Australian Government

Biosecurity Australia

Revised Draft Import Risk Analysis Report for Apples from New Zealand

Part B

December 2005

Please note that this is a draft document for comment only. It has been issued to give all interested parties an opportunity to comment and to draw attention to any errors, misinterpretations, typographical errors and gaps in the data. Any comments should be submitted to Biosecurity Australia within the comment period allowed (usually 60 days). The draft will then be revised to take account of the comments received and will be released as a final document at a later date.

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Cover image: Apple orchard in New Zealand.

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Introduction

This section outlines:

- the legislative basis for Australia's biosecurity regime
- Australia's international rights and obligations
- Australia's ALOP and risk management
- import risk analysis
- policy determination.

Australian legislation

The *Quarantine Act 1908* and its subordinate legislation, including the *Quarantine Proclamation 1998*, are the legislative basis of human, animal and plant quarantine in Australia.

Some key provisions are set out below.

Quarantine Act: scope

Subsection 4 (1) of the *Quarantine Act 1908* defines the scope of quarantine as follows.

> *In this Act, quarantine includes, but is not limited to, measures for, or in relation to:*
> *(i) the examination, exclusion, detention, observation, segregation, isolation, protection, treatment and regulation of vessels, installations, human beings, animals, plants or other goods or things; or*
> *(ii) the seizure and destruction of animals, plants, or other goods or things; or*
> *(iii) the destruction of premises comprising buildings or other structures when treatment of these premises is not practicable; and*
> *having as their object the prevention or control of the introduction, establishment and spread of diseases or pests*[1] *that will or could cause significant damage to human beings, animals, plants, other aspects of the environment or economic activities.*

Section 5D of the *Quarantine Act 1908* covers the level of quarantine risk.

> *A 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 or the Cocos Islands; 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.*

Section 5D of the *Quarantine Act 1908* includes harm to the environment as a component of the level of quarantine risk.

[1] The term 'pest' used throughout this report is the collective term used for insect pests, plant diseases, viruses, bacteria and fungi that could harm plants. The formal definition used is the one provided in the International Plant Protection Convention (IPPC): 'any species, strain, or biotype of plant, animal or pathogenic agent injurious to plants or plant products'.

Environment is defined in Section 5 of the *Quarantine Act 1908,* in that it:

> *includes all aspects of the surroundings of human beings, whether natural surroundings or surroundings created by human beings themselves, and whether affecting them as individuals or in social groupings.*

Quarantine Proclamation

The *Quarantine Proclamation 1998* is made under the *Quarantine Act 1908*. It is the principal legal instrument used to control the importation to Australia of goods of quarantine (or biosecurity) interest. The Proclamation empowers the Director of Quarantine to grant a permit to import.

Section 70 of the *Quarantine Proclamation 1998* sets out the matters to be considered when deciding whether to grant a permit to import.

> *In deciding whether to grant a permit to import a thing into Australia or the Cocos Islands, or for the removal of a thing from the Protected Zone or the Torres Strait Special Quarantine Zone to the rest of Australia, a Director of Quarantine:*
>
> *(a) must consider the level of quarantine risk if the permit were granted; and*
>
> *(b) must consider whether, if the permit were granted, the imposition of conditions on it would be necessary to limit the level of quarantine risk to one that is acceptably low; and*
>
> *(ba) for a permit to import a seed of a kind of 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*
>
> *(c) may take into account anything else that he or she knows that is relevant.*

Development of biosecurity policy

As can be seen from the above extracts, the legislation establishes the concept of the level of biosecurity (quarantine) risk as the basis of decision-making under Australian quarantine legislation.

Import risk analyses (IRAs) are a significant contribution to the information available to the Director of Animal and Plant Quarantine – the decision maker for the purposes of the Quarantine Proclamation. Import risk analysis is conducted within an administrative process – known as the IRA process and described in the *Import risk analysis handbook* (BA, 2003).[2]

The purpose of the IRA process is to deliver a policy recommendation to the Director of Animal and Plant Quarantine that is characterised by sound science, transparency, fairness and consistency.

Australia's international rights and obligations

It is important that import risk analysis conforms with Australia's rights and obligations as a World Trade Organization (WTO) member country. These rights and obligations derive principally from the WTO's *Agreement on the Application of Sanitary and Phytosanitary Measures* (SPS Agreement), and in the case of plants and plant products from the International Plant Protection Convention (IPPC).

The SPS Agreement recognises the right of WTO member countries to determine the level of SPS protection they deem appropriate, and to take the necessary measures to achieve that

[2] Available at http://www.daff.gov.au

protection. Sanitary (human and animal health) and phytosanitary (plant health) measures typically apply to trade in or movement of animal- and plant-based goods within or between countries. The SPS Agreement applies to measures that may directly or indirectly affect international trade and that protect human, animal or plant life or health from pests and diseases or a member's territory from a pest.

The SPS Agreement provides for the following:

- the right of WTO member countries to determine the level of SPS protection (appropriate level of protection or ALOP) they deem appropriate;
- an importing member has the sovereign right to take measures to achieve the level of protection it deems appropriate to protect human, animal or plant life or health within its territory;
- an SPS measure must be based on scientific principles and not be maintained without sufficient scientific evidence;
- an importing member shall avoid arbitrary or unjustifiable distinctions in levels of protection, if such distinctions result in discrimination or a disguised restriction on international trade;
- an SPS measure must not be more trade restrictive than required to achieve an importing member's ALOP, taking into account technical and economic feasibility;
- an SPS measure should be based on an international standard, guideline or recommendation where these exist, unless there is a scientific justification for a measure which results in a higher level of SPS protection to meet the importing member's ALOP;
- an SPS measure conforming to an international standard, guideline or recommendation is deemed to be necessary to protect human, animal or plant life or health, and to be consistent with the SPS Agreement;
- where an international standard, guideline or recommendation does not exist or where, in order to meet an importing member's ALOP, a measure needs to provide a higher level of protection than accorded by the relevant international standard, such a measure must be based on a risk assessment; the risk assessment must take into account available scientific evidence and relevant economic factors;
- where the relevant scientific evidence is insufficient, an importing member may provisionally adopt SPS measures on the basis of available pertinent information. In such circumstances, members shall seek to obtain the additional information necessary for a more objective assessment of risk and review the SPS measure accordingly within a reasonable period of time;
- an importing member shall accept the measures of other countries as equivalent, if it is objectively demonstrated that the measures meet the importing member's ALOP.

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.

ALOP can be illustrated using a 'risk estimation matrix' (see Table 1). The cells of this matrix describe the product of likelihood[3] and consequences – termed 'risk'. When interpreting the risk estimation matrix, it should be remembered that, although the descriptors for each axis are similar ('low', 'moderate', 'high', etc.), the vertical axis refers to *likelihood* and the horizontal axis refers to *consequences*.

Table 1 Risk estimation matrix

Likelihood of 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 entry, establishment and spread

The band of cells in Table 1 marked 'very low risk' represents Australia's ALOP or tolerance of loss.

Risk management and sanitary and phytosanitary (SPS) measures

Australia's plant and animal health status is maintained through the implementation of measures to facilitate the importation of products while protecting the health of people, animals and plants.

Australia bases its national measures on international standards where they exist and where they deliver the appropriate level of protection from pests and diseases. However, where such standards do not achieve Australia's level of biosecurity protection, or relevant standards do not exist, Australia exercises its right under the SPS Agreement to take appropriate measures, justified on scientific grounds and supported by risk analysis.

Australia's approach to addressing requests for imports of animals, plants and their products, where there are biosecurity risks is, where appropriate, to draw on existing SPS measures for similar products with comparable risks. However, where measures for comparable biosecurity risks have not previously been established, further action would be required to assess the risks to Australia and determine the SPS measures needed to achieve Australia's ALOP.

[3] The terms 'likelihood' and 'probability' are synonymous. 'Probability' is used in the *Quarantine Act 1908* while 'likelihood' is used in the WTO SPS Agreement. These terms are used interchangeably in this draft IRA Report.

Import risk analysis (IRA)

Description

In animal and plant biosecurity, IRA identifies the pests and diseases relevant to an import proposal, assesses the risks posed by them and, if those risks are unacceptable, specifies the measures that could be taken to reduce those risks to an acceptable level. These analyses are conducted via an administrative process (described in the *IRA Handbook*) that involves, among other things, notification to the WTO, consultation and appeal.

Undertaking IRAs

Biosecurity Australia may undertake an IRA if:

- there is no relevant existing biosecurity measure for the product and pest/disease combination; or
- a variation in established policy is desirable because pests or diseases, or the likelihood and/or consequences of entry, establishment and spread of the pests or diseases could differ significantly from those previously assessed.

Environment and human health

When undertaking an IRA, the Quarantine Act requires the Director of Animal and Plant Quarantine to ensure that environmental factors are considered in the decision-making process. A memorandum of understanding (MOU) is in place between Biosecurity Australia and the Department of the Environment and Heritage to facilitate input of advice on environmental matters in import risk analyses.

Biosecurity Australia also consults with other Commonwealth agencies where they have responsibilities relevant to the subject matter of the IRA, for example, Food Standards Australia New Zealand (FSANZ) and the Australian Government Department of Health and Ageing.

The IRA process in summary

The process consists of the following major steps.

Initiation**:** This is the stage where the identified need for an IRA originates.

Scheduling and Scoping**:** At this stage, Biosecurity Australia considers all the factors that affect scheduling. Consultation with stakeholders, including States, Territories and other Commonwealth agencies, is involved. There is opportunity for appeal by stakeholders at this stage.

Risk Analysis**:** Here, the major scientific and technical work relating to risk assessment and risk management is performed. A panel with outside expertise may be engaged to provide advice. There is detailed consultation with stakeholders.

Reporting**:** Here, the final results of the IRA are communicated formally to stakeholders. The Eminent Scientist Group provides independent advice to the Director of Animal and Plant Quarantine (Secretary of the Department of Agriculture, Fisheries and Forestry). There is opportunity for appeal by stakeholders at this stage. Biosecurity Australia then delivers the biosecurity policy recommendation arising from the IRA to the Director of Animal and Plant Quarantine for decision.

Policy determination

The Director of Animal and Plant Quarantine makes the final policy determination. Biosecurity Australia then notifies the proponent/applicant, registered stakeholders and the WTO of the final policy determination. The final IRA report, the policy determination, the outcomes of any appeals and Biosecurity Australia's responses to issues raised, are provided to the proponent/applicant and registered stakeholders, and placed on the Biosecurity Australia website and on the public file. Biosecurity Australia notifies AQIS of the new policy and liaises with AQIS on implementation.

New Zealand's access applications

New Zealand had access to the Australian market for fresh apple fruit until 1921. In that year Australia banned New Zealand apples from entering Australia, following the introduction and establishment of the disease fire blight in Auckland in 1919. In 1986 and again in 1989, New Zealand applied to regain access to Australian fresh apple fruit markets. However, both applications were rejected, mainly because of unresolved issues relating to the risk of the disease entering Australia through trade in fresh fruit from fire blight-affected orchards in New Zealand.

The Australian Quarantine and Inspection Service (AQIS) received a further application for access of fresh apples into Australia from New Zealand in December 1995. The application contained a pest list for New Zealand apples and details of New Zealand's research work on fire blight. The application included the statement that 'the export of mature apples produced under New Zealand conditions (regardless of the fire blight [disease] status of the orchard) will not be a viable pathway for the introduction of *Erwinia amylovora* into Australia'. This claim was based on the scientific literature available at the time, as well as additional research carried out in New Zealand. According to the New Zealand proposal, apples could be sourced from trees with active fire blight as long as they were mature and free of trash when packed. No other risk management measures were proposed by New Zealand in the original request. After analysis, this application was also rejected in 1998.

New Zealand submitted a new application in January 1999, requesting a review of available risk management options for apples from New Zealand, with a view to trade occurring under phytosanitary measures that were the least trade restrictive necessary to meet the level of protection deemed appropriate by Australia. In support of this request, the New Zealand Ministry of Agriculture and Forestry (MAFNZ) stated that the AQIS decision of December 1998 was 'very narrow in focus and did not address off-shore risk mitigation measures'. At this time data were provided in support of cold storage as an effective risk management option for fire blight.

