nutrients may wash from the apple waste and enter the calyx under higher water potentials. However, if water can enter the calyx then water may also wash *E. amylovora* bacteria from the waste into the soil. Soil is likely to be an adverse environment for *E. amylovora* (see below).

- In addition, under wet conditions saprophytic micro-organisms will colonise the waste and metabolise available nutrients. *Erwinia amylovora* is not considered a good competitor against other epiphytic bacteria that are naturally found on surface of apple or pear fruit fruit (Roberts *et al.* 1989; Temple *et al.* 2007; Paulin 2010a). The epiphytic bacterium *Pantoea agglomerans* has been shown to survive at significantly higher numbers than *E. amylovora* during fruit maturation to harvest (Temple *et al.* 2007). Detection frequency of epiphytic bacteria on apple fruit is not affected by cold storage over a period of 80–114 days (Roberts *et al.* 1989).
- *Pantoea agglomerans* is likely to be associated with New Zealand apple fruit as it is the biological control agent in the widely used commercial product Blossom Bless (MAFNZ 2011). Blossom Bless is used to manage *E. amylovora* blossom infections and is applied when a computer model predicts climatic conditions are suitable (MAFNZ 2011). Therefore, the apples most likely to have a calyx infestation of *E. amylovora* are the ones most likely to contain *P. agglomerans*.
- Bacteria differ markedly in growth rate under optimum conditions. For example, representative members of the Enterobacteriaceae have a generation time of 20 minutes or less, and many other common saprophytic bacteria have a doubling time of less than 45 minutes, whereas plant pathogenic bacteria have a markedly slower growth rate (Mason 1935). *Erwinia amylovora* has a doubling time of 66–94 minutes at optimal temperature (Hildebrand 1938; Billing 1974b; Shrestha *et al.* 2005). In contrast, under optimal conditions *P. agglomerans* has an estimated doubling time of approximately 30–35 minutes (Para and Baratti 1984; ca. from Figure 7 in Jung *et al.* 2002).
- In addition to the direct competition from saprophytes many strains of *P. agglomerans* are antagonistic to *E. amylovora* though the production of antibiotics (Wilson and Lindow 1993; Vanneste 1996; Wilson *et al.* 1992). *Pantoea agglomerans* is also known to reduce the pH of its environment (Pusey *et al.* 2008) to levels that are known to reduce, or even stop, *E. amylovora* growth (Shreatha *et al.* 2005). Antagonistic strains of *P. agglomerans* associated with imported apples will further reduce the capacity of *E. amylovora* to grow on apple waste.
- The availability of nutrients, including complex structural polysaccharides that *E. amylovora* is not known to metabolise (Billing *et al.* 1961), would also favour the growth of saprophytic micro-organisms. *Erwinia amylovora* is known to be nutritionally fastidious (Schroth *et al.* 1974), uses a much smaller range of carbon sources than saprophytes (Cabrefiga *et al.* 2007), and therefore specific nutrients or carbon sources may not be available for growth to occur in waste material. The slow growth rate of *E. amylovora* and specific nutritional requirements will limit its capacity to compete with saprophytes on apple waste.
- Apple waste disposed of in compost may be subjected to high temperatures (60°C), which would kill *E. amylovora* – many pathogens, including Enterobacteriaceae, are killed within a few days during composting (Anonymous, 2004b; Noble and Roberts 2004). The thermal death point of *E. amylovora* ranges from 45 to 50 ºC (van der Zwet and Keil 1979) and 10 minutes is required at 50 ºC in laboratory cultures (Billing *et al.* 1961). For example, *E. amylovora* is known to be reduced to undetectable levels during composting of host material for seven days at temperatures of greater than 40 ºC (Bruns *et al.* 1993). At higher compost temperatures of 55 ºC, less than two and half days is required to remove *E. amylovora* (Noble and Roberts 2004). Apple waste disposed of in landfills or compost heaps would be rapidly contaminated and colonised by saprophytic micro-

organisms, hastening the decay process and minimising the likelihood of *E. amylovora* survival.

- Similarly, mammals or birds could consume apple waste and remove *E. amylovora* from the environment.
- When cores are discarded into the general soil environment, *E. amylovora* can survive for a limited period provided there are high levels of inoculum; 10^6 cfu per gm of soil (Ark 1932; Hildebrand *et al.* 2001; Thomson 1969).
- Bacteriophages that destroy *E. amylovora* have been readily isolated from soil beneath apple and pear trees (Baldwin and Goodman 1963; Erskine 1973; Hendry *et al.* 1967; Schnabel *et al.* 1998). *Erwinia amylovora* is often overgrown with other bacteria when isolations are done from organic material, suggesting that the pathogen may not survive long in that environment (AQIS 1998a). Survival in soil is not considered to be epidemiologically significant (Roberts *et al.* 1998).
- Survival of *E. amylovora* under unfavourable conditions such as on nitrocellulose filters, in non-host plants as well as in inoculated mature apples and in infested apple stem sections was studied by Jock *et al.* (2005). These authors found that in a sterile dry environment an *E. amylovora* EPS mutant, and to a lesser extent its parental wild-type strain decreased within 3 weeks to a low titre. However, under moist conditions the decrease of viable cells occurred only partially for both strains. In tissues of mature apples, *E. amylovora* cells slowly dispersed and could still be recovered after several weeks of storage at room temperature at a low titre.

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

- Bacteria that have survived fruit maturation, packing house procedures, storage and transport, ambient temperatures and a range of adverse environmental effects, and micro-organism competition, and remain in a viable state in the calyx of an imported apple would then need to be transferred to a host.
- Fire blight bacteria do not have a specific dispersal mechanism. To transfer *E. amylovora* to a susceptible host, a vector must pick up the bacteria in sufficient numbers to initiate a new infection. Many genera of arthropods and insects have been associated with the transmission of *E. amylovora* (van der Zwet and Keil 1979). However, this situation relates to insects attracted to active cankers on a host with bacterial ooze, that is known to be attractive to, and readily sticks to, insects (Paulin 2010a; Paulin 2010b).
- It has been speculated that birds, particularly starlings could be involved in fire blight transmission (Billing and Berrie 2002). Although they are known to inhabit landfill sites and are capable of pecking fruit, no evidence is found in the literature to confirm their involvement (Paulin 2010a).
- The most likely mechanism of transfer of bacteria from discarded apples to a receptive site in a susceptible host is by browsing insects (AQIS 1998a; Deckers 2010; Paulin 2010a). Discarded apples are attractive to a wide range of insects and this attraction may be increased by rotting. Bees are known to be involved in the secondary spread of fire blight disease from infected blossoms (Thomson 2000).
- Browsing insects would most likely be attracted to the exposed flesh of a partially eaten apple because of easy access to nutrients. To access *E. amylovora* bacteria, insects attracted to waste would need to enter the apple calyx, which is the remains of dried flower parts and is likely to be free of nutrients. In closed calyx varieties the likelihood a

vector would come into contact with *E. amylovora* would even be lower unless some mechanical damage or fruit rotting allowed access for vectors.

- Once a vector came into contact with viable bacteria in the calyx the bacteria would need to adhere to the vector. Bacteria in the calyx are unlikely to be in a metabolic state to produce extra cellular polysaccharides (EPS) that are fresh, and therefore 'sticky' and also attractive to potential insect vectors (Paulin 2010a; Paulin 2010b). The lack of fresh EPS on bacteria in the calyx is likely to limit the number of bacteria adhering to a vector.
- Contaminated vectors that travel directly to a site receptive to infection have the highest likelihood of transferring bacteria to an infection site. However, browsing insects will not necessarily visit a receptive site directly after being contaminated with bacteria. Bacteria are more likely to be deposited on non receptive material as receptive sites are limited and are not always available throughout the year (see discussion below in *Ability of the pest to initiate infection of a suitable host*). In addition, the majority of fruit will be imported during autumn and winter, well before host flowering (MAFNZ 2011), when hosts are most receptive to infection.
- Once bacteria have adhered to a browsing insect, they will be removed from the relatively protected calyx and will then be exposed to lower humidity and UV light (during daylight) that will further increase bacterial mortality.
- The vector transmission of *E. amylovora* from apple waste is considered a particularly unlikely occurrence (Paulin 2010a), there is no evidence to support this can happen and therefore the likelihood of this occurring is rather small (Deckers 2010).
- A recent laboratory experiment has shown that Mediterranean fruit fly can act as a vector of *E. amylovora* from infested apple fruit (Ordax *et al.* 2010b). In this experiment, apples where infested with high concentrations of fresh bacterial suspension at 11 cuts on the fruit surface (ca. 16.5×10^6 cfu per fruit: in comparison, the highest number of bacteria recorded from freshly harvested fruit, from the calyx and fruit surface is ca. 700 cfu per fruit (Sholberg *et al.* 1988)).
- Flies were then introduced to two apples soon after inoculation, caged on the fruit for 48 hours, and were seen actively feeding on the bacterial suspension under optimal conditions for the pathogen and the vector survival. The exposed flies were then transferred to receptive hosts. Under these artificial conditions, with fresh bacteria in suspension on the fruit surface, the flies become contaminated and transferred bacteria to a suitable host that had been wounded and caused infection.
- This study showed transmission could occur under favourable artificial conditions, which do not replicate conditions that would occur with imported apple fruit. In the pathway considered in this review of policy, bacteria are within the adverse environment of the calyx, in low numbers and in an attenuated state. The experiment of Ordax *et al.* (2010b) is more closely aligned to the vector transfer of *E. amylovora* from oozing cankers on plant material, a method of dispersal that is already well known in the epidemiology of the fire blight (van der Zwet and Keil 1979).
- It has been previously considered that rotting of the apple could involve multiplication of fire blight bacteria resulting in the production of bacterial ooze, known to be attractive to insects, and this would assist in vector transfer of bacteria.
- However, mature fruit do not have a suitable carbohydrate source (amylum) necessary for rapid bacterial growth and there is no evidence to support the bacterial growth of *E. amylovora* in apple waste (Deckers 2010; Paulin 2010a). Even when the fruit cortex is

artificially inoculated with high levels of fresh inoculum symptoms failed to develop (Anderson 1952; Dueck, 1974a; Nachtigall *et al.* 1985).

- A recent study has reaffirmed that the flesh of fresh apple fruit does not lead to the multiplication of *E. amylovora* to produce symptoms or bacterial ooze (Ordax *et al.* 2010b).
- In the absence of supporting evidence, the development of bacterial ooze on discarded apple waste is considered negligible.
- Taylor *et al.* (2003a) artificially inoculated 600 apple calyces with 10^6 cfu of a genetically marked strain of *E. amylovora* for two seasons (a total of 1200 inoculated fruit) during flowering. The infested apples were hung in apple orchards near open receptive flowers for a 20-day period over two consecutive seasons. The study did not use damaged apples, that may be more attractive to insects, but it did provide a large source of fresh inoculum in the calyx, in very close proximity to apple blossoms, during a period that contained highly suitable conditions for fire blight infection. *E. amylovora* was not detected by either culture or PCR tests on apple flowers, leaves, rain water, or trapped insects.
- Hale *et al.* (1996) also reported that there was no detectable spread of *E. amylovora* from heavily infested calyces. Bacteria are disseminated by water, but are vulnerable to desiccation if the water film dries out before they reach the infection site (Maas Geesteranus and de Vries 1984). However, it is difficult to imagine a likely scenario of movement of *E. amylovora* from the calyx of an apple to a suitable infection point involving water as a vector.
- Mechanical transmission of fire blight bacteria has also been considered possible. For example, packing of New Zealand fruit in packing houses closely associated with apple orchards could result in the exposure of workers and equipment to *E. amylovora* bacteria. However, given the location of the bacteria in the calyx and the likely mode of importation there does not seem to be a suitable pathway. Mechanical transfer from apple fruit is not considered relevant for the distribution of fire blight (Deckers 2010; Paulin 2010a). In the absence of supporting new evidence the mechanical transfer of *E. amylovora* is likely to be negligible.

Ability of the pest to initiate infection of a suitable host

- Once a vector has been contaminated with bacteria it will need to transfer the bacteria to a receptive host, in suitable numbers, while conditions are suitable for epiphytic growth on the stigma and subsequent movement to the hypanthium for infection to occur.
- In addition to blossoms, infection can also be initiated under suitable conditions in the absence of flowers through numerous natural openings including stomata and hydathodes (Rosen 1935; Hildebrand 1937) or wounds (Beer 1990) caused by insect damage, hail damage or by any mechanical damage.
- There is no accepted threshold number of bacteria required to initiate an infection, and this may vary with environmental and host factors. One cell of *E. amylovora* can potentially infect pomaceous flowers through the hypanthium. However, the minimum infective dose generally depends on environmental conditions, pathogen aggressiveness, and host susceptibility. The likelihood of infection increases with inoculum load and high levels of fresh inoculum ($>10^4$ cfu) are required for high rates of infection (Cabrefiga and Montesinos 2005; Pusey and Smith 2008).
- Hildebrand (1939) reported that a single bacterium, from an active culture, was sufficient to cause infection in detached flowers when placed directly in the hypanthium and

incubated under optimal conditions in the greenhouse, and that this success rate increased with higher doses of inoculum. However, this experiment occurred under conditions to maximise infection with bacteria in optimal condition and directly inoculating the hypanthium; a process that would not occur during the importation of apples (Deckers 2010; Paulin 2010a). It has also been reported that experiments that manipulate bacteria to very low numbers are extremely difficult to perform and results from these manipulations should be considered with caution (Paulin 2010a).

- Van der Zwet *et al.* (1994) showed under optimal conditions that five bacteria, placed directly onto the nectaries, were sufficient to cause fire blight symptoms in apple flowers in one season, but in another season a minimum of 5000 bacteria per blossom were required for infection to occur. However, the experimental technique inoculated the hypanthium in unopened flowers (something which cannot occur in the field), where humidity would be higher than in open flowers and the bacteria would have some protection from UV light. This type of inoculation experiment removed the need for bacterial multiplication on the stigma that is required under natural conditions for infection to occur.
- Low populations of viable or actively dividing *E. amylovora* artificially inoculated on to healthy pear stigmas under optimal conditions can multiply rapidly to high populations and infection rate increases as inoculum levels increase (Thomson 1986; Thomson *et al.* 1999).
- Artificial inoculations of pear flowers with 100 cfu resulted in infections that were positively correlated with incubation temperature (Beer and Norelli 1975).
- Experiments were conducted in New Zealand (Hale *et al.* 1996) to determine the number of *E. amylovora* cells required to infect apple and cotoneaster flowers. These authors reported that when flowers were inoculated with 1 to 10^4 cfu per flower under ideal conditions, disease symptoms did not develop and *E. amylovora* were detected. Fire blight symptoms were only observed when the inoculum dose of *E. amylovora* exceeded 10^6 cfu (Taylor *et al.* 2003b).
- In host plants, the most susceptible site is the stigma in flowers, and the population of *E. amylovora* on stigmas is 1 to 6 log units higher than in other flower parts (Thomson 2000). Flowers are abundant in spring in pome and other susceptible fruit trees, and from late winter to early summer on some susceptible amenity plants. The flowering stage is the only stage when injury to tissue is not required for insects or wind-driven rain to cause infection by *E. amylovora*.
- Non-host plants that allow survival and limited multiplication of *E. amylovora* (Johnson 2004; Johnson *et al.* 2006) may slightly extend the potential "infection" period. However, this is unlikely to significantly increase the likelihood of establishment as infection of a host plant via this route would then require two rather than one transfer events. That is transfer of bacteria from an imported apple to a non-host plant then transfer from the non-host plant to a host plant.
- For *E. amylovora* to establish initially, factors such as availability, numbers and distribution of susceptible hosts are important considerations. In Australia, abundant susceptible apple plants are grown as monocultures in orchards. A large number of alternative hosts are also present in apple growing areas in hedgerows and along roadsides. The host must be at a stage of development susceptible to infection.
- The most receptive plant organs to infection are the flowers present during spring. The age of the flowers has an influence on the growth and establishment of *E. amylovora* (Gouk

and Thomson 1999). These authors showed that under New Zealand conditions, 1- to 3-day-old flowers supported bacterial populations but bacterial numbers did not increase in flowers older than three days. Thomson (1986) and Thomson *et al.* (1999) showed that flowers were colonised over a period of 2 to 6 days, but the incidence of blossom infection increased from 0 to 100% in only two warm days in an orchard with numerous oozing cankers.

- In contrast, stigmas of crab-apple trees supported bacterial growth in 4- to 10-day-old flowers, depending on temperature and pollination. However, disease incidence was relatively high only when hypanthia were inoculated at ages between 0 to 4 days (Pusey 2004). Later it was shown infection rates steadily decreased over a 10 day period from flower opening (Pusey and Smith 2008).
- There are also several species of amenity trees that are sparsely distributed but able to produce flowers almost throughout the year (Merriman 1996). However, trade data indicates the majority of imported fruit will arrive in Australia before spring (MAFNZ 2011), separating the importation of inoculum temporally from the most likely point of infection.
- In addition to the host and pathogen, the third factor required for successful disease establishment involves the environmental conditions. *E. amylovora* is capable of growing between 6 ºC and 37 ºC, with optimum temperature conditions spanning 25 ºC to 27 ºC in laboratory conditions (Billing *et al.* 1961). Under field conditions, immediately after a wetting event caused by rain or heavy dew, colonised flowers would be infected when the average daily temperature is equal to or greater than 16 ºC and petals are intact (Steiner *et al.* 2000).
- Rain or dew facilitates the movement of *E. amylovora* from the stigmas to the hypanthium where infection may occur (Thomson, 1986; Thomson and Gouk, 1992). Steiner (1990) and Lightner and Steiner (1993) demonstrated that rain, hail, wind and dew could act as initiators of epidemics of fire blight.
- The climatic requirements of fire blight would limit the number of suitable infection periods during a year. For example, in winter when temperatures are too low for bacterial growth and in summer when moisture can be limiting factor (Van Der Zwet and Keil 1979; Steiner 1990; Deckers 2010; Paulin 2010a).
- Successful infection could take place if viable bacteria were present to infect susceptible host tissues under favourable environmental conditions, provided that each step listed above is completed. If there is a very low likelihood of the entire chain of events being completed, then there is a very low risk of establishment of fire blight. However, a break in any step of this chain of events would prevent the establishment of the disease.
- There is currently no evidence that supports the hypothesis that *E. amylovora* located in a calyx of an imported apple can initiate an infection in a suitable host under natural or experimental conditions. It is considered the likelihood of this occurring would be exceptional (Deckers 2010) or extremely low (Paulin 2010a). In contrast, it has been well established that the calyx of mature apple fruit is an unfavourable environment for *E. amylovora*, where the bacteria are attenuated, cannot multiply, and over time will die.
- There is indirect evidence from epidemiological work that supports the proposition that fire blight is not moved by the trade in apples. Pulsed-field gel electrophoresis (PFGE) patterns of *E. amylovora* strains in Europe and the Mediterranean region were studied by Jock *et al.* (2002). These authors observed a well ordered pattern of distribution of PFGE types without any evidence of mixing in spite of unrestricted trade in fruit in most

European countries. The authors concluded that the patterns of distribution of strains suggest a sequential spread of fire blight from England and Egypt into neighbouring countries. If fruit trade between countries resulted in numerous introductions of fire blight bacteria, it would be expected that PFGE patterns would be similar in different areas.

- New Zealand has been exporting apples to Taiwan and China for several years without specific risk management measures for fire blight (MAFNZ 2011). China is the largest producer of apples in the world (Branson *et al.* 2004). There have been no reports of fire blight in either of these export destinations. Exports of apples from the southern to northern hemisphere would land fruit during spring when host plants are flowering and at the most susceptible stage for infection.

Conclusion on probability of distribution

For *Erwinia amylovora* to be distributed to a suitable site on a susceptible host within Australia, any bacteria imported would need to remain in a viable state and be transferred in sufficient numbers to either the blossom or a wound on a host plant.

As discussed in assessing the probability of importation, *Erwinia amylovora* is likely to be present in a viable state in the calyx in low numbers, and in only a small proportion of imported apples. The calyx is an adverse environment for *E. amylovora* and during retail storage and display, then purchase by consumers, the decline in bacterial numbers will continue. The decline in bacterial numbers will be accelerated by removal of fruit from any cold storage and subsequent exposure to ambient temperatures. Apple waste that enters regulated waste disposal or composting would remove any *E. amylovora* from the environment. Under wet conditions, competition from other micro-organisms would further decrease bacterial survival on any remaining apples. In particular, imported apples with highest chance of *E. amylovora* infestation are likely to be associated with anatagonistic bacteria that are known to survive and grow significantly better under adverse conditions than *E. amylovora*. For infested fruit that do enter the environment under dry conditions, water loss is likely to prevent any *E. amylovora* bacteria utilising nutrients in the apple waste, limiting their ability to recover from an attenuated state and then multiply.

If any attenuated bacteria survived these adverse conditions, then transfer to a host would need to occur. Vectors would need to come into contact with any viable bacteria that are restricted to the calyx. Physical access for vectors can be restricted in closed calyx apple varieties and vectors are unlikely to be attracted to the calyx as it is free from nutrients. Bacteria would subsequently need to adhere to a browsing insect which is unlikely in the absence of extracellular polysaccharides that assist in vector attraction and adherence to the vector. Any *E. amylovora* adhering to insects would then need to be transferred to a restricted number of receptive sites on a host, and under suitable climatic conditions to initiate an infection.

The most susceptible stage for infection in hosts is the blossom. If *E. amylovora* bacteria were to infect a blossom in Australia, it would first need to survive the many months from the autumn apple harvest in New Zealand until the Australian spring when hosts are typically in flower. There is no evidence that naturally occurring *E. amylovora* bacteria in apple calyces can survive this length of time. Further, there is no direct evidence that vector transmission can occur under natural conditions from apple waste, even though it has been hypothesised. A rating of ‘extremely low’ for the probability of distribution of *E. amylovora* via the calyx of some imported apples is supported.

Overall probability of entry

The overall probability of entry is determined by combining the probability of importation (moderate) with the probability of distribution (extremely low) using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Erwinia amylovora* will enter Australia as a result of trade in the commodity and be distributed in a viable state to a suitable host: **EXTREMELY LOW**.

4.1.2 Probability of establishment

The likelihood that *E. amylovora* will establish within Australia based on a comparison of factors in the source and destination areas that affect pest survival and reproduction is **HIGH**.

- In the estimating the probability of distribution, the PRA has already considered the sequence of events necessary to allow sufficient infective inoculum to reach a suitable infection site under suitable climatic conditions to initiate infection. The probability of establishment will consider whether this initial infection will lead to the longer term infection that will result in the completion of the pathogen lifecycle on host plants through an entire year to account for seasonal differences that may affect establishment.

Availability of suitable hosts, alternative hosts in the PRA area

- In Australia the sub-family Maloideae has at least 16 host genera susceptible to fire blight, each containing several species (given within parentheses). They are: serviceberry, *Amelanchier* spp. (6); chokeberry, *Aronia* spp. (3); Japanese quince, *Chaenomeles* spp. (5); cotoneaster, *Cotoneaster* spp. (30); hawthorn, *Crataegus* spp. (19); quince, *Cydonia* spp. (3); loquat, *Eriobotrya* sp. (1); *Heteromeles* sp. (1); apple, *Malus* spp. (17); medlar, *Mespilus* sp. (1); *Photinia* spp. (4); firethorn, *Pyracantha* spp. (8); pear, *Pyrus* spp. (9); Indian hawthorn, *Rhaphiolepis* spp. (2); and mountain ash, *Sorbus* spp. (23) (AQIS 1998a).
- Occasionally, natural infections of *E. amylovora* occur on species not belonging to the sub-family Maloideae; for example, on Japanese plums (*Prunus salicina*) when there is an active source of inoculum of *E. amylovora* nearby (Mohan and Thomson, 1996). In Germany, *E. amylovora* infection was detected on young fruits of plums (*P. domestica*) (Berger *et al.* 2000).
- The potential for *E. amylovora* to grow epiphytically on flowers of non-host species of fire blight such as *Acer* (maple), *Amelanchier* (serviceberry), *Cytisus* (Scotch broom), *Populus (*cottonwood), *Prunus* (stone fruit), *Rubus* (blackberry, raspberry), *Salix* (willows) and *Symphoricarpos* (snowberry) has been reported in USA (Johnson 2004; Johnson 2006). Most of these hosts are present in Australia.
- *Rubus* spp. could serve as potential sources for establishment of fire blight. Strains of *E. amylovora* pathogenic to *Rubus* spp. were originally described as *E. amylovora* f. sp. *rubi* (Starr *et al.* 1951). A subgroup within this group seemed to be capable of cross-pathogenicity with Maloideae (Momol *et al.* 1997).
- Australia has a similar mix of apple varieties to New Zealand. The majority of Australian apple and pear cultivars planted are highly susceptible to *E. amylovora* (Vanneste *et al.* 2002). Many of the new high-density plantings of apple are on fire blight susceptible rootstocks of M.9 and M.26. Commercial apples are grown in orchards in temperate Australia. Apples are also grown in many suburban backyards.

- Some highly susceptible alternative hosts (cotoneaster and hawthorn) are commonly grown as hedgerows in home gardens, along roadsides and in parks. In Tasmania, hawthorn and cotoneaster are planted along the roads for hundreds of kilometres. Alternative hosts are also present as feral plants, but their populations are generally scattered. Derelict and abandoned apple orchards were found in a survey conducted in the Adelaide Hills in South Australia and such orchards may be present in other areas (Creeper and Nicholson 2005).
- Of the recorded hosts, fire blight is a serious bacterial disease affecting apple, pear, quince, loquat, hawthorn, cotoneaster and firethorn. It is considered these primary hosts will provide the highest chance of fire blight establishing in Australia (Paulin 2010a).
- Detailed information on exact flowering times for pome fruit production areas is not available. Flowering patterns vary with latitude and altitude. However, it has been shown for the Goulburn Valley that the flowering period for apple and pear coincides with suitable infection periods for *E. amylovora* (Gouk 2008).
- The estimated flowering time of host plants susceptible to *E. amylovora* in the Adelaide Botanic Gardens is given by Merriman (2002). He showed that host plants (for example, *Malus* spp., *Pyrus* spp., *Cotoneaster* spp., *Crataegus* spp., *Sorbus* spp., *Amelanchier* spp., *Cydonia* spp., *Mespilus* spp., *Prunus* spp., *Rubus* spp., *Rhaphiolepis* spp.) mostly flower in spring, with some commencing flowering at the end of winter. *Cotoneaster* spp. And *Photinia* spp. Flower in spring and summer. Production of secondary blossoms (rat-tails) in late spring and early summer is likely to prolong the potential period of disease establishment.
- Susceptibility of native plants to *E. amylovora* is unknown. However, none of the few native plants in the Rosaceae are closely related to any known hosts of fire blight.

Suitability of the environment

- *Erwinia amylovora* is native to North America and was initially recorded from England in 1958 (van der Zwet and Kiel 1979). Since then is has established across continental Europe and to Mediterranean countries in Europe, Middle East and North Africa (CABI 2002; Bonn and van der Zwet 2000). Many of these countries, particularly the Mediterranean countries, have climates broadly similar to temperate regions of Australia (Peel *et al.* 2007).
- An incursion of *E. amylovora* was detected in Melbourne in May 1997 and subsequently eradicated (Rodoni *et al.* 1999). It is not known how long the disease was present but the period of time was sufficient for bacterial growth to allow the expression of symptoms.
- In most years, environmental conditions in many Australian apple and pear growing areas (notably the Goulburn Valley) are favourable for infection (Penrose *et al.* 1988; Wimalajeewa and Atley 1990; Fahy *et al.* 1991). Apple production in Australia is confined to high rainfall areas. In these areas, the temperature during the blossoming period is higher than the threshold required for fire blight development (Roberts 1991).
- Incidence of blossom blight increased at relative humidity above 60%, with 100% infection at relative humidity above 85% (Norelli and Beer 1984). These climatic conditions occur in the spring in most locations where pome fruit is grown and less frequently in summer.
- During winter, low temperatures are likely to limit suitable infection periods (Steiner 1990).