Australia's previous risk analyses

AQIS began a risk analysis for fire blight in 1996, following the International Standard for Phytosanitary Measures No. 2 (ISPM No. 2): *Part 1 – Import regulations: Guidelines for pest risk analysis* (FAO, 1996a). First, an issues paper (AQIS, 1996) was released, noting that the research quoted in the New Zealand proposal was based on orchards that had been inspected and found to be free of fire blight symptoms. Therefore AQIS considered that this research should form the basis of any risk management measures to be developed based on the New Zealand submission. The issues paper also identified other pests of quarantine concern and provided background information on fire blight. A paper from the Australian Bureau of Agricultural and Resource Economics (Bhati and Rees, 1996) on the probable costs of fire blight disease to the Australian industry was attached to this issues paper. Stakeholders were asked to provide relevant comments on the paper directly to AQIS within 60 days of its release. At industry request an extension of time was provided for comment, so the final consultation period was approximately four months. Submissions were received from State departments of agriculture, industry and other parties. All submissions discussed the threat of fire blight, but some also highlighted other pests of quarantine concern. The submission from MAFNZ reasserted that apples were not a vector for fire blight, and that alternative risk management measures did not therefore need to be considered in the PRA.

A draft PRA was released in April 1997 (AQIS, 1997), requesting comments within 60 days. However, before the expiry of the comment period, it was reported that the bacterium causing fire blight, *E. amylovora,* was present on two shrubs in the Royal Botanic Gardens, Melbourne. The original two host plants were destroyed and extensive surveys were carried out but no further evidence of fire blight in Australia was found. In March 1998, AQIS released a summary of the national survey program and the subsequent eradication action (AQIS, 1998b), and announced that the New Zealand proposal was to be reconsidered. It called for any further submissions on the draft PRA by the end of April 1998.

The draft risk analysis of the New Zealand proposal had been largely completed and was being considered by stakeholders, before a new modified risk analysis process developed in response to the Nairn review into quarantine was released (*Australian Quarantine – A shared responsibility – The Government Response*, 1997). The new process included provisions for three consultations with stakeholders during the preparation of the IRA.

On 10 December 1998, AQIS released the final IRA concerning the importation of apple fruit from New Zealand. In preparing this final IRA, AQIS reviewed the available scientific literature, sought opinion from stakeholders, considered all the material provided during the consultation process and followed ISPM No. 2: *Part 1 – Import regulations: Guidelines for pest risk analysis* (FAO, 1996a). The IRA determined that fresh apples would not be permitted entry to Australia under the conditions proposed by New Zealand, and that this determination complied with Australia’s international rights and obligations under the Agreement on the Application of SPS Measures.

Australia’s current risk analysis

Following New Zealand’s request, AQIS, in February 1999, advised stakeholders that it would conduct a further IRA for the importation of apples from New Zealand.

Biosecurity Australia (formerly a part of AQIS) released a draft IRA on apples from New Zealand to stakeholders on 11 October 2000. It recommended the importation of New Zealand apples to Australia subject to 11 phytosanitary measures, including rigorous inspection and disinfestation regimes in orchards, packing houses and stores. It was available for public comment for 60 days.

A revised draft IRA was released in February 2004 for stakeholder comment. Following the request from stakeholders, an extension of the formal comment period until 23 June 2004 was granted. Over 200 submissions were received.

In creating Biosecurity Australia (BA) as a prescribed Agency in late 2004, the Australian Government undertook that BA would review and reissue the draft IRA previously issued. Because of the substantial comments that had been received on the previously issued draft report, BA committed to considering these comments in releasing a new revised IRA – this document. During the preparation of this revised IRA, the IRA team held numerous further meetings and also met with key stakeholders.

All the comments received on the previous draft have been considered in preparing this document. As indicated, the IRA team met separately with several key stakeholders to clarify information they had provided in their written submissions. The IRA team also considered the final report of the Senate Committee on Rural and Regional Affairs and Transport (Commonwealth of Australia, 2005) and the relevant scientific and technical information in publicly available documents from the WTO Japan–USA apples dispute case.

Scope

The scope of this analysis is the importation of mature apple fruit free of trash, either packed or sorted and graded bulk fruit from New Zealand.

The New Zealand request for access in 1995 was for ‘mature New Zealand apples, free from trash’. In January 1999 New Zealand formally requested Australia undertake ‘an import risk analysis on a modified (i.e. to the New Zealand proposal of 1995) proposal for the importation of apples from New Zealand’.

The nature of the modification was elaborated in February 1999 to a ‘request that AQIS review available risk management options with view to establishing phytosanitary measures that are the least trade restrictive in respect of New Zealand apple exports while ensuring the level of protection deemed appropriate by Australia is met’.

Another factor relevant to the scope is the mode of export to Australia. In previous risk analyses it was assumed that fruit would be exported to Australia as export quality fruit packed in boxes ready for further distribution. However, there have been substantial changes in the structure of the industry and the export trade in New Zealand over recent years and this assumption may no longer be valid. Biosecurity Australia discussed this issue with New Zealand on several occasions but has not received any clear indication on the mode of trade.

Therefore in this analysis no assumptions have been made as to the mode of trade. Scenarios that cover the import of packed fruit ready for distribution and bulk fruit that is stored, graded and packed in Australia have been considered in relevant parts of this IRA.

Risk Analysis Panel formation

Biosecurity Australia informed stakeholders on 8 October 2001 that a Risk Analysis Panel (RAP) would complete the IRA for New Zealand apples. This approach was adopted in order to utilise more efficiently the available scientific and other expertise, and also allow more comprehensive attention to stakeholders’ issues. The appointment of seven panel members was confirmed on 10 January 2002 and the RAP then comprised the following people:

Dr Bill Roberts (Chairman)	Biosecurity Australia’s Principal Scientist. Department of Agriculture, Fisheries and Forestry.
Mr Bill Hatton	A specialist in fruit production with expertise in growing, packing and shipping various fruit.
Mr David Cartwright	A plant pathologist and Manager Plant Health, Department of Primary Industries and Resources, South Australia.
Dr Kent Williams	Principal Research Scientist, CSIRO Sustainable Ecosystems.
Mr Ian Armour	An owner and manager of an apple production business.
Dr Brian Stynes	A plant pathologist and former General Manager, Plant Biosecurity, Biosecurity Australia.
Mr Mike Kinsella	Passed away in January 2002. No replacement was sought.

The panel was initially known as a Risk Analysis Panel (RAP). However, its title was changed to Import Risk Analysis (IRA) team, consistent with the terminology used in the release of the Biosecurity Australia’s *Import Risk Analysis Handbook* 2003 (BA, 2003).

Method for import risk analysis

Introduction

The technical component of an IRA for plants or plant products is termed a 'pest risk analysis' or PRA.

A PRA is carried out in three discrete stages.

- Stage 1: Initiation of the PRA
- Stage 2: Pest risk assessment
- Stage 3: Pest risk management.

Approach to pest risk analysis (PRA)

Like most quarantine agencies, Biosecurity Australia generally undertakes pest risk analyses using a qualitative approach where the likelihoods of various events are considered and evaluated using descriptive terms that are linked to probability intervals. However, in responding to issues raised by some stakeholders, Biosecurity Australia adopted a semi-quantitative risk analysis of New Zealand apples in the previous revised *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004)[4] report to reinforce the transparency and objectivity of the analysis wherever possible. This approach used a semi-quantitative method where feasible, but dealt with data deficits by accepting qualitative assessments as inputs. This draft has continued to use the semi-quantitative framework supplemented where appropriate with qualitative analysis.

In some cases there may be no need to undertake a new risk analysis but an existing analysis or policy can be used where this is relevant or appropriate. ISPM No.2: *Part 1 – Import regulations: Guidelines for pest risk analysis* (FAO, 1996a) specifically allows for this situation in stating that:

> Prior to proceeding with a new PRA, a check should be made as to whether the pathway or pest has already been subjected to the PRA process, either nationally or internationally. If a PRA exists, its validity should be checked as circumstances may have changed. The possibility of using a PRA from a similar pathway or pest, that may partly or entirely replace the need for this PRA, should also be investigated.

Existing risk assessments or policies can be validated by examining the pest records associated with continued trade in horticultural commodities from various countries. A relevant example is the continued importation of New Zealand stone fruit into Australia (excluding Western Australia) and the proposed extension of this policy for New Zealand stone fruit into Western Australia (2005).

In this report several different approaches have been used to assess the risk of pests and consider risk management measures.

[4] Available at http://www.daff.gov.au

These can be divided into four broad groupings as follows:

- contaminant pests for which Australia has existing risk mitigation strategies
- pests that have either been recently assessed by Biosecurity Australia or for which there are established risk mitigation strategies
- pathogens for which no recent PRA has been completed by Biosecurity Australia
- arthropods for which no recent PRA has been completed by Biosecurity Australia.

The allocation of specific pests to the four broad groups was based on the categorisation process (see later) and information on previous IRAs.

Contaminant pests

Contaminant pests included:

- New Zealand flower thrips
- burnt pine longhorn beetle
- wheat bug
- click beetle.

These pests have not been subjected to further assessment as they are not pests of mature apple fruit. If they were to be detected within apple consignments (assuming importation is approved) they would be treated as any other contaminant. Commodities already imported from New Zealand where contaminant pests such as these are potentially an issue include timber, *Prunus* spp. and kiwi fruit. For more information on these commodities the reader is directed to the AQIS Import Conditions database. There are no special risks associated with apples in regard to these contaminants. Information on the risk mitigation measures for contaminant pests is given in the section on risk management and draft operational framework.

Pests that have been assessed previously

Pests that have been recently assessed by Biosecurity Australia include:

- grey-brown cutworm
- leafrollers
- codling moth
- mealybugs
- Oriental fruit moth
- oystershell scale.

These pests have the potential to be present on stone fruit from New Zealand. Stone fruit has been imported to Australia (except Western Australia) from New Zealand for many years. In 2005 an extension of existing policy was developed proposing the importation of stone fruit into Western Australia. As part of the policy extension, these pests were assessed using a qualitative risk assessment process following the *Guidelines for import risk analysis, draft September 2001* (BA, 2001).[5] In order to increase transparency and facilitate access to information by stakeholders a qualitative risk analysis for each of these pests is presented in this report. These analyses use the same methodology as those presented in the extension of policy for stone fruit. However, it should be noted that for some pests there are variations between apples and stone fruit from New Zealand in the probability of entry, establishment and spread. These variations reflect differences in host preferences and differences in the way that the pests infest apples and stone fruit. These differences translate into differing likelihoods for importation and ultimately for entry, establishment and spread. Some intermediate consequence scores vary slightly; however, the final consequence ratings are the same.

[5] Available at http://www.daff.gov.au

Pests that have not been assessed previously

Pathogens for which no recent PRA has been completed by Biosecurity Australia

In the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) a semi-quantitative analysis was undertaken on fire blight, European canker and apple scab.

The IRA team reviewed the methodology used in the 2004 draft report noting that it was appropriate for pests that remain associated with imported apples to final use and discard of waste, and therefore should be used for the three pathogens. A summary of this methodology is given later in this section.

Arthropods for which no recent PRA has been completed by Biosecurity Australia

The semi-quantitative model used in the previous *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) had the following possible limitations when used for assessing some arthropod pests:

- A single apple unit is not relevant to these pests because they are mobile at some life stage and may move to establish a viable population.
- These pests could enter the environment from several points along the distribution pathway and not only with the waste from utility points.
- The lifecycles and environmental conditions necessary for the successful entry, establishment and spread of these pests vary considerably from those of pathogens.

In the 2004 draft the IRA team dealt with these limitations by adjusting some model values for the arthropod pests. However, several stakeholders raised significant issues about this approach. In order to address the limitations inherent in the model when dealing with mobile pests the IRA team decided to vary the methodology used for:

- apple leafcurling midge
- garden featherfoot.

Further details of the methodology for apple leafcurling midge and garden featherfoot are given later in this section.

Stage 1: Initiation of this PRA

This PRA was initiated by a request from New Zealand in January 1999 for Australia to review its policy for the importation of mature apple fruit (*Malus* × *domestica* Borkhausen). It builds upon an analysis completed in December 1998 of the risks associated with the ‘unrestricted’ importation of New Zealand apples, a further analysis, and draft IRAs released in October 2000 and February 2004.

Stage 2: Pest risk assessment

The process for pest risk assessment in this draft IRA can be broadly divided into four interrelated processes:

- pest categorisation
- assessment of the probability of entry, probability of establishment and probability of spread
- assessment of consequences

- combining the probability of entry, establishment and spread with the estimate of consequences to estimate the unrestricted risk.

The methods used for these four processes are described in detail below.

Pest categorisation

Pest categorisation is a process to examine, for each pest, whether the criteria in the definition of a quarantine pest are satisfied; that is, whether the pests identified should be considered as either 'quarantine pests' or not. The objective of pest categorisation is, therefore, to screen a large and frequently unmanageable list of potential quarantine pests, before doing the more in-depth examinations within the risk assessment proper.

The International Plant Protection Convention (FAO, 2003) defines a quarantine pest as:

> 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.

An endangered area is 'an area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss'.

Elements in the categorisation of a pest

ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) states that the categorisation of a pest as a quarantine pest includes the following primary elements:

- identity of 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.

Further details on these elements are provided in ISPM No. 11.

Categorisation process used in this IRA

Based on the above elements, the pest categorisation was carried out in six steps.

- Step 1 Compilation of species lists
- Step 2 Presence or absence within Australia
- Step 3 Potential for being on fruit
- Step 4 Potential for establishment or spread
- Step 5 Potential for consequences
- Step 6 Final categorisation.

Step 1 Compilation of species lists

Species identified as being associated with apple fruit or apple orchards in New Zealand were derived from three sources. These included lists provided by New Zealand (MAFNZ, 1999a) (MAFNZ, 2002b) (MAFNZ, 2000b), literature research by Biosecurity Australia and comments provided by stakeholders on the revised *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004). Consolidated lists of 326 arthropod and mollusc species and 117 pathogens were compiled and are provided in Part C of this document.

Step 2 Presence or absence within Australia

Each species recorded in step 1 was assessed for presence within Australia by reviewing published records, checklists and catalogues, various pest and disease databases, and consulting relevant specialists. Species were classified as:

- 'Yes' if present in Australia,
- 'Yes*' if present but not widely distributed and being officially controlled or where regional freedoms exist within Australia,
- 'No' if there was no evidence of its presence in Australia, or
- 'Uncertain' if the organism is not identified to species level.

Step 3 Potential for being on the pathway

Only species categorised as 'No', 'Uncertain' or 'Yes*' in step 2 were assessed for their potential to be on the pathway. This was based on the scope that the pathway being assessed in this draft IRA is fruit free of trash. The potential was then categorised as 'Likely' or 'Not likely'. Table 2 provides the criteria used to assess the potential of a species to be on the pathway.

These criteria have been revised since the draft IRA in 2004 to properly reflect the current quarantine policy for dealing with pests that do not live on or in the commodity being imported. The policy on the interception of pests not known to be pests of the imported commodity (contaminants) requires that the consignment be held until the quarantine status of the contaminants is determined. If the pests are determined to be a quarantine pest the importer is given the options of treatment of the consignment to remove the pest, re-export of the consignment or destruction of the consignment.

On the basis of this established policy, pests not known to be directly associated with mature apple fruit from New Zealand have been removed from the pest categorisation process and will be dealt with using existing policy for contaminants.

Table 2 Potential of a species to be on the pathway

Potential for being on pathway	Description of criteria	Arthropod examples	Pathogen examples
Likely	The species would be likely to be on the pathway if at least one life stage lives in or on mature apple fruit.	apple leafcurling midge	fire blight
Not likely	The species would be unlikely to be on the pathway if it does not live in or on mature apple fruit (but may be found on other parts of the apple plant).	Bailey's apple rust mite	root rot

Step 4 Potential for establishment or spread

The potential for establishment or spread was assessed as 'feasible' for all those species rated as 'likely' in step 3.

A rating of 'feasible' for the potential for establishment or spread is based on:

- New Zealand's climate varies from warm subtropical in the far north to cool temperate in the far south. Similar conditions exist in the PRA area – Australia – which has tropical, subtropical, temperate and cool temperate conditions.
- Apples are grown in many parts of Australia and ecological conditions in these areas are similar to those of New Zealand, or environmental conditions are ameliorated by cultural practices.
- Potential alternative hosts are present in Australia.

Step 5 Potential for consequences

The potential for consequences was assessed only for species with the rating of 'Likely' for potential for being on pathway and 'Feasible' for potential for establishment or spread. The potential for consequences was categorised as 'Significant' or 'Not significant'. The criteria for these categories are set out in Table 3.

Table 3 Criteria for categorisation of the potential for consequences

Potential for consequences	Description of criteria	Arthropod examples	Pathogen example
Significant	The species would have potential for consequences in the PRA area if: (i) it has been reported as a pest with significant economic impact (ii) it is known to be polyphagous, or (iii) it is known to be a vector of a disease.	apple leafcurling midge	fire blight
Not significant	The species would not exhibit potential for consequences in the PRA area if: (i) it has been reported as a pest with no significant economic impact (ii) it has been reported only as a scavenger or secondary feeder on fungi or bacteria, or (iii) it is a potential biocontrol agent and is known to attack pest species only.	platygasterid parasitic wasp	Mouldy core rot

Step 6 Final categorisation

The final outcome of pest categorisation is to determine if the species needs to be considered further. Thus the question 'Consider species further?' was answered as 'Yes', 'Yes*'[6] or 'No'.

A species was not considered further in the analysis if it was assessed as being present in Australia, or it was absent from Australia but was rated as 'Not likely' for its potential for being on the pathway, or 'Not significant' for its potential for consequences. It should be noted that, for some species that are not present in Australia, even if the answer to the question 'Consider species further' is 'No' in this import risk analysis, they may still be potential quarantine pests for Australia. While the species is unlikely to be on the pathway for

[6] 'Yes*' indicates that the species is present but not widely distributed and is being officially controlled or is absent where regional freedoms exist within Australia.

importation of New Zealand apples it could be a candidate for importation on other commodities.

Assessment of the probability of entry, establishment and spread

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 to an endangered area, and subsequently be transferred to a suitable host.

The probability of entry is based on pathway scenarios depicting necessary steps in the sourcing of the commodity for export, its processing, transport and storage, its utilisation in Australia, and the generation and disposal of waste. Scenarios for importation and distribution are described in detail in separate discussions.

The probability of establishment and spread encompasses biological factors associated with the likelihood that a pest will successfully propagate on or in that host, and disperse from there to other populations of susceptible hosts. The probability of establishment and spread is obtained from an examination of biologic factors associated with compatibility of the host and environment, and the availability of necessary mechanisms for dispersal. These factors are summarised in ISPM No. 11 *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004), and will be described in detail in a separate discussion.

All of the pests assessed in this draft follow the general approach shown above for the assessment of the probability of the entry, establishment and spread. However, the details of the approach used to estimate the individual components vary depending of the specific pests being considered. Various factors relevant to the assessment of the probability of entry, establishment and spread are discussed in this section.

Projected volume of trade in New Zealand apples

The amount of apple fruit that might be imported from New Zealand if importation was to proceed for a prescribed period without phytosanitary restrictions is an important factor in estimating the probability of importation. The period that was chosen for the purpose of this analysis was 12 months. A 12-month period is a convenient interval to estimate the possible volume of trade and the risk analysis methodology uses a one year volume of trade as an input value. Several stakeholders have assumed that because one year of trade is used then any quarantine protection based on the model is only sufficient for one year. This is not correct. The methodology used, including the matrices used for deciding if the assessed risks are above or below Australia's ALOP, are based on an input value of one year's trade. The methodology is based on Australia's policy of on-going quarantine protection and provides outputs that are totally consistent with this policy.

Because there is no existing trade in apple fruit from New Zealand, the volume of apples that might be imported during 12 months was difficult to estimate. The difficulty was compounded by the fact that trade in apple fruit will not necessarily be limited to a single clearly defined market. For example, apples might be imported in packed cartons for table consumption, but might also be imported in bulk bins for repacking or for processing into fruit juices or other products. The size of these markets would be dictated by many interrelated factors, including the supply of and demand for apples within Australia, the cost of shipment, and any price differential between production of apples in Australia and New Zealand.

In this IRA, the experts assumed a market penetration of approximately 20% of the domestic fresh market if New Zealand apples were permitted entry. Based on this, the most likely number of individual apples that may come into Australia was calculated as shown below.

This calculation was based on the 2002 production figures (ABS, 2003) but production can vary significantly from year to year. For example, the production of apples decreased by about 23% in the 2003 production year.

Total Australian production for 2002	=	325,500 t
Amount utilised for processing	=	40% (130,200 t)
Exports for 2002	=	25,920 t
Balance – domestic fresh fruit	=	169,380 t
	=	9,410,000 cartons (18 kg each)
20% of domestic fresh fruit	=	1,882,000 cartons
20% of domestic fresh fruit as individual fruits (assuming an average count per carton of 100)	=	188,200,000 apple fruit (Approximately 200 million apples)

This information was entered into the simulation model as a Pert distribution L ~ Pert (100,000,000; 200,000,000; 400,000,000). Where certain pests were of concern to Western Australia only, the volume of apples likely to be imported into that state was estimated as one-tenth of the above figures, based on the proportion of the Australian population that resides in Western Australia (1.9 million) compared with 19.4 million in whole of Australia.

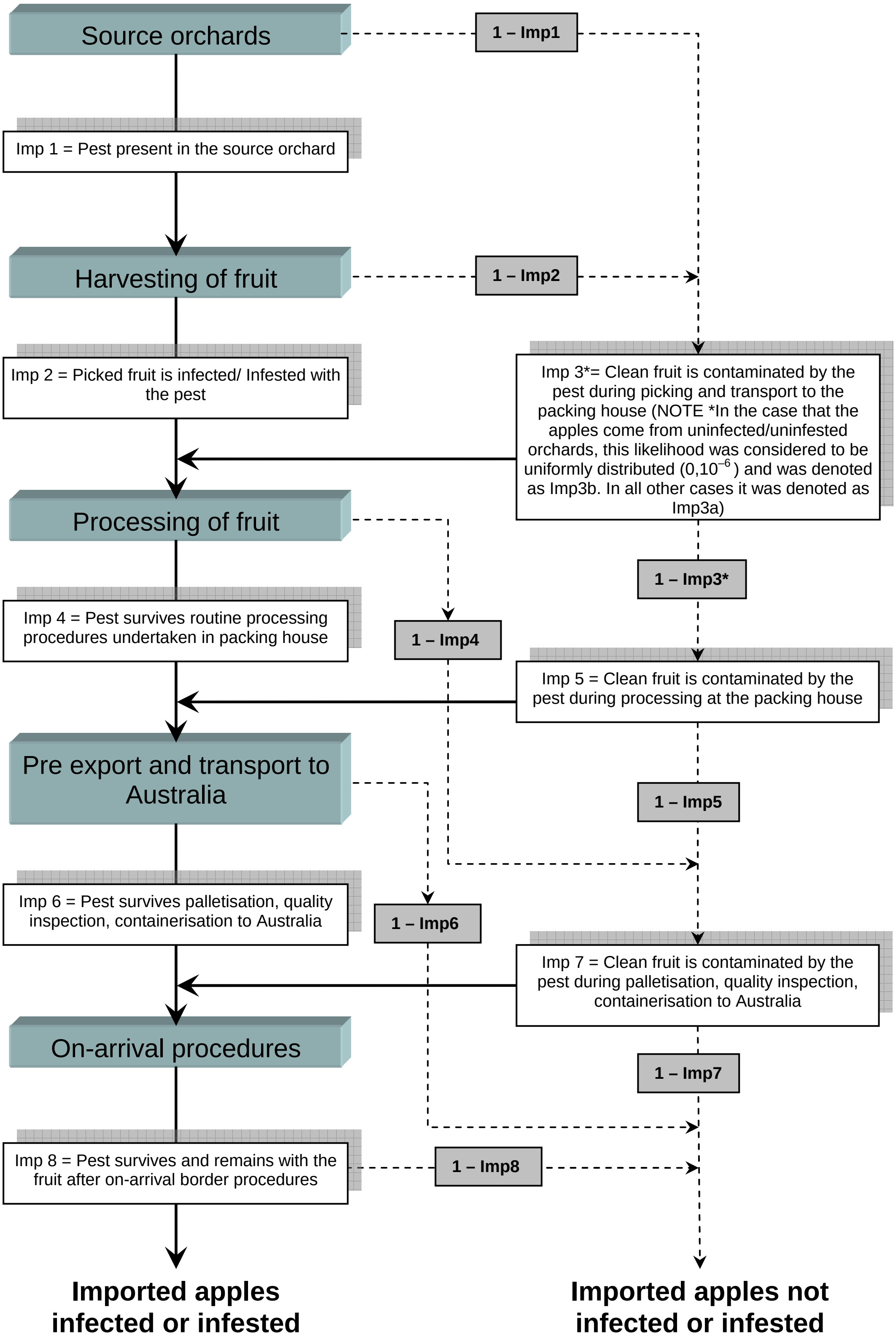
MAFNZ has suggested that the estimated volume used in the model may be substantially above the volumes that would be imported from New Zealand. This issue was discussed further with New Zealand and Australian industry representatives but conflicting information on the potential volume was provided. The IRA team has decided to continue to use the same volume figures used in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) as shown above.