- Hailstorms are common in pome fruit growing areas in Australia (QFVG 2000). These cause injuries on plant tissues, predisposing them to infection (Brooks 1926; Keil *et al.* 1966).
- Several potential infection days and multiple infection periods for fire blight occur at blossoming in apple production areas of Queensland, New South Wales and Victoria (Atley 1990; Fahy *et al.* 1991; QFVG 1996; Wimalajeewa and Atley 1990).
- A recent study has confirmed that the Goulburn Valley in Victoria, the main pome fruit region of Australia, has suitable climatic conditions for inoculum production and infection in spring that coincide with the main blossom period and results in many potential high risk infection events (Gouk 2008). This study used the two most important predictive models for blossom infection that have been used effectively in North America and New Zealand to predict infective events and manage blossom infection (Steiner 1990; van der Zwet *et al.* 1994; Biggs *et al.* 2008; Manktelov and Tate 2001).

Reproductive strategy and the potential for adaption

- Stable differences in virulence of some strains have been found on different genotypes of varieties of apple (Norelli *et al.* 1984).
- In artificial favourable conditions at 25–30 °C the doubling time of multiple isolates of *E. amylovora* ranged from 66–90 minutes (Hildebrand *et al.* 1398; Billing 1974b; Shreatha *et al.* 2005). Similar growth rates were recorded for *E. amylovora* in host tissue (Billing 1974b). Only one day of optimum temperature would be sufficient for low populations of *E. amylovora* to multiply to 10^5 to 10^6 cfu per blossom (Thomson *et al.* 1999) provided there is no competition from other micro-organisms and that nutrient, temperature and humidity are optimal.
- The stigmas of blossoms are the most receptive sites for initiation of new infections, where bacteria can multiply rapidly. Bacterial populations often reach 10^6 to 10^7 cfu per healthy flower (Thomson 1986; Johnson *et al.* 2009). However, blossom infection occurs only when bacteria reach the hypanthium (floral cup) under favourable conditions (Thomson 2000).
- One bacterium placed directly in the hypanthium was sufficient to cause blossom infection under controlled inoculations in the laboratory (Hildebrand, 1937). In some seasons five bacteria, and in another 5000 were sufficient to cause blossom infection (van der Zwet *et al.* 1994). However, as previously discussed the experimental methods employed in these studies do not occur under field conditions. For inoculum sourced from a canker, inoculum levels are unlikely to be limiting as bacterial ooze can contain 10^8 to 10^{10} cfu/ml (Beer 1979).
- Hale *et al.* (1996) found that when blossoms were inoculated with between 1 to 10^4 cfu, there were no disease symptoms and *E. amylovora* could not be detected in the blossoms. Taylor *et al.* (2003b) demonstrated that successful infection of flowers occurred only when the populations of *E. amylovora* exceeded 10^6 cfu on flowers that are less than four days old.
- Exopolysaccharides in *E. amylovora* capsules prevent cells from losing water, which can be an important means of survival under dry environmental conditions (Geider 2000). Polysaccharide material is readily rehydrated, enhancing the viability of bacterial cells (Keil and van der Zwet 1972a). Bacteria can also form dry strands of polysaccharide material. These are present mainly during blooming and are considered important in dissemination (Ivanoff and Keitt 1937).

- *Erwinia amylovora* can survive in the previous year's cankers (Beer and Norelli 1977) and as latent infections in internal stem tissues (Brooks 1926; Miller 1929). *Erwinia amylovora* can remain viable on fruit spurs following blossom infection until bud burst the following spring (Dye 1949).
- *Erwinia amylovora* could survive 11 weeks in nectar and 8 weeks in honey at 4°C. Survival was much shorter at higher temperatures. Debris, wax and propolis (glue used by bees to cement combs to hives and close up cells) were poor media for survival. In pollen, *E. amylovora* survived 40 weeks at 15°C and more than 50 weeks at 4°C (Wael *et al.* 1990).
- Under low relative humidity, the bacteria can survive in the dry exudate from cankers for up to 1 or 2 years (Rosen, 1938; Hildebrand, 1939) but under humid conditions survival time was much shorter (Hildebrand, 1939).
- *Erwinia amylovora* can survive in the dark for considerable periods, but is killed rapidly on exposure to ultraviolet light/full sunlight (Southey and Harper 1971).
- The importance of VBNC state, biofilm/aggregates and sigma factor on the survival of *E. amylovora* has been discussed previously. Preliminary evidence suggests that the above factors may have a role to play in the survival of *E. amylovora*, and although they are not completely understood under field conditions, they would be taken into account in the survival studies of *E. amylovora* bacteria in the calyx.
- Repeated use of streptomycin can result in the development of resistant strains of *E. amylovora* (Thomson *et al.* 1993; Jones and Schnabel 2000). Streptomycin resistance in bacteria can occur as a result of chromosomal mutation of the gene *rps*L or gene acquisition by plasmids or transposons (Jones and Schnabel 2000). Resistance determined by a chromosomal gene in the bacterium is not readily transferred during cell division but genes in acquired (plasmid) resistance strains are readily transmissible from one bacterium to another, even if these two bacteria belong to different species or genera (Vanneste and Voyle 1999).
- Streptomycin-resistant strains have been found in Hawke's Bay in New Zealand since 1991 (Thomson *et al.* 1993; Vanneste and Yu 1993). Continued monitoring up to year 2000 failed to find streptomycin resistance outside Hawke's Bay.[9] Since finding streptomycin resistance the use of this chemical has become much more targeted and is now based on a predictive system. For example, in 2004 only 10% of apple blocks used streptomycin (MAFNZ 2005a). The reduction in the quantity and frequency of use of streptomycin will reduce the chance of resistant strains developing. More recent information, over a period from 2006/07 to 2009/10, has reported on average, only 6.3% of blocks applied streptomycin (BSG 2011).
- Bacteria can become resistant to streptomycin either by enzymatic modification of streptomycin or from the modification of the target molecule. Based on the type of resistance, streptomycin resistant bacteria can be categorised into two groups. Group A bacteria are resistant to extremely high levels of streptomycin, but the resistance cannot be transferred to other bacteria. Bacteria belonging to group B are resistant to lower levels of streptomycin but this resistance is transferable to other bacteria including bacteria from other species or other genera. All strains of *E. amylovora* isolated from Hawke's Bay

[9] http://www.hortnet.co.nz/publications/nzpps/resist/streptom.htm. Accessed on 6 June 2005.

belong to group A (Vanneste 2004). The development of streptomycin resistance in *E. amylovora* was because of the mutation of genes and not plasmid-borne (Thomson *et al.* 1993). On the basis of available information, the transfer of streptomycin resistance genes from one organism to another would not occur.

Cultural practices and control measures

- Streptomycin is the most effective chemical to control fire blight, particularly at blossoming (van der Zwet and Keil 1979), but it is not a registered chemical in Australia.
- New chemicals (for example, oxytetracycline, fosetyl-aluminium, oxolinic acid) have been tested in the USA and found to be effective as replacements for copper compounds and streptomycin (Psallidas and Tsiantos 2000). These chemicals are currently not registered for use in Australia for control of fire blight.
- Naturally occurring bacterial antagonists (for example, *Pantoea agglomerans* [synonym: *Erwinia herbicola*] and *Pseudomonas fluorescens*) have proven to be effective against blossom infection (Johnson and Stockwell 2000; Cabrefiga *et al*. 2007) although results can be variable in some locations (Sundan *et al.* 2009). Application of *Pseudomonas fluorescens* strain A506 (Blightban A506®) applied to emerging flowers controlled fire blight by pre-emptive competitive exclusion of *E. amylovora* (Lindow *et al.* 2004). Mixtures of *P. fluorescens* and *P. agglomerans* were more effective in suppressing flower infection by *E. amylovora* (Johnson *et al.* 2004).
- Commercial formulations of strains of *Pseudomonas fluorescens* and *Pantoea agglomerans* (synonym: *Erwinia herbicola*), that produce antibiotics and compete for space and nutrients, have been used as biocontrol agents (Wilson and Lindow 1993; Vanneste 1996). *Pantoea agglomerans* is recorded from rosaceous hosts in Australia (APPD 2003) as *Erwinia herbicola*. *P. fluorescens* has not been reported on rosaceous hosts in Australia.
- New antagonists for the control of *E. amylovora*, such as non-virulent strains of *E. amylovora*, yeasts, Gram-positive bacteria and mixtures of bacteriophages specific to *E. amylovora* have shown promise in cultural tests or greenhouse assays, but have not been widely tested under field conditions (Ritchie and Klos 1977; Palmer *et al.* 1997).
- Use of prohexadione-calcium, a plant growth regulator, which reduces vegetative shoot growth in apple led to lowered incidence of fire blight (Deckers and Schoofs 2004; Norelli and Miller 2004).
- Commercial orchards in Australia do not employ any specific management methods that would limit the establishment of *E. amylovora*. However, general pruning practices may incidentally remove cankered wood. However, symptoms of fire blight can resemble other diseases (Rodoni *et al.* 1999) and may initially be considered unimportant.
- Less use of disease control and heavy pruning practices in garden and household situations may favour establishment of the disease.

Conclusion on probability of establishment

If *E. amylovora* has infected a suitable host, the disease can develop quickly and survive within a perennial host for multiple years. *Erwinia amylovora* is known to have established in a number of countries with very similar climatic conditions to Australia. *Erwinia amylovora* has previously infected hosts in Australia under natural conditions. Computer models that have been shown to accurately predict infection events indicate that many parts of Australia are climatically suitable for *E. amylovora*, including the major pome fruit growing regions. In addition, there are several suitable ornamental hosts that are widely scattered across Australia.

In countries where *E. amylovora* occurs, the application of antibiotics and antagonistic bacteria are the most effective strategies to manage infection periods during blossom. However, the products used overseas are not registered for use against *E. amylovora* in Australia and there is no need for them to be applied prophylactically for a bacterium that is not known to occur in Australia. In addition, fire blight symptoms can be confused with other diseases and may go unnoticed or assumed to be of no significance. As there are currently no targeted management practices that would be effective against *E. amylovora* in commercial production sites, there would be nothing to prevent *E. amylovora* establishing a persistent population. Further, control measures of any sort are unlikely to be applied on amenity or feral hosts and this would increase the likelihood of the pathogen establishing. The evidence supports an assessment rating of 'high' for the establishment of *E. amylovora*.

4.1.3 Probability of spread

The likelihood that fire blight will spread based on a comparison of factors in the area of origin and in Australia that affect the expansion of the geographic distribution of the pest is: **HIGH**.

Suitability of the natural/or managed environment

- Apples and pears in commercial orchards would be conducive to localised disease spread. Suitable host plants in nurseries distributed across states could rapidly spread the disease to new districts. The scattered distribution of host plants in household/garden situations and wild amenity plants would confine disease spread to localised areas.
- Given the geographical location of Western Australia and Tasmania there are natural barriers that would limit the natural spread of the pathogen across those borders.
- Fire blight is native to North America and was initially recorded from England in 1958 (van der Zwet and Kiel 1979). Since then is has spread across continental Europe and to Mediterranean countries in Europe, Middle East and North Africa (CABI 2002; Bonn and van der Zwet 2000). Many of these countries, particularly the Mediterranean countries, have climates broadly similar to temperate regions of Australia (Peel *et al.* 2007).
- More recently, fire blight has continued to spread in the Mediterranean region and has now been recorded from Syria and Morocco (Ammouneh *et al.* 2007; Fatmi and Bougsiba 2008).
- Most years, environmental conditions in many Australian apple and pear growing areas (notably the Goulburn Valley) are favourable for infection and spread of *E. amylovora* (Penrose *et al.* 1988; Wimalajeewa and Atley 1990; Fahy *et al.* 1991; Gouk 2008). Large areas of land are planted with cultivars of apple and pear susceptible to fire blight as a monoculture (for example, the Goulburn Valley, Granite Belt, Batlow).
- Flowering periods extend over three months, for example, from the second week of September to the third week of November in Orange, New South Wales (Penrose *et al.* 1988).
- Alternative hosts in the vicinity of orchards are available either as intentionally planted trees or volunteer plants established from seeds dispersed in the environment (Billing 1980).
- Hail, strong winds or thunderstorms cause injuries to plant tissues, predisposing them to infection (Brooks 1926; Keil *et al.* 1966). Rain (wind-blown or splashed) is probably the major factor in spreading primary inoculum from oozing overwintering cankers (Miller 1929), and is also a means of secondary spread of *E. amylovora* inoculum (Thomson

1986). The presence of ooze, accompanied by warm temperatures and rain, provides ideal conditions for spread and infection (Hildebrand 1939). During rain, dried ooze is rehydrated and then spread by splash dispersal (Eden-Green 1972).

- Rain also indirectly aids survival and spread of the bacterium by diluting nectar in the hypanthium, thus providing more favourable conditions for multiplication (Ivanoff and Keitt 1941).
- Streptomycin is the most effective chemical to control fire blight, particularly at blossoming (van der Zwet and Keil 1979), but it is not currently a registered chemical in Australia.
- Recent research has identified the effectiveness of kasugamycin as a product that controls blossom infestation and subsequent shoot infection in apple and pears (McGhee and Sundin 2011: Adaskaveg *et al.* 2011). However, this product is not currently a registered chemical in Australia.

Presence of natural barriers

- The major apple production areas are confined to six states of Australia and, to a small extent, the Australian Capital Territory. More than one growing region occurs in some states. These areas have differing climatic conditions and are separated by long distances, including desert areas between some states. There is potential for rapid spread within growing areas but spread between major production areas would be slower depending on movement of infected plants.

Potential for movement with commodities, conveyances or vectors

- There is circumstantial evidence that *E. amylovora* can be spread long distances over land or sea by birds (Meijneke 1974; Billing 1974a) or aerosols transported by high altitude air currents (Meijneke 1974).
- The studies on PFGE patterns of *E. amylovora* strains in Europe and the Mediterranean region indicate a sequential spread from England and Egypt into neighbouring countries (Jock *et al.* 2002). These authors concluded that the pattern types were well grouped without any observed mixing. If *E. amylovora* was introduced via trade in apples the PFGE patterns would have been several rather than single pattern in different parts of Europe, North Africa and the Middle East.
- The pathogen can spread from infected to healthy trees via pruning tools, hands, boots and machinery (Psallidas and Tsiantos 2000). It also can spread through trash (leaves, stems, twigs and soil).
- *Erwinia amylovora* can survive on artificially contaminated wood for limited periods, but transfer from there has not been demonstrated on uninjured fruit (Ceroni *et al.* 2004).
- The pathogen has spread over long distances through movement of planting material (Bonn 1979; van der Zwet and Walter 1996; Calzolari *et al.* 1982). The detection of *E. amylovora* in vegetative material can be difficult (Rodoni *et al.* 1999). A recent review has stated *E. amylovora* can survive for many years in the xylem tissue and symptoms do not express until the xylem is damaged and the bacteria invade the parenchyma tissue (Billing 2011). These are factors that could assist in the spread of *E. amylovora* in planting material.
- Seventy-seven genera of arthropods have been implicated in the secondary spread of *E. amylovora* from oozing cankers and infested blossoms. These include honeybees, aphids, pear psylla (*Psylla pyricola*), tarnished plant bug (*Lygus pratensis*), leafhoppers and numerous flies (van der Zwet and Keil 1979).

- Australia has at least 27 of these species or closely related species (AQIS, 1998b). Several crawling, browsing, flying insects or other animals have the potential to spread bacterial ooze from overwintering cankers to blossoms (Schroth *et al.* 1974). Pollinating insects, primarily bees, are agents of secondary spread of the pathogen.
- Managed hives of honeybees are used in contract pollination of apple orchards. Feral honey bees can also act as pollinators. Bees generally fly up to two to four kilometres to forage, and are major vectors in the rapid spread of *E. amylovora* (Hoopingarner and Waller, 1992).
- In Germany, Hildebrand *et al.* (2000) detected *E. amylovora* in 4.3% of insects examined, but of the insects caught from apple trees with localised symptoms, only 2.1% were contaminated with *E. amylovora*. This pathogen could be detected in or on green lacewing (*Chrysoperla carnea*) for at least five days after coming in contact with the bacterium, and in or on aphids (*Aphis pomi*) for 12 days following contact (Hildebrand *et al.* 2000).
- People (for example, consumers, gardeners, nursery workers) handling infected immature apples could unknowingly transfer the inoculum to susceptible host plants.

Potential natural enemies

- It has been reported that one reason why Australian orchards have remained free of fire blight is in part due to natural antagonists (Sosnowski *et al.* 2009). There is evidence for a unique microflora consisting of closely related related saprophytic *Erwinia* species in Australian orchards, which requires further investigation (Sosnowski *et al.* 2009)

Conclusion on probability of spread

Erwinia amylovora has a proven ability to spread across a continent and within a number of countries that have similar climatic conditions to Australia. Computer models indicate the suitability of Australian climatic conditions for blossom infection and there is a wide distribution of multiple hosts within Australia. Once cankers form on hosts, numerous insect vectors are able to quickly spread the pathogen over distances of kilometres. Longer distance spread would be facilitated by movement of asymptomatic planting material via the nursery industry.

Targeted and general management practices likely to be effective against *E. amylovora* are not currently employed in Australia and the lack of disease management would initially favour rapid increases in inoculum levels that would facilitate *E. amylovora* being spread by vectors. The evidence supports a rating of 'high' for the spread of *E. amylovora*.

4.1.4 Overall probability of entry, establishment and spread

The probability of entry, establishment and spread is determined by combining the probability of entry, of establishment and of spread using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Erwinia amylovora* will enter Australia by the pathways discussed in this PRA, be distributed in a viable state to susceptible hosts, establish in that area and subsequently spread within Australia is: **EXTREMELY LOW** as set out below.

Table 4.2 Probability of entry, establishment, and spread for *Erwinia amylovora*

Importation	Distribution	Entry	Establishment	Spread	PEES*
Moderate	Extremely low	Extremely low	High	High	Extremely low

*Probability of entry, establishment and spread.

4.1.5 Consequences

The consequences of the entry, establishment and spread of *Erwinia amylovora* in Australia have been estimated according to the methods described in Table 2.3 on page 11.

Based on the decision rules described in Table 2.4 on page 12, that is, where the consequences of a pest with respect to a single criteria is '**F**', the overall consequences are estimated to be **HIGH**.

Reasons for the ratings are provided below:

Criterion	Estimate and rationale
Direct	
Plant life or health	**F – Significant at the national level:** • Fire blight, caused by *E. amylovora* is a serious disease of pome fruit trees worldwide (Schroth *et al.* 1974) and is the most destructive disease of pears (Agrios 1997). • Fire blight epidemics can develop rapidly in orchards with no history of the disease, killing many large limbs or even whole trees. In some instances, fire blight causes no significant economic damage, even in orchards with severe blight in the previous season. Within these extremes, the incidence and severity of the disease can vary between orchards and seasons (Steiner 2000a). • In addition to pome fruit, *E. amylovora* can infect several host species belonging to the sub-family Maloideae of the family Rosaceae (CABI 2005). Introduced plants belonging to the sub-family Maloideae are widespread in Australia. Susceptibility of native plants to *E. amylovora* is unknown. However, none of the few native plants in the Rosaceae are closely related to any known hosts of fire blight. • In New Zealand, losses for the Hawke's Bay region were estimated to be at least NZ$10 million during 1998 (Vanneste 2000). • In 1976–77, the annual damage in the USA from fire blight was estimated at US$2–5 million, despite regular control of the disease (Kennedy 1980). A fire blight outbreak on apple trees in south-west Michigan in May 2000 caused losses estimated at US$42 million, including US$10 million in crop losses for the season and US$9 million in tree losses. Tree losses are reported to include 220 000 young trees and 80 000 prime bearing age trees (MDA 2001) and another source reported a total of 377 000 trees were lost because of fire blight (Longstroth 2001). • Importantly, when the impact of fire blight in one year results in the large scale death of fruit bearing trees, production losses will continue until new plantings become established. It has been reported that in Michigan there would be an additional US$23 million in crop losses expected (Longstroth 2001; Longstroth 2002). • On the west coast of the USA, fire blight was first recorded in California in the 1880's (van der Zwet and Keil 1979. Young orchards were frequently wiped out and bearing orchards recorded severe production losses of 20–50% (Bonn and van der Zwet 2000). • In Europe, fire blight has caused variable damage between countries and depending on the host and variety (Bonn and van der Zwet 2000). In England, after initial outbreaks in pears in the 1960's, fire blight is now considered to be of minor importance. In contrast, in one nursery alone, fire blight resulted in $6 million damage to orchard and nursery trees in 1982 (Bonn and van der Zwet 2000). In some Mediterranean countries fire blight has also been prevalent and has caused damage in Cyprus and Israel. For example, in Cyprus fire blight resulted in some cultivars ('Beurre Superfine' pear and 'Pera Pedi' apple) being totally destroyed (Bonn and van der Zwet 2000). • The Australian pome fruit industry is highly valuable. For example, the gross value of industry by State for the 2006/2007 financial year is (ABS 2008); o Victoria, $330 million o South Australia, $80 million o NSW, $77.5 million o Queensland, $33.9 million o Western Australia, $41 million o Tasmania, $38.5 million • The loss of production in a worst-case scenario, for all production areas in Australia, has been estimated at

Criterion	Estimate and rationale
	50% and 20% for pear and apple respectively (Roberts 1991). • Bhati and Rees (1996) estimated that the annual potential loss in pome fruit production would be $125 million if *E. amylovora* were to establish in all regions of Australia. This represents 37.5% of the gross annual value of pome fruit production in Australia. • If fire blight were to establish, and assuming disease severity was high from year to year, the value of lost production between 1997 and 2002 would have been $424 million in Victoria, $141 million in New South Wales, $97 million in Tasmania, $66 million in Western Australia, $50 million in South Australia and $49.4 million in Queensland, equivalent to a total of $827 million over this five-year period assuming disease severity were similar from year to year (Oliver *et al.* 1997). It is estimated that, if fire blight were to establish, up to 30% of total Australian production would be lost over five years (TAPGA 2002). • However, as mentioned previously disease severity is unlikely to be high from year year (van der Zwet and Kiel 1979; Paulin 2010a) as its prevalence is limited by suitable climatic conditions. • For South Australia, a 10% loss of yield has been estimated to cost growers about $3.5 million or at least $11.1 million of gross South Australian food revenue (AAPGA 2000). • Street (1996) estimated the loss of annual income as a result of a fire blight outbreak in Stanthorpe to be $20.9 million, of which growers in the Shire of Stanthorpe would lose $7 million. Queensland Fruit and Vegetable Growers (QFVG) predicted an annual production loss of $20.9 million, if fire blight occurred in the Granite Belt region (QFVG 2000). • Hinchy and Low (1990) estimated an annual loss of $77 million, if fire blight became established in the Goulburn Valley. If fire blight infection was 5% in the Goulburn Valley, the estimated cost for pears would be $2.9 million each year (Bhati and Rees 1996). Oliver *et al.* (1997) estimated that the total revenue loss for the Goulburn Valley as a result of fire blight would have been $410 million between 1997 and 2002 assuming disease severity were similar from year to year. • More recently a study has estimated the consequences of *E. amylovora* in Australia could in the range of $33 to $95 million per year depending on the model used to estimate consequences and confidence assigned to those estimates (Cooke *et al.* 2009). • If *E. amylovora* were to occur in the Goulburn Valley, prevention and control measures would be implemented. Dead trees would be replaced, tolerant varieties would be replanted or other crops might even replace pome fruit. Pome fruit production in this region could permanently decline by 55% to 60% (Kilminster, 1989). • One tonne of pears used for canning returns $270 to the grower, and is converted to approximately $1890 worth of canned pears at the wholesale level. One tonne of fresh apples returns about $400 to the grower, worth about $1375 at the wholesale market. It is estimated that fruit valued at $80 million at the farm gate is valued at $400 million at wholesale, and double that at retail level (NVFA 2000). Ardmona and SPC (now amalgamated) canning factories in Shepparton, Victoria, generate sales of $415 million a year, of which approximately $120 million is in exports (Commonwealth of Australia 2001). Ardmona bought about $30 million worth of fruit per year, and canned fruit generated added value amounting to $160 million. A reduction in the throughput of pome fruit products would result in capital-intensive processing plants, designed for continuous operation in the Goulburn Valley, being underused (Kilminster 1989). • Wittwer (2004) concluded that if fire blight established in the Goulburn Valley region the value of lost aggregate household consumption would be $870 million or a 1.4% long-term decline in the Goulburn Valley's income. • The conclusion of these predictive studies is the fact that potential consequences could be high if fire blight reached outbreak conditions as reported overseas. These predictions estimate direct impacts of a scale that are not seen overseas where fire blight is present as they assume a consistently high impact from year to year. International experience shows disease impact is certainly not consistent from year to year where the disease is known to occur as outbreaks sporadically. However, the impact of a single severe outbreak year in Michigan resulted in lasting consequences through the removal of diseased trees and a long term loss of productivity until replanted trees reached commercial maturity. • It has been reported that the disease incidence is higher when fire blight first establishes in a new country and then its prevalence declines and it appears more sporadically (Atkinson 1971; Bonn and van der Zwet 2000). Australia has not selected for resistant varieties of apple and pear, nor currently applies targeted disease management measures that may limit the impact of fire blight. Further, the major pome fruit producing region in Australia is reported to have a very suitable climate based on fire blight predictive models (Gouk 2008). These factors could allow for more severe and regular damage in Australia compared to countries where the disease has been established for many decades and were targeted management practices have been developed and widely adopted by industry. • The consequence of fire blight establishing in Australia has been considered and the direct impact of fire blight is unlikely to be highly significant at the regional level (Paulin 2010a). However, alternative opinions support the contention that the consequences of fire blight to plant health are high (Deckers 2010; Schrader 2010) and this is equivalent to the rating considered for consequences expected in other regions (Sgrillo 2010). Further, it is recognised that it is very difficult to quantify the disease development in terms of economic loss (Paulin 2010b). In taking the uncertainty around the likely consequences into account, including recent expert opinion and the concentration of the pome fruit industry in one State, a rating of 'F' is considered appropriate.