Importation steps

The following importation scenario is used for fire blight, European canker, apple scab, apple leafcurling midge and garden featherfoot.

The 'biological pathway', or ordered sequence of steps undertaken in sourcing, processing and exporting a commodity up to the point where it is released from quarantine by the importing country is termed the 'importation scenario' (see Figure 1). The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand and the end-point is 'the arrival in Australia' of infected or infested fruit or packaging materials. In this context, 'arrival in Australia' is taken to mean the release of imported apples from the port of entry – whether this is an airport or a shipping port.

Figure 1 Importation scenario for apple fruit from New Zealand



Importation steps are summarised below. Note that, because the pathways include the opportunity for contamination of clean fruit, the importation scenario is not a simple sequence following Imp1 to Imp8.

- Importation step 1 (Imp1): proportion of orchards in which the pest is present.
- Importation step 2 (Imp2): proportion of fruit coming from an infected or infested orchard that is infected or infested.
- Importation step 3 (Imp3a): proportion of clean fruit from infected or infested orchards that is contaminated during picking and transport to the packing house.
- Importation step 3 (Imp3b): proportion of clean fruit from uninfected or uninfested orchards that is contaminated during picking and transport to the packing house.
- Importation step 4 (Imp4): proportion of infected or infested fruit that remains infected or infested after routine processing procedures in the packing house.
- Importation step 5 (Imp5): proportion of clean fruit that is contaminated during processing in the packing house.
- Importation step 6 (Imp6): proportion of infected or infested fruit that remains infected or infested during palletisation, quality inspection, containerisation and transportation to Australia.
- Importation step 7 (Imp7): proportion of clean fruit that is contaminated during palletisation, quality inspection, containerisation and transportation.
- Importation step 8 (Imp8): proportion of infected or infested fruit that remains infected or infested after on-arrival minimum border procedures for the unrestricted analyses.

These importation steps represent an approximation of the trade in apples sufficient to estimate the proportion of fruit that will be infected/infested. While more complicated pathways could be considered, such as allowing Imp5 to vary depending on the infection status of the orchard, this was not done because the IRA team concluded that the added complexity would not lead to significant differences in the assessment.

The following sections on the eight importation steps broadly describe the guidelines followed in allocating likelihoods for each step. Details considered in deciding these likelihoods are given in the individual pest risk assessments. Each importation step has been considered conditionally on an apple arriving at the given point in the pathway. In most cases, however, the likelihoods are evaluated independently of the previous likelihoods; that is, they are fixed regardless of the pathway that is being considered. The exception to this is Imp3, which is dependent on whether apples have been sourced from an infected/infested or uninfected/uninfested orchard.

Importation step 1 (Imp1)

The likelihood assigned to the first importation step represents the uncertainty about the proportion of orchards in New Zealand that are infected or infested with a given pest.

The proportion of infected or infested orchards was determined largely by four groups of factors: climate and environment, orchard management, varietal susceptibility, and pest epidemiology. In most cases, these groups of factors are interrelated and, as a result, there are areas within New Zealand within which the prevalence of infection or infestation is either higher or lower or, in some cases, in which the pest is known to be absent. Information available on these aspects was considered in determining the likelihood for this step.

Importation step 2 (Imp2)

The likelihood assigned to the second importation step represents the uncertainty about the proportion of apples coming from infected or infested orchards that would be infected or infested. Because this likelihood is inherently complex, it was approached in each pest risk assessment systematically by considering the following questions using available information.

- How likely is infestation or infection of apple fruit at the time of picking?

- How likely is infestation or infection on an individual block within an infected or infested orchard?
- How likely is infection or infestation on each tree on an infected or infested block?
- How likely is the pest to be on or in apple fruit selected from an infected or infested tree?

Importation step 3 (Imp3 a/b)

The likelihood assigned to the third importation step represents the uncertainty about the proportion of clean apples becoming infected during picking and transport to the packing house. This likelihood depends on whether apples are coming from an infected or infested source orchard and on the ability of each pest to persist in or on bins, other containers or equipment used to transport apples.

The likelihood of infested/infected fruit from infested/infected orchards is denoted by Imp3a and is estimated in the individual assessments. Some pathogens may lead to the production of infective materials, such as ooze or damaged flesh, that can be rubbed off on the surface of other apples, containers or equipment, persist in a stable form, and infect other apples in the same or subsequent batches of apples. The ability of some arthropods to move freely among apples or within the environment may influence the likelihood that they will persist in inadequately cleaned bins or contaminate clean bins in the field.

In the case that the apples come from uninfected or uninfested orchards, this likelihood (Imp 3b) was universally considered to be uniformly distributed between 0 and 10^{-6}. In these cases, transmission can only occur through residual contamination of bins and other equipment that has previously come into contact with infected apples.

Importation step 4 (Imp4)

The likelihood assigned to the fourth importation step represents the uncertainty about the proportion of apples in or on which pests survive during routine processing, packing and cold storage before transport. For many pests, this likelihood was dictated largely by whether the surface of fruit was infected or infested, or whether the pest lived inside the fruit. External pests are likely to be more vulnerable to physical treatments (for example, washing and brushing) and chemical treatments (for example, dips and waxing).

Because this likelihood is complex, it was approached in each pest risk assessment systematically by considering the following questions using available information about the processes used in New Zealand packing houses and the proportion of the packing houses using these processes.

- How likely is the pest’s survival after post-harvest treatments and temporary cold storage?
- How likely is the pest’s survival after flotation dump?
- How likely is the pest’s survival after high-volume/high-pressure washing?
- How likely is the pest’s survival after brushing?
- How likely is the pest’s survival, or the persistence of infected or infested fruit, after sorting and grading?
- How likely is the pest’s survival after waxing?
- How likely is the pest’s survival after cold storage of fruit before transport?

Importation step 5 (Imp5)

The likelihood assigned to the fifth importation step represents the uncertainty about the proportion of clean apples that would become infected or infested during routine processing, packing and cold storage before transport.

Consideration was given to the characteristics of the pest, in particular its tolerance to the physical, chemical and thermal processes used in the packing house and its ability to move among apples. Other factors considered included the quality management practices within packing houses, the most important being adherence to rigorous hygiene practices at steps such as water baths or brushing where contamination may be most likely to occur.

Importation step 6 (Imp6)

The likelihood assigned to the sixth importation step represents the uncertainty about the proportion of apples in or on which pests survive routine practices used during palletisation, quality inspection, containerisation and transport to Australia. Consideration was given to the physical characteristics of the pest, its resilience to a range of temperatures, aspects of its lifecycle, and the nature of its infection or infestation of apple fruit.

Importation step 7 (Imp7)

The likelihood assigned to the seventh importation step represents the uncertainty about the proportion of clean apples that would become infected or infested during palletisation, quality inspection, containerisation and refrigerated transport to Australia. Consideration was given to the tolerance of the pest to the physical and thermal processes, and its ability to move among apples or among cartons or bins.

Importation step 8 (Imp8)

The likelihood assigned to the eighth and final importation step represents the uncertainty about the proportion of apples in or on which pests survive and remain with the fruit after on-arrival minimum border procedures.

The factors considered here relate only to the minimum border procedures used by relevant government agencies. There is some AQIS inspection, such as verification of the commodity as described in the shipping documents, verifying external and internal contamination of containers and their packaging. Possible AQIS on-arrival inspection for quarantine pests associated with apples is not considered in the assessment of unrestricted risk.

Calculating the probability of importation

The overall probability that an imported apple was infected/infested was the sum of the proportions associated with each of the ten individual pathways (Table 4). Given the structure of the model, the proportion of apples that are infected or infested and the probability that a particular apple is infected or infested are equal. The proportions for the pathways are tabulated in Table 4. These pathways were obtained from an analysis of the importation scenario in Figure 1.

In each simulation, the proportions for each pest combined with the projected volume of trade in New Zealand apples provides an estimate of the number of infested/infected apples that may be imported.

Table 4 The number of infected or infested apples that might be imported during 12 months

Probability	Description and calculation
No. imported $_{infected}$	The number of infected or infested apples that might be imported during 12 months = Annual volume x $P_{Importation\ (apple)}$
Annual volume	The number of apples that might be imported into Australia during 12 months 100,000,000 = Minimum 200,000,000 = Most likely 400,000,000 = Maximum
$P_{Importation\ (apple)}$	The probability that an individual imported apple will be infected or infested = Path1 + Path2 + Path3 … Path10
Path1	The probability that an apple fruit will follow pathway 1 = Imp1 x Imp2 x Imp4 x Imp6 x Imp8
Path2	The probability that an apple fruit will follow pathway 2 = (1–Imp1) x Imp3b x Imp4 x Imp6 x Imp8
Path3	The probability that an apple fruit will follow pathway 3 = (1–Imp1) x (1–Imp3b) x Imp5 x Imp6 x Imp8
Path4	The probability that an apple fruit will follow pathway 4 = (1–Imp1) x (1–Imp3b) x (1–Imp5) x Imp7 x Imp8
Path5	The probability that an apple fruit will follow pathway 5 = (1–Imp1) x Imp3b x (1–Imp4) x Imp7 x Imp8
Path6	The probability that an apple fruit will follow pathway 6 = Imp1 x (1–Imp2) x Imp3a x Imp4 x Imp6 x Imp8
Path7	The probability that an apple fruit will follow pathway 7 = Imp1 x (1–Imp2) x (1–Imp3a) x Imp5 x Imp6 x Imp8
Path8	The probability that an apple fruit will follow pathway 8 = Imp1 x (1–Imp2) x Imp3a x (1–Imp4) x Imp7 x Imp8
Path9	The probability that an apple fruit will follow pathway 9 = Imp1 x (1–Imp2) x (1–Imp3a) x (1–Imp5) x Imp7 x Imp8
Path10	The probability that an apple fruit will follow pathway 10 = Imp1 x Imp2 x (1–Imp4) x Imp7 x Imp8

Estimating the probability of entry establishment and spread

The approach shown below was used to estimate the probability of entry, establishment and spread for fire blight, European canker and apple scab. Although a similar structure was also used for apple leafcurling midge and garden featherfoot, the details vary and the approach taken with these is described in a separate section.