Criterion	Estimate and rationale
Other aspects of the environment	**A – Indiscernible at the local level:** • There are no known direct impacts of fire blight on any other aspects of the environment. • There are 17 Australian native plant species that belong to the main family Rosaceae, viz Aphanes australiana, Geum urbanum, Prunus turneriana, five species of Acaena and nine species of Rubus. Prunus turneriana belong to the sub family Amygdaloideae and all other sixteen species to the sub family Rosoideae. Hence, there are no Australian native plants belonging to the sub family Maloideae to which most fire blight susceptible hosts belong. • Occasionally some Rosaceae species which are not within Maloideae have been shown to be susceptible to fire blight. Among Prunus species (Amygdaloideae) only P. salicina (Japanese plum) and P. domestica (European plum) are susceptible under natural conditions (see data sheet in Part C). Susceptibility of P. turneriana has not been tested but like most other Prunus species is unlikely to be susceptible under natural conditions. • The strain of *E. amylovora* affecting Rubus species (*E. amylovora* f.sp. *rubi*) appears to be different from that infecting Malus and Pyrus (see data sheet in Part C). Therefore the strain infecting apple in New Zealand is unlikely to infect Rubus species native to Australia. Further, there are no reports of fire blight detection on Rubus species in New Zealand.
Indirect	
Eradication, control etc.	**E – Significant at the regional level:** • In the USA, management of fire blight adds about 30% to chemical costs and an additional US$100 per acre for pruning costs annually. These figures translate to $700 and $1000 per hectare for pears and apples respectively, and $275 per hectare for pruning (Oliver *et al.* 1997). • In the event of a fire blight outbreak, industry and the Australian Commonwealth and State Governments would incur substantial costs, associated with losses of production and trade restrictions, regulatory enforcement and implementation of the contingency plan (control/eradication and surveillance/monitoring). • The loss in revenue to the Australian pome fruit and nursery industries as a result of the detection of *E. amylovora* in the Royal Botanic Garden Melbourne in 1997 was estimated at $20 million (Rodoni *et al.* 2006). These authors estimated the cost of surveys, eradication programs, diagnostics and publicity at $2.2 million. Eradication of *E. amylovora* has also been tried in other countries without success and highlight the difficulty and expense involved (Sosnoski *et al.* 2009). However, in Norway eradication events continue as the program has severely reduced the prevalence of the disease in combination with unfavourable seasonal conditions (Sosnoski *et al.* 2009). • Two scenarios for the economic impact of a fire blight outbreak in the Goulburn Valley were examined. In the first scenario, a loss of $260 million was predicted for an outbreak that caused a 30% yield loss and where the disease was eradicated in five years. In the second scenario, predicted losses were $870 million when the disease outbreak was not controlled and yield reduction for apple and pear was estimated at 20% and 50% respectively (Rodoni *et al.* 2006). • The *E. amylovora* eradication program carried out in and around Melbourne cost the Australian Government and the Victorian Government about $2.8 million (ANAO 2000). • Adamson (2006) estimated that if fire blight were to establish in Australia, the apple industry which now returns $33,000–40,000 per ha would result in a net loss of $11 000–18,000 per ha. This author also estimated that there are one million trees over the age of six years valued at $99.4 million in 2001–02. Therefore, payment of compensation for growers affected by fire blight could involve large sums of money. • The suggested that the costs of replanting a hectare of apples in the Batlow region of NSW would be around $10,000 (Commonwealth of Australia, 2001) and could be as high as $40,000 (APAL 2005). • The use of streptomycin is no longer allowed in many countries due to development of resistant strains and residue problems. However, as an emergency measure streptomycin may be allowed in Australia as is done in Germany, under strict regulations (Moltmann *et al.* 2006). However, given the concern about antibiotic use, streptomycin may not be approved for routine fire blight control. • Several novel chemical and biological materials are now registered for commercial use to control fire blight as alternatives to streptomycin. The use of growth-regulating acylcyclohexanediones such as prohexadione-Ca ('Apogee') (Bazzi *et al.* 2003; Norelli *et al.* 2003) and biological control agent Pseudomonas fluorescens strain A506 ('BlightBan A506') are good examples. Other promising and environmentally friendly approaches, especially the use of systemic acquired resistance inducers and other biological agents, are showing promising results for potential use in the future. • Additional costs would be incurred for modification of orchard management programs, including the use of chemicals, disinfestation of machinery, and regulatory enforcement of quarantine conditions. • If eradication was attempted organic growers may be compelled to use streptomycin (in the absence of an effective alternative). This would result in these growers immediately losing their certification for growing organic apples and the premium prices associated with the sale of such products (Commonwealth of Australia 2001). • The eradication action taken in Melbourne was successful, when the disease was restricted to a limited number of hosts in a Botanic Garden. Successful eradication is less likely to occur when early detection does not occur.
Domestic trade	**E – Significant at the regional level:** • The indirect impact on domestic trade or industry would be minor at the national level, significant at a

Criterion	Estimate and rationale
	regional level and highly significant at the district level. A rating of 'E' was therefore assigned to this criterion. • Restrictions in interstate movement and trade of fruit and susceptible host plants are likely to occur, as they did after the detection of *E. amylovora* in the Royal Botanic Gardens Melbourne. The costs incurred by the Victorian pome fruit and nursery industries were around $7 million in lost sales and depressed prices, as a result of restrictions on the movement of host plants and related produce (Rodoni *et al.* 2006). • The viability of several other sectors associated with pome fruit production, such as packing houses, transport operators, packaging suppliers, repairers of agricultural equipment, agricultural suppliers, the banking and finance sector and retail industries in general within all growing regions, would certainly be affected. • Kilminster (1989) concluded that a fire blight outbreak in Australia would result in at least a 50% reduction in fresh apple fruit in both the export and domestic markets. Supplies to the juicing sector could decline by 30–40% if the apple supply fell by 50%. • The transport sector is estimated to generate a turnover of $471 million in the Goulburn Valley, Victoria. This represents 1050 jobs, or around 4.6% of local employment. The freight industry's value is estimated at $218 million, representing around 500 jobs. Transport operators in the Goulburn Valley spend around $33.4 million annually, of which 76% is spent locally. Each year, trucks to the value of $52 million are purchased locally. • The value of interactions with the banking and finance sector in the Goulburn Valley is around $3.4 million, and around $21 million from this region's business services sector, annually. • Fertilisers and chemicals constitute 10% of total grower costs for pome fruit production in the Goulburn Valley. It is estimated that growers purchase $7– 8 million worth of sprayers. Based upon an assumed 40% reduction in pome fruit production, this region would be expected to lose between $2 to 3 million annually (Street 1996). • Australia is currently the world's fourth largest exporter of honey. In Victoria alone, 38 300 beehives are used for pollination in pome fruit orchards (Commonwealth of Australia 2001). An outbreak of fire blight could lead to a reduction in bee foraging, resulting in lowered production of honey and fewer hives being available for contract pollination of orchards.
International trade	**A – Unlikely to be discernible at the local level** • The estimated loss of export revenue for 1997 would have been $25 million, with a total loss of $183 million between 1997 and 2002 (Oliver *et al.* 1997). • Apples and pears are exported to premium markets in the UK and European countries, and to the bulk markets of south-east Asia. At present, none of these countries impose restrictions on apple imports from countries where *E. amylovora* occurs. • Access to other markets in countries free from *E. amylovora* could be affected. Several importing countries will either: not import fruit from Australia, suspend imports pending scrutiny of data concerning the disease or impose phytosanitary measures, which could result in Australia losing competitive advantage over other producers. South American countries, for example, require fruit to be chlorine dipped, and Japan delayed approving the importation of apples from Tasmania for two years pending the outcome of disease surveys, after detection of *E. amylovora* in the Royal Botanic Gardens Melbourne. As a result, lost sales revenue for the Tasmanian industry was estimated at $10 million (Rodoni *et al.* 2006). Further as a consequence of the detection of *E. amylovora* in Melbourne the Philippines temporarily suspended the trade in apples, China required three annual surveys for fire blight in Tasmania – a condition that China still requires for apples exported from Tasmania to China despite eradication of the disease. • However, it is now extremely unlikely trade in apples would be affected as countries free of fire blight, including China and Japan, have recently removed targeted import requirements for this pathogen. • Streptomycin, the most effective chemical for fire blight control, is not registered for use in the horticultural industry. It may be permitted for emergency use in the event of a fire blight outbreak in Australia. Absence of any maximum residue limits for streptomycin may also affect trade at least in the short term.
Environmental and non-commercial	**A – Unlikely to be discernible at the local level** • Any indirect impacts of fire blight on the environment are unlikely to be discernible at the local level. A rating of 'A' was assigned to this criterion. • One issue that was considered was the potential effect on the environment of chemicals that may be used to control fire blight should it establish. The assessment on this point concentrates on the indirect impacts (not direct impacts such as cost as suggested by one stakeholder) of the use of chemicals such as copper and antibiotic sprays (mainly streptomycin). • Copper sprays are already in use in Australia to control a range of pests of plants including apples. It is unlikely that the use of copper sprays for fire blight control would lead to any discernable increased impact on the environment compared to the current use of copper sprays. • Streptomycin or any other antibiotic sprays are not currently registered for the control of plant pests in Australia but possibly could be permitted for emergency use under strict controls in an eradication program. Registration for more widespread use would require the evaluation of the environmental impact of the use of antibiotics. Significant issues that would need to be considered include the potential that resistance to the antibiotic may develop (streptomycin resistance has been found overseas (Thomson *et al.* 1993)) and the potential for residues in other products such as honey.

4.1.6 Unrestricted risk estimate

Unrestricted risk is the result of combining the probability of entry, establishment and spread with the estimate of consequences. Probabilities and consequences are combined using the risk estimation matrix shown in Table 2.5 on page 12.

Unrestricted risk estimate for *Erwinia amylovora*	
Overall probability of entry, establishment and spread	Extremely low
Consequences	High
Unrestricted risk	Very Low

As indicated, the unrestricted risk for *Erwinia amylovora* has been assessed as 'very low', which achieves Australia's ALOP. Therefore, additional risk management measures are not recommended for this pest.

4.2 Apple leaf curling midge

Dasineura mali

Dasineura mali is a fly with four life stages: egg, larva (or maggot), pupa and adult. *Malus* species (apple and crab-apple trees) are the only hosts of *D. mali*. This species is native to northern Europe, and has been introduced to both North America and New Zealand (Gagné 2007).

The adult is a small fly, 1.5–2.5 mm long, with dusky wings covered by fine dark hairs. Adult females have a characteristic red abdomen. Eggs are transparent pink to orange-red in colour and laid on the edge or upper surface of unfolding leaves. Sometimes eggs are laid singly, but most often are laid in groups, with 30–40 eggs being considered typical. Larvae are tiny legless maggots that are pink in colour when they first emerge from eggs, then turn pale-yellow, becoming reddish-orange as they develop into the final larval stage (instar) (Hortresearch 1999b) . When fully grown, larvae are 1.5–2.5 mm long (LaGasa 2007). Pupation takes place in a white silken cocoon 2–2.5 mm in length (LaGasa 2007). Mature pupae are brown in colour, distinct from the orange colour of the late instar larvae that forms the cocoon (Tomkins 1998).

The adult female deposits eggs in the leaf folds or along the margins of immature apple leaves (LaGasa 2007). After hatching the tiny larvae begin feeding, causing the margins of the apple leaves to become tightly curled (galled) (Tomkins 1998). Infested leaves eventually roll into distorted tubes and may discolour becoming red to brown and then brittle, before they finally drop from the tree (Antonelli and Glass 2005). Terminal shoots are stunted as a result of this leaf damage. Some of the larvae pupate in the damaged or rolled leaves, while most drop to the ground to pupate and overwinter, emerging as adults the following spring. The midge can complete multiple generations per year, depending on latitude (Tomkins 1998).

In New Zealand, apple leaf curling midge is known to occur from Clyde in the Central Otago district, to Auckland on the north island. At its southernmost distribution apple leaf curling midge is thought to have only two generations per year, while up to seven generations are reported in Hamilton on the north island (Tomkins 1998), although that latter figure is debated and four to five generations are considered more likely (Cross 2010). In New Zealand, *D. mali* survives the winter as cocooned pre-pupae or pupae (Tomkins 1998).

The risk posed by *D. mali* is that mature larvae or pupae may be present on apple fruit. While the larvae preferentially pupate in the ground, there are reports from New Zealand of pupation occurring on apple fruit (Lowe in Smith and Chapman 1995; HortResearch 1999b). In these cases, the pupal cocoon is firmly attached to the outside of the fruit at either the stalk end or calyx end. If viable cocooned apple leaf curling midges were to survive packing house processes, storage and transport, midges could enter the Australian environment and have the potential to establish a population.

4.2.1 Probability of entry

Probability of importation

The likelihood that *Dasineura mali* will arrive in Australia with the importation of fresh apples for consumption from New Zealand is: **MODERATE**.

Supporting information for this assessment is provided below:

Association of the pest with the crop

- *Dasineura mali* is considered widespread in New Zealand. Tomkins (1998) reports that it '*is probably found wherever apple trees are grown in New Zealand*'.
- While infestation levels reportedly vary between apple cultivars, no cultivar is considered to be immune from infestation (Tomkins 1998). The key factor for infestation of leaves, as determined during host susceptibility trials, was the availability of fresh terminal growth when adult midges have emerged from pupation and commenced flying (Todd 1959). A similar conclusion was reached by Smith and Chapman (1995).
- Present in New Zealand since the 1950's (Morrison 1953), *D. mali* was considered a secondary pest that was effectively controlled by insecticides applied for other insect pests. However, in the early 1990's pest pressures had reportedly increased, particularly in the Auckland district, Hawke's Bay, and Nelson (Wilton 1994). These reports were confirmed in the Waikato district near Auckland (Tomkins *et al.* 1994).
- Rogers *et al.*. (2006) state that *D. mali* activity and significance as a pest declined following the introduction of Integrated Fruit Production (IFP) program to the apple sector through the mid to late 1990's.
- The seasonal abundance of *D. mali* is significantly affected by climatic factors. In particular, the dry summers in Hawke's Bay and Otago districts are reported to reduce population size and delay the emergence of subsequent generations (Tomkins *et al.*. 2006). Importantly, rain events result in the softening of leaf rolls, which assists mature larvae escape leaf rolls in order to pupate (Tomkins 1998).

Ability of the pest to survive existing pest management

- Insecticides are not recommended for control of *D.mali* in producing blocks of mature trees as biological control is considered more effective (Pipfruit NZ 2008b). Further, the low abundance of vigorous growing material late in the season also limits the impact of *D. mali*. In recently planted orchards, or for recently grafted trees, foliar applications of diazinon is recommended if more than 50 per cent of new shoots are infested with eggs.
- Control of *D. mali* in New Zealand involves a range of biological control agents such as the egg parasitoid *Platygaster demades* (Hymenoptera: Platygasteridae) and predatory mites such as *Anystis* spp. (Acarina: Anystidae) (Shaw and Wallis 2008). The mirid bug *Sejanus albisignata* (Hemiptera: Anthocoridae) is also noted as a predator of *D. mali* eggs (Shaw and Wallis 2008).
- *Platygaster demades* lays its eggs in the eggs of *D. mali*, with larvae developing inside the growing midge. *Platygaster demades* adults emerge a few days after *D. mali* spins its cocoon, killing the midge in the process (HortResearch 1999b).
- High levels of parasitism by *P. demades* has been reported in New Zealand, but is related to how closely the emergence of the parasitoid and *D. mali* are synchronised (Shaw *et al.* 2005). In the Nelson district, parasitism rates of up to 83 per cent of the first *D. mali* generation were found, though second generations of *D. mali* were parasitised at rates as low as 3 per cent. However in third and fourth generations, which occurred from late January until early March, parasitism rates of 53 per cent and 58 per cent were recorded. In a fifth generation in April, a parasitism rate of 80 per cent occurred. These late generations are those that would be present as well developed larvae and pupae during harvest of apples in New Zealand.

- Similar parasitism results were found in the North Palmerston district, which is between Wellington and Hawke's Bay. In that study, the parasitism rates were 55, 41, 68 and 73 per cent of the first, second, third and fourth (overwintering) generations respectively (He and Wang 2007).

Association of the pest with the commodity pathway

- *Dasineura mali* primarily pupates in the ground, but occasionally mature larvae may spin cocoons and pupate on fruit (Tomkins 1998; Hortresearch 1999b). In those cases, cocoons are firmly attached to the skin of the fruit at either the stalk or calyx end (HortResearch 1999b). Contamination of fruit by pupae is considered incidental, occurring when mature larvae exiting leaf rolls get caught around the stem or calyx of fruit when attempting to drop to the ground.
- However, presence of cocoons on fruit is not a reliable indicator that live insects are present. *Dasinuera mali* pupae may have already completed development and emerged, resulting in empty cocoons, or pupae may have been killed due to parasitism or other factors.
- In the Waikato region (near Auckland), Tomkins *et al.* (1994) found fruit infestation levels up to 11.5 per cent, with 98 per cent of those fruit contaminated by only a single cocoon. However, up to three cocoons were found on some fruit. The highest levels of contamination and damage to shoots and leaves were found in unsprayed blocks and blocks treated only with the insecticide dimethoate. Tomkins *et al.* (1994) noted that the incidence of *D. mali* was rapidly increasing at that time, with up to 93 per cent of shoots having been damaged.
- Similarly, Tomkins (1998) noted that most fruit was contaminated by only a single pupal cocoon, but that up to 40 cocoons per fruit had been observed in fruit from unsprayed orchards, though this is considered exceptional.
- During trials of the IFP program that involved a total of 88 orchards across all major production areas, *D. mali* contamination of apple fruit, as assessed in the field, was found to range from 0.05 per cent to 1.40 per cent, with an average of 0.60 per cent, sampled across all growing regions (Walker *et al.* 1997).
- Data collected from fruit submitted to packinghouses from 1999 to 2003 indicates that the mean level of *D. mali* fruit infestation, sorted by year and by variety, was in all cases below 0.2 per cent for Nelson and below 0.03 per cent for Hawke's Bay (MAFNZ 2005b). The maximum midge infestation for any one processing line (described in the data as typically 15–50 field bins in Nelson and 15–70 field bins in Hawke's Bay) of apples reached 5.36 per cent in Nelson (compared with the average infestation of 0.19 per cent in the same year and for the same apple variety) and 5.45 per cent in Hawke's Bay (compared to the average of 0.03 per cent). These figures were taken from field incidence.
- Rogers *et al.* (2006) found that between 37 and 42 per cent of *D. mali* cocoons found on fruit were unoccupied, compared with 63 per cent of cocoons found to be unoccupied by Tomkins *et al.*. (1994). Of all cocoons present, 59 per cent were determined to contain only dead pupae, based on a visual assessment and prodding of pupae (Rogers *et al.* 2006). If a pupa did not move when prodded it was considered to be dead. Expressed as a proportion of occupied cocoons, 75 per cent contained dead pupae (Rogers 2008)
- Based on the data available, an average of around 50 per cent of *D. mali* cocoons found on fruit might be occupied by a pupa, either dead or alive, with as few as 25 per cent of

those pupa being viable. This would suggest that of all cocoons found on fruit, as few as 13 per cent might contain a viable pupa. However, there is clearly a substantial difference between in the cocoon occupancy rates found by Tomkins *et al.* (1994) and Rogers *et al.* (2006) and that highlights either seasonal variations or production site variations, or both. Recognising that the available data reflects only limited studies at two specific points in time and that there is likely to be variation from season to season and from orchard to orchard, an upper limit to the number of cocoons containing viable pupae in the range of 30 to 50 per cent is adopted.

Ability of the pest to survive packing, transport and storage conditions

- If infested leaves were to contaminate field bins, there would be some opportunity for midge larvae to move from leaves to fruit. If larvae were to move onto fruit, it is uncertain whether they would be of a suitable development stage to immediately spin a pupal cocoon or otherwise become attached to the apple skin so as to remain on the apple after washing and brushing processes. The relative absence of fresh leaf material on producing apple trees during the harvest period also suggests that any such contamination would be unlikely.
- Standard post-harvest processing includes washing and brushing of apples. As pupal cocoons are firmly attached in the calyx or stem end of apples, it is not clear whether brushing would reliably reach and dislodge cocoons. Similarly, washer pressure may not be adequate to remove all cocoons.
- Walker and Bradley (2006) found that while high pressure water washing did reduce the contamination of fruit from 0.38 per cent to 0.33 per cent, the results were not statistically significant. Utilising newer high pressure washing also yielded results that were not statistically significant. These washing processes were developed primarily for other pests of potential quarantine concern, including mealybugs and leafrollers.
- *Dasineura mali* is a quarantine pest for the state of California. *Dasineura mali* has been detected during pre-clearance inspection of New Zealand applies destined for the US market (MAFNZ 2005b).
- Data from 2001–2004 from endpoint inspections for the US market indicated average fruit contamination levels ranging from 0.10 per cent to 0.38 per cent, with an average across all years of 0.16 per cent (Pipfruit NZ 2005). This indicates that low level infestations can remain associated with fruit after the post-harvest processing of apples in New Zealand and can subsequently be detected during quarantine inspections.
- *Dasineura mali* has also been detected in several USA ports on New Zealand apples exported to the USA (USDA-APHIS 2003), further indicating that *D. mali* is, at least occasionally, associated with export consignments and can be detected during quarantine inspections.
- If apple leaf curling midges were to survive and remain associated with apples through post-harvest grading and packaging, they would then be subjected to cold storage with the consignment.
- Commercially, apples are cold stored to maintain freshness and reduce loss in quality. For example, a storage temperature range between 1°C and 10°C is recommended by one retailer (Woolworths 2010), though it is expected that any extended period of storage would occur at the lower end of this temperature range.
- For apples destined for Australia, the period of any cold storage could range from a few days to many months. However, no data is available that indicates the effect of

commercial cold storage temperatures on the viability of apple leaf curling midge pupae. As *D. mali* overwinters as late larvae or pupae, it is likely that it could survive for extended periods of cold storage. Indeed, if only moderately low temperatures were utilised, the effect on *D. mali* is likely to be negligible.

Conclusion on probability of importation

In summary, *Dasineura mali* is likely to be present in most or all orchards producing export fruit both during the growing season and during harvest. Further, infestation of fruit is a recorded phenomenon, with cocoons able to remain associated with apple fruit throughout post-harvest processing. This is supported by the evidence that *D. mali* cocoons have been detected during end-line quarantine inspections in New Zealand.

However, evidence indicates that while *D. mali* is present in orchards, the populations are at low levels during the harvest period, are subject to biological control in orchards, and are only incidentally associated with apple fruit if larvae happen to get caught in either the stem or calyx end of an apple when falling to the orchard floor to pupate. Further, the data from New Zealand indicates that a large proportion of cocoons associated with apple fruit are either not occupied by pupae, contain pupae that have been parasitised, or contain pupae that have died due to other reasons. Allowing for variations between seasons, between 30 and 50 per cent of any cocoons found on fruit are likely to contain a potentially viable pupa. Based on historic inspection data from New Zealand, less than 3 per cent of consignments are found to hold *D. mali* pupae, with infestations rates averaging around 0.16 per cent.

The information presented indicates that there is potential for some consignments of apples from New Zealand to contain apple leaf curling midge pupae that are viable and remain undetected during the minimal on-arrival quarantine processes at the Australian border. Recognising that there is potential for this event to occur, though not with certainty in all consignments or in all years, indicates that the probability that viable *D. mali* would be imported into Australia should be assigned a risk rating of ‘moderate’.

Probability of distribution

The likelihood that *Dasineura mali* will be distributed within Australia in a viable state, as a result of the processing, sale or disposal of the commodity is: **VERY LOW**.

Supporting information for this assessment is provided below:

Distribution of the imported commodities in the PRA area

- Minimal on-arrival inspection procedures include only a check that the consignment is as described on the commercial documentation and that its integrity has been maintained. Therefore, as this process does not include any inspection of fruit, any infestation would not be detected. Any infested fruit would therefore be released from quarantine to importers.
- Imported fruit will be distributed throughout Australia as wholesalers and retailers are located at multiple locations and this would facilitate the distribution of any infested fruit.
- Any viable apple leaf curling midge pupae would need to survive transportation and storage within the PRA area. Fruit is typically stored and transported in refrigerated containers maintained at cool temperatures and receival temperatures in the range of 1–10 ºC are required by a major retailer (Woolworths 2010).
- While there have been no studies to determine the cold tolerance of *D. mali*, this pest is known to overwinter as a cocooned larva or pupa (Tomkins 1998), and studies into

emergence of adults utilised a 7 day period at 4°C to simulate an overwintering scenario (Tomkins *et al.* 2000). In the absence of contradictory information it is assumed that short duration cold storage of fruit would have little or no effect on survival of any *D. mali* associated with apple fruit. The ability for a range of ages of larval or pupal *D. mali* to overwinter would, in part, be one explanation for the extended period of emergence of first generation midges found by Tomkins *et al.* (2006).

- Imported fruit may be packed by orchard wholesalers that would be in close proximity to commercial fruit crops. Orchard wholesaler waste may be dumped at a site within the premises or in landfills close to orchards. Before waste is finally disposed of, it could remain exposed to the elements (for example, in a skip) near the packing house.
- However, export data from New Zealand shows that the majority of fruit exported is in retail-ready boxes or trays that do not require repacking (MAFNZ 2011). It is very likely the majority of fruit will be distributed to retailers, potentially through wholesale markets, without the need for re-packing. Only a small volume relative to the total imports would be expected to be re-packed in Australia.

Availability of hosts

- The only hosts for *D. mali* are *Malus* species (which includes apple and crab-apple trees). Apples are grown commercially in most states of Australia and are also grown as backyard fruit trees at some households. Both apples and crab-apples may be found as ornamental, amenity, or feral trees in Australia.
- Empty cocoons can be found on apple fruit and this has been attributed to midges that have completed pupation (Tomkins *et al.* 1994). While it is not considered that a site other than the calyx or stem end of an apple would need to be located by midges in order to complete pupation, disposal of fruit within the vicinity of a host tree would be required otherwise there would be no opportunity for eggs to be laid on suitable host material within Australia.
- Suitable host material in the form of young leaves and flowers are mostly present during spring, though some flushes of growth may occur throughout the growing season and until late summer. While some of this suitable leaf material may be present on trees when the first fruit are imported from New Zealand each year (around March), any adult midges emerging after this time, but before suitable material were present in spring would not survive long enough to potentially initiate an infestation. Therefore, any imported midges would need to overwinter in Australia until suitable host material became available.
- On heavily infested trees, *D. mali* is reported to lay ‘a few’ eggs on older leaves that are already infested with larvae (HortResearch 1999b). However, it is not clear whether well-developed leaves present during or after harvest would be attractive to female midges or whether the larvae emerging from eggs on mature leaves would be able to complete development.

Completion of development

- The life stage of any *D. mali* imported into Australia on apple fruit would be cocooned larvae or pupae and would need to complete development within Australia.
- To complete pupation, any midges entering Australia would not need to find a new pupation site. Empty cocoons can be found on apple fruit and this has been attributed to midges that have completed development (Tomkins *et al.* 1994). The disposal of any waste material to compost facilities, or the decay of any waste material disposed of in the

environment may affect the survival of any cocooned midges that enter Australia. The effect of this has not been quantified.

- Environmental conditions would need to be suitable for pupation to be completed. In laboratory studies, pupation lasted 30 days at a constant temperature of 23°C (MAFNZ 2006a). A lower developmental threshold has not been specifically determined for *D. mali*, but recent evidence suggested that midges would complete pupation after 295 degree-days were accumulated above 6.44°C (Cross 2010), based on the data presented by Shaw *et al.* (2005).
- Following any cold storage, late stage larvae and pupae would need to complete development. Given the potential range of ages in any midges on imported apples, it would be expected that the emergence of adult midges would occur over a period of time. An emergence period spanning six to eight six weeks has been recorded for field populations of midges pupating in the soil (Tomkins *et al*. 2006). If any imported midges were to enter diapause due to cold storage conditions, suitable conditions to break diapause would need to occur. If suitable conditions did not occur, pupae may remain in diapause until the following year (Cross 2010).
- If any midge pupae entering Australia were not to be exposed to suitable environmental conditions for a sufficient length of time, it is likely that they would not be able to complete their development. The length of time necessary would be dependent on how far developed the pupae are, but if they were developed, it has been suggested that adult emergence could occur almost as soon as environmental conditions were suitable (Cross 2010).
- Of any pupae present on imported apples, a proportion are likely to be parasitized by *Platygaster demades* which lays its eggs onto *D. mali* eggs. The parasitoid develops inside the growing *D. mali* larva and emerges from the pupa. Parasitism rates reported by Shaw *et al.* (2005) in the Nelson district ranged from 53 per cent to 80 per cent for the third, fourth and fifth generations of *D. mali*, which are the generations most likely to be associated with mature, harvest ready, fruit.
- Similar parasitism results were found in the North Palmerston district, which is between Wellington and Hawke's Bay. In that study, the parasitism rates were 55, 41, 68 and 73 per cent of the first, second, third and fourth (overwintering) generations respectively (He and Wang 2007).

Risks from by-products and waste

- Although the intended use of fresh fruit is human consumption, waste material would be generated (e.g. overripe and damaged fruit, uneaten portions and apple cores). Whole apples or parts of the fruit may be disposed of at multiple locations throughout Australia in compost bins or amongst general household or retail waste.
- For apples imported in a retail ready state, no additional sorting or grading would be expected to occur. Boxes would be sold at wholesale markets or imported directly by retail operations, possibly for further re-distribution.
- It is unlikely that any significant volume of waste material would be produced from the handling, sale and movement of 'retail ready' apples. Waste material would however be produced at the retail level, where any produce damaged in transit or affected by post-harvest degradation is removed during retail display of apples. Such waste would be principally whole apples and may be placed in bins to end up in either composting facilities, landfills, or with general waste.

- For apples imported in bulk bins for repacking, any grading or repacking operation has the potential to generate a quantity of waste material. Such material would be due to downgrading or "culling" fruit showing damage, degradation, or otherwise considered not suitable for market.
- Orchard wholesaler waste may be disposed of into isolated areas within the orchard itself or in landfills close to the orchard. These disposal sites are surrounded mostly by pome fruit grown as a monoculture and wild and amenity plants are less abundant.
- Apples purchased via retail outlets could enter the environment after being purchased by consumers. The majority of the population (and therefore the majority of apple consumption) is in the capital cities that are significant distances from most commercial apple orchards. However, hosts of *D. mali* are present in home gardens, parks and roadsides in large cities.
- A relatively high proportion of household and retail waste would be managed through regulated refuse collection and disposal services. Managed waste will remove fruit from the household and environment, reducing the likelihood that susceptible plants will be exposed to this pest.
- Consumers may occasionally discard fruit waste along roadsides and recreation areas.