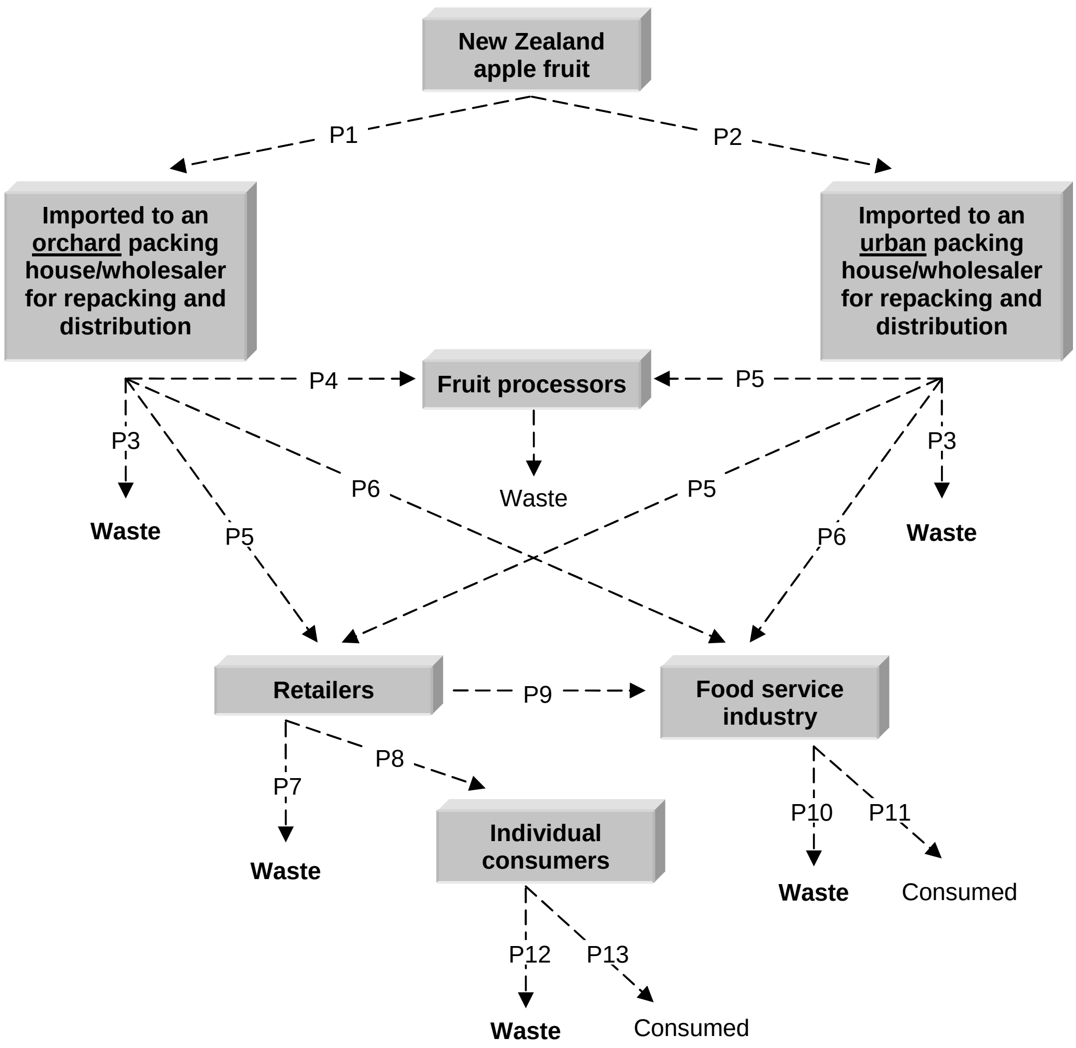
Utilisation of apple fruit in Australia and generation of waste

The purpose of this part of the risk analysis is to identify and quantify, as far as is practical, the likely pattern of distribution and utilisation of imported apple fruit and the generation and disposal of apple waste. The pathways of distribution, utilisation and waste generation are shown in Figure 2. There are five key points (termed '*utility points*') at which apples are distributed or utilised and at which apple waste will be generated. These include two pathways from importers/wholesalers (which have been delineated because of the proximity of orchard-based premises to high-density commercially grown fruit), to retailers, then to the food service industries, and finally to individual consumers. Although included in the diagram, fruit products and the processed and concentrated waste generated during the manufacture of fruit juices and other products by fruit processors was not considered a significant phytosanitary risk.

The proportion of imported apples that may be channelled through each of these utility points and the proportion that might subsequently be discarded whole or in part as waste are calculated below.

The characteristics of fruit distribution, vendor practices, and waste disposal at the various utility points are discussed in general terms in the text below. The implications of each for the likelihood of exposure are explored in detail in the individual pest risk assessments.

Figure 2 Utilisation of apple fruit in Australia and generation of waste



Definitions for the proportions shown in Figure 2 are given below.

P1	=	The proportion of imported fruit that might be imported directly to an orchard packing house for repacking
	=	Uniform (0.7, 1). This range was used to consider the effect of a large proportion of apples being sent to orchard packing houses. Other scenarios were trialled in which this range was significantly reduced to consider the effect of a large proportion of apples being sent to urban packing houses.
P2	=	The proportion of fruit that might be imported directly to urban wholesalers for repacking
	=	1–P1
P3	=	The proportion of fruit that may spoil during repacking and storage
	=	Uniform (10^{-6}, 10^{-3})
P4	=	The proportion of imported fruit that might be channelled by wholesalers (orchard-based or urban) to fruit processors
	=	0 (considered a low volume pathway of rare occurrence)
P5	=	The proportion of imported fruit that might be channelled from wholesalers (orchard-based or urban) to retailers
	=	1–(P3+P6)
P6	=	The proportion of imported fruit that might be channelled from wholesalers (orchard-based or urban) to the food service industry
	=	Uniform (10^{-3}, 5 x 10^{-2})
P7	=	The proportion of fruit purchased by retailers that might spoil and be discarded before sale
	=	Uniform (10^{-3}, 5 x 10^{-2})
P8	=	The proportion of fruit purchased by retailers that might be channelled to individual consumers
	=	1–(P7 + P9)
P9	=	The proportion of fruit purchased by retailers that might be channelled to the food service industry
	=	Uniform (0, 10^{-6})
P10	=	The proportion of fruit purchased by the food service industry that might spoil and be discarded, or be discarded by the consumer
	=	Uniform (5 x 10^{-2}, 0.3)
P11	=	The proportion of fruit purchased by the food service industry that might be consumed or utilised
	=	1–P10
P12	=	The proportion of fruit purchased by consumers that might be discarded whole or in part as waste
	=	Uniform (0.7, 1)
P13	=	The proportion of fruit purchased by consumers that might be consumed without generation of any waste
	=	1–P12

The above proportions for use of apple fruit and generation of waste at utility points were developed in consultation with stakeholders, fruit distributors and waste management experts. These were considered by the IRA team before it made its decision on ratings. The proportion P12 was considered to be between 70 and 100% in this analysis because most consumers discard at least some part of each purchased apple. The last column in Table 5 shows the calculation of the proportions of imported apple fruit discarded at each utility point.

Table 5 Summary: utilisation of apple fruit in Australia and generation of waste

Utility point	Proportion of imported apple fruit utilised	Proportion of apple fruit discarded as waste by each utility point	Proportion of imported apple fruit discarded as waste
Orchard-based re-packers and wholesalers	P1	P3	P1 x P3
Urban re-packers and wholesalers	P2 = (1–P1)	P3	P2 x P3
Retailers	P5 = 1–(P3+P6)	P7	P5 x P7
Food service industry	= P6 +P9 x P5	P10	(P5 x P9 + P6) x P10
Consumers	P5 x P8 = P5 x (1–P7–P9)	P12	P5 x P8 x P12

Exposure

The term exposure is applied to the likelihood of transfer of the pest from an infested or infected apples (waste) to a susceptible host plant. This is a complex variable dependent on a number of critical factors. A sequence of events needs to be completed for successful exposure of host plants to pests from infested or infected apples, in order for a pest to establish in Australia. An analysis of key steps in the sequence of events that would need to occur in order for successful exposure includes a consideration of factors such as:

- viability of the pest
- survival mechanism of the pest
- transfer mechanism(s) of the pest
- host receptivity
- environmental factors.

Exposure groups

The term 'exposure group' denotes a category of susceptible host plants in Australia, and may be based on species, geographic location or the manner in which it is managed. The purpose of an exposure group is to delineate certain collections of susceptible host plants for which the likelihood of exposure[7], or the impact of a pest, are likely to be meaningfully different. This enabled a more precise and transparent assessment of overall risk.

[7] Likelihood of exposure is the likelihood that a pest will be distributed to an endangered area and subsequently transferred to a susceptible host. BA takes 'transfer' in this context to describe the exposure of a suitable site on a suitable host to a sufficient dose of a pest to initiate infection.

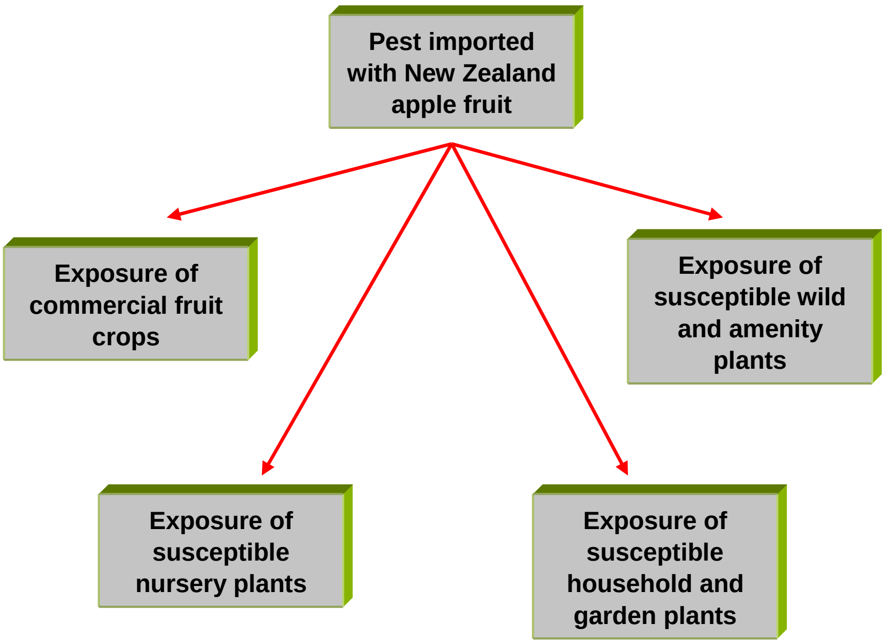
Exposure groups identified in this analysis include (see Figure 3):

- susceptible commercial fruit crops
- susceptible nursery plants
- susceptible household and garden plants, including weed species
- susceptible wild (native and introduced) and amenity plants including susceptible plants growing on farmland (includes abandoned and derelict orchards).

These are abbreviated as commercial fruit crops, nursery plants, household and garden plants and wild and amenity plants in various tables and figures that follow. The actual plant species composition of exposure groups is dependent on the host range of each pest.

Table 6 summarises the calculations for the fruit wasted at utility points.

Figure 3 Exposure groups for pests of New Zealand apples



Proximity

The term 'proximity' expressed in this report refers to the likelihood that a utility point is sufficiently close to a host plant in a particular exposure group. Different pests have different host ranges and spread mechanisms so proximity values will vary according to the specific pest. Proximity values also vary according to utility point. For example, orchard based wholesalers will be very close to commercial fruit crops but consumers who live in cities will not be close to commercial fruit crops but a proportion of them will be close to household and garden plants that are pest hosts. Relevant proximity factors are discussed in each pest section.

Estimation of the probability of establishment and the probability of spread

The calculation of the probability of establishment and spread involves examination of the factors relevant to the successful colonisation of a susceptible host, and to the subsequent establishment and spread within the larger population of susceptible hosts. Establishment and spread begins with the assumption that a sufficient or sustainable number of pests have been transferred to a suitable site near or on a susceptible host plant.

The probability of establishment and spread for the four utility points were estimated by the model to provide combined estimates for establishment and spread.

The probability of establishment and spread is calculated as PPES = PE x PS where PE is the probability of establishment and PS is the probability of spread. These are both specified as distributions and the standard simulation technique used to calculate the uncertainty of PPES.

IPPC criteria for establishment and spread

The assessment of establishment and spread followed the guidelines in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004), summarised below.

Probability of establishment

The probability of establishment for each exposure group is derived from a comparative assessment of those factors in the source country and the 'PRA area' that are considered pertinent to the ability of a pest to survive and propagate.

These factors are listed below:

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

Whether hosts and alternate hosts are present and how abundant or widely distributed they may be; whether hosts and alternate hosts occur within sufficient geographic proximity to allow the pest to complete its lifecycle; whether there are other plant species, which could prove to be suitable hosts in the absence of the usual host species; whether a vector, if needed for dispersal of the pest, is already present in the PRA area or is likely to be introduced; and whether another vector species occurs in the PRA area.

Suitability of environment

Factors in the environment (for example, suitability of climate, soil, pest and host competition) that are critical to the development of the pest, its host and (if applicable) its vector, and to their ability to survive periods of climatic stress and complete their lifecycles, should be identified. It should be noted that the environment is likely to have different effects on the pest, its host and its vector. This needs to be recognised in determining whether the interaction between these organisms in the area of origin is maintained in the PRA area to the benefit or detriment of the pest. The probability of establishment in a protected environment, for example, in glasshouses, should also be considered.

Cultural practices and control measures

Where applicable, practices used during the cultivation/production of the host crops should be compared to determine whether there are differences in such practices between the PRA area and the origin of the pest that may influence its ability to establish.

Pest control programs or natural enemies already in the PRA area, which reduce the probability of establishment, may be considered. Pests for which control is not feasible should be considered to present a greater risk than those for which treatment is easily accomplished. The availability (or lack) of suitable methods for eradication should also be considered.

Other characteristics of the pest affecting the probability of establishment

Reproductive strategy of the pests and method of pest survival – characteristics, which enable the pest to reproduce effectively in the new environment, such as parthenogenesis/selfcrossing, duration of the lifecycle, number of generations per year, resting stage, should be identified.

Genetic adaptability – whether the species is polymorphic and the degree to which the pest has demonstrated the ability to adapt to conditions like those in the PRA area should be considered, e.g., host specific races or races adapted to a wider range of habitats or to new hosts. This genotypic (and phenotypic) variability facilitates a pest's ability to withstand environmental fluctuations, to adapt to a wider range of habitats, to develop pesticide resistance and to overcome host resistance.

Minimum population needed for establishment – if possible, the threshold population that is required for establishment should be estimated.

Probability of spread

The partial probability of spread for each exposure group is derived from a comparative assessment of those factors in the source country and 'PRA area' considered pertinent to the expansion of the geographical distribution of a pest.

These factors include:

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

Annual probability of entry, establishment and spread

The annual probability of entry, establishment and spread is obtained from the 'partial' probabilities of entry, establishment and spread obtained for each exposure group. Table 6 and Table 7 set out the way the relevant factors are combined to estimate these partial probabilities.

Table 6 Number of infected fruit wasted at a utility point

No. imported $_{infected}$	The number of infected or infested apples that might be imported during 12 months without phytosanitary restrictions = Table 4
For each of the five utility points: orchard wholesalers; urban wholesalers; retailers; food service; and consumers	
Wasted $_{Utility\ point}$	The proportion of imported apples that are channelled to, and subsequently discarded by, a utility point = Table 5
No. wasted $_{Utility\ point}$	The number of imported infected or infested apples that are expected to be channelled to, and subsequently discarded by, a utility point = No. imported $_{infected}$ x Wasted $_{utility\ point}$

Table 7 Partial probability of entry, establishment and spread (PPEES) resulting in entry, exposure, establishment and spread of susceptible host plants within the exposure groups

Probability	**Description and calculation**
For each of the four exposure groups: commercial fruit crops; nursery plants; household and garden plants; and wild and amenity plants	
$PPEES_{\text{Exposure group}}$	Probability that at least one pest that enters Australia with imported New Zealand apples will gain direct exposure to the exposure group and result in an establishment and spread event. $= 1 – (1–PPEES_{\text{Exposure group from orchard wholesalers}}) \times (1–PPEES_{\text{Exposure group from urban wholesalers}}) \times (1–PPEES_{\text{Exposure group from retailers}}) \times (1–PPEES_{\text{Exposure group from food service}}) \times (1–PPEES_{\text{Exposure group from consumers}})$
For each of the four exposure groups: commercial fruit crops; nursery plants; household and garden plants; and wild and amenity plants, and for each of the five utility points: orchard wholesalers; urban wholesalers; retailers; food service; and consumers	
$PPEES_{\text{Exposure group from utility point}}$	Probability that at least one pest will gain exposure to susceptible plants in the exposure group and result in establishment and spread, as a result of waste generated by utility point and discarded near host plants $= 1–(1– PPES_{\text{Exposure group}} \times Exp_{\text{Exposure group from utility point waste}})^{\text{Waste units from utility point near exposure group}}$
$Exposure_{\text{Exposure group from utility point waste}}$ (Exp)	Probability that exposure of susceptible hosts within the exposure group would result from utility point discarding a single infected apple = pest-specific estimate
$Waste\ units_{\text{From utility point near exposure group}}$	Number of infested or infected whole or part apples that might be discarded by utility point near susceptible host plants within the exposure group $= No.\ wasted_{\text{Utility point}} \times Proximity_{\text{Utility point near exposure group}}$
$Proximity_{\text{Utility point near exposure group}}$	Proportion of utility point situated near an exposure group = pest-specific estimate
$PPES_{\text{Exposure group}}$	Partial probability of establishment and spread for relevant exposure group. This is defined in the section *Estimation of the probability of establishment and the probability of spread*.

Calculation of the overall annual probability of entry, establishment and spread is explained in Table 8. The calculations consider the probability that entry, establishment and spread might occur by at least one of the available routes – that is, as a result of the exposure, establishment and spread of at least one group of susceptible hosts. In probability terms, the probability of at least one event occurring is equivalent to ‘one minus’ the probability that no events occur (since either at least one or no events must occur). Thus the focus of the sub-calculations in Table 8 is the probability that each group of susceptible hosts will not be exposed and that establishment and spread will not occur.

The calculations shown in Table 8 were carried out for each simulation (using the spreadsheet-based simulation model) and hence, since some of the inputs to these calculations are probability distributions, the outcome of the entire simulation is a probability distribution.

Table 8 Calculation of probability of entry, establishment and spread

Probability	Description and calculation
PEES	The probability of entry, establishment and spread $= 1–(1–PPEES_{Commercial}) \times (1–PPEES_{Nursery}) \times (1–PPEES_{Household}) \times (1–PPEES_{Wild})$

The probability of entry, establishment and spread in the simulation model is based on exposure of hosts to infected/infested fruit discarded as waste near susceptible host plants. That is, it is assumed that host exposure would take place only from infected/infested fruit discarded as waste. This may not be true for every single apple.

A host may be exposed to an infected/infested fruit before it goes into the waste pathway. For example, an insect may fly out during transport of apples or when pallets or boxes are opened at wholesalers or retailers, and find a susceptible host. Similarly, a worker or a customer in a supermarket may touch a fruit infected/infested with bacteria before it goes into the waste dump and then touch a susceptible nursery plant in the same store. Alternatively, an individual may take an infected/infested fruit from a utility point to some distant location so that the fruit does not go in the normal waste pathway. The model focuses on higher volume/higher risk pathways and does not cover pathways that do not contribute significantly to the overall risk.

The scenario of a pest escaping from the utility point applies more to arthropods which are mobile than to other pests. This is the major reason for using a different model in the PRAs for arthropod pests.

Approach to modelling arthropods

The model modified for arthropods consisted of the following steps.

Step 1 Estimating the probability of importation

The estimation of the probability of importation was evaluated in the same way as described in the pathogen risk analysis. This provided a transparent estimate of the anticipated proportion of infected fruit coming to Australia.

Step 2 Estimating the distribution of apples to utility points

The distribution of the expected numbers of infested apples arriving at each of the utility points was evaluated using the same model used in the pathogen risk analyses.

Step 3 Scenario analysis

It was the experts' view that the risk posed by mobile arthropod pests depended on the number of pests that reach each physical location. To characterise this, the infected fruit was divided between assumed numbers of physical locations that make up each utility point. The proportion of these locations that would be near exposure groups was then calculated and this data was used to support the analysis.

The numbers of infested apples per establishment per utility point were calculated using the proximity values and the following assumptions:

- apple imports will arrive over a six-month period from March to August (26 weeks)
- the number of orchard wholesalers is seven
- the number of urban wholesalers is six
- the number of retail outlets is 5000 (IBISWorld, 2004; IBISWorld, 2005)
- the number of food service outlets is 5000. There are over 60,000 food service outlets in Australia although not all would serve apples (ABS, 2001)
- the number of households where apples are consumed is estimated to be 6 million. This figure is based on an estimated 7.4 million households in Australia (ABS, 2004). The percentages of households which purchase fruit are 77 % in summer and 92 % in winter (HAL, 2004).

Similar scenarios over one week, 26 weeks and 52 weeks were also analysed. These calculations were used to produce tables which provided indicative estimates of the expected amount of infected/infested material that could reach each location.

Several scenarios were run varying the proportions of fruit being channelled to urban and orchard wholesalers to obtain a distribution. One set of scenarios was run with 70–100% of imported apples being distributed to orchard packing houses and the remainder (0–30%) being distributed to urban wholesalers. Another set of scenarios was run with 0.1–5% of imported apples being distributed to orchard packing houses and the remainder (95–99.9%) being distributed to urban wholesales. Estimates of the number of infested fruit were calculated by running a series of simulations of the model to estimate the distribution of the number of infested fruit per week to each utility point, based on the two scenarios (higher proportion of apples sent either to orchard wholesalers or to urban wholesalers).

Step 4 Estimation of the partial probabilities of entry, establishment and spread for each utility point exposure group combinations.

The scenario analysis as described in step 3 provided distributions that are indicative of the numbers of pests arriving in individual groupings of fruit over different periods. This result can be combined with the pest's ability to establish and spread based on its biological and ecological characteristics. These factors are described in the previous section on establishment and spread for pathogens.

For each utility point exposure group the likelihood of at least one establishment and spread event happening was estimated by the experts to develop 20 partial probabilities of entry, establishment and spread. In assessing these probabilities, the IRA team was aware that the calculated scenarios were indicative and only reflected the average case, and that it should factor this uncertainty into its assessments.

The alternative approach of trying to calculate these probabilities fully quantitatively was considered impractical because of the complexity and the lack of comprehensive data representing all the necessary relationships. Making assessments at the utility point scale allowed the experts to use all their relevant knowledge rather than being constrained to the limited structure provided by the simple model.

Step 5 Combining partial probabilities of entry, establishment and spread

The partial probabilities estimated are then combined via a simulation using a spreadsheet model and @RISK using a similar approach to that used for pathogens (Table 9 below).

Table 9 Calculation of probability of entry, establishment and spread for arthropods

Probability	Description and calculation
PEES	The probability of entry, establishment and spread = 1–(1–PPEES Orchard packing house, Commercial) x (1–PPEES Orchard packing house, Nursery) x (1–PPEES Orchard packing house, Household) x (1–PPEES Orchard packing house, Wild) x (1–PPEES Urban packing house, Commercial) x (1–PPEES Urban packing house, Nursery) x (1–PPEES Urban packing house, Household) x (1–PPEES Urban packing house, Wild) x (1–PPEES Retail, Commercial) x (1–PPEES Retail, Nursery) x (1–PPEES Retail, Household) x (1–PPEES Retail, Wild) x (1–PPEES Food services, Commercial) x (1–PPEES Food services, Nursery) x (1–PPEES Food services, Household) x (1–PPEES Food services, Wild) x (1–PPEES Consumers, Commercial) x (1–PPEES Consumers, Nursery) x (1–PPEES Consumers, Household) x (1–PPEES Consumers, Wild)
$\text{PPEES}_{\text{Utility, Exposure,}}$	The estimated probability that the *Utility* point causes at least one establishment and spread event in the specified *Exposure* group.

Assessment of consequences

The following methodology was used to assess the consequences for all pests analysed in this import risk analysis.

Criteria for assessing the consequences associated with a pest are outlined in the relevant Acts and agreements, and in the standards prepared by the international organisations.

In particular:

- The *Quarantine Act 1908* requires decision-makers to take into account the likelihood of harm being caused (to humans, animals, plants, other aspects of the environment, or economic activities) and the probable extent of the harm (Section 5D).
- The *SPS Agreement* states that:

  > members shall take into account as relevant economic factors; the potential damage in terms of loss of production or sales in the event of entry, establishment and spread of a pest or disease; the costs of control or eradication in the territory of the importing member; and the relative cost-effectiveness of alternative approaches to limiting risks.