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

- *Dasineura mali* is capable of independent flight. After emerging from cocoons, any midges within the vicinity of apple or crab-apple trees would be able to move to them without requiring the aid of wind or a vector.
- Adult male *D. mali* have been recorded to fly distances of at least 50 metres (Cross and Hall 2009), though longer distance flight may also be possible (Cross 2010). While specific studies on the flight potential of females have not been conducted, similar flight distances would be expected.
- Suckling *et al.* (2007) further reported that the maximum colonisation distance for females was 30m.

Ability of the pest to initiate infestation of a suitable host

- As neither the male or female adult midges feed on apple foliage infestation is only considered here to have the potential to occur if a mating pair of midges were present in the same location.
- Adult female midges held at 4°C with moisture available survive 4–5 days, and rarely 6 days. Further, most male and female midges held at 18–20°C in a low airflow environment survived less than one day (Cross 2010). A shorter life span of 1–2 days has also been reported (Suckling *et al.* 2007).
- Based on field studies, Todd (1959) determined that maximum emergence of adult midges extended over five days, but that three days later only a limited number of midges could be observed. While definitive studies are not available, the available data indicates that adult midges are short lived, surviving up to four days under field conditions and less if conditions are not favourable.
- In New Zealand, emergence of *D. mali* adults after winter can span a six to eight week period (Tomkins *et al.* 2006). This might be explained by either a range of developmental ages of midges being present in the overwintering generation, or be due to the individual midge's response to environmental and other cues to complete pupation. In either case, a

"window of emergence" would be expected for random populations of midges that were to enter Australia.

- For mating to occur, at least one male and one female midge would need to be within flight range of each other during a limited period of time.
- With no post-harvest processing, fruit contamination levels up to 5.45 per cent in a single "line" has been recorded in exceptional years (MAFNZ 2005b). In typical years, the average level of contamination across all "lines" is substantially below 0.2 per cent.
- However, export endpoint inspections are considered to be more representative of the commercial trade in apples. As indicated under the probability of importation, an average fruit contamination level of cocoons ranges from 0.10 per cent to 0.38 per cent with some variation between seasons (Pipfruit NZ 2005).
- Further, as reported by Tomkins *et al.* (1994), 63 per cent of cocoons on fruit did not contain pupae. Rogers *et al.* (2006) reported a more conservative figure between 37 and 42 per cent.
- The parasitism levels of 53 to 58 per cent reported by Shaw *et al.* (2005) for third and fourth generation *D. mali* and 68 to 73 per cent parasitism reported by He and Wang (2007), suggests that at least half of all pupae in cocoons would most likely already be dead, or fail to emerge.
- As described in Section 3, a standard packinghouse practice in New Zealand for apples includes a minimum sample of 600 fruits being inspected for evidence of pests. The detection of a quarantine pest, including *D. mali*, would rule that processing line ineligible for the Australian market. Based on a 600 fuit sample where no pests are found the maximum level of fruit infestation would not exceed 0.5 per cent. With approximately half of those infestations being cocoons that are empty or contain non-viable pupae, a maximum infestation level of 0.25 per cent of fruit with viable insects would occur.
- However, based on historic inspection for the US market, infestation levels after packing house processes are 0.16 per cent (Pipfruit NZ 2005). Allowing for empty cocoons and parasitised midges, the proportion of fruit with potentially viable midges is 0.08 per cent.
- Vail *et al.* (1993) presented formulae to calculate the number of fruit required for a chance of a mating pair occurring if an infestation level is specified. Using those methods, if imported fruit with a 0.08 per cent infestation rate of viable pupa were to enter the Australian environment, 263 fruit would need to be disposed of in one place to result in a 1 per cent chance of a potential mating pair existing. This uses the observed average infestation rate of 0.16 per cent from New Zealand exports to the US (Pipfruit NZ 2005) and assumes only 50 per cent of cocoons contain a viable pupa. Higher rates of parasitism, or pupal mortality, as seen in many of the research results, greatly increase the number of fruit that would be required.
- The limited life span of adult *D. mali* also needs to be taken into account. As reported by Tomkins *et al.* (2006), the emergence period for *D. mali* in New Zealand spans six to eight weeks. Given the limited life span of adult midges in the environment, any individual would only be present for a small portion of the predicted emergence period, thereby reducing the chance that a mating event could occur.
- The scenario of a large number of apples being disposed of in one place and within the flight range of *D. mali* of a host is very unlikely to occur in a domestic or retail environment. However, it might occur in commercial repacking facilities.

- Any apples disposed of would need to remain in a suitable condition for pupation to complete. If disposed of in the environment, any rotting of apples, or unfavourable climatic conditions, may reduce the number of emerging adults.

Conclusion on probability of distribution

In summary, for *Dasineura mali* to successfully distribute within Australia and result in the potential for eggs to be laid on a suitable host plant in Australia, any pupae entering Australia would need to both survive until emergence and be in sufficient proximity to both a host plant and an individual of the opposite sex within a limited window of opportunity.

Considering the infestation rates observed for commercially washed and brushed apple fruit in New Zealand, a significant number of apples would need to be disposed of at the same place for a chance of a mating pair to occur. When the proportion of empty cocoons found contaminating fruit, the impact of parasitism, and the delayed emergence of adults from cocoons is taken into account, a very large quantities of apples would need to be disposed of into a single environmental location, and within the flight range of *D. mali* of a suitable host plant. It is considered that this specific sequence of events would be very unlikely to occur and therefore the likelihood that *D. mali* will be distributed within Australia in a viable state is assessed as 'very low'.

Overall probability of entry

The overall probability of entry is determined by combining the probability of importation (moderate) with the probability of distribution (very low) using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Dasineura mali* will enter Australia as a result of trade in the commodity and be distributed in a viable state to a suitable host is: **VERY LOW**.

4.2.2 Probability of establishment

The likelihood that *Dasineura mali* will establish based on a comparison of factors in the source and destination areas that affect pest survival and reproduction: **MODERATE**.

In estimating the probability of distribution, the PRA has already considered the sequence of events necessary to result in a viable mating pair of *D. mali* midges to be present at the same time and within the vicinity of a host plant. The probability of establishment will consider whether the presence of a mating pair could lead to eggs being laid on suitable host tissue and result in both an initial and subsequent generations of *D. mali* in Australia. For establishment to complete successfully, the introduction of *D. mali* would need to result in a population that is able to survive throughout an entire year.

Supporting information for this assessment is provided below:

Availability of suitable hosts and alternative hosts in the PRA area

- The only hosts for *D. mali* are apple trees (including crab-apple). Apples are grown commercially in most states of Australia and are also grown as backyard fruit trees at some households. Both apples and crab-apples may be found as ornamental, amenity, or feral trees in Australia.
- However, while hosts are available in both urban and rural environments, only young leaves and the bracts of flowers are considered suitable host material for *D. mali* to develop on (Tomkins 1998). Therefore, any *D. mali* emerging in Australia would only

have the potential to lay eggs and establish a founding population in a specific seasonal window.

- Young leaves and flowers are mostly present during spring, though some flushes of growth may occur throughout the growing season and until late summer. While some suitable leaf material might be present on trees when the first fruits are imported from New Zealand each year (around March), any adult midges emerging after this time, but before suitable material was present in spring would not survive long enough to be able to lay eggs at a suitable site for larvae to subsequently feed.
- On heavily infested trees, *D. mali* is reported to lay a small number of eggs on older leaves that are already infested by larvae (HortResearch 1999b). However, it is not clear whether well-developed leaves present during or after harvest would be attractive to female midges or suitable for egg laying in the absence of preferred unfolding leaves.

Suitability of the environment

- The likely sites for initial establishment of *D. mali* in Australia would be anywhere that imported material is disposed of. This could be in any urban, periurban or rural area. However, as discussed under the probability of distribution, the greatest likelihood of a large volume of apples being disposed of in one place would be at or near a re-packing facility.
- However, even if a mating pair of midges were present in the vicinity of a host plant, the environmental conditions where this occurred may not be suitable for *D. mali* to survive.
- In Europe, *D. mali* is reported as present in Finland, Norway and Sweden in the north and Bulgaria, Italy, and Macedonia in the south (CABI CPC 2008). This distribution spans the latitudes from around 38°N to 65°N. *Dasineura mali* has not been reported in Greece, Turkey, or Spain, for example, even though apples are grown in these countries. This suggests that environmental conditions can be unfavourable for *D. mali*, even where apples are grown.
- The northernmost parts of New Zealand are at a latitude of 35°S, with Auckland being at around 37°S. This is approximately the same latitude as Albany in Western Australia, Adelaide in South Australia and Wollongong in New South Wales.
- Extended cold conditions may be required to break any diapause in midges entering the Australian environment (Cross 2010). Diapause is known for other species of *Dasineura* (Axelsen *et al.* 1997), though definitive studies have not been completed for *D. mali* (Cross 2010). Cold storage during transport of apples may be sufficient to break diapause.
- Laboratory studies have indicated that adult *D. mali* are sensitive to dry conditions (Hall and Cross 2006). Hot dry conditions experienced in some inland horticultural growing regions may be unsuitable for *D. mali* to establish a population.
- *Dasineura mali* is established in Washington State, USA, (CABI CPC 2008), but only in coastal areas west of the Rocky Mountain (Cross 2010). The absence of sufficient summer rainfall has been proposed as the reason why *D. mali* has not established in inland Washington State (Cross 2010).
- It is possible that the relatively dry environmental conditions in many regions of Australia where apple and crab-apple trees are grown would be unsuitable for *D. mali* to survive long enough to establish a persistent population. This, along with potential absence of suitable conditions to enter or break diapauses, would appear to be the case in countries such as Greece, Turkey and Spain that produce apples, but have no records of *D. mali* (CABI CPC 2008).

- Dry conditions are also reported to both reduce and delay subsequent generations of *D. mali* (Tomkins *et al.* 2006). Importantly, rain events result in the softening of leaf rolls which assists mature larvae escape to pupate (Tomkins 1998). Dry conditions are likely to reduce the number of successful generations and this may increase the likelihood of local extinction.
- When the climatic data presented in Figures 3.2–3.11 is compared, it can be seen that areas such as Stanthorpe in Queensland have a similar temperature range to the Waikato district and Hawke's Bay. Stanthorpe also has substantially more summer rainfall, a factor for potential survival of *D. mali*. While it substantially north of the Waikato district in New Zealand, the high altitude results in moderated climatic conditions that appear to be suitable for *D. mali* to establish. Broadly similar conditions also exist in Batlow, New South Wales.

Reproductive strategy and the potential for adaptation

- *Dasineura mali* needs to mate in order to produce viable eggs.
- Adult female midges release a pheromone to attract male midges for mating (Harris *et al.* 1996). The pheromone has been isolated (Hall and Cross 2006).
- Females are reported to commence "calling" for mates two hours after emerging from pupation (Suckling *et al.* 2007).
- The pheromone has subsequently been utilised to develop a trap for male *D. mali* (Cross and Hall 2009). The greatest catch of male midges occurred in traps at ground level. In tests involving a geographically isolated apple orchard it was also found that the greatest catch of male midges occurred within 10 meters of the edge of the orchard. However, midges were trapped at distances up to 50 meters. Greater distances were not tested.
- If a male midge were present within flight range of a female midge, it is considered likely that pheromones would attract the male midge and that mating could then occur.
- Subsequent to mating, female midges are reportedly attracted by volatiles released by apple foliage, with a marked preference for immature foliage (Galanihe and Harris 1997). It is likely that females would be able to find suitable host material for egg laying, if it were present.

Cultural practices and control measures

- In New Zealand, the parasitoid wasp *P. demades* provides control of *D. mali* (Tomkins *et al.* 2000). However, *P. demades* is not present in Australia.
- Generalist predators such as *Anystis sp*. and *Sejanus albisignata* also provide some control of *D. mali* in New Zealand (Shaw and Wallis 2008). While *Sejanus* species are not recorded from Australia, there are two species of *Anystis* in Australia, *A. wallacei* and *A. baccarum* (AICN 2005). These species, or other generalist predators, may result in some mortality in any *D. mali* populations. However, it is not considered that they would prevent *D. mali* from establishing a founding population.
- European earwig (*Forficula auricularia*) has also been established as a predator of *D. mali* larvae and will bite through leaves to access its prey (He *et al.* 2008). European earwig is widespread in Australia (AICN 2005), but while it may reduce population sizes of *D. mali*, it is unlikely to prevent a persistent population establishing.
- The habit of midge larvae feeding in leaf rolls is likely to reduce the impact of any insecticides sprayed in the vicinity of an establishing population of *D. mali*. Further, any such chemical sprays are unlikely to be applied to wild, amenity, or backyard apple trees.

Conclusion on probability of establishment

In summary, if a male *Dasineura mali* were to be present within close proximity to a female at the same time, the male midge would be assisted in locating the female by pheromones making it likely that mating would occur. However, there is only a limited seasonal window during which any resulting mated female would have suitable plant material on which to lay eggs. Further, the potential areas within Australia where *D. mali* could establish a persistent population appear to be restricted to areas with favourable climatic conditions.

While there may be some impact from predation of any *D. mali* eggs by generalist predators already present in Australia, there is no evidence that environmental conditions would not be suitable in at least some parts of Australia for eggs to hatch and larvae to commence development. Higher temperatures and drier conditions in many areas in Australia may be unfavourable for midges, but the effect may only be to delay pupation and subsequent generations of *D. mali*, not necessarily to prevent development and subsequent pupation completely.

The formation of leaf rolls or galls as a result of midge larvae feeding would create a protected environment which would limit any impact that predators and pesticides may have on developing midges. However, whatever protective advantage leaf rolls provide *D. mali*, they are not sufficient to allow *D. mali* to establish in areas where the climate is not suitable. However, if larvae were to survive until this time and climatic conditions sutiable, it is likely that they would be able to develop through to pupal stages and for a second generation to occur.

Therefore, both environmental and biological factors are expected to result in some mortality of any initial generations of *D. mali*, and likely prevent establishment in many regions of Australia. However, there would remain potential for establishment in the southern latitudes, and at higher altitudes, if a mating pair was to occur. As a signiciant part of the Australian population is located in Melbourne, Canberra and Hobart, a significant proportion of imported fruit could be expected to be distributed to these, more suitable areas for *D. mali*. The probability of *D. mali* establishing a population in Australia, if a mating pair were to occur, would then be limited only by a seasonal window of suitable host material. It is possible, though not certain, that a population could establish and persist into the foreseeable future and this supports a risk rating of ‘moderate’.

4.2.3 Probability of spread

The likelihood that *Dasineura mali* will spread based on a comparison of those factors in the area of origin and in Australia that affect the expansion of the geographic distribution of the pest is: **MODERATE**.

Supporting information for this assessment is provided below:

Suitability of the natural/or managed environment

- The northernmost parts of New Zealand are at a latitude of 35° south, with Auckland being at around 37° south. This is approximately the same latitudes as Albany in Western Australia, Adelaide in South Australia, Shepparton in Victoria and Wollongong in New South Wales.
- From Europe, *D. mali* is reported as present in Finland, Norway and Sweden in the north and Bulgaria, Italy, and Macedonia in the South (CABI CPC 2008). *Dasineura mali* has not been reported in Greece, Turkey or Spain, for example, even though apples are grown in these countries and there are no quarantine measures in place against *D. mali*. The

distribution of *D. mali* appears to have reached an equilibrium with the pest spanning the northern latitudes from 38°N to 65°N (CABI CPC 2008; Cross 2010). This indicates that environmental conditions are unfavourable for *D. mali*, even in places where apples are grown.

- Diapause is known for other species of *Dasineura* (Axelsen *et al.* 1997). As host material for *D. mali* is not present all year long, larvae or pupae would need to enter diapauses to survive the winter months. While definitive studies have not been conducted to establish the conditions required to break diapause in *D. mali*, an extended period of exposure to cold temperatures is believed to be necessary (Cross 2010). Researchers have used extended storage at cold temperatures to simulate conditions that may be required to break diapauses (Tomkins *et al.* 2000).
- While extended cold conditions occur in some regions of Australia, especially at southern latitudes, it is likely that appropriate triggers for *D. mali* to enter and exit diapauses would not occur in all locations. Therefore, it is unlikely that *D. mali* could spread to all areas of Australia and establish persistent populations.
- Laboratory studies have indicated that adult *D. mali* are sensitive to dry conditions (Hall and Cross 2006).
- It is possible that the relatively dry environmental conditions in many regions of Australia where apple and crab-apple trees are grown would be unsuitable for *D. mali* to spread. These areas are likely to be at more northern latitudes where temperatures are higher, and also drier inland areas.
- Based on the evidence from the northern hemisphere, it could be inferred that *D. mali* could spread as far north as 38°S, or to include the southernmost parts of South Australia, Victoria, and all of Tasmania. Alternately, as the northernmost parts of New Zealand are at a latitude of 35°S, with Auckland and the Waikato district being at around 37°S, it could be inferred that *D. mali* has potential to spread to areas such as Albany in Western Australia, Adelaide in South Australia and Wollongong in New South Wales.
- However, inferring distribution only from latitude information is likely to be unreliable. The climatic data presented in Figures 3.2–3.11 shows that commercial apple growing areas such as Stanthorpe in Queensland have a similar temperature range to the Waikato district and Hawke's Bay and substantially more summer rainfall. While it is substantially north of the Waikato district in New Zealand, the high altitude results in moderated climatic conditions that appear to be suitable for *D. mali* to establish. Broadly similar conditions also exist in Batlow, New South Wales.
- Therefore, it is presumed that there are likely to be areas within Australia with climatic conditions suitable for *D. mali* to spread to, even if they do not occur across the whole of the continent.
- While some pest control programs, including the use of insecticides, would be in place in commercial apple orchards in Australia, these are not targeted for *D. mali* and therefore would be unlikely to prevent *D. mali* spreading to commercial orchards.
- Pest control programs are unlikely to be applied in most urban environments. Therefore, it is not likely that *D. mali* would be prevented from spreading to, or within, urban environments.

Presence of natural barriers

- The main Australian commercial apple orchards are in six states of Australia with natural barriers existing between these areas including arid areas, climatic differentials and long geographic distances.
- Adult *D. mali* is capable of independent flight. Adult males have been trapped with pheromone lures at distances up to 50m (Cross and Hall 2009) though longer distances were not tested. At most, the adult flight range is probably limited to a few hundred meters. This limited capacity for dispersal would limit unaided spread to only nearby areas where hosts are present.
- Unfavourable climatic conditions such as deserts and arid areas separate many of Australia's urban areas and many commercial growing areas. The unfavourable conditions and absence of host material in these areas would limit unaided spread to defined areas.

Potential for movement with commodities, conveyances or vectors

- *Dasineura mali* eggs and larvae are associated primarily with leaves of apple and crab-apple trees. Cocoons containing either mature larvae or pupae are primarily found in the soil underneath trees, though may occasionally be found in leaf rolls, on fruit, or underneath bark and around pruning cuts (HortResearch 1999b).
- The importation of apple stocks from Holland was attributed to the means of the introduction of *D. mali* to New Zealand (Morrison 1953). This suggests that long distance spread of *D. mali* would be aided by movement of nursery stock.
- Trees grown in planter bags and described as "heavily infested" were used by Tomkins *et al*. (2000) as a source of *D. mali* pupae from soil for emergence experiments across five sites in New Zealand. That study reported a total of 1 884 midge and *P. demades* adults being trapped in one instance. This indicates that *D. mali* could be moved long distances in the soil associated with nursery stock and potted trees.
- As discussed under the probabilities of importation and distribution, fruit produced under commercial systems that include in-field pest control, and have been washed and brushed are unlikely to move sufficient numbers of *D. mali* to result in long distance spread. However, fruit that has not passed through standard washing, brushing and grading processes may contribute to some long distance spread of *D. mali*.
- While some interstate movement restrictions apply to both nursery stock and apple fruit, such restrictions would not prevent intra-state spread of *D. mali*. Interstate restrictions, which are targeted at other pests, may also be insufficient to prevent spread.

Conclusion on probability of spread

In summary, having established a persistent population in a single location, the independent flight capability of adult *Dasineura mali* has the potential to allow localised spread, either within an orchard or between adjacent orchards. If *D. mali* were to establish in an urban area, short distance flight could also spread between properties and within a township or city generally. Long distance spread would rely on the movement of infested commodities. Historically, movement of infested nursery stock has been attributed to the spread of *D. mali* between countries and could result in the spread of this pest between major areas of Australia.

Ultimately, environmental conditions in some regions of Australia would be expected to limit the areas which *D. mali* could spread to, with its range expected to be restricted to southern latitudes and higher altitudes, although definitive studies would be required to better define with accuracy where this pest could spread to. These southern areas and higher altitude areas

such as Stanthorpe do, however, contain either a large proportion of Australia's residential areas or commercial apple production sites.

Based on this information, the likelihood that *D. mali* will spread within Australia is moderated by the range of environmental conditions that are expected to be suitable for the pest's survival, and also by the limited capacity for independent movement. This information supports a risk rating for spread of 'moderate'.

4.2.4 Overall probability of entry, establishment and spread

The probability of entry, establishment and spread is determined by combining the probability of entry, of establishment and of spread using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Dasineura mali* will enter Australia by the pathways discussed in this PRA, be distributed in a viable state to susceptible hosts, establish in that area and subsequently spread within Australia is: **VERY LOW** as set out below.

Table 4.3 Probability of entry, establishment, and spread for *Dasineura mali*

Importation	Distribution	Entry	Establishment	Spread	PEES*
Moderate	Very low	Very low	Moderate	Moderate	Very low

*Probability of entry, establishment and spread.

4.2.5 Consequences

The consequences of the entry, establishment and spread of *Dasineura mali* in Australia have been estimated according to the methods described in Table 2.3 on page 11.

Based on the decision rules described in Table 2.4 on page 12, that is, where the consequences of a pest with respect to one or more criteria is '**D**', the overall consequences are estimated to be **LOW**.

The reasoning for these rating is provided below:

Criterion	Estimate and rationale
Direct	
Plant life or health	**D – Significant at the district level:** • The only known hosts for apple leaf curling midge are Malus species (CABI CPC 2008); this includes apple and crab-apple trees. Developing midge larvae feed on leaves, causing affected leaves to curl tightly, discolour, and potentially drop of the tree (Berry and Walker 1989). • Feeding damage can be severe in young, developing trees where damage to the terminal growth can cause permanent stunting of the tree (Collyer and van Geldermalsen 1975; Kolbe 1982). However, mature trees are reported to be able to withstand considerable damage (Penman 1984). • Feeding damage can affect a significant proportion of new growth, with 9–40% of leaves on new shoots being damaged according to research by Smith and Chapman (1995). Severe defoliation may also occur if fresh terminal growth is available late in the season and if midge populations are high (Todd 1959). However, despite the potential for damage to foliage, fruit production in mature trees is not reported to be affected, even when midge damage is severe (Todd 1959; Antonelli and Glass 2005). • Fruit damage has been reported to occur if populations are high (HortResearch 1999b), particularly during flowering (Tomkins 1998), though such reports appear to be rare (Cross 2010). • MacPhee and Finnamore (1978) report that in the native range of apple leaf curling midge it has occasionally been an economic pest (England). However, they also reported the in the 1930's it was a significant concern in USA soon after its introduction in the east coast. • Surveys of Apple leaf curling midge have shown it has potential to be a significant pest, or at least cause concern to growers in most apple growing regions of New Zealand (Smith and Chapman, 1995; Tomkins *et al*., 1994). However, these reports were prior to the introduction of the integrated fruit production system. • If apple leaf curling midge were to be introduced to Australia, and in the absence of control measures or effective biological control agents, midge populations could rapidly increase in those areas where the climate is suitable. As discussed under the probability of establishment and the probability of spread, this could include areas where a large proportion of the Australian population reside, and numerous areas where commercial apple production occurs. • Damage is likely to affect developing fruit trees, nursery stock and also cause some cosmetic damage to amenity and wild trees, though these are not common in urban areas.
Other aspects of the environment	**A – Indiscernible at the local level:** • There are no known direct impacts of apple leaf curling midge on any other aspects of the environment. There have been no reports of reduction of keystone species, reduction of plant species that are major components of ecosystems and endangered native plant species, or significant reduction, displacement or elimination of other plant species.
Indirect	

Criterion	Estimate and rationale
Eradication, control etc.	**D – Significant at the district level:** • Eradication may be attempted if any incursion were limited to a specific, well defined area. Costs for an eradication campaign are likely to be high, with potential removal of large numbers of host trees and extensive application of chemical sprays being required. • If eradication were not attempted, growers and fruit tree nurseries would likely need to employ some level of control for apple leaf curling midge to limit damage. • While biological controls effective against apple leaf curling midge are established in New Zealand, similar control programs are not developed in Australia for this pest. • Control programs, in the absence of effective natural enemies have relied upon chemical spray programs, particularly early in the season, although these are not considered as effective as biological control (Shaw *et al*. 2003; Pipfruit NZ 2008). • Establishment, or changes to, an integrated pest management program to include apple leaf curling midge in Australian orchards is likely to take a number of years while seasonal timings for chemical sprays are determined and natural enemies are either introduced or augmented in orchards. While this occurs, it is expected that there would be a substantial increase in the use of insecticides for control of apple leaf curling midge because of difficulties involved in estimating optimum times for insecticide application.
Domestic trade	**D – Significant at the district level:** • If apple leaf curling midge were present in Australia, restrictions on domestic trade may be imposed on the movement of fruit, either intra- or inter-state. • Any domestic movement restrictions are likely to result in either reduced movement of fruit, impacting on growers, or additional costs in meeting any quarantine requirements. • Damage to fruit has been reported, including the skin being distorted by bumps (Tomkins 1998) caused by high populations of apple leaf curling midge affecting developing fruitlets. While such damage is apparently rare (Cross 2010), a reduction in the aesthetic quality could result in of fruit not meeting consumer expectations and result in reduced acceptance of fruit that is slightly affected right through to outright rejection of imperfect fruit.
International trade	**D – Significant at the district level:** • For the period January–October 2010, Australia exported 3 949 tonnes of apples with a value of AUD$6.99 million. • In the case of New Zealand, apple leaf curling midge larvae and pupae found on harvested fruit can lead to the rejection of fruit for pre-clearance export to countries such as Japan (Lowe, 1993) or treatment upon arrival in California (Anonymous, 2002). • If apple leaf curling midge became established in Australia, trading partners may reject consignments of apples infested with apple leaf curling midge.
Environmental and non-commercial	**B – Minor significance at the local level:** • Control measures can be broadly classified into two categories: chemical control or biological control. • Increased insecticide use could cause undesired effects on the environment. The introduction of new biological control agents could affect existing biological control programs. • The only hosts of apple leaf curling midge are apples. These are mainly grown under intensive cultivation in orchards or as a backyard fruit tree. There would be little effect on environmentally sensitive or protected areas because few apple trees grow in such areas. • There could be some unintended side-effects on the environment due to changes in pest control programs in apple orchards and in nurseries, though this are only likely to occur, at most, on a small scale.

4.2.6 Unrestricted risk estimate

Unrestricted risk is the result of combining the probability of entry, establishment and spread with the estimate of consequences. Probabilities and consequences are combined using the risk estimation matrix shown in Table 2.5 on page 12.

Unrestricted risk estimate for *Dasineura mali*	
Overall probability of entry, establishment and spread	Very low
Consequences	Low
Unrestricted risk	Negligible

As indicated, the unrestricted risk for *Dasineura mali* has been assessed as 'negligible', which achieves Australia's ALOP. Therefore, additional risk management measures are not recommended for this pest.

4.3 European canker

Neonectria ditissima

European canker, caused by the fungus *Neonectria ditissima*, is an important disease affecting apples, pears and many species of hardwood forest trees (Swinburne 1975; Castlebury *et al.* 2006). The disease mostly affects branches and trunks of trees, causing cankers. Infection is initiated through leaf and bud scars, bark disruptions such as pruning cuts and wounds, or woolly aphid galls (Swinburne 1975). In apples and pears, the fruit can also be infected and develop rots. Foliage is not affected (Butler 1949).