- IPPC expands the ‘relevant economic factors’ described in the *SPS Agreement* to differentiate between the ‘direct’ and ‘indirect’ effects of a pest, and provides examples of factors that will typically be relevant to an import risk analysis.

In each case, consequence assessments do not extend to considering the benefits or otherwise of trade in a given commodity, or the impact of import competition on industries or consumers in the importing country.

The direct and indirect consequences considered in this draft IRA are discussed below, based on the framework provided in the *Guidelines for import risk analysis, draft September 2001* (BA, 2001).

Direct criteria

Plant life or health

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the direct consequences on plant life or health are:

- known or potential host plants
- types, amount and frequency of damage
- crop losses, in yield and quality
- biotic factors (e.g. adaptability and virulence of the pest) affecting damage and losses
- abiotic factors (e.g. climate) affecting damage and losses
- rate of spread
- rate of reproduction
- control measures (including existing measures), their efficacy and cost
- effect of existing production practices
- environmental effects.

Human life or health

This factor is listed in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) as a factor that is not directly relevant to the scope of the IPPC but may need to be considered as part of a comprehensive risk analysis of a proposed import.

Any other aspects of environmental effects not covered above

(For example, the physical environment or other life forms – micro-organisms, etc.).

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the direct consequences on any other aspects of the environment are:

- reduction of keystone plant species
- reduction of plant species that are major components of ecosystems (in terms of abundance or size), and endangered native plant species (including effects below species level where there is evidence of such effects being significant)
- significant reduction, displacement or elimination of other plant species.

Indirect criteria

Indirect consequences are the costs resulting from natural or human processes associated with the incursion of a pest.

Control, eradication, etc.

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the indirect consequences on eradication, control, etc.:

- changes to producer costs or input demands, including control costs
- feasibility and cost of eradication or containment
- capacity to act as a vector for other pests
- resources needed for additional research and advice.

Domestic trade and international trade

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the indirect consequences on domestic and international trade (the two are considered separately):

- effects on domestic and export markets, including particular effects on export market access
- changes to domestic or foreign consumer demand for a product resulting from quality changes.

Environment

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the indirect consequences on the environment:

- environmental and other undesired effects of control measures
- social and other effects (e.g. tourism)
- significant effects on plant communities
- significant effects on designated environmentally sensitive or protected areas
- significant change in ecological processes and the structure, stability or processes of an ecosystem (including further effects on plant species, erosion, water table changes, increased fire hazard, nutrient cycling, etc.)
- costs of environmental restoration.

Communities

Examples from ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004) that could be considered for the indirect consequences on the communities are: effects on human use (for example, water quality, recreational uses, tourism, animal grazing, hunting, fishing). This is listed under indirect effects on environment in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004). Further examples that could be considered, not listed in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004), include reduced rural and regional economic viability, loss of social amenity and any side effects of control measures.

Conclusion

In summary, the direct and indirect consequences described above collectively cover the economic, environmental and social effects of a pest. Given this, the consequences are also mutually exclusive – that is, an effect is not assessed more than once. In particular, the direct effects of a pest on a native or wild species are assessed under the criterion describing the 'animal or plant life and health, including animal and plant production losses', whereas the indirect or 'flow-on' effects on the environment are assessed under the last indirect criterion.

Describing the impact of a pest

The objective of the assessment of likely consequences is to determine the likely impact of a pest on the Australian community as a whole. Industry effects and effects on sections of the Australian community are directly relevant to the assessment, but the assessment is focused across all of Australia. However, for pests of regional quarantine concern the impact was assessed at the regional rather than the national level.

The impact of a pest or disease on each direct and indirect consequence criterion is estimated at four levels – local, district, regional and national – and the values derived are translated into a single qualitative score, A–G (Table 10). In this context, the terms 'local', 'district', 'regional' and 'national' are defined as follows.

Local: An aggregate of households or enterprises – e.g. 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, such as the 'North West Slopes and Plains' or 'Far North Queensland'.

Region: A geographically or geopolitically associated collection of districts – generally a state, although there may be exceptions with larger states such as Western Australia.

National: Australia-wide.

At each level, the quantum of impact is described as 'unlikely to be discernible', of 'minor significance', 'significant' or 'highly significant'.

An 'unlikely to be discernible' impact is not usually distinguishable from normal variation in the criterion.

An impact of 'minor significance' is not expected to threaten economic viability, but would lead to a minor increase in mortality/morbidity or a minor decrease in production. For non-commercial factors, the impact is not expected to threaten the intrinsic value of the criterion – though the value of the criterion would be considered to be disturbed. Effects would generally be reversible.

A 'significant' impact would threaten economic viability through a moderate increase in mortality/morbidity, or a moderate decrease in production. For non-commercial factors, the intrinsic value of the criterion would be considered as significantly diminished or threatened. Effects may not be reversible.

A 'highly significant' impact would threaten economic viability through a large increase in mortality/morbidity, or a large decrease in production. For non-commercial factors, the intrinsic value of the criterion would be considered as severely or irreversibly damaged.

When assessing impact, the frame of reference will be the impact of each pest on the community as a whole rather than the directly affected parties.

A related consideration is the *persistence* of an effect. In general, the consequences will be considered greater if the effect is prolonged – as is the case if it is thought to persist for several production cycles or if regeneration will take several generations. If an effect is not prolonged, then consequences are likely to be less serious.

Table 10 The assessment of local, district, regional and national consequences

Impact score	national	regional	district	local
G	highly significant	highly significant	highly significant	highly significant
F	significant	highly significant	highly significant	highly significant
E	minor	significant	highly significant	highly significant
D	unlikely to be discernible	minor	significant	highly significant
C	unlikely to be discernible	unlikely to be discernible	minor	significant
B	unlikely to be discernible	unlikely to be discernible	unlikely to be discernible	minor
A	unlikely to be discernible	unlikely to be discernible	unlikely to be discernible	unlikely to be discernible

Level

Note: *There are minor variations in the scoring system for consequences used in this analysis compared with some other analyses released by BA and with the* Guidelines for import risk analysis, draft September 2001 *(BA, 2001). The methodology allows for an additional category* ('unlikely to be discernible') *at the local level. This means that the letters used to represent rows in the matrix are different to those given in the draft Guidelines. This does not affect the final consequence rating.*

Approach to the consequence assessment for pests of New Zealand apple fruit

In this analysis, a single assessment of consequences was determined for each pest. This is because the outbreak scenario is the same for each of the identified exposure groups (see *Probability of distribution* above).

The assessment of consequences for New Zealand apple fruit was carried out in two steps.

- The magnitude of impact of a pest on each of the direct and indirect criteria was evaluated.
- The magnitude of impact obtained for each of the direct and indirect criteria was combined to give an overall (qualitative) estimate of the consequences of establishment or spread.

The first step was undertaken using the descriptive (qualitative) system outlined above.

The second step was undertaken following the decision rules below. These rules are mutually exclusive and will be addressed in the order that they appear in the list. For example, *if the first set of conditions does not apply, the second set will be considered. If the second set does not apply, the third set will be considered…* and so forth, until one of the rules applies.

- Where the consequences of a pest with respect to any direct or indirect criterion are 'G', the overall consequences are considered to be 'extreme'.
- Where the consequences of a pest with respect to more than one criterion are 'F', the overall consequences are considered to be 'extreme'.
- Where the consequences of a pest with respect to a single criterion are 'F' and the consequences of a pest with respect to each remaining criterion are 'E', the overall consequences are considered to be 'extreme'.

- Where the consequences of a pest with respect to a single criterion are ‘F’ and the consequences of a pest with respect to remaining criteria is not unanimously ‘E’, the overall consequences are considered to be ‘high’.
- Where the consequences of a pest with respect to all criteria are ‘E’, the overall consequences are considered to be ‘high’.
- Where the consequences of a pest with respect to one or more criteria are ‘E’, the overall consequences are considered to be ‘moderate’.
- Where the consequences of a pest with respect to all criteria are ‘D’, the overall consequences are considered to be ‘moderate’.
- Where the consequences of a pest with respect to one or more criteria are ‘D’, the overall consequences are considered to be ‘low’.
- Where the consequences of a pest with respect to all criteria are ‘C’, the overall consequences are considered to be ‘low’.
- Where the consequences of a pest with respect to one or more criteria are ‘C’, the overall consequences are considered to be ‘very low’.
- Where the consequences of a pest with respect to all criteria are ‘B’, the overall consequences are considered to be ‘very low’.
- Where one or more direct or indirect effects are ‘B’, the overall consequences associated with the outbreak scenario are considered to be ‘negligible’.
- Where all direct and indirect effects are ‘A’, the overall consequences associated with the outbreak scenario are considered to be ‘negligible’.

Unrestricted risk

Risk is a function of the likelihoods of an event occurring and the consequences or impact resulting from that event. A combination of probabilities of entry, establishment and spread with the results of the consequence assessment provided estimates of the ‘unrestricted annual risk’ associated with each pest if apples were imported from New Zealand for 12 months without phytosanitary measures. Probabilities and consequences were combined using the risk estimation matrix in Table 11.[8]

[8] Note: This matrix (Table 11) is the same as Table 1. It has been repeated here for convenience.

Table 11 Risk estimation matrix

Likelihood of 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 entry, establishment and spread

Stage 3: Pest risk management

Risk management describes the process of identifying and implementing measures to mitigate risks so as to achieve Australia's ALOP, or tolerance for loss, while ensuring that any negative effects on trade are minimised. The ALOP is considered a societal value judgement that reflects the maximal risk (or expected loss) from a disease incursion that Australia considers acceptable.

To implement risk management appropriately, it is necessary to understand the difference between 'unrestricted' and 'restricted' risk estimates. Unrestricted risk estimates are those derived in the absence of any specific risk management. In contrast, restricted or mitigated risk estimates are those derived when risk management is applied.

The result of the risk assessment for New Zealand apples is an unrestricted risk estimate for each of the identified pests of quarantine concern. This was compared with Australia's ALOP, which is shown in the risk estimation matrix (Table 11) as the band of cells associated with a 'very low' risk. This step is termed risk evaluation. An unrestricted risk that is either 'negligible' or 'very low' meets Australia's ALOP and was considered acceptable. In this situation, risk management is not justified. However, where an unrestricted risk is 'low', 'moderate', 'high' or 'extreme', it exceeds Australia's ALOP and therefore risk management measures are required.

Pests that have an estimate of unrestricted risk that exceeds Australia's ALOP require risk management measures. The approaches outlined above for assessing the unrestricted risk of pests are also used to assess the effect of potential risk management measures. For example, the effect of sourcing apples from orchards with a low prevalence of a pest insect can be assessed by modifying Imp2 or the effect of various inspection regimes assessed by modifying Imp6 and re-running the model. A discussion on potential risk management measures is included in the section for each pest. It is possible that some quarantine treatments will cause harm to the environment. In this analysis, quarantine treatments were not recommended unless any potential harm to the environment was assessed – this includes harm from residues. In making this judgement, relevant considerations included local legal requirements, manufacturer's advice on usage and national or international standards.

General issues

Representing quantitative information

The approach used in the 2004 draft was to assign descriptive terms to quantitative ranges, (‘high’, ‘moderate’, ‘low’, etc). These terms were used throughout the text to represent these quantitative ranges. However, this caused some confusion with some stakeholders applying their own interpretation to the terms rather than the meanings set out in the methodology. In order to overcome this problem, in this draft, the descriptive terms are only used for qualitative values. Numbers are given for quantitative values.

Quantitative data on a probability, or estimates of other numeric quantities were modelled either as a point estimate or, as a probability distributions. Three types of distributions were used:

- Pert
- Uniform
- Triangular.

The Pert distribution was used in the case of volume of apples likely to be imported. The Pert distribution has three parameters, its minimum, and most likely and maximum values.

A Uniform distribution is one that has a maximum and minimum value, but for which each value in the continuous range of values between these limits occurs with the same probability. Uniform distributions were used in cases where insufficient information was available to determine the most likely value.

A Triangular distribution is one that has a maximum, a most likely, and a minimum value. It does not have to be symmetric, it can be skewed to the left or right by entering a most likely value toward the minimum and maximum values. This distribution was used when information (for example, literature and expert opinion) on the most likely value was available.