Typically, infection of fruit occurs at the blossom end, through either open calyx, lenticels, scab lesions or wounds caused by insects (Swinburne 1964, 1975; McCartney 1967). Sometimes the rot can develop at the stem-end (Bondoux and Bulit 1959; Swinburne 1964) or rarely on the surface of the fruit when the skin is damaged (Bondoux and Bulit 1959). Apple varieties vary greatly in their susceptibility to the disease, but no variety is immune (McKay 1947).

The disease was detected in 1954 in six blocks within four orchards in Spreyton, Tasmania, but it was eradicated by 1991 (Ransom 1997). The disease is not known to occur in Australia (APPD 2005).

The fungus produces two types of spores: conidia in spring and summer, and ascospores in autumn and winter. Spores are dispersed by rain splash and wind. Spores germinate over a temperature range of 2–30°C, the optimum being 18–24°C in laboratory experiments (Munson 1939). Under field conditions, temperatures of 11–16°C with a measure of leaf wetness provide the best predictors of disease prevalence (Beresford and Kim 2011).

The risk pathway of particular relevance to *N. ditissima* is primarily any latent infection in fruit that would not have been detected during harvesting or during sorting and packing processes.

4.3.1 Probability of entry

Probability of importation

The likelihood that *N. ditissima* will arrive in Australia with the trade in fresh apples for consumption from New Zealand is: **VERY LOW**.

Supporting information for this assessment is provided below:

Association of the pest with the crop

- The disease mostly affects branches and trunks of trees of a range of species, including apples, causing cankers. Infection is initiated through leaf and bud scars, bark disruptions such as pruning cuts and wounds, or woolly aphid galls (Brook and Bailey 1965; Swinburne 1975).
- Apple varieties vary greatly in their susceptibility to the disease, but no variety is immune (McKay 1947).

- In New Zealand, *N. ditissima* has been reported in Auckland, the Waikato, Coromandel, Northland, Taranaki, Westland, Gisborne, Bay of Plenty, Hawke's Bay and Nelson.[10] European canker has been established in Auckland, the Waikato, Bay of Plenty and Taranaki for many years and now occurs in some orchards in the wetter parts of the Nelson district, with isolated instances of infection in the Gisborne area (Wilton 2002a). The incidence and severity of the disease in these districts varies between seasons, depending on environmental conditions and orchard practices.
- European canker is not regarded as a major disease in New Zealand outside the Auckland region where the disease has been endemic since the 1930's (Atkinson 1971).
- The restricted distribution and prevalence of European canker in New Zealand is likely to be linked to moisture. European canker is a disease present in damp climates (Butler 1949) and climatic conditions are critical to its development, both through inoculum production and infection by *N. ditissima* (Munson 1939; Dubin and English 1974). The sporulation, dispersal and infection by *N. ditissima* require mild conditions with prolonged periods of wetness (McCraken *et al.* 2003b).
- Temperature and duration of wetness have been shown to be the critical factors contributing to infection (Swinburne 1975; Latorre *et al.* 2002). *Neonectria ditissima* readily survives at temperatures between 2°C and 30°C, in ideal artificial growth conditions, with the optimum temperature for disease development being 18°C –24°C (Munson 1939; Butler 1949). Under controlled environmental conditions using high fungal inoculum levels (10^6 conidia per millilitre) and performing inoculations less than 1 hour after leaf abscission, conidia germinate in a temperature range of 6°–32°C with no infection occurring at 5°C regardless of the wetness duration (Latorre *et al.* 2002). A minimum of 2–6 hours of wetness was required at the optimum temperature, with a longer wetting period required at lower temperatures (Latorre *et al.* 2002; Grove 1990a).
- In Europe, European canker is an important disease in regions with annual rainfall of 653 mm to 791 mm, and average summer temperatures between 8°C (minimum) and 21°C (maximum) (McCraken *et al.* 2003b).
- However, annual rainfall alone is considered a poor predictor of disease prevalence (Latorre 2010; Swinburne 2010a) and duration of leaf wetness in combination with suitable temperature provide a more reliable predictor of European canker (Swinburne 2010a). Recent work predicts disease prevalence under field conditions is best predicted by temperatures of 11°C–16°C and a measure of leaf wetness (number of rainfall days per month) (Beresford and Kim 2011).
- Under field conditions, infection incidence varies significantly depending on the season. Latorre *et al.* (2002) report that variations of 0.01% to 48.3% incidence have been obtained on one-year-old twigs taken from the same unmanaged orchard in both dry and wet seasons. Field data obtained in California indicated that several days of free moisture were required to obtain high levels of infection (Dubin and English 1974).
- In New Zealand, European canker is established in the wetter districts of the Waikato region (average annual rainfall 1190 mm) and Auckland (1240 mm), and has restricted distribution in the Nelson (970 mm) and Gisborne (1051 mm) regions (Atkinson 1971; MAFNZ 2004). The disease has been recorded in Hawke's Bay (803 mm) but MAFNZ

[10] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 March 2011.

(2004) states that there was no evidence of subsequent infection. European canker has not been recorded in the drier districts of Otago (360 mm) or Marlborough (655 mm)[11]. Later work predicts the current distribution of European canker in New Zealand based on temperature and leaf wetness (Beresford and Kim 2011).

- A survey of apple sites throughout New Zealand in 1990 found 2% of sites were infected with *N. ditissima* occurring predominantly in Northland, Auckland, Waikato, Coromandel, Bay of Plenty and Nelson (Braithwaite 1996).
- European canker is endemic in the Waikato and Auckland districts that contribute ≤3% of total apple export trade from New Zealand (MAFNZ 2000a; Pipfruit NZ 2010).
- A survey detected only one tree with European canker in Nelson and that tree was subsequently removed (MAFNZ 2000c). However, by 2002 the disease appeared to have spread to some orchards in the Motueka and Moutere area and pockets of Waimea orchards of Nelson (Murdoch 2002).
- The establishment and spread of the disease in these areas was attributed to extraordinarily wet springs and autumns during 1998, 2000 and 2001 and coincided with large-scale introductions of planting material from Waikato (MAFNZ 2004). There are no restrictions on the movement of planting material between districts in New Zealand and this could present a pathway for introducing new inoculum. Murdoch (2002) and Wilton (2002a) confirm that the spread of European canker out of the Auckland and Waikato areas has been through the movement of infected nursery plants or graft wood.
- European canker has been reported three times in Hawke's Bay on samples collected between 1967 and 1975[12]. Since this time there have been no further reports of European canker symptoms in the Hawke's Bay area (MAFNZ 2004). The disease is considered absent from Hawke's Bay, Wairarapa, Marlborough, Canterbury and Otago (Wilton 2002b; Wilton 2004).
- In Nelson, where the disease occurs sporadically in wet seasons, 28% of the total export trade is produced (Pipfruit NZ 2010). The rest of the apple export trade is supplied from the Hawke's Bay and Otago (about 69%) where the disease has not been recorded since 1975 or has never been recorded.

Association of the pest with the commodity pathway

- In apple species, fruit can also be infected and may develop rots. Foliage is not affected (Butler 1949). Typically, infection of fruit occurs at the blossom end, through the open calyx, lenticels, scab lesions or wounds caused by insects. This is called 'eye rot' (McCartney 1967; Swinburne 1964; Swinburne 1975). Sometimes the rot can develop at the stem-end (Bondoux and Bulit 1959; Swinburne 1964) or rarely on the fruit's surface when the skin is damaged (Bondoux and Bulit 1959).
- In France, the rot has been recorded from fruit, and has been observed to spread to the seed cavity, and the fungus has been isolated from the mycelium surrounding the seeds (Bondoux and Bulit 1959), but this has not been observed in California (McCartney 1967). In dessert varieties of fruit, infection can lead to the development of rot before harvest (Swinburne 1964; Swinburne 1971a; Swinburne 1975), but infection usually remains latent and generally develops into a rot during storage (Bondoux and Bulit 1959;

[11] http://www.niwa.cri.nz/edu/resources/climate/summary/summary.xls. Checked on 15 November 2005.
[12] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 March 2011.

Swinburne 2010a). In cooking varieties, rots rarely become apparent until after fruit has been stored for 3–7 months (Swinburne 1975).

- Latency of infection is reported to be associated with accumulation of benzoic acid, a substance toxic to fungi in the acid condition in young and immature fruit (Swinburne 1975). An infection occurring in young, immature fruit will not grow because of high benzoic acid toxicity. However, as acidity decreases and sugar levels increase with ripening, the toxicity of benzoic acid decreases and the fungus resumes growth. The typical rainfall and temperature patterns of major New Zealand apple export areas would suggest latent infection is very unlikely to occur as conditions during fruiting are not favourable for conidia production and subsequent fruit infection (Beresford and Kim 2011).
- For fruit to become infected with *N. ditissima*, prolonged periods of wetness in the summer months is required for (a) the production of spores (conidia) on active stem cankers, (b) the dissemination of those spores in run-off from cankers onto the developing fruit and (c) a sufficient period of leaf-wetness to allow the deposited spores to germinate and colonise limited areas within the calyx or lenticels. All three events need to occur for fruit to become infected (Swinburne 2010a).
- In Europe, where rainfall in summer coincides with spore release and flower/fruit production, fruit rot can be a major problem (Swinburne 1975). For example, in south east England, a survey of fruit rots showed *N. ditissima* resulted in only 0.1–0.2% of fruit losses on average over three years from 100 orchards (Berrie 1989). However, in 1987/88, after a very wet July and August, a survey of 16 commercial stores recorded mean losses to *N. ditissima* rots had increased to 4.3% and one store recorded 50% losses (Berrie 1989).
- In France, even when European canker is on the tree (Bondoux and Bulit 1959) and conditions of temperature and free moisture are suitable (Latorre *et al.* 2002), under favourable wet summer conditions fruit infection only occurs exceptionally and reached a maximum of 2% in one fruit lot (Bondoux and Bulit 1959).
- In the south east of England, under artificial conditions with high inoculum and humidity, fruit infection has been recorded to occur most readily up to four weeks after flowering and infection can continue to occur on fruit one week before harvest under suitable conditions (Xu and Robinson 2010).
- By contrast, in California, United States, rainfall and infection of plant material generally occur in winter. Fruit infection is rare, only occurring when there is unusually high summer rainfall (Nichols and Wilson 1956; McCartney 1967).
- The USA situation is similar to that in the two main apple growing regions of New Zealand, Hawke's Bay and Nelson, both areas being in the rain shadows of mountain ranges with a high percentage of cloudless days, long growing seasons and high light intensity. Because of the low summer rainfall, irrigation is usually necessary. Overhead irrigation that could assist in disseminating spores and cause fruit infection is only used for frost management and is only common in the Otago district where European canker has never been recorded (MAFNZ 2011). In addition, low temperatures that would justify frost management are not conducive to European canker (Beresford and Kim 2011) if *N. ditissima* was recorded from the region in the future.
- Fruit rot caused by *N. ditissima* has been reported in New Zealand (Brook and Bailey 1965; Braithwaite 1996). A study showed that of 3300 rotted fruit sent for examination to

HortResearch between 1999 and 2005, seven (0.21%) collected from the Waikato region were found to be infected with *N. ditissima* (MAFNZ 2005a).

- A search on New Zealand's Hortnet[13] found no literature on fruit rot caused by *N. ditissima*, whereas there was extensive information available on other apple fruit rots in New Zealand including apple scab (*V. inaequalis)*, bitter rot (*Glomerella cingulata)*, black rot *(Botryosphaeria obtusa)*, ripe rot *(Pezicula* spp.) and various core rots, suggesting that European canker rots are not an important issue in New Zealand apples.
- Fruit infection will only occur if cankers are present in the orchards (Bondoux and Bulit 1959) and exposed to prolonged periods of wetness to induce spore production and dispersal. Given that climatic conditions typically reported for major export areas (Hawke's Bay, Nelson and Otago which produce 97% of export fruit) during the harvest periods are normally dry and not conducive to spore release and winters are not too wet (NIWA 2004), fruit infection is extremely unlikely to occur.
- In the higher rainfall areas of Auckland and the Waikato region, where European canker is present and climatic conditions are more conducive to cankers on trees mainly due to wetter winters (NIWA 2004), fruit could become infected during the harvest period. Fruit infected late in the season, and showing no obvious rot symptoms, could be picked from these orchards.
- Recent research has supported the suitability of the Auckland region for European canker disease based on a worldwide comparison of climate suitability (Beresford and Kim 2011). However, the study highlights that the Auckland region has on average poor climate conditions for fruit infection and this information is supported by the very low level of fruit infections recorded from New Zealand (Brook and Bailey 1965; Braithwaite 1996; MAFNZ 2005a).

Ability of the pest to survive existing pest management

- All export orchards are registered with Pipfruit NZ Inc and utilise either the Integrated Fruit Production program or a certified organic program that includes various disease management programs. These programs provide guidance for targeted management of a range of pathogens including European canker and other fungi such as those that cause mildew and apple scab that would limit the prevalence of European canker in trees (Latorre 2010; Swinburne 2010a).
- Fruit can only enter export packing houses once compliance with the IFP program spray recommendations have been confirmed by spray diary clearance by auditing organisations independent of the industry (MAFNZ 2011).
- In addition, various disease management measures to control summer fruit rots in New Zealand orchards, including cultural practices (removal of diseased wood and rotting fruit from trees and orchard floors) and the use of fungicides from late November/early December until withholding periods (MAFNZ 2005a) would greatly reduce the likelihood of *N. ditissima* infections being present.
- European canker rots were last reported in New Zealand from a survey conducted from 1999 to 2005 (MAFNZ 2005a). During this time, the IFP program has been adopted by New Zealand growers (Wiltshire 2003) and further refined by Pipfruit NZ Inc (MAFNZ 2011). This includes a high level of awareness by orchard managers and best practice

[13] http://www.hortnet.co.nz. Checked on 4 March 2011.

management recommendations including removal of cankered wood and the application of fungicides. It is likely the broad adoption of the IFP program has contributed to the lack of detections of European canker rots.

- A recent study on fruit rots in New Zealand sampled over 12,000 apples from the Hawke's Bay area, that included treatments to promote rot development (wounding, cold storage), and found no European canker rots (Scheper *et al.* 2007).
- In mature dessert apple varieties, fruit infected with European canker can rot in the field before harvest (Swinburne 1975), with affected fruit either falling before maturity or being eliminated during picking (Bondoux and Bulit 1959), thereby reducing the likelihood of latent infections in export fruit. In cooking varieties and immature fruit, fruit infections can remain latent and express themselves after 3–7 months of storage (Swinburne 1975; Snowdon 1990a) especially if contamination occurs towards the end of the season (Bondoux and Bulit 1959). New Zealand does not export immature apples or significant volumes of cooking varieties.

Ability of the pest to survive packing, transport and storage conditions

- Fungicidal dips before storage of fruit are not used in New Zealand (MAFNZ 2003a) indicating that storage rots are not a significant issue in New Zealand.
- Packing houses utilise disinfectants such as chlorine or Tsunami® and, increasingly, Nylate® during water washing procedures and in dump tanks. In 2005, only 53% of pack houses used disinfectants. In 2011, 99% of export fruit produced under the IFP program are disinfected (MAFNZ 2011). The concentration of chlorine used varies between 5 and 50 ppm and peroxyacetic acid (Tsunami®), and bromo-chloro-dimethylhydantoin (Nylate®), as alternatives to chlorine, as per label instructions. Monitoring of disinfectants is done manually at specific times on each day or automatically (MAFNZ 2005a). For fruit produced under organic methods, contributing approximately 8% of exports (Pipfruit NZ 2010), fruit wash tank water is regularly replaced to remove contaminating material (MAFNZ 2011).
- In 2005, 93% of packing houses used high pressures washing (MAFNZ 2005a). High pressure washing is now standard practice and is used at 100% of export packing houses (MAFNZ 2011). The increased use of high pressure sprays is likely to increase the penetration of disinfectants, when used on non organic fruit, into the protected region of the calyx. It is likely the use of disinfectants, when used on non organic fruit, will kill the majority of conidia (Swinburne 2010a). For organic fruit, it has been reported that high pressure washing can be as effective in removing micro-organisms as 200 ppm chlorine (Beuchat 1999).
- *Neonectria ditissima* conidia from various inoculum sources that could contaminate fruit or survive disinfectants and washing are unlikely to be a source for infection as they are sensitive to desiccation even at high relative humidity (Latorre 2010; Swinburne 2010a). Dubin and English (1975) reported that viability of spores dropped by 67% after 3 h exposure at 11°C even at 88% relative humidity. Munson (1939) reported that germination falls off steadily to zero after desiccation in the atmosphere of a laboratory for 5 to 6 days.
- Standard packing house procedures will remove fruit that does not meet export quality requirements, including fruit rots (MAFNZ 2011). Only latent infections in fruit are likely to pass undetected during packing and sorting procedures.
- Once latently infected fruit has entered the packing house, external treatments (washing and brushing) are unlikely to adversely affect survival of internal infections.

- Once latently infected fruit has entered the supply chain, cold storage conditions are unlikely to adversely affect survival. European canker is known to survive temperatures as low as 2°C (Munson 1939; Butler 1949) and mycelia are known to grow at temperatures approaching 0°C (Lortie and Kuntz 1963).
- For fruit that is stored for a significant time, re-inspection occurs to ensure fruit meets market requirements (MAFNZ 2011). It is likely that latently infected fruits that can develop rots during this time (Berrie *et al.* 2007) will be removed during this inspection.

Conclusion on probability of importation

In summary, while *N. ditissima* has been recorded in New Zealand, and within some apple producing areas, climatic conditions both limit the distribution of this pathogen and its incidence in those regions where it is recorded. The limited distribution and prevalence greatly reduces the potential for a source of inoculum to be present in orchards that might produce apples for export. Further, specific environmental conditions are required over an extended period of time to produce spores that could potentially infect fruit. As discussed, these conditions are unlikely to occur in any export region. The very low level of fruit infections recorded in New Zealand supports this limited potential for fruit infection.

Further, export fruit is produced in orchards using targeted and general management measures to control *N. ditissima*. These management measures limit the inoculum levels within an orchard and therefore reduce the opportunity for fruit infection, even when climatic conditions are favourable. In the packing house, fruit are then treated with disinfectants/high pressure sprays that will limit surface contamination of short lived spores. Grading procedures will also remove apples with visible fruit rots to meet commercial and phytosanitary requirements. The evidence supports a rating of 'very low' for the importation of *N. ditissima*.

Probability of distribution

The likelihood that *N. ditissima* will be distributed in a viable state within Australia with imported fruit and transferred to a suitable host is: **VERY LOW**.

Supporting information for this assessment is provided below:

Distribution of the imported commodity in the PRA area

- Minimal on-arrival inspection procedures, that may include a visual inspection of the fruit surface, are unlikely to detect latently infected fruit.
- Imported fruit will be distributed throughout Australia as wholesalers and retailers are located at multiple locations and would facilitate the distribution of latently infected fruit.
- *Neonectria ditissima* would need to survive transportation and storage within the PRA area. Fruit is typically stored and transported in refrigerated containers maintained at cool temperatures and receival temperatures in the range of 1–10 ºC are required by a major retailer (Woolworths 2010). *Neonectria ditissima* is known to survive temperatures from 2°C to 30°C (Munson 1939; Butler 1949) and mycelia are known to grow at temperatures approaching 0°C (Lortie and Kuntz 1963). Thus, transport and storage conditions are unlikely to have any impact on the survival of latent *N. ditissima* infections in imported apples distributed for sale.
- Imported fruit may be packed by orchard wholesalers that would be in close proximity to commercial fruit crops. Orchard wholesaler waste may be dumped at a site within the premises or in landfills close to orchards. Before waste is finally disposed of, it could remain exposed to the elements (for example, in a skip) near the packing house.

- Occasionally workers and visitors could discard apple cores in the orchard itself. The packing of New Zealand fruit from bulk bins and/or the repacking of boxes of New Zealand fruit would bring packing house workers and host trees (apples and pears) into close proximity to both New Zealand apples and apple waste.
- However, data from New Zealand shows that the majority of fruit exported is in retail-ready boxes or trays that will not require repacking in Australia (MAFNZ 2011). It is very likely the majority of fruit will be distributed to retailers, potentially through wholesale markets, without the need for re-packing. Only a small volume would likely to be re-packed in Australia.

Availability of hosts

- A large number of suitable hosts for European canker infection are widely distributed throughout Australia, with apples (*Malus* spp.) and pears (*Pyrus* spp.) grown commercially in most states. Most commercial apple fruit cultivars are susceptible to *N. ditisima* (Anonymous 1988; CABI 2003).
- Common hosts of this fungus include tree species in the genera *Acer* (maple), *Aesculus* (horse chestnut), *Alnus* (alder), *Betula* (birch), *Carya* (hickory), *Cornus* (dogwood), *Corylus* (hazel), *Fagus* (beech), *Fraxinus* (ash), *Juglans* (walnut and butternut), *Liriodendron tulipifera* (tulip tree), *Malus* (apple), *Populus* (aspen), *Prunus* (cherry), *Pyrus* (pear), *Quercus* (oak), *Salix* (willow), *Sorbus* (rowan tree), *Tilia* (American basewood) and *Ulmus* (elm) (CABI 2005; Flack and Swinburne 1977).
- Apples purchased via retail outlets could enter the environment after being purchased by consumers. The majority of the population (and therefore the majority of apple consumption) is in the capital cities that are significant distances from most commercial apple and pear orchards. However, hosts of European canker are present in many home gardens, parks and roadsides in large cities.
- Many suitable hosts are commonly grown in Australia and are present in areas where apples would be sold and consumed. However, host susceptibility is variable between species and only some of these host species are highly susceptible to *N. ditissima* (Flack and Swinburne 1977) and they will be subject to the same climatic requirements necessary for infection as apple trees.

Risks from by-products and waste

- Although the intended use of fresh fruit is human consumption, waste material would be generated (e.g. overripe and damaged fruit, uneaten portions and apple cores). Whole or parts of the fruit may be disposed of at multiple locations throughout Australia in compost bins or amongst general household or retail waste.
- Fruit discarded near susceptible hosts could be a source of inoculum for initial infections in new areas. Such fruit discarded into the environment could rot and potentially develop viable fungal inoculum that could initiate new infections. Fruit trees in commercial orchards are planted in high-density monocultures of suitable hosts. Fruit trees and ornamental plants that are hosts of *N. ditissima* may be found in household gardens, although their density would be low. The use of irrigation may create climatic conditions more conducive for infection to household and garden plants.
- Orchard wholesaler waste is disposed of into isolated areas within the orchard itself or in landfills close to the orchard. These disposal sites are surrounded mostly by pome fruit grown as a monoculture and wild and amenity plants are less abundant. Consumers may also occasionally discard fruit waste along roadsides and recreation areas.

- A relatively high proportion of household and retail waste would be managed through regulated refuse collection and disposal services. Managed waste will remove *N. ditissima* from the household and environment, reducing the likelihood that susceptible plants will be exposed to this pathogen.
- Apple waste disposed of in compost may be subjected to high temperatures (60°C), which can be expected to kill the fungus – many fungi are killed within a few days during composting (Anonymous 2004b). European canker mycelia growth is retarded at 30°C and it is killed at 37°C under laboratory conditions (Munson 1939). Apple waste disposed of in landfills or compost heaps would be rapidly contaminated and colonised by saprophytic microorganisms, hastening the decay process and minimising the likelihood of conidia development. Similarly insects, mammals or birds could consume apple waste.

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

- European canker can produce two types of spores, conidia and ascospores (Swinburne 1975). Conidia are known to be dispersed by rain splash and ascospores by wind (Swinburne 1975).
- When European canker was present in Tasmania, only conidia were reported as an inoculum source on host plants (Ransom 1997). Ascospores are more likely to form on cankers on woody parts of plants (Swinburne 1975) and have only rarely been recorded on fruits under specific favourable conditions (Dillon-Weston 1927; Swinburne 2010a).
- Even under damp English conditions, perithecia rarely develop on infected fruit in waste dumps (Swinburne 1964). Perithecia are the structures on which ascospores form, and without their development to maturity, no ascospores can be produced (Swinburne 1975). There is only one study that reported perithecia and ascospores on fruits collected from trees (Dillon-Weston 1927). Here only three apples collected from a total of 700 mummified fruit from an English orchard infected with *N. ditissima* cankers developed perithecia (0.4%) although the number increased to 49 (7%) when the fruit were incubated in the laboratory under more favourable conditions than would exist in the field (Dillon-Weston 1927). The production of ascospores on fruit does not feature in any subsequent epidemiological study (Swinburne 2010a).
- There is no evidence that perithecia would fully develop and produce ascospores on fruit under the typically drier conditions experienced in Australia (Latorre 2010; Swinburne 2010a). It is extremely unlikely that airborne ascospores would play a role in the distribution of European canker from latently infected apples to a suitable host in Australia.
- Although wind disperses some conidia in the absence of rain (Swinburne 1971b) they are mainly splash-dispersed (Munson 1939) and this is considered the only realistic mode of dispersal for conidia from infected apples (Latorre 2010; Swinburne 2010a).
- Before dispersal can occur, conidia will need to be produced by the fruit that entered Australia with a latent infection and that has not been disposed, composted, eaten or colonised by saprophytic micro-organisms. That small proportion of remaining fruit will require extended periods of suitable temperature and moisture for this to occur (Swinburne 1971b) and prolonged periods of 100% humidity are considered necessary for conidia production (Swinburne 2010a).
- Fruit rotting in retail packs or in a domestic environment at less than 100% relative humidity is unlikely to produce conidia (Swinburne 2010a). When conidia are formed from rots they do so in relatively small numbers (Swinburne 2010b).

- Even in regions such as Northern Ireland (Loughgall) with rain in all seasons and moderate temperatures, more than five hours of leaf wetness was required for spore discharge to resume from mature cankers following a few dry days throughout the year (Swinburne 1971b). Conidia production from cankers is lowest during autumn (Swinburne 1975) and in one study no conidia were produced for several months of the year (Swinburne 1971b).
- The situations in regions with pronounced dry periods, such as California, conidia are not produced during summer when rainfall is low (Wilson 1966). Spore formation from mature cankers on trees does not begin until several days after the first significant rainfall event of the rainy period (Wilson 1966).
- *Neonectria ditissima* does not produce resting cells and spores are killed by prolonged desiccation from high temperature and low relative humidity (Dubin and English 1975). Liquid phase water is required for germination of conidia and their viability is sharply reduced when exposed to relative humidity between 85 to 100% for 3 to 12 hours at 11°C and 19°C (Dubin and English 1975). Once conidia are produced from rots they will only survive for short periods of time without moisture (Latorre 2010; Swinburne 2010a).
- The most probable maximum distance for dispersal by rain splash of conidia from cankers on trees is 10 m (Marsh 1940). One report suggests this might actually be as much as 125 m under stormy conditions (Swinburne 1975) but this is not supported by data. These studies relate to conidia produced from cankers on trees; the distances are likely to be far less for conidia originating from the upper surface of infected fruit on the ground. Conidia produced on the sides and base of discarded fruit will have minimal opportunity to disperse.
- It has been reported that in East Malling, England, approximately 50kg of discarded canker wood were pulverized and placed under potted trees of a highly susceptible apple variety, Spartan (Swinburne 2010b). No cankers were observed on the trees subsequently; suggesting it is very unlikely conidia produced near the ground will transfer to a host and cause infection.

Vectors

- Transfer of *N. ditissima* by birds or insects has not been demonstrated and *N. ditissima* does not have any specific insect vectors or mechanisms to allow transmission from apples to a suitable host. Birds inhabit branches of trees and also feed on discarded fruit. Although it is theoretically possible that birds could get spores on their feet or beaks while feeding on a discarded fruit and then transfer them to a branch of a susceptible plant, there is no evidence to support this can or has occurred.
- The possible role of woolly aphid as a vector has been mentioned (Brook and Bailey 1965; Marsh 1940; Munson 1939) although infection through this route has not been demonstrated and its involvement is doubted by some (McKay 1947). Wiltshire (1914) found that while woolly aphids carried conidia of the canker fungus, inoculation of the fungus through this means was unsuccessful. Woolly aphid is a common apple pest in Australia; however, it is unlikely that aphids would colonise a discarded fruit and transfer *N. ditissima* to a healthy tree.
- The role of vectors transferring conidia from fruit has been considered recently and there is no supporting evidence this can occur (Latorre 2010; Swinburne 2010a). In the absence of supporting evidence, vector transmission of conidia is considered to be extremely unlikely.

Ability of the pest to initiate infection of a suitable host

- After conidia has been successfully produced and transferred to a susceptible host, temperature and duration of wetness are critical factors contributing to successful infection (Swinburne 1975; Latorre *et al.* 2002). *Neonectria ditissima* readily survives at temperatures from 2 ºC to 30 °C (Munson 1939; Butler 1949) with the optimum temperature for disease development being between 18 ºC to 24 ºC under laboratory conditions. These conditions are quite common in temperate and subtropical parts of Australia. However, under field conditions, temperatures in the range of 11 ºC –16 ºC are a better predictor of disease prevalence (Swinburne 2010a; Beresford and Kim 2011).
- A minimum of 2 to 6 hours wetness duration is required at the optimum temperature (20°C) in the laboratory with a longer wetting period required at lower temperatures for infection to occur (Latorre *et al.* 2002; Grove 1990a). Swinburne (1975) reported that a minimum of 6 hours wetness duration was required for significant infection to take place. Under artificial conditions, Latorre *et al.* (2002) demonstrated that 2 hours wetness duration was sufficient for disease development at 20°C when inoculations were performed within 1 h of leaf abscission when leaf scars were highly susceptible. No infection occurred at 5°C, regardless of the duration of the wetness period (Latorre *et al.* 2002).
- Dubin and English (1974) found that under field conditions in California, *N. ditissima* infections only occur where rainfall is abundant for long periods of time. Field data indicated that several days of free moisture were required to obtain high levels of infection.
- Some regions in Australia with a high number of rainfall days during some months from autumn to spring have been shown to be marginally suitable for infection. In summer, low rainfall and high temperatures are unfavourable for disease development (Beresford and Kim 2008; Beresford and Kim 2011).
- Environmental conditions in nurseries, including use of overhead irrigation, may create favourable microclimates and be conducive to disease infection.
- The number of conidia required to initiate an infection varies depending on environmental and host factors. In artificial inoculations under optimal laboratory conditions as few as 10 or 12 conidia have produced infections (McCraken *et al.* 2003b; Cooke 2003). In field experiments where leaf scars where artificially inoculated, then covered with a plastic bag to maintain humidity, five conidia were insufficient to initiate infection, while 50 to 500 did so readily (Dubin and English 1974).
- Entry points for infection by *N. ditissima* are available throughout most of the year (Swinburne 1975) with wound sites caused by leaf fall in autumn and leaf cracks from onset of spring bud burst presenting natural infection sites (Wiltshire 1921; Wilson 1966). Winter pruning cuts (Marsh 1939) and lesions caused by other pathogens such as *V. inaequalis* present other entry points for infection (Swinburne 1975; Brook and Bailey 1965).
- The age of leaf scars and wound sites, and then rainfall, are critical for infection (Swinburne 1975). Under experimental conditions infection via the leaf scar could occur up to four weeks after leaf fall (Wilson 1966). However, field tests in California indicated that only 5% of leaf scars can remain susceptible to infection for 10 days when inoculated with 300 conidia and covered in a plastic bag to maintain humidity (Dubin and English 1974). Leaf scars are highly susceptible to infection within the first hour after leaf fall and become much less susceptible over the next hour (Crowdy 1952).

- The susceptibility of pruning cuts to infection decreases considerably after a seven-day period (Seaby and Swinburne 1976).
- Therefore, although entry points could be available all year, their susceptibility to infection decreases quickly and infection can only occur when they coincide with suitable climatic conditions.
- When European canker was present in Tasmania, there were no restrictions on the movement of apple fruit from the Spreyton area (Tasmanian Government Proclamation 1955) and there are no records of it initiating infection by fruit from this source.

Conclusion on probability of distribution

In summary, very low numbers of latently infected fruit that have been imported in some years are likely to survive transport and storage conditions. Most imported fruit will be disposed in a variety of ways that will result in the eventual death of *N. ditissima* through managed waste disposal, composting, being out-competed by other micro-organisms and desiccation. The remaining latently infected fruit that survives these processes will then need to be exposed to favourable climatic conditions including high levels of moisture with suitable temperatures to allow *N. ditissima* to produce conidia. As discussed, Australia has marginal climatic conditions for *N. ditissima* that will limit production of conidia on fruit. The conidia that are produced from rots occur in low numbers and they can only be dispersed short distances by rain splash. Therefore, only infected fruit that have been disposed of in very close proximity to a suitable host could result in successful dispersal.

Infection will then occur only if a suitable number of spores reach a host that is receptive to infection under favourable climatic conditions. Australia has marginal climatic conditions that will limit infection. Conidia require a wound on a host plant for infection to occur and these are not available throughout the year. Once a receptive infection site is made, the receptivity of the site decreases quickly further limiting the availability of infection sites through the year. It is very unlikely that these specific criteria for successful dispersal of *N. ditissima* would occur and therefore the evidence supports a rating of 'very low' for the distribution of *N. ditissima*.

Overall probability of entry

The overall probability of entry is determined by combining the probability of importation (very low) with the probability of distribution (very low) using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Neonectria ditissima* will enter Australia as a result of trade in the commodity and be distributed in a viable state to a suitable host is: **EXTREMELY LOW**.

4.3.2 Probability of establishment

The likelihood that European canker will establish within Australia based on a comparison of factors in the source and destination areas that affect pest survival and reproduction is **MODERATE**.

Supporting information for this assessment is provided below:

- In estimating the probability of distribution, the PRA has already considered the sequence of events necessary to allow infective inoculum to reach a suitable infection site under suitable climatic conditions to initiate infection. The probability of establishment will

consider whether this initial infection will lead to the longer term infection that will result in the completion of the pathogen lifecycle on host plants through an entire year to account for seasonal differences that may affect establishment.

Availability of suitable hosts, alternative hosts in the PRA area

- In Australia, apples and pears are grown in most states as commercial crops with most apple cultivars being susceptible, although susceptibility is greater in some than in others. All apple cultivars are apparently susceptible to canker to some degree (Anonymous 1988; Swinburne 1975). Breeding programs seeking to develop resistant cultivars are still in progress (CABI 2003).
- During the outbreak of *N. ditissima* in Tasmania, varietal susceptibility was recorded with Granny Smith and Delicious cultivars showing severe symptoms often with systemic infection (Ransom 1997). Granny Smith is still a major variety of apple grown in Australia. For example, Victoria produces 39% of Australia's apples and 22% of these are Granny Smith (APAL 2008).
- Nurseries with high numbers of susceptible host plants are widely dispersed throughout Australia.
- Apples and pears are grown as backyard household and garden plants along with many other alternative wild and amenity plants, although they are generally scattered and present in low density.
- Braun (1997) reports that European canker was present in hedgerows of maple and poplar trees around orchard blocks in Nova Scotia, but suggested the random distribution of the canker within the orchard indicated the inoculum originated from within the orchard rather than from the surrounding hedgerows. Flack and Swinburne (1977) reported that European canker in apple trees was more numerous in rows adjacent to hedges infected with European canker.

Suitability of the environment

- European canker has previously established in Tasmania and was considered to have persisted there for many decades until it was officially eradicated in the 1990's (Ransom 1997). Of the blocks infected, two were severely affected by *N. ditissima* and 200 trees were removed (Ransom 1997). This information shows that once hosts are infected, damage can reach high levels, and European canker can persist, despite eradication efforts (removing diseased wood), for many decades under Australia climatic conditions in one location.
- Infection is initiated through leaf and bud scars, bark disruptions such as pruning cuts and wounds, or woolly aphid galls (Swinburne 1975). Entry sites for infection by *N. ditissima* on new hosts near the initially infected plant are available during most of the year. However, successful infection depends on the existence of receptive infection sites synchronized with adequate moisture and suitable temperature (Latorre 2010; Swinburne 2010a).
- Recent climate models have confirmed Tasmania as marginal for European canker (Beresford and Kim 2011). This work predicts with some accuracy the suitability of the climate for European canker around the world. Although this work does not cover other areas of Australia, an earlier version of this work presented information that predicts other apple growing regions of Australia would also be marginally suitable for European canker (Beresford and Kim 2008).

- Another climate model predicted a greater range of locations that would be suitable for European canker in Australia (Baker and Mewett 2009). However, this study noted that conditions in Australia are typically less conducive (warmer and drier) than regions of the world where European canker is highly prevalent. The model also predicts regions of New Zealand are very suitable for European canker where the disease is rarely present or absent. This work may be considered a more conservative model in predicting European canker establishment.
- Nursery plantings as well as household and garden plants are not solely dependent on natural rainfall and are regularly irrigated throughout the growing period. This means that wetness and humidity around these plants could be favourable for establishment of the disease.

Reproductive strategy and the potential for adaption

- Currently there is no information on strains of the fungus exhibiting fungicide tolerance or the ability to overcome some resistance observed in certain apple cultivars.
- Under suitable environmental conditions, production of conidia and ascospores on plants can occur throughout the year and their tolerance of low temperatures are considered special adaptations that *N. ditissima* has developed (Marsh 1940). In vitro, the germination rate was 2.6 times faster for ascospores than conidia, suggesting that European canker may be more aggressive in areas where abundant ascospores are produced during leaf fall (Latorre *et al.* 2002).
- However, although perithecia were observed on host plants in Tasmania during the European canker outbreak, these did not mature to form ascospores (Ransom 1997). Ascospores have only been recorded from the most suitable climatic regions in New Zealand (Brook and Bailey 1965) that are considered more suitable for European canker than regions in Australia (Beresford and Kim 2011).
- In Sonoma County, California, where the climate is more typical of much of temperate Australia, ascospores were only produced in two of an eight year period (Wilson 1966). It is not certain that ascospores would be produced under Australian conditions, but if they were, it is likely to be an irregular event linked to seasons and years with suitable climatic conditions.
- The number of conidia required to initiate an infection varies depending on environmental and host factors. In artificial inoculations under optimal laboratory conditions as few as 10 to 12 conidia have produced infections (McCraken *et al.* 2003b).
- In field experiments where leaf scars where artificially inoculated, then covered with a plastic bag to maintain humidity, five conidia were insufficient to initiate infection, while 50 to 500 did so readily (Dubin and English 1974). It has been reported that approximately 1000 conidia are required for leaf scar infection (CABI 2003).
- The primary method of survival of the pest is in cankers on infected trunks and branches of affected host plants. The fungus grows slowly into the wood, while the host produces callus around the canker year after year. The fungus can survive on infected twigs and branches left on the orchard floor.
- *Neonectria ditissima* can survive as a latent and symptomless infection in susceptible apple trees for up to 3 to 4 years (Berrie *et al.* 2000; Lovelidge 2003; McCracken *et al.* 2003a; McCraken *et al.* 2003b), resuming growth during more conducive climatic conditions. The latent infection of trees may be the reason for the length of time required to achieve eradication in Tasmania (Swinburne 2010a).

- Spores do not appear to help in long-term survival as they are killed by prolonged desiccation (Dubin and English 1975).

Cultural practices and control measures

- Integrated pest management programs (IPM) used in Australia, including fungicide applications to control apple scab and other fungal pests (e.g. powdery mildew), will assist in reducing opportunities for the establishment of the pest. However, it is acknowledged that IPM is only a management tool and may not always reduce the opportunities for establishment of pests, for in some seasons no matter what IPM program was in place, if environmental conditions were conducive, pests could occur.
- Less use of disease control and heavy pruning practices in garden and household situations may favour establishment of the disease.

Conclusion on probability of establishment

In summary, if *N. ditissima* were to have infected a host in Australia, it would be able to survive and multiply within such a host, many of which occur within Australia. *Neonectria ditissima* previously survived at one location in Tasmania for several decades, with some blocks severely affected, but without completing its entire life cycle. However, in New Zealand it has not established in all areas of that country with establishment being limited by climatic factors.

The climatic suitability for *N. ditissima* will vary in Australia with apple growing areas considered climatically marginal for the pathogen. In many areas and years the climate is unlikely to support the establishment of *N. ditissima*. In commercial orchards, standard management practices to control other fungal diseases and remove disease wood will further limit establishment. While it is not certain that *N. ditissima* would establish following successful distribution, it is an event that could occur in some years and locations. Therefore the evidence supports a rating of 'moderate' for the establishment of *N. ditissima*.

4.3.3 Probability of spread

The likelihood that *N. ditissima* will spread based on a comparison of factors in the area of origin and in Australia that affect the expansion of the geographic distribution of the pest is: **MODERATE**.

Supporting information for this assessment is provided below:

Suitability of the natural/or managed environment

- Apart from apples, the spread of the disease to other host species in the natural environment has been reported in both the USA and Europe. In New Zealand, *N. ditissima* is recorded on three alternative hosts, namely, loquat (*Eriobotrya japonica*), kowhai (*Sophora microphylla*) and coprosma (*Coprosoma areolate*) trees.[14]
- Braun (1997) reports European canker was present in hedgerows and on maple and poplar trees around orchard blocks in Nova Scotia but suggested the random distribution of the canker within the orchard indicated the inoculum originated from within the orchard rather than from the surrounding hedgerows. Flack and Swinburne (1977), however, reported that European canker in apple trees was more numerous in rows adjacent to hedges infected with European canker.

[14] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 March 2011.

- The fact the disease spread to a few closely located orchards in Spreyton in Tasmania, probably after a single entry point, or a cluster of closely related events, indicates that the managed environment of Australia can support local spread, although the extent of dispersal was quite limited despite being present for many years.
- The lack of spread may have been because of the absence of airborne ascospores which are better suited to long-distance dispersal than conidia (Ransom 1997), combined with marginal climatic conditions (Beresford and Kim 2011). The use of chemicals to control apple scab may also have limited disease spread (Latorre 2010; Swinburne 2010a).
- There were no reports of the disease spreading to wild and amenity plants, including forest plants or household and garden plants during the 40-year eradication program in Tasmania (Ransom 1997). However, in addition to the lack of ascospore detection in Spreyton (Ransom 1997), the limited spread can also be attributed to the eradication program which began within two years of confirmation of the disease (Ransom 1997).
- The eradication program involved the use of chemicals to prevent the development of sporodochia, removal and burning of severely infected trees, prohibition of movement of propagation material out of the quarantined zone, etc. Without the eradication effort, the spread of European canker could have occurred as was reported by P.J. Samson (cited in Ransom 1997) who said that 'it could easily have become established in the region if left unchecked'.
- However, European canker symptoms were reported to be present for about 20 years prior to commencement of the European canker eradication program and the pathogen failed to spread beyond a limited number of closely located orchards (Ransom 1997).
- Apples and pears in commercial orchards could be conducive to localised disease spread. Suitable host plants in nurseries distributed across states could rapidly spread the disease to new districts. The scattered distribution of host plants in household/garden situations and wild amenity plants would confine disease spread to localised areas.

Presence of natural barriers

- Given the geographical location of Western Australia and Tasmania there are natural barriers that would limit the natural spread of the pathogen across those borders.

Potential for movement with commodities, conveyances or vectors

- Fruit (including pods), bark and stems (above-ground shoots, trunks and branches) as host plant parts that can carry spores and hyphae (vegetative tissue) of the pathogen both internally and externally (CABI 2003). Therefore, the nursery, hardwood timber and mulch industries can also be involved in spread of the pest. Foliage is not affected (Butler 1949) and leaf trash is unlikely to present a pathway unless twigs with active canker are present.
- When European canker was present in Tasmania, there were no restrictions on the movement of apple fruit from the Spreyton area (Tasmanian Government Proclamation 1955) and there are no records of it spreading by fruit from this source.
- Long-distance movement of European canker is primarily the result of movement of infected nursery stock. A study in the UK, called the 'Millennium trial' concluded that approximately 6% of the infection in new orchards could be associated with nurseries but this figure could sometimes be larger (McCraken *et al.* 2003b). Disease establishment in new regions through nursery stock can be significant in low rainfall areas where the plants can remain symptomless for three to four years. There are no cost effective methods for detecting the pathogen in symptomless wood, making it difficult to estimate the size of the

problem. In situations of high disease pressure, which only occur during periods of highly favourable leaf wetness and temperature, movement of inoculum from neighbouring sources is of more concern than nursery infection (McCraken *et al.* 2003b).

- In New Zealand, European canker has been introduced to new areas through the introduction of planting material (Murdoch 2002; Wilton 2002a) despite the routine application of fungicides to cuttings (MAFNZ 2003a). Symptomless planting material is likely to be the main method of the long distance spread of European canker to new areas in Australia.
- Apples would be used mostly for consumption by humans and would be widely consumed around the states and territories. However, there is no evidence in the literature that indicates that long-distance spread of disease is due to movement of fruit. Conidia can develop in rotted fruit but whether this contributes to local spread has never been demonstrated (Latorre 2010; Swinburne 2010a).
- Involvement of insects and birds as vectors is speculated (Butler 1949; Agrios 1997). In particular, the possible role of woolly aphid as a vector has been mentioned (Brook and Bailey 1965; Marsh 1940; Munson 1939) although infection through this route has not been demonstrated and its involvement is doubted by some (McKay 1947). In the absence of supporting evidence, vector transmission of conidia is considered to be extremely unlikely.

Conclusion on probability of spread

In summary, the restricted spread of *N. ditissima* in Tasmania, even before eradication efforts commenced, show the spread of this pathogen under Australian conditions in this instance was restricted. This is supported by recent information that in general Australia has a marginal climate for *N. ditissima* including major production areas. The marginal climate will limit the production of airborne spores that could assist in the rapid local spread of the disease.

When *N. ditissima* was present in Tasmania, there is no information that planting material was moved from the infested area, and after pathogen detection, this was prohibited by regulation. Latent infection (asymptomatic) of planting material is known as an important method of allowing the spread of *N. ditissima,* particularly in regions of low rainfall. Latent infection by *N. ditissima* in hosts that would be used for planting material, that cannot be adequately detected, would then be transported over longer distances through the nursery industry. The presence of multiple host species, which are scattered in distribution in the PRA area, would assist in the spread of the pathogen when climatic conditions are favourable. The evidence therefore supports a rating of 'moderate' for the spread of *N. ditissima*.

4.3.4 Overall probability of entry, establishment and spread

The probability of entry, establishment and spread is determined by combining the probability of entry, of establishment and of spread using the matrix of rules shown in Table 2.2 on page 9.

The likelihood that *Neonectria ditissima* will enter Australia by the pathways discussed in this PRA, be distributed in a viable state to susceptible hosts, establish in that area and subsequently spread within Australia is: **EXTREMELY LOW** as set out below.

Table 4.4 Probability of entry, establishment, and spread for *Neonectria ditissima*

Importation	Distribution	Entry	Establishment	Spread	PEES*
Very Low	Very low	Extremely low	Moderate	Moderate	Extremely low

*Probability of entry, establishment and spread.

4.3.5 Consequences

The consequences of the entry, establishment and spread of *N. ditissima* in Australia have been estimated according to the methods described in Table 2.3 on page 11.

Based on the decision rules in Table 2.4 on page 12, that is, where the consequences of a pest with respect to one or more criteria are '**D**', the overall consequences are estimated to be **LOW**.

The reasoning for these ratings is provided below:

Criterion	Estimate and rationale
Direct	
Plant life or health	**D – Significant at the district level:** • Establishment of European canker in districts with suitable climatic conditions could be significant with reduced yields and additional orchard practices required (see below). • European canker is one of the most economically damaging diseases of apple in Europe, North America and South America (Grove 1990a; Latorre *et al.* 2002; Anonymous 2005b). In Spreyton (Tasmania), Ransom (1997) cites a personal communication from P.J. Samson which said, 'the diseased wood collapsed rapidly after infection, suggesting that disease posed a very real threat to apple production'. Atkinson (1971) states the disease also causes considerable damage to trees in private gardens in New Zealand. The main economic impact of the disease results from destruction and removal of individual trees or whole orchards because of girdling of branches, which can significantly reduce crop production yields (Anonymous 1991). Presence of the disease substantially increases costs of winter pruning, fungicide treatments and the removal of stem lesions and infected branches (including fruit wood) contributes significantly to reductions in both fruit yields and profitability. However, this damage occurs in regions with a suitable climate for inoculum production, dispersal and infection. • In some apple cultivars under favourable environmental conditions, e.g. Northern Ireland, fruit rot can also be a significant problem. Fruit rot generally develops in the field or before harvest, although storage losses of 10–60% of the stored fruit crop have been reported in various parts of the world (Swinburne 1964; Swinburne 1975). The climatic conditions that allow for significant fruit rots in Northern Ireland include summer rainfall that promotes fruit infection (Swinburne 2010a). This is unlikely to occur in the typically drier and hotter climate of Australia compared to Northern Ireland. • Nurseries producing or selling pome fruit and other host plants can be affected significantly if the disease establishes, as tree structure can be compromised by removing cankers. The appearance of canker lesions on the main stems of young trees in newly planted orchards can at times require tree replacement, ranging from 10% (Lovelidge 1995) to the whole plantation (Grove 1990a). During the eradication effort in Tasmania: (a) more than 200 trees out of approximately 1600 had to be removed and burnt (b) Delicious and Granny Smith showed severe symptoms, often with systemic infection, necessitating removal of whole trees of these cultivars (c) at least 30% of the trees with infected limbs removed subsequently developed further infection with entire trees requiring removal (Ransom 1997). This behaviour of the disease under Australian conditions supports the conclusion that the impact on plant life and health, particularly of apple and pear where the disease is most damaging (CABI 2005), would be significant at a district level and of major significance at the local level. • *Neonectria ditissima* is responsible for damage to many host species used for timber through reductions in both quality and quantity of marketable logs, although there are no estimates of the magnitude of loss (Flack and Swinburne 1977). Such hosts are not grown as commercial forest trees in Australia. Although *Prunus serotina* (black cherry) and *Juglans nigra* (black walnut) are listed as hosts, there are no reports indicating significant economic consequences to these industries. The damage to species used as garden, amenity and household plants could be significant, affecting isolated populations of poplar, beech and other ornamental host plants. Although *Malus*, *Pyrus* and some *Prunus* species are hosts to *N. ditissima*. Lohman and Watson (1943) studying *Nectria* species associated with diseases of hardwoods concluded that *N. ditissima* cannot be considered strictly a canker-*Nectria* of Rosaceous hosts. • In Australia, recent climate models have confirmed Tasmania as marginal for European canker (Beresford and Kim 2011). This work predicts with some accuracy the suitability of the climate for European canker around the world. Although this work does not cover other areas of Australia, an earlier version of this work presented information that predicts that most other apple growing regions of Australia would be marginally suitable for European canker (Beresford and Kim 2008). These apple growing areas include the major production area of the Goulburn Valley in Victoria. The marginal climatic suitability of Australia will limit any potential impact *N. ditissima* may have on host plants.

Criterion	Estimate and rationale
Other aspects of the environment	**C – Significant at the local level:** • The Australian community places a high value on its forest and garden environments and several hosts of *N. ditissima* constitute a component of these environments. Such hosts are sparsely distributed however, and any impact would be restricted to the district level. There was no evidence of infection in alternative host plants in Tasmania (Ransom 1997); however, this may have been because of marginal climatic conditions (Beresford and Kim 2011) and the absence of airborne ascospores that are better suited to long-distance dispersal than conidia (Ransom 1997). • Many host plants of *N. ditissima* are forest, garden and amenity plants and these are generally scattered or found in localised patches. There was no evidence of infection or damage to such plants in Tasmania during the eradication program (Ransom 1997). However, the disease is known to be common on such environmental hosts in North America and Europe (CABI 2003) particularly in cool and wet climates. In the event of establishment and spread of the disease in Melbourne's elm tree population, there could be highly significant effects when seasonal conditions are highly suitable. The City of Melbourne has calculated the 6500 elm trees in the City of Melbourne are each worth approximately $10,000 (Shears 2005) and an outbreak of European canker could be significant at the local level. *N. ditissima* has not been reported to infect *Eucalyptus* spp. (Keane *et al*. 2000). • *Neonectria* canker is considered to be most severe on stressed trees[15], a situation highly applicable to trees in the dry, low nutrient soils of the Australian environment. Further, any damage to branches or twigs exposing the cambium can provide infection courts (Lortie 1964). Opportunities for damage are likely to be greater in a stressed environment. Further, *N. ditissma* has been collected from quite a few non-host species in New Zealand[16] indicating that the spores are widespread when conidia and ascospores are produced. With such spread of spores, trees in stressed environments are likely to be easily infected. However, the typically drier conditions of Australia are unsuitable for disease development.
Indirect	
Eradication, control etc.	**D – Significant at the district level:** • Once established, European canker is both difficult and expensive to eradicate. Except for Tasmania (Australia) and the Republic of Korea, other countries with the disease have not been able to eradicate it. Even in Tasmania where the outbreak was restricted to only four orchards, the eradication process required nearly 40 years (Ransom 1997). • General control methods for European canker include fungicide sprays, paints applied to pruning cuts, cultural control, improving host plant resistance and the prevention of fruit rot (Swinburne 1975; CABI 2003). Implementing these measures would require a multifaceted approach that would increase the costs to growers depending on the severity of the disease from year to year. • Cultural practices and chemical measures used to control apple scab (*V. inaequalis*) in Australian apple growing regions would assist in controlling European canker. Fungicides commonly used for apple scab control in Australia including Bordeaux mixture, copper oxychloride, captan, carbendazim, dodine, dithianon and other chemicals (Williams *et al*. 2000) are reported to also control European canker (Atkinson 1971; Brook and Bailey 1965). The above fungicides can reduce cankers by 65 to 90%, although spray treatments alone cannot eradicate existing infections and must be supplemented by removing cankers and treating wounds with an effective paint (Cooke 1999). New generation chemicals such as strobuliruns provide effective control of European canker (Lolas and Latorre 1997; Creemers and Vanmechelen 1998). • If the disease establishes in wild or amenity plant species (for example, crab-apple, elm and willow) control would be more difficult, as they are not subject to any integrated pest management programs and application in an urban situation would be difficult.
Domestic trade	**D – Significant at the district level:** • Currently pome fruit can move freely across all states and territories borders except for Western Australia, but the detection of the disease in one state could result in the application of quarantine restrictions by other states on planting material. Restrictions were placed on the movement of nursery stock from disease affected areas in Tasmania (Ransom 1997). This could have a highly significant impact locally and significant consequences across a district, particularly for nurseries involved in propagation of planting stock. For example, the incursion and eradication of *E. amylovora* in Victoria was estimated to cost the Victorian nursery industry around $3 million as a result of trade restrictions placed on movement of nursery stock (Rodoni *et al*. 2004).

[15] http://www.extension.umn.edu/yardandgarden/ygbriefs/p431nectria.html Checked on 15 March 2011.

Criterion	Estimate and rationale
International trade	**A –Indiscernible at the local level:** • Major export markets for Australian apples include Malaysia, Singapore and the United Kingdom, with Sri Lanka, Indonesia, Philippines, China (Hong Kong), Taiwan, Fiji and Papua New Guinea constituting other significant markets. Current exports to Japan are for Fuji apples from Tasmania only. All varieties of apples from any part of Australia are permitted for export to the other countries. Of these importing countries, European canker is not recorded in the tropical countries Malaysia, Singapore, Sri Lanka, Philippines, China (Hong Kong), Taiwan, Fiji and Papua New Guinea, mainly because of the lack of host plants and favourable climatic conditions. The disease is already present in all apple growing countries other than Australia. The impact of an outbreak of European canker in Australia would not have a discernible impact on the current apple export trade. • An outbreak in forest species will not impact on Australian timber exports because timber from species that are hosts to European canker is not exported from Australia. • New Zealand is able to export apples to most markets around the world, regardless of the presence of European canker in the export production areas, including countries that do not have the disease. Similarly there are no phytosanitary restrictions on the movement of apple fruit exported from Japan to countries free of *N. ditissima* (Fukuda 2005). Therefore, if the disease did become established in Australia it would not affect the international export of fruit.
Environmental and non-commercial	**B – Minor Significance at the local level:** • Establishment of European canker could necessitate increased chemical usage in some situations and this may have undesirable effects on the local environment as well as being of minor significance on the future placement of plant species (for example, elm trees) at the local level. • Sustainability of communities in the nine or so major apple growing areas across Australia is significant to the local economy. Tourism in these areas, especially during harvesting periods, can be significant and depends on the health of the fruit crop. • There could be minor social impacts at a local level if several orchards were affected by European canker, owing to reduced crop yields.

4.3.6 Unrestricted risk estimate

Unrestricted risk is the result of combining the probability of entry, establishment and spread with the estimate of consequences. Probabilities and consequences are combined using the risk estimation matrix shown in Table 2.5 on page 12.

Unrestricted risk estimate for *Neonectria ditissima*	
Overall probability of entry, establishment and spread	Extremely Low
Consequences	Low
Unrestricted risk	Negligible

As indicated, the unrestricted risk estimate for *N. ditissima* has been assessed as ‘negligible’, which achieves Australia’s ALOP. Therefore, additional risk management measures are not recommended for this pest.

4.4 Pest risk assessment conclusions

Key to Table 4.2 (starting next page)

Genus species [EP]	pests for which policy already exists. The outcomes of previous assessments and/or reassessments in this IRA are presented in table 4.2
Genus species [state/territory]	state/territory in which regional quarantine pests have been identified

Likelihoods for entry, establishment and spread

N	negligible
EL	extremely low
VL	very low
L	low
M	moderate
H	high
P[EES]	overall probability of entry, establishment and spread

Assessment of consequences from pest entry, establishment and spread

PLH	plant life or health
OE	other aspects of the environment
EC	eradication control etc
DT	domestic trade
IT	international trade
ENC	environmental and non-commercial
A-G	consequence impact scores are detailed in section 2.2.3
	A Indiscernible at the local level
	B Minor significance at the local level
	C Significant at the local level
	D Significant at the district level
	E Significant at the regional level
	F Significant at the national level
	G Major significance at the national level
URE	unrestricted risk estimate. This is expressed on an ascending scale from negligible to extreme.

Table 4.5 Summary of unrestricted risk estimates for quarantine pests associated with mature fresh apple fruit from New Zealand

Pest name	Likelihood of						Consequences							URE
	Entry			Establishment	Spread	P[EES]								
	importation	distribution	Overall				direct		indirect				Overall	
							PLH	OE	EC	DT	IT	ENC		
DOMAIN BACTERIA														
Fire blight (Enterobacteriales: Enterobacteriaceae)														
Erwinia amylovora	M	EL	**EL**	**H**	**H**	**EL**	F	A	E	E	A	A	**H**	**VL**
DOMAIN EUKARYA														
Apple leafcurling midge (Diptera: Cecidomyiidae)														
Dasineura mali	M	VL	VL	L	M	VL	D	A	D	D	D	B	L	N
European canker (Hypocreales: Nectriaceae)														
Neonectria ditissima	VL	VL	**EL**	**M**	**M**	**EL**	D	C	D	D	A	B	**L**	**N**

5 Pest risk management

This chapter provides information on the management of identified quarantine pests. This non-regulated analysis reviews only three of the pests of quarantine concern: fire blight (caused by *Erwinia amylovora*), European canker (caused by *Neonectria ditissima*), and apple leaf curling midge (*Dasineura mali*). The conclusions presented in this draft report are that when the New Zealand apple industry's standard commercial practices for production of export grade fruit are taken into account, the unrestricted risk for all three pests assessed achieves Australia's appropriate level of protection (ALOP). Therefore, no additional quarantine measures are recommended, though New Zealand will need to ensure that the standard commercial practices detailed in this review are met for export consignments. These practices include:

- Application of the integrated fruit production system, or an equivalent, to manage pests and diseases in orchard
- Testing to ensure that only mature fruit is exported to Australia
- Maintenance of sanitary conditions in dump tank water
- High pressure water washing and brushing of fruit in the packing house
- A minimum 600 fruit sample from each lot of fruit packed is inspected and found free of quarantine pests for Australia.

In addition, the 2006 final IRA report considered a further 13 pests, nine of which were determined to pose a risk that exceeded Australia's ALOP and for which measures were recommended. For clarity the conclusions of the 2006 final IRA report for those additional 13 pests are presented below.

Table 5.1 Summary of the assessment of unrestricted risk for quarantine pests

Pest	Unrestricted risk	Additional Measures Required?
2011 Non-regulated analysis		
Fire blight (*Erwinia amylovora*)	Very Low	N
European canker (*Neonectria ditissima*)	Negligible	N
Apple leaf curling midge (*Dasineura mali*)	Negligible	N
2006 Final IRA report		
Garden featherfoot (*Stathmopoda horticola*)	Negligible	N
Grey-brown cutworm (*Graphania mutans*)	Very low	N
Leafrollers: Brownheaded leafroller (*Ctenopseustis herana*) Brownheaded leafroller (*Ctenopseustis obliquana*) Greenheaded leafroller (*Planotortrix excessana*) Greenheaded leafroller (*Planotortrix octo*) Native leafroller (*Pyrogotis plagiatana*)	Low	Y
Apple scab (*Venturia inaequalis*) (WA only)	Moderate	N[17]
Codling moth (*Cydia pomonella*) (WA only)	Low	Y
Mealybugs: Citrophilus mealybug (*Pseudococcus calceolariae*) (WA only) Mealybug (*Planococcus mali*) (WA only)	Low	Y
Oriental fruit moth (*Grapholita molesta*) (WA only)	Very low	N
Oystershell scale (*Diaspidiotus ostreaformis*) (WA only)	Negligible	N

In referring to the recommendations of the 2006 final IRA report it is noted that New Zealand's standard practice of sampling 600 fruit per lot during packing operations was not specifically taken into account. Thus, for leafrollers and mealybugs, the recommendation in the 2006 final IRA report was for phytosanitary inspection of 600 fruit per lot, with any lots found to contain leafrollers to be withdrawn from export, and for any lots found to contain mealybugs to be withdrawn from export to Western Australia. For leafrollers, additional actions were recommended to determine the level of internal fruit infestation.

As the 600 unit inspection is already undertaken as standard practice during packing house operations, no further inspection is required. Any lot found to be infested with leafrollers or mealybugs is to withdraw from export to Australia or Western Australia, depending on the pest(s) detected. Alternately, lots may be subjected to a suitable remedial action, such as an approved fumigation treatment to ensure there are no viable quarantine pests.

[17] Subsequent to the release of the release of the *Final Import Risk Analysis Report for Apples from New Zealand* in November 2006, *Venturia inaequalis* has been detected in Western Australia and is no longer considered a regional quarantine pest. Quarantine measures are therefore not required.

5.1 Pest risk management measures and phytosanitary procedures

The pest risk management measures are based on the requirement for New Zealand growers and packing houses to adhere to existing commercial practices described in this report (refer to Section 3) and as summarised in the introduction to this chapter. These standard practices are subject to verification and audit by the Biosecurity Services Group prior to the commencement of trade, and as required. These practices include;

- The application of the integrated fruit production system, or an equivalent, to manage pests and diseases in the orchard.
- Testing of fruit from a new variety and block combimation on-arrival at the packing house. Fruit maturity will be tested using the starch pattern index. The testing will ensure that only mature fruit is exported to Australia.
- The maintenance of sanitary conditions in the dump tank and the high pressure spray water through use of sanitisers at label rates that are monitored daily for concentration and pH. Alternatively, dump tank and the high pressure spray water sanitation is mantained through regular replacement of water.
- The use of high pressure water washing and brushing of fruit in the packing house.
- A minimum 600 fruit sample from each lot of fruit packed is inspected and found free of quarantine pests for Australia. A lot of fruit is "a number of units of a single commodity, identifiable by its homogeneity of composition, origin etc., forming part of a consignment" (FAO 2009). In New Zealand, this includes the volume of fruit of a single variety packed at one time and which has been picked from one orchard on one day. New Zealand packing houses often refer to this as a 'line' of fruit.

In this section, discussion of the management options is divided into two parts. Risk management measures are evaluated for quarantine pests for the whole of Australia (including Western Australia) where the unrestricted risks exceed Australia's ALOP. Following this, risk management options are discussed for the quarantine pests for Western Australia only, because these pests occur in other parts of Australia but are absent from Western Australia.

Table 5.2 Summary of phytosanitary measures recommended for quarantine pests for mature fresh apple fruit from New Zealand

Pest	Measures
Arthropods	
Leafrollers: Brownheaded leafroller (*Ctenopseustis herana*) Brownheaded leafroller (*Ctenopseustis obliquana*) Greenheaded leafroller (*Planotortrix excessana*) Greenheaded leafroller (*Planotortrix octo*) Native leafroller (*Pyrogotis plagiatana*)	Option 1: Withdrawl of export lots found during packing house inspections to be infested with leafrollers (minimum 600 unit inspection per lot) Option 2: Methyl bromide fumigation at an approved rate for export lots found during packing house inspections to be infested with leafrollers (minimum 600 unit inspection per lot)
Codling moth (*Cydia pomonella*) (WA only)	Option 1: Pest free areas of pest free places of production or production sites (ISPM4, 10) Option 2: Areas of low pest prevalence Option 3: Methyl bromide fumigation

Pest	Measures
Mealybugs: (WA only) Citrophilus mealybug (*Pseudococcus calceolariae*) Mealybug (*Planococcus mali*)	Option 1: Withdrawl of export lots found during packing house inspections to be infested with mealybugs (minimum 600 unit inspection per lot) Option 2: Methyl bromide fumigation at an approved rate for export lots found during packing house inspections to be infested with mealybugs (minimum 600 unit inspection per lot)

5.1.1 Pest risk management for quarantine pests for the whole of Australia

The 2006 final IRA report identified five species of leafrollers as quarantine pests for the whole of Australia and having an unrestricted risk above Australia's ALOP.

Management for leafrollers

Option 1: Withdrawl of export lots found to be infested with leafrollers

The 2006 final IRA report recommended that each lot be inspected on the basis of a 600-unit sample selected at random across the whole lot. A unit is one piece of fruit. That inspection is undertaken as standard practice in New Zealand apple packing houses. If leafrollers of quarantine concern to Australia are detected during that inspection, the lot should be removed from export to Australia. The removal of any lots found to be infested with leafrollers would reduce the likelihood of importation for leafrollers to at least 'very low'. The restricted risk would then be reduced to at least 'very low', which would achieve Australia's ALOP.

Also identified in the 2006 final IRA report was some uncertainty over the level of internal infestation by brownheaded leafrollers (*Ctenopseustis* spp.) and greenheaded leafrollers (*Planotortrix* spp.). For that reason, New Zealand is requested to provide additional information to address the issue of internal infestation. One way to verify the level of internal infestation would be the examination of a 600 cut fruit sample for the presence of internal larvae of brownheaded and greenheaded leafrollers from export lots. The 600 cut fruit sample could be taken from reject fruit. Based on the results, the need for fruit cutting will be reviewed.

Option 2: Methyl bromide fumigation of lots found to be infested with leafrollers

Instead of withdrawing from export lots found to be infested with leafrollers, a methyl bromide fumigation treatment of could be undertaken.

Where fumigation with methyl bromide is utilised as the remedial action for leafrollers, it must be carried out for 2 hours according to the specifications below:

- 32 g/m^3 at a pulp temperature of 21 °C or greater – minimum concentration time (CT) product of 47 g.h/m^3; or
- 40 g/m^3 at a pulp temperature of 16 °C or greater – minimum CT product of 58 g.h/m^3; or
- 48 g/m3 at a pulp temperature of 10 °C or greater – minimum CT product of 70 g.h/m^3.

It is recommended that fruit should not be fumigated if the pulp temperature is below 10 °C and that fumigations should be carried out in accordance with AQIS fumigation standards or an equivalent.

All pre-shipment (off-shore) fumigation certificates would need to contain the following fumigation details:

- the name of the fumigation facility
- the date of fumigation
- rate of methyl bromide used, that is initial dosage (g/m^3)
- the fumigation duration (hours)
- ambient air temperature during fumigation (°C)
- minimum fruit pulp temperature during fumigation (°C).

The objective of this measure is to reduce the likelihood of importation for leafrollers to at least 'very low'. The restricted risk would then be reduced to at least 'very low', which would achieve Australia's ALOP.

5.1.2 Pest risk management for pests for Western Australia only

Under the risk management and operational framework section, the 2006 final IRA report proposed that fruit not be permitted access to Western Australia as no suitable risk management measures had been identified for apple scab (caused by *Venturia inaequalis*). The report further noted that if measures were to be developed that the measures recommended for mealybugs and codling moth, as listed in the pest specific risk assessments, would need to be applied.

Since the 2006 final IRA report, there have been detections of *Venturia inaequalis* in Western Australia and containment and eradication efforts have not been put in place. As a result, this pathogen is no longer considered a regional quarantine pest for Western Australia. It is therefore proposed that importation of apples into the states of Western Australia be permitted, subject to measures listed in section 5.1.1 and supplemented by the measures in this section that are specific to produce destined for Western Australia.

Management for mealybugs

Option 1: Withdrawl of export lots found to be infested with mealybugs

The 2006 final IRA report recommended that each lot be inspected on the basis of a 600-unit sample selected at random across the whole lot. A unit is one piece of fruit. That inspection is undertaken as standard practice in New Zealand apple packing houses. If mealybugs of quarantine concern to Western Australia are detected during that inspection, the lot should be removed from export to Western Australia. The removal of any lots found to be infested with mealybugs would reduce the likelihood of importation for mealybugs to at least 'very low'. The restricted risk would then be reduced to at least 'very low', which would achieve Australia's ALOP.

Option 2: Methyl bromide fumigation of export lots found to be infested with mealybugs

Instead of withdrawing from export lots found to be infested with leafrollers, a methyl bromide fumigation treatment of could be undertaken.

Where fumigation with methyl bromide is utilised as the remedial action for mealybugs, it must be carried out for 2 hours according to the specifications below:

- 32 g/m^3 at a pulp temperature of 21 °C or greater – minimum concentration time (CT) product of 47 $g.h/m^3$; or

- 40 g/m^3 at a pulp temperature of 16 °C or greater – minimum CT product of 58 g.h/m^3; or
- 48 g/m3 at a pulp temperature of 10 °C or greater – minimum CT product of 70 g.h/m^3.

It is recommended that fruit should not be fumigated if the pulp temperature is below 10 °C and that fumigations should be carried out in accordance with AQIS fumigation standards or an equivalent.

All pre-shipment (off-shore) fumigation certificates would need to contain the following fumigation details:

- the name of the fumigation facility
- the date of fumigation
- rate of methyl bromide used, that is initial dosage (g/m^3)
- the fumigation duration (hours)
- ambient air temperature during fumigation (°C)
- minimum fruit pulp temperature during fumigation (°C).

The objective of this measure is to reduce the likelihood of importation for mealybugs to at least 'low'. The restricted risk would then be reduced to at least 'very low', which would achieve Australia's ALOP.

Management for codling moth

The 2006 final IRA report recommended three alternate measures for codling moth: sourcing fruit from pest free areas, pest free places of production or pest free production sites; sourcing fruit from areas of low pest prevalence; or methyl bromide fumigation. Visual inspection was not assessed as an effective measure due to the potential for infestations to be undetectable by visual means.

Option 1: Area freedom

Area freedom is a measure that might be applied to manage the risk posed by codling moth. If MAFNZ wishes to consider pest free areas or pest free places of production or pest free production sites as a potential management measure for codling moth, the Biosecurity Services Groups would assess any proposal from New Zealand.

The requirements for establishing pest free areas are set out in ISPM 4: *Establishment of pest free areas* (FAO 1996) and ISPM 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO 1999).

MAFNZ would be responsible for the establishment of pest free area status through official surveys and monitoring. Survey results must be submitted to the Biosecurity Services Group before access can be considered.

Option 2: Areas of low pest prevalence

Low pest prevalence is a measure that might be applied to manage the risk posed by codling moth to Western Australia. The requirements for establishing areas of low pest prevalence are set out in ISPM 22: *Requirements for the establishment of areas of low pest prevalence* (FAO 2005). As noted in the 2006 final IRA report, MAFNZ administers an export phytosanitary certification program for the export of apples to Taiwan to manage the risk of codling moth. A similar program for production and export of apples to Western Australia might be applied to manage the risk posed by codling moth. Components of such a program could include:

- registration of grower designated production sites
- monitoring and trapping for codling moth
- specific codling moth control requirements
- specific requirements for submission of fruit to packing houses
- grower compliance agreement.

MAFNZ would be responsible for the establishment of areas of low pest prevalence by official surveys and monitoring. These survey results must be submitted to the Biosecurity Services Group before access could be considered.

Option 3: Methyl bromide fumigation

It is recommended that the methyl bromide fumigation treatment could be performed for consignments where fruit cannot be sourced under Option 1, or Option 2, and when codling moth is detected at either pre-clearance in New Zealand or on-arrival inspection in Australia.

Where fumigation with methyl bromide is utilised as the measure for codling moth, it must be carried out for 2 hours according to the specifications below:

- 32 g/m^3 at a pulp temperature of 21 °C or greater – minimum concentration time (CT) product of 47 g.h/m^3; or
- 40 g/m^3 at a pulp temperature of 16 °C or greater – minimum CT product of 58 g.h/m^3; or
- 48 g/m3 at a pulp temperature of 10 °C or greater – minimum CT product of 70 g.h/m^3.

It is recommended that fruit should not be fumigated if the pulp temperature is below 10 °C and that fumigations should be carried out in accordance with AQIS fumigation standards or an equivalent.

All pre-shipment (off-shore) fumigation certificates would need to contain the following fumigation details:

- the name of the fumigation facility
- the date of fumigation
- rate of methyl bromide used, that is initial dosage (g/m^3)
- the fumigation duration (hours)
- ambient air temperature during fumigation (°C)
- minimum fruit pulp temperature during fumigation (°C).

The objective of these measures is to reduce the likelihood of importation for codling moth to at least ‘very low’. The restricted risk would then be reduced to at least ‘very low’, which would achieve Australia’s ALOP.

5.1.3 Consideration of alternative measures

Consistent with the principle of equivalence detailed in ISPM 11: *Pest risk analysis for quarantine pests including analysis of environmental risks and living modified organisms* (FAO 2004), Biosecurity Australia will consider any alternative measure proposed by MAFNZ, providing that it achieves Australia's ALOP. Evaluation of such measures or treatments will require a technical submission from MAFNZ that details the proposed treatment and includes data from suitable treatment trials.

5.2 Operational systems for maintenance and verification of phytosanitary status

A system of operational procedures is necessary to maintain and verify the phytosanitary status of fresh apple fruit from New Zealand. This is to ensure that the recommended risk management measures have been met and are maintained.

It is recommended that MAFNZ or other relevant agency nominated by MAFNZ, prepare a documented work plan for approval by the Biosecurity Services Group that describes the phytosanitary procedures for the pests of quarantine concern for Australia and the various responsibilities of all parties involved in meeting this requirement.

Details of the operational system, or equivalent, will be determined by agreement between the Biosecurity Services Group and MAFNZ.

5.2.1 Audit and verification

The objectives of the recommended requirement for audit and verification are to ensure that:

- an effective approved documented system is in operation for the orchard, the packing house and during transport.

The phytosanitary system for apple export production, certification of export orchards, pre-export inspection and certification is subject to audit by the Biosecurity Services Group. An initial audit will be conducted by the Biosecurity Services Group before commencement of exports. Audits may be then conducted at the discretion of the Biosecurity Services Group during the entire production cycle and as a component of any pre-clearance arrangement, if such an arrangement is entered into.

Biosecurity Services Group orchard audits will measure compliance with orchard registration and identification, pest/disease management including maintenance of a spray diary/monitoring, record management, the administration and verification of area freedom status for any pests as relevant and if accepted by Australia.

Biosecurity Services Group packing house audits of participants in the export program will include the verification of compliance with packing house responsibilities, traceability, labelling, segregation and product security, and the MAFNZ certification processes.

5.2.2 Registration of export orchards

The objectives of this recommended procedure are to ensure that:

- apple fruit is sourced from registered export orchards producing export quality fruit, as the pest risk assessments are based on existing commercial production practices

- export orchards from which apple fruit is sourced can be identified so investigation and corrective action can be targeted rather than applying it to all contributing export orchards in the event that live pests are intercepted.

5.2.3 Registration of packing houses and treatment facilities and auditing of procedures

The objectives of this recommended procedure are to ensure that:

- apple fruit is sourced only from registered packing houses, processing export quality fruit, as the pest risk assessments are based on existing commercial packing activities
- reference to the packing house and the orchard source (by name or a number code) are clearly stated on cartons destined for export of fresh apple fruit to Australia for trace back and auditing purposes.

It is recommended that packing houses be registered before commencement of harvest each season. A list of registered packing houses should be kept by MAFNZ and maintained as current in order to facilitate trace-back of any consignment.

Registration of packing houses and treatment facilities in the initial export season would include an audit program conducted by the Biosecurity Services Group before exports commence. After the initial approval, MAFNZ would be required to audit facilities at the beginning of each season to ensure that packing houses and treatment facilities are suitably equipped to carry out the specified phytosanitary tasks and treatments. Records of MAFNZ audits would be made available to the Biosecurity Services Group on request.

Packing houses will be required to identify individual orchards with a unique identifying system and identify fruit from individual orchards by marking cartons or pallets (i.e. one orchard per pallet) with a unique orchard number or identification.

Where apple fruit is fumigated prior to export, this process could only be undertaken in facilities that have been registered with and audited by MAFNZ for that purpose. MAFNZ would be required to register all export fumigators, as well as fumigation facilities before export activity commences. Registered fumigators would need to comply with the current MAFNZ standards for export facilities, and also comply with Australian Fumigation Accreditation Scheme (AFAS) standards. Copies of registration and fumigation chamber test records would need to be made available to AQIS if requested.

5.2.4 Packaging and labelling

The objectives of this recommended procedure are to ensure that:

- apple fruit recommended for export to Australia is not contaminated by quarantine pests or regulated articles (e.g. trash, soil and weed seeds)
- unprocessed packing material (which may vector pests not identified as being on the pathway) is not imported with fresh apple fruit
- all wood material used in packaging of the commodity complies with AQIS conditions (see AQIS publication *Cargo Containers: Quarantine aspects and procedures*)
- secure packaging is used if consignments are not transported in sealed containers directly to Australia

- the packaged apple fruit is labelled with the orchard registration number for the purposes of trace back to registered orchards
- the pre-cleared status of apple fruit is clearly identified.

5.2.5 Specific conditions for storage and movement

The objectives of this recommended procedure are to ensure that:

- product for export to Australia is secure by segregation from non-precleared product and to prevent mixing or cross-contamination with produce destined elsewhere
- the quarantine integrity of the commodity during storage and movement is maintained.

5.2.6 Freedom from trash

All apples for export must be free from trash, foreign matter and pests of quarantine concern to Australia. Freedom from trash will be confirmed by the inspection procedures. Export lots or consignments found to be contain trash, foreign matter, or pests of quarantine concern to Australia should be withdrawn from export unless and approved remedial action is available and applied to the export lot or consignment.

5.2.7 Pre-export phytosanitary inspection and certification by New Zealand authorities

The objectives of this recommended procedure are to ensure that:

- all consignments have been inspected in accordance with official procedures for all visually detectable quarantine pests and other regulated articles (including soil, animal and plant debris) at a standard 600 unit sampling rate per lot whereby one unit is one apple fruit
- an international phytosanitary certificate (IPC) is issued for each consignment upon completion of pre-export inspection and treatment to verify that the relevant measures have been undertaken offshore
- each IPC includes:
  - a description of the consignment (including orchard number and packing house details)

  and

  - an additional declaration that '*The fruit in this consignment has been produced in New Zealand in accordance with the conditions governing entry of fresh apple fruit to Australia and inspected and found free of quarantine pests'.*

5.2.8 On-arrival quarantine inspection

The objectives of this recommended procedure are to ensure that:

- consignments undergo appropriate quarantine inspection on arrival in Australia.

On arrival, AQIS will undertake a documentation compliance examination for consignment verification purposes, followed by quarantine inspection before release from quarantine on arrival in Australia. The inspection will verify that the consignment is as described on the

phytosanitary certificate and that required phytosanitary actions have been undertaken. To verify the phytosanitary status of the consignment, AQIS will randomly sample 600 fruit from each consignment.

5.2.9 Remedial action(s) for non-compliance

The objectives of the recommended requirements for remedial action(s) for non-compliance are to ensure that:

- any quarantine risk is addressed by remedial action, as appropriate
- non-compliance with import requirements is addressed, as appropriate.

5.3 Uncategorised and other pests

If an organism, including contaminating pests, is detected on apple fruit, either in New Zealand or on-arrival in Australia, that has not been categorised, it will require assessment by the Biosecurity Services Group to determine its quarantine status and whether phytosanitary action is required. Assessment is also required if the detected species was categorised as not likely to be on the import pathway. If the detected species was categorised as on the pathway but assessed as having an unrestricted risk that achieves Australia's ALOP due to the rating for likelihood of importation, then it would require reassessment. The detection of any pests of quarantine concern not already identified in the analysis may result in remedial action and/or temporary suspension of trade while a review is conducted to ensure that existing measures continue to provide the appropriate level of protection for Australia.

5.4 Audit of protocol

Prior to the first season of trade, a representative from the Biosecurity Services Group will visit areas in New Zealand that produce apples for export to Australia. They will audit the implementation of agreed import conditions and measures including registration, operational procedures and any treatment facilities.

5.5 Review of policy

The Biosecurity Services Group reserves the right to review the import policy after the first year of trade or when there is reason to believe that the pest and phytosanitary status in New Zealand has changed.

MAFNZ must inform the Biosecurity Services Group immediately on detection in New Zealand of any new pests of apples that are of potential quarantine concern to Australia or a significant change in the application of existing commercial practices considered in this draft report.

6 Conclusion

The findings of this draft report for the non-regulated analysis of existing policy for apples from New Zealand report are based on a comprehensive analysis of relevant scientific literature. Biosecurity Australia considers that the risk management measures proposed in this draft report will provide an appropriate level of protection against the pests identified as associated with the trade in apple fruit from New Zealand. Biosecurity Australia will consider any other measures suggested by stakeholders that would achieve Australia's ALOP.

Appendices

Appendix A Categorisation for quarantine pests considered in this review

As detailed in section 2.2.1, pest categorisation is the process that 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, as defined in ISPM 5: *Glossary of phytosanitary terms* (FAO 2009).

A comprehensive pest categorisation for apples from New Zealand was presented as Part C of the *Final import risk analysis report for apples from New Zealand* which was published in November 2006. For clarity, the entries from the categorisation table presented in that final IRA report for the three pests considered in this review are reproduced below.

Scientific name	Common name/s	Reference for presence in New Zealand	Presence in Australia Reference	Potential for being on mature apple fruit Comments if applicable	Potential for establishment or spread	Potential for consequences Comments if applicable	Consider species further?
Bacteria							
Erwinia amylovora (Burrill 1882) Winslow *et al.* (1920) emend. Hauben *et al.* 1998 (Syn. = *Micrococcus amylovorus* (Burrill 1882); *Bacillus amylovorus* (Burrill 1882) Trevisan 1889; *Bacterium amylovorus* (*sic*) (Burrill 1882) Chester (1897)) [Enterobacteriaceae: Enterobacteriales]	Fire blight	MAFNZ (2000b); MAFNZ (2002b)	No *E. amylovora* was detected in the Melbourne Royal Botanic Garden in 1996 and its eradication was confirmed by a survey in 1997 (Jock *et al*., 2000)	Likely Fire blight is endemic in New Zealand. Fruit sourced from infected orchards have the potential to carry epiphytic bacteria (Hale *et al*., 1987)	Feasible	Significant (Bonn, 1999); (Vanneste, 2000)	Yes
Fungi							
Neonectria galligena (Bres.) Rossman & Samuels (1999) (Syn. = *Nectria galligena* Bres. (1901); *Fusarium heteronemum* Berk. & Broome (1865); *Cylindrocarpon heteronema* (Berk. & Broome) Wollenw. [as '*heteronemum*'] (1926); *Cylindrocarpon mali* (Allesch.) Wollenw. (1928)) [Hypocreales: Nectriaceae]	European canker; eye rot; cylindrocarpon fruit rot	MAFNZ (2000b); MAFNZ (2002b)	No (APPD, 2005) Has been eradicated from Tasmania (Ransom, 1997)	Likely It causes a primary fruit spot. Latent fruit infections may occur (Swinburne, 1971a)	Feasible	Significant (Swinburne, 1970)	Yes

Scientific name	Common name/s	Reference for presence in New Zealand	Presence in Australia Reference	Potential for being on mature apple fruit Comments if applicable	Potential for establishment or spread	Potential for consequences Comments if applicable	Consider species further?
Insects - Diptera							
Dasineura mali Keiffer *[Diptera: Cecidomyiidae]*	Apple leafcurling midge	MAFNZ (2000b)	No (McLaren and Fraser, 1994)	Likely Larvae are primary pest on foliage; larvae can pupate on fruit (MAFNZ, 2000b)	Feasible	Significant Apple tree shoots damaged and tree growth retarded resulting in decreased fruit yield in Europe and New Zealand (Tomkins *et al*., 1994); (Smith and Chapman, 1995); (CABI, 2000)	Yes

Appendix B Additional quarantine pest data

DOMAIN BACTERIA	
Quarantine pest	***Erwinia amylovora* (Burrill 1882) Winslow *et al.* 1920, emend. Hauben *et al.* 1998**
Synonyms	*Micrococcus amylovorus* Burrill 1882 *Bacillus amylovorus* (Burrill 1882) Trevisan 1889 *Bacterium amylovorum* (Burrill 1882) Chester 1901
Common name(s)	fire blight
Main hosts	Besides the species in the genera *Malus* and *Pyrus*, there are 129 species of plants belonging to 37 genera of the family Rosaceae that have been reported to be susceptible to *E. amylovora* (van der Zwet and Keil, 1979). These authors showed that most of the hosts are susceptible only when inoculated artificially. The natural host range of *E. amylovora* is now generally considered to be restricted to genera of the subfamily Maloideae (formerly: Pomoideae) of the family Rosaceae (CABI 2007). Plants belonging to the subfamilies Rosoideae and Amygdaloideae can also be affected (Momol and Aldwinckle 2000). Primary hosts of economic and epidemiological significance: *Cotoneaster* spp. (cotoneaster), *Crataegus* spp. (hawthorns), *Cydonia oblonga* (quince), *Eriobotrya* spp. (bolanchin, loquat, etc.), *Malus* spp. (apple), *Prunus salicina* (Japanese plum), *Pyracantha* spp. (firethorn) and *Pyrus* spp. (pears) (Douglas 2006; CABI 2007) Secondary hosts: *Amelanchier* spp. (serviceberry), *Chaenomeles* spp. (flowering quince), *Mespilus* spp. (medlar), *Rubus* spp. (blackberry, raspberry) and *Sorbus* spp. (mountain ash, rowan) (Douglas 2006; CABI 2007) Within each genus given as hosts of fire blight, there are species or cultivars that may show high level of resistance under natural conditions or artificial inoculations (van der Zwet and Keil 1979; CABI 2007).
Distribution	Presence in Australia: *Erwinia amylovora* was detected on Cotoneaster in the Melbourne Royal Botanic Garden in 1997, and its eradication was confirmed by national survey (Rodoni *et al.* 1999; Jock *et al.* 2000). Presence in the US: Every region of the US (Bonn and van der Zwet 2000), AL, CA, CO, CT, GA, IL, LA, MD, ME, MI, NC, NY, OH, OR, PA, TX, UT, VA, WA, WV, WI (CABI 2007) Presence elsewhere: Albania, Armenia, Austria, Belgium, Bermuda, Bosnia and Herzegovina, Bulgaria, Canada, Croatia, Cyprus, Czech Republic, Denmark, Egypt, France, Germany, Greece, Guatemala, Hungary, Iran, Ireland, Israel, Italy, Jordan, Lebanon, Luxembourg, Macedonia, Mexico, Moldova, Montenegro, Netherlands, New Zealand, Norway, Poland, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom (CABI 2007)
DOMAIN EUKARYA	
Quarantine pest	***Dasineura mali* (Kieffer, 1904)**
Synonyms	*Perrisia mali* Kieffer, 1904
Common name(s)	apple leafcurling midge, apple leaf midge
Main hosts	*Malus* spp. are the only hosts of *D. mali* (Tomkins 1998)
Distribution	Presence in Australia: No record found Presence in the US: MA, NY, WA (CABI 2007; CABI/EPPO 2008) Presence elsewhere: Argentina, Austria, Belgium, Bosnia-Herzegovina, Bulgaria, Canada, Finland, France, Germany, Hungary, Italy, Macedonia, Netherlands, New Zealand, Norway, Poland, Romania, Russia, Serbia, Slovenia, Sweden, Switzerland, United Kingdom (CABI 2007; CABI CPC 2008)
DOMAIN FUNGI	
Quarantine pest	***Neonectria ditissima* (Tul. & C. Tul.) Samuels & Rossman**
Synonyms	*Cylindrocarpon heteronema* (Berk. & Broome) Wollenw. (Anamorph) *Cylindrocarpon mali* (Allesch.) Wollenw. *Cylindrocarpon willkommii* (Lindau) Wollenw. *Fusarium heteronemum* Berk. & Broome *Fusarium mali* Allesch. *Fusarium willkommii* J. Lindau *Nectria galligena* Bres. *Nectria magnoliae* M.L. Lohman & Hepting

	Neonectria galligena (Bres.) Rossman & Samuels
Common name(s)	European canker
Main hosts	*Acer* spp. (maples), *Aesculus* sp. (horse-chestnut), *Alnus incana* (grey alder), *Betula* spp. (birches), *Carpinus betulus* (common hornbeam), *Carya* spp. (hickories), *Cornus nuttallii* (Pacific dogwood), *Corylus avellana* (hazel), *Fagus* spp. (beeches), *Frangula alnus* (alder buckthorn), *Fraxinus* spp. (ashes), *Juglans* spp. (walnuts), *Liriodendron tulipifera* (yellow poplar), *Malus pumila* (apple), *Nyssa sylvatica* (blackgum), *Populus* spp. (poplars), *Prunus serotina* (black cherry tree), *Pyrus* spp. (pears), *Quercus* spp. (oaks), *Rosa* spp. (rose), *Rhus typhina* (staghorn sumac), *Salix* spp. (willows), *Sorbus aucuparia* (rowan), *Tilia americana* (American basswood), *Ulmus* spp. (elms) (CABI 2007)
Distribution	Presence in Australia: The disease has been eradicated from Tasmania (Ransom 1997). No record found from any other states. Presence in the US: CA, CT, FL, IL, IN, MA, MD, ME, MI, MN, MS, NC, ND, NH, NJ, NY, OR, PA, RI, SD, TN, VA, VT, WA, WV (CABI 2007, Farr and Rossman 2009) Presence elsewhere: Afghanistan, Argentina, Austria, Belgium, Bulgaria, Canada, Chile, China, Czech Republic, Denmark, Estonia, Faeroe Islands, France, Germany, Greece, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland, Italy, Japan, South Korea, Lithuania, Lebanon, Macedonia, Madagascar, Malaysia, Mexico, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Saudi Arabia, Slovakia, South Africa, Spain, Sweden, Switzerland, Syria, Taiwan, Ukraine, United Kingdom, Uruguay (CABI 2007, Farr and Rossman 2009)

Appendix C Biosecurity framework

Australia's biosecurity policies

The objective of Australia's biosecurity policies and risk management measures is the prevention or control of the entry, establishment or spread of pests and diseases that could cause significant harm to people, animals, plants and other aspects of the environment.

Australia has diverse native flora and fauna and a large agricultural sector, and is relatively free from the more significant pests and diseases present in other countries. Therefore, successive Australian Governments have maintained a conservative, but not a zero-risk, approach to the management of biosecurity risks. This approach is consistent with the World Trade Organization's (WTO's) Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement).

The SPS Agreement defines the concept of an 'appropriate level of protection' (ALOP) as the level of protection deemed appropriate by a WTO Member establishing a sanitary or phytosanitary measure to protect human, animal or plant life or health within its territory. Among a number of obligations, a WTO Member should take into account the objective of minimising negative trade effects in setting its ALOP.

Like many other countries, Australia expresses its ALOP in qualitative terms. Australia's ALOP, which reflects community expectations through Australian Government policy, is currently expressed as providing a high level of sanitary and phytosanitary protection, aimed at reducing risk to a very low level, but not to zero.

Consistent with the SPS Agreement, in conducting risk analyses Australia takes into account as relevant economic factors:

- the potential damage in terms of loss of production or sales in the event of the entry, establishment or spread of a pest or disease in the territory of Australia
- the costs of control or eradication of a pest or disease
- and the relative cost-effectiveness of alternative approaches to limiting risks.

Roles and responsibilities within Australia's quarantine system

Australia protects its human[18], animal and plant life or health through a comprehensive quarantine system that covers the quarantine continuum, from pre-border to border and post-border activities.

Pre-border, Australia participates in international standard-setting bodies, undertakes risk analyses, develops offshore quarantine arrangements where appropriate, and engages with our neighbours to counter the spread of exotic pests and diseases.

At the border, Australia screens vessels (including aircraft), people and goods entering the country to detect potential threats to Australian human, animal and plant health.

[18] The Australian Government Department of Health and Ageing is responsible for human health aspects of quarantine.

The Australian Government also undertakes targeted measures at the immediate post-border level within Australia. This includes national co-ordination of emergency responses to pest and disease incursions. The movement of goods of quarantine concern within Australia's border is the responsibility of relevant state and territory authorities, which undertake inter- and intra-state quarantine operations that reflect regional differences in pest and disease status, as a part of their wider plant and animal health responsibilities.

Roles and responsibilities within the Department

The Australian Government Department of Agriculture, Fisheries and Forestry is responsible for the Australian Government's animal and plant biosecurity policy development and the establishment of risk management measures. The Secretary of the Department is appointed as the Director of Animal and Plant Quarantine under the *Quarantine Act 1908* (the Act).

The Biosecurity Services Group (BSG) within the Department takes the lead in biosecurity and quarantine policy development and the establishment and implementation of risk management measures across the biosecurity continuum, and:

- though Biosecurity Australia, conducts risk analyses, including IRAs, and develops recommendations for biosecurity policy as well as providing quarantine policy advice to the Director of Animal and Plant Quarantine
- through the Australian Quarantine and Inspection Service, develops operational procedures, makes a range of quarantine decisions under the Act (including import permit decisions under delegation from the Director of Animal and Plant Quarantine) and delivers quarantine services
- coordinates pest and disease preparedness, emergency responses and liaison on inter- and intra-state quarantine arrangements for the Australian Government, in conjunction with Australia's state and territory governments.

Roles and responsibilities of other government agencies

State and territory governments play a vital role in the quarantine continuum. The BSG work in partnership with state and territory governments to address regional differences in pest and disease status and risk within Australia, and develops appropriate sanitary and phytosanitary measures to account for those differences. Australia's partnership approach to quarantine is supported by a formal Memorandum of Understanding that provides for consultation between the Australian Government and the state and territory governments.

Depending on the nature of the good being imported or proposed for importation, Biosecurity Australia may consult other Australian Government authorities or agencies in developing its recommendations and providing advice.

As well as a Director of Animal and Plant Quarantine, the Act provides for a Director of Human Quarantine. The Australian Government Department of Health and Ageing is responsible for human health aspects of quarantine and Australia's Chief Medical Officer within that Department holds the position of Director of Human Quarantine. Biosecurity Australia may, where appropriate, consult with that Department on relevant matters that may have implications for human health.

The Act also requires the Director of Animal and Plant Quarantine, before making certain decisions, to request advice from the Environment Minister and to take the advice into

account when making those decisions. The Australian Government Department of Sustainability, Environment, Water, Population and Communities (DSEWPC) is responsible under the *Environment Protection and Biodiversity Conservation Act 1999* for assessing the environmental impact associated with proposals to import live species. Anyone proposing to import such material should contact DSEWPC directly for further information.

When undertaking risk analyses, Biosecurity Australia consults with DSEWPC about environmental issues and may use or refer to DSEWPC's assessment.

Australian quarantine legislation

The Australian quarantine system is supported by Commonwealth, state and territory quarantine laws. Under the Australian Constitution, the Commonwealth Government does not have exclusive power to make laws in relation to quarantine, and as a result, Commonwealth and state quarantine laws can co-exist.

Commonwealth quarantine laws are contained in the *Quarantine Act 1908* and subordinate legislation including the Quarantine Regulations 2000, the Quarantine Proclamation 1998, the Quarantine (Cocos Islands) Proclamation 2004 and the Quarantine (Christmas Island) Proclamation 2004.

The quarantine proclamations identify goods, which cannot be imported, into Australia, the Cocos Islands and or Christmas Island unless the Director of Animal and Plant Quarantine or delegate grants an import permit or unless they comply with other conditions specified in the proclamations. Section 70 of the Quarantine Proclamation 1998, section 34 of the Quarantine (Cocos Islands) Proclamation 2004 and section 34 of the Quarantine (Christmas Island) Proclamation 2004 specify the things a Director of Animal and Plant Quarantine must take into account when deciding whether to grant a permit.

In particular, a Director of Animal and Plant Quarantine (or delegate):

- must consider the level of quarantine risk if the permit were granted, and
- must consider whether, if the permit were granted, the imposition of conditions would be necessary to limit the level of quarantine risk to one that is acceptably low, and
- for a permit to import a seed of a plant that was produced by genetic manipulation – must take into account any risk assessment prepared, and any decision made, in relation to the seed under the Gene Technology Act, and
- may take into account anything else that he or she knows is relevant.

The level of quarantine risk is defined in section 5D of the *Quarantine Act 1908*. The definition is as follows:

reference in this Act to a *level of quarantine risk* is a reference to:

(a) the probability of:

(i) a disease or pest being introduced, established or spread in Australia, the Cocos Islands or Christmas Island; and

(ii) the disease or pest causing harm to human beings, animals, plants, other aspects of the environment, or economic activities; and

(b) the probable extent of the harm.

The Quarantine Regulations 2000 were amended in 2007 to regulate keys steps of the import risk analysis process. The Regulations:

- define both a standard and an expanded IRA,
- identify certain steps, which must be included in each type of IRA,
- specify time limits for certain steps and overall timeframes for the completion of IRAs (up to 24 months for a standard IRA and up to 30 months for an expanded IRA),
- specify publication requirements,
- make provision for termination of an IRA, and
- allow for a partially completed risk analysis to be completed as an IRA under the Regulations.

The Regulations are available at www.comlaw.gov.au.

International agreements and standards

The process set out in the *Import Risk Analysis Handbook 2011* is consistent with Australia's international obligations under the SPS Agreement. It also takes into account relevant international standards on risk assessment developed under the International Plant Protection Convention (IPPC) and by the World Organisation for Animal Health (OIE).

Australia bases its national risk management measures on international standards where they exist and when they achieve Australia's ALOP. Otherwise, Australia exercises its right under the SPS Agreement to apply science-based sanitary and phytosanitary measures that are not more trade restrictive than required to achieve Australia's ALOP.

Notification obligations

Under the transparency provisions of the SPS Agreement, WTO Members are required, among other things, to notify other members of proposed sanitary or phytosanitary regulations, or changes to existing regulations, that are not substantially the same as the content of an international standard and that may have a significant effect on trade of other WTO Members.

Risk analysis

Within Australia's quarantine framework, the Australian Government uses risk analyses to assist it in considering the level of quarantine risk that may be associated with the importation or proposed importation of animals, plants or other goods.

In conducting a risk analysis, Biosecurity Australia:

- identifies the pests and diseases of quarantine concern that may be carried by the good
- assesses the likelihood that an identified pest or disease or pest would enter, establish or spread

- assesses the probable extent of the harm that would result.

If the assessed level of quarantine risk exceeds Australia's ALOP, Biosecurity Australia will consider whether there are any risk management measures that will reduce quarantine risk to achieve the ALOP. If there are no risk management measures that reduce the risk to that level, trade will not be allowed.

Risk analyses may be carried out by Biosecurity Australia's specialists, but may also involve relevant experts from state and territory agencies, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), universities and industry to access the technical expertise needed for a particular analysis.

Risk analyses are conducted across a spectrum of scientific complexity and available scientific information. An IRA is a type of risk analysis with key steps regulated under the Quarantine Regulations 2000. Biosecurity Australia's assessment of risk may also take the form of a non-regulated analysis of existing policy or technical advice to AQIS. Further information on the types of risk analysis is provided in the *Import Risk Analysis Handbook 2011*.

Glossary

Term or abbreviation	Definition
Abiotic	Relating to non-living objects, substances and processes (e.g. geological, geographical and climatic factors)
Abscission	The normal shedding from a plant of an organ that is mature or aged, e.g. a ripe fruit, an old leaf
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 2009).
Aestivate	Also 'estivate' – to pass the summer in a dormant or torpid state
Apoplast	The contents of a plant cell, excluding the cell cytoplasm (i.e. the cell walls and spaces between cells)
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).
Area	An officially defined country, part of a country or all or parts of several countries (FAO 2009).
Area of low pest prevalence (ALPP)	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 2009).
Arthropod	The largest phylum of animals, including the insects, arachnids and crustaceans
Ascospore	A sexual spore produced in a perithecia
Attenuated	To weaken or grow less
Bacteriophage	A virus that infects a bacterium
Biological control	Also 'biocontrol' – a method of controlling pests and diseases in agricultural production that relies on the use of natural predators rather than chemical agents
Biosecurity Australia	The unit, within the Biosecurity Service Group, responsible for recommendations for the development of Australia's biosecurity policy.
Biosecurity Service Group (BSG)	The group responsible for the delivery of biosecurity policy and quarantine services within the Department of Agriculture, Fisheries and Forestry.
Biotic	Relating to living organisms, substances and processes
Calyx	A collective term referring to all of the sepals in a flower
Cambium	Hard woody tissue (bark) found in the stems of perennial dicotyledons
Canker	General term for a large number of different plant diseases characterised by the appearance of small areas of dead tissue
Certificate	An official document which attests to the phytosanitary status of any consignment affected by phytosanitary regulations (FAO 2009).
Cfu	Colony forming unit, CFU is used to determine the number of viable bacterial cells in a sample
Conidiophore	A simple or branched, fertile hypha bearing conidiogenous cells from which conidia are produced
Conidium	A non-motile, usually deciduous, asexual spore
Consignment	A quantity of plants, plant products and/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 2009).
Control (of a pest)	Suppression, containment or eradication of a pest population (FAO 2009).
Crawler	Intermediate mobile nymph stage of certain Arthropods
Crotch	Area where tree trunk splits into two or more limbs
Cultivar	A cultivated plant selection that can be propagated reliably in a prescribed manner
Cytoplasm	A jelly-like material composed mostly of water that fills the cell, maintaining its shape and consistency whilst also providing suspension to the organelles

Term or abbreviation	Definition
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 2009).
Endemic	Belonging to, native to, or prevalent in a particular geography, area or environment
Endophytic (of a pest)	Describes the endophytic (internal) colonisation (infection) of the core of an apple or the plant itself, and is generally associated with the development of disease symptoms
Entry (of a pest)	Movement of a pest into an area where it is not yet present, or present but not widely distributed and being officially controlled (FAO 2009).
Epidemiology	The study of factors influencing the initiation, development and spread of infectious disease; the study of disease in populations of plants
Epiphytic (of a pest)	Describes the epiphytic colonisation (infestation) of the surface, calyx and stem-end of apple fruit, although the fruit and plant is unlikely to display disease symptoms
Establishment	Perpetuation, for the foreseeable future, of a pest within an area after entry (FAO 2009).
Exopolysaccharide	A high molecular-weight polymer composed of saccharide (sugar) subunits produced by cells, often to prevent them from losing moisture under dry environmental conditions
Exudation	Active secretion of fluid from cells as a result of disease or injury
Fecundity	The fertility of an organism
Fresh	Living; not dried, deep-frozen or otherwise conserved (FAO 2009).
Fruitlet	A very small fruit soon after formation
Fumigation	A method of pest control that completely fills an area with gaseous pesticides to suffocate or poison the pests within
Genotype	The specific genetic makeup (or genome) of an individual organism
Genus	A taxonomic category ranking below a family and above a species and generally consisting of a group of species exhibiting similar characteristics. In taxonomic nomenclature the genus name is used, either alone or followed by a Latin adjective or epithet, to form the name of a species
Gram negative bacteria	Bacteria that are not stained dark blue or violet by Gram staining, in contrast to Gram positive bacteria. The difference lies in the cell wall of the two types; in contrast to most Gram positive bacteria, Gram negative bacteria have only a few layers of peptidoglycan and a secondary cell membrane made primarily of lipopolysaccharide.
Gram positive bacteria	Bacteria that are stained dark blue or violet by Gram staining, in contrast to Gram negative bacteria, which are not affected by the stain. The stain is caused by a high amount of peptidoglycan in the cell wall, which typically, but not always lacks the secondary membrane and lipopolysaccharide layer found in Gram negative bacteria.
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 2009).
Host range	The collection of hosts that an organism can utilise as a partner or parasite.
Hypanthium	A bowl-shaped part of a flower consisting of the bottoms of the sepals, petals and stamens stuck together. It is present in all members of the Rosaceae (rose) family
Hypha	A long branching filament that along with other hyphae (plural), forms the feeding structure of a fungus called the mycelium.
Import permit	Official document authorising importation of a commodity in accordance with specified phytosanitary import requirements (FAO 2009).
Import risk analysis	An administrative process through which quarantine policy is developed or reviewed, incorporating risk assessment, risk management and risk communication.
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	The 'epiphytic' colonisation of the surface of a plant, or plant organ, and is characterised by the absence of disease symptoms

Term or abbreviation	Definition
Infestation (of a commodity)	Official document authorising importation of a commodity in accordance with specified phytosanitary import requirements (FAO 2009).
Inoculum	Pathogen or its parts, capable of causing infection when transferred to a favourable location
Inspection	Official visual examination of plants, plant products or other regulated articles to determine if pests are present and/or to determine compliance with phytosanitary regulations (FAO 2009).
Instar	A stage of insect larval development which is between two moults
Intended use	Declared purpose for which plants, plant products, or other regulated articles are imported, produced, or used (FAO 2009).
Interception (of a pest)	The detection of a pest during inspection or testing of an imported consignment (FAO 2009).
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 IPCC (FAO 2009).
Introduction	The entry of a pest resulting in its establishment (FAO 2009).
Keystone species	Any species that exerts great influence on an ecosystem, relative to its abundance
Larva	A juvenile form of animal with indirect development, undergoing metamorphosis (for example, insects or amphibians)
Lenticel	A small oval/rounded spot on the stem or branch of a plant, from which the underlying tissues may protrude or roots may issue, either in the air, or more commonly when the stem or branch is covering with water or earth.
Lot	A number of units of a single commodity, identifiable by its homogeneity of composition, origin etc., forming part of a consignment (FAO 2009).
Lysed	Dissolution or destruction of cells
Mature fruit	Commercial maturity is the start of the ripening process. The ripening process will then continue and provide a product that is consumer–acceptable. Maturity assessments include colour, starch index, soluble solids content, flesh firmness, acidity, and ethylene production rate
Midge	A small two-winged insect belonging to the Order Diptera
Mortality	The total number of organisms killed by a particular disease
Mycelium	The vegetative body of a fungus, consisting of hyphae
National Plant Protection Organization (NPPO)	Official service established by a government to discharge the functions specified by the IPPC (FAO 2009).
Nectary	The gland that secretes nectar, usually located at the base of the flower
Nymph	The immature form of some insect species that undergoes incomplete metamorphosis. It is not to be confused with a larva, as its overall form is already that of the adult
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 2009).
Orchard	A contiguous area of apple trees operated as a single entity
Ovule	A structure found in seed plants that develops into a seed after fertilisation
Parasitoid	An insect parasitic only in its immature stages, killing its host in the process of its development, and free living as an adult (ISPM 5)
Pathogen	A biological agent that can cause disease to its host
Pathway	Any means that allows the entry or spread of a pest (FAO 2009).
PCR	Polymerase chain reaction; is a technique in molecular genetics that permits the analysis/detection of any short sequence of DNA (or RNA) even in samples containing only minute quantities of DNA or RNA.
Pedicel	The stalk of a flower
Peduncle	A flower stalk, or stem
Perithecium	A flask or jug-shaped fungal fruiting body that is slightly open at one end
Pest	Any species, strain or biotype of plant, animal, or pathogenic agent injurious to plants or plant products (FAO 2009).

Term or abbreviation	Definition
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 2009).
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 2009).
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 2009).
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 conditions 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 2009).
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 2009).
Pest risk assessment (for quarantine pests)	Evaluation of the probability of the introduction and spread of a pest and of the associated potential economic consequences (FAO 2009).
Pest risk management (for quarantine pests)	Evaluation and selection of options to reduce the risk of introduction and spread of a pest (FAO 2009).
Petiole	The stalk of a leaf, attaching the blade to the stem
Phenotype	An individual organism's total physical appearance and constitution, or a specific manifestation of a trait, such as size or eye colour, that varies between individuals
Pheromone	Any chemical produced by a living organism that transmits a message to other members of the same species
Phloem	In vascular plants, the tissue that carries organic nutrients to all parts of the plant where needed
Phytosanitary certificate	Certificate patterned after the model certificates of the IPPC (FAO 2009).
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 2009).
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 2009).
Polyphagous	Feeding on a relatively large number of hosts from different genera.
Polyphagous	Feeding on a relatively large number of host plants from different plant families
Polysaccharide	A relatively rich carbohydrate composed of simple sugars linked together
Pome fruit	A type of fruit produced by flowering plants in the subfamily Maloideae of the Family Rosaceae
PRA area	Area in relation to which a pest risk analysis is conducted (FAO 2009).
Propagule	A reproductive structure, e.g. a seed, a spore, part of the vegetative body capable of independent growth if detached from the parent
Pupa	An inactive life stage that only occurs in insects that undergo complete metamorphosis, for example butterflies and moths (Lepidoptera), beetles (Coleoptera) and bees, wasps and ants (Hymenoptera)
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 2009).
Quarantine pest	A pest of potential economic importance to the area endangered thereby and not yet present there, or present but not widely distributed and being officially controlled (ISPM 5)
Quiescent	Inactive, latent, or dormant, referring to a disease or pathological process
Quorum sensing	The ability of bacteria to communicate and coordinate behaviour via signalling molecules
Regulated article	Any plant, plant product, storage place, packing, 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 2009).
Restricted risk	Risk estimate with phytosanitary measure(s) applied.

Term or abbreviation	Definition
Rootstock	A stump with an established healthy root system, onto which a tree part (scion) with fruiting properties desired by the propagator, during the process of plant propagation by mechanical grafting
rpoS	The *rpoS* (RNA polymerase, sigma S) gene encodes the sigma factor σ^S and regulates expression of a number of genes that serve to maintain viability of bacteria during periods of starvation and environmental stress
Saprophyte	An organism deriving its nourishment from dead organic matter
Scion	A tree part with fruiting properties desired by the propagator that is grafted onto a rootstock.
Sepal	A segment of the calyx of a flower. In a 'typical' flower, sepals are green and lie under the more conspicuous petals
Sporodochia	A cluster of condidiophores that arise from a stroma or a mass of hyphae
Spread	Expansion of the geographical distribution of a pest within an area (FAO 2009).
Spread (of a pest)	Expansion of the geographical distribution of a pest within an area (ISPM 5)
Spread potential (of a pest)	Likelihood of the spread of a pest
SPS Agreement	WTO Agreement on the Application of Sanitary and Phytosanitary Measures (WTO 1995).
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.
Stigma	A part of the female organ of a flower, essentially the terminal part of a pistil
Stoma	(Also 'stomate') A tiny opening or pore, found mostly on the undersurface of a plant leaf, and used for gaseous exchange
Streptomycin	An antibiotic used in the control of fire blight
Symptomless	Without any visible indication of disease by reaction of the host, e.g. canker, wilt
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 (FAO 2009).
Thorax	The division of an animal's body located between the head and abdomen. In insects, the thorax is one of the three main segments of the body
Trash	Soil, splinters, twigs, leaves and other plant material, other than fruit stalks.
Unrestricted risk	Unrestricted risk estimates apply in the absence of risk mitigation 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
Virulence	The relative ability of an infectious agent to do damage to a host organism
Xylem	In vascular plants, the tissue that carries water up the root and stem

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