Most pests were assessed using a semi-quantitative approach based on information represented by numerical ranges. In all cases the assessors were instructed to consider carefully whether they were confident that the range they had chosen would contain the actual value and that that the chosen distribution reflected their beliefs. In particular they were instructed not to be constrained by the intervals suggested in the draft Guidelines. However, qualitative risk analysis has been used for several pests.

There are also circumstances, such as when the results from the estimation of the probability of entry, establishment and spread need to be combined with the assessment of consequences, where qualitative terms are used. Table 12 sets out the nomenclature used for qualitative and semi-quantitative data. Table 13 gives the matrix of ‘rules’ used for combining descriptive likelihoods. The methods used in these situations follow those set out in Biosecurity Australia’s *Guidelines for import risk analysis, draft September 2001* (BA, 2001).

Table 12 Nomenclature for qualitative likelihoods, corresponding semi-quantitative probability intervals and their probability distributions

Likelihood	Descriptive definition	Probability interval	Midpoint	Probability distribution
High	The event would be very likely to occur	$0.7 \rightarrow 1$	0.85	Uniform (0.7, 1)
Moderate	The event would occur with an even probability	$0.3 \rightarrow 0.7$	0.5	Uniform (0.3, 0.7)
Low	The event would be unlikely to occur	$5 \times 10^{-2} \rightarrow 0.3$	0.175	Uniform (5×10^{-2}, 0.3)
Very low	The event would be very unlikely to occur	$10^{-3} \rightarrow 5 \times 10^{-2}$	2.6×10^{-2}	Uniform (10^{-3}, 5×10^{-2})
Extremely low	The event would be extremely unlikely to occur	$10^{-6} \rightarrow 10^{-3}$	5×10^{-4}	Uniform (10^{-6}, 10^{-3})
Negligible	The event would almost certainly not occur	$0 \rightarrow 10^{-6}$	5×10^{-7}	Uniform (0, 10^{-6})

Table 13 A matrix of 'rules' for combining descriptive likelihoods

	High	Moderate	Low	Very low	Extremely low	Negligible
High	High	Moderate	Low	V. Low	E. Low	Negligible
Moderate		Low	Low	V. Low	E. Low	Negligible
Low			V. low	V. Low	E. Low	Negligible
Very low				E. Low	E. Low	Negligible
Extremely low					Negligible	Negligible
Negligible						Negligible

The model in context

The key role of the model is to provide a transparent framework for the assessment of the risks and the consideration of any proposed risk management measures.

During the process of redrafting, the IRA team sought advice from biometricians in the Bureau of Rural Sciences (BRS) on various aspects of the semi-quantitative model and the statistics of sampling and inspection. Significant issues raised by BRS are summarised in the appendix. All these issues were considered in detail by the IRA team in developing this revised draft.

The structure and form of the model was developed by the IRA team taking into account relevant information, stakeholder comments and the expert advice provided by BRS. The model was then used to estimate the unrestricted risks using input values developed by the IRA team taking into account relevant scientific information and expert opinion. The efficacy of different risk management options was assessed by modifying appropriate input values to take account of the effect of different options. The model was then re-run to give the restricted risk values.

In considering the outputs of the model the IRA team was aware that the model is based on various assumptions and has limitations that must be considered. In reaching conclusions on the risk and possible risk management measures the IRA team took into account the outputs of the model, the limitations of the model and the full range of technical and scientific information available.

Summary of apple pests categorised

In Part C of this document 443 pests potentially associated with apples in New Zealand were categorised according to their presence or absence in Australia, including regulatory status where applicable, their potential for being on the pathway (association with apple fruit), their potential for establishment or spread in Australia, and the potential consequences of establishment or spread.

Table 14 is a summary of the total number of species that:

- are known to be associated with apples in New Zealand
- are absent, or whose presence in Australia is uncertain, or are of regional concern
- have the potential for being on the pathway
- have the potential for establishment or spread
- have the potential for consequences
- are considered further in the risk assessment.

Table 14 Summary of the revised pest categorisation

Groups	Associated with apples in New Zealand	Not in Australia, uncertain or of regional concern	Potential for being on pathway (Likely)	Potential for establishment or spread (Feasible)	Potential for consequences (Significant)	No. of species to be considered further
Insects	284	162	19	19	13	13
Mites	35	18	4	4	0	0
Snails	3	2	0	0	0	0
Spiders	4	2	0	0	0	0
Bacteria	3	1	1	1	1	1
Fungi	94	26	14	14	2	2
Nematodes	8	0	0	0	0	0
Viruses	9	0	0	0	0	0
Diseases of unknown etiology	3	2	0	0	0	0
Total	**443**	**213**	**38**	**38**	**16**	**16**

List of species to be considered further

As shown in Table 14, 16 species required further consideration in the risk assessment. These included eight species of insects, one bacterium and one fungus to be considered for the whole of Australia (Table 15) and, in addition, five insects and one fungus to be considered for Western Australia only (Table 16).

Table 15 Pests of apple fruit considered further for the whole of Australia

Insects	
Apple leafcurling midge	*Dasineura mali* Keiffer (Diptera: Cecidomyiidae)
Garden featherfoot	*Stathmopoda horticola* Dugdale (Lepidoptera: Oecophoridae)
Grey-brown cutworm	*Graphania mutans* (Walker) (Lepidoptera: Noctuidae)
Brownheaded leafroller	*Ctenopseustis herana* (Felder & Rogenhofer) (Lepidoptera: Tortricidae)
Brownheaded leafroller	*Ctenopseustis obliquana* (Walker) (Lepidoptera: Tortricidae)
Greenheaded leafroller	*Planotortrix excessana* (Walker) (Lepidoptera: Tortricidae)
Greenheaded leafroller	*Planotortrix octo* Dugdale (Lepidoptera: Tortricidae)
Native leafroller	*Pyrgotis plagiatana* (Walker) (Lepidoptera: Tortricidae)
Pathogens	
Fire blight	*Erwinia amylovora* (Burrill) Winslow et al.
European canker	*Neonectria galligena* (Bres.) Rossman & Samuels

Table 16 Pests of apple fruit considered further for Western Australia

Insects	
Codling moth	*Cydia pomonella* (L) (Lepidoptera: Tortricidae)
Mealybug	*Planococcus mali* Ezzat & McConnell (Hemiptera: Pseudococcidae)
Citrophilus mealybug	*Pseudococcus calceolariae* (Maskell) (Hemiptera: Pseudococcidae)
Oriental fruit moth	*Grapholita molesta* Busck (Lepidoptera: Tortricidae)
Oystershell scale	*Diaspidiotus ostreaeformis* (Curtis) (Hemiptera: Diaspididae)
Pathogens	
Apple scab	*Venturia inaequalis* (Cooke) G. Winter

Risk assessments for potential pests Australia-wide

Fire blight

European canker

Apple leafcurling midge

Garden featherfoot

Grey-brown cutworm

Leafrollers

Fire blight

Introduction

Fire blight, caused by the bacterium *Erwinia amylovora* (Burrill 1882) Winslow et al., 1920 has been reported in over 40 countries including New Zealand (Bonn and van der Zwet, 2000). Fire blight-like symptoms were detected on cotoneaster in the Royal Botanic Gardens in 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). Although the mode of introduction of fire blight into the Royal Botanic Gardens in Melbourne is unknown, it is unlikely this disease detection was associated with the introduction of planting material.

Biology

Cells of *E. amylovora* are Gram-negative rods about 0.3 x 1–3 µm in size, surrounded by a capsule of polysaccharide material (Paulin, 2000). *E. amylovora* is capable of growing between 3ºC–37ºC with optimum temperature for growth being 25ºC–27ºC (Billing et al., 1961) although minor variations have been reported concerning these temperature requirements.

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). These hosts belong to the sub-family Maloideae of the family Rosaceae (CABI, 2005). *Rosa rugosa* (sub-family Rosoideae) (Vanneste et al., 2002) and *Prunus salicina* (sub-family Amygdaloideae) (Mohan and Thomson, 1996) are other host species in the family Rosaceae susceptible to infection by *E. amylovora*. 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).

The pathogen overwinters almost exclusively in the previous season's cankers (Beer and Norelli, 1977) and the primary inoculum is produced mostly as 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). An outbreak of fire blight may be caused by as few as one to four cankers per hectare (Brooks, 1926). 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 fruits. Flowers are highly susceptible to infection by *E. amylovora* (Keil and van der Zwet, 1972), 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. Steiner (2000a) indicated that *E. amylovora* is a competent epiphyte capable of colonising and multiplying on the surfaces of plants. However, Leben (1965) reported that *E. amylovora* is not a strict epiphyte on the leaf surface. Leaves are rarely infected, but prone to infection after hail damage (Beer, 1990). *E. amylovora* was not detected on leaves before the appearance of fire blight symptoms in the orchard (Miller and Schroth, 1972; Miller and van Diepen, 1978), but was present on leaves shortly after the appearance of disease symptoms (Crosse et al., 1972). 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). In contrast, *E. amylovora* was detected on 100% of leaves using a polymerase chain reaction (PCR) technique in orchards free of fire blight symptoms, but it was not known whether bacteria detected using this technique were alive or dead (McManus and Jones, 1995).

Infected 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 the dry flower parts subsumed into the calyx-end (Hale et al., 1987). The bacteria could be present at the stalk-end of mature fruit or the fruit surface, (van der Zwet et al., 1990). In rare instances *E. amylovora* has been recovered from internal tissues of maturing fruit, but only when the fruits were within 15 cm of the inoculum source of severely blighted trees (van der Zwet et al., 1990). In Canada, *E. amylovora* was recovered from mature apples harvested from an orchard inter-planted with fire blight-infected pears (Sholberg et al., 1988). These authors also isolated an average of $10^{3.3}$ cfu of viable *E. amylovora* per mL of water washed off apples at harvest, from a severely infected, hail-damaged orchard in Canada.

Other information relevant to the biology and epidemiology of *E. amylovora* is available in the data sheet in Appendix 3 in Part C.

Risk scenario

There is a significant body of literature (see later sections) confirming the potential presence of fire blight bacteria on mature symptomless apple fruit. The importation risk scenario of particular relevance to *E. amylovora* is one that is associated with the epiphytic (external) infestation. Epiphytic infestation can occur at the stem- and calyx-end and on the surface of mature fruit. *E. amylovora* cannot be detected by visual inspection.

The potential for endophytic infection (bacteria occurring internally in the tissues) was also considered. If endophytic infection occurs early, such fruit would probably fall off or remain mummified on the tree. It is also possible that late infections may not express internal symptoms until after a period of cold storage. However, there is little evidence in the literature to support the occurrence of endophytic infection of symptomless mature apple fruit.

Importation of trash is another potential pathway for introduction of *E. amylovora.* Although the scope of the analysis is apples free of trash the risks associated with trash were considered. It was concluded that leaves and small twigs taken from apple trees at the time of harvest are no more likely to be carrying *E. amylovora* than fruit and therefore do not present a special risk over and above that presented by fruit.

The relevant onshore risk scenario is that fire blight bacteria carried on fruit or persisting on apple waste material is transferred to a suitable host plant and disease is initiated. Disease initiation was considered in the context of imported packed fruit, as well as fruit exported to Australia in bulk bins with final grading and packing carried out in Australia. Consideration was also given to the possibility of active infection developing in fruit damaged during handling, transport and storage. A more detailed discussion of the relevant scenarios is provided in the sections concerning proximity and exposure.

Probability of importation

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry. The importation scenario is divided into eight steps. The available evidence supporting the likelihood assessments for each step is provided in the text that follows.

Importation step 1: Likelihood that *E. amylovora* is present in the source orchards in New Zealand is 1.

Pathogen/disease distribution

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 48% of orchards are located) and Auckland, 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).

Erwinia amylovora was detected in New Zealand both from orchards with fire blight symptoms (Hale et al., 1987; Clark et al., 1993) and those without symptoms (Clark et al., 1993).

The proportion of designated export areas (DEAs) withdrawn from the export program to Japan because of the presence of *E. amylovora* within orchards and buffer zones after three inspections in the 1994 to 1995 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 to 1996 season the DEA rejection rate was 56.1% in Nelson and 16.1% in Blenheim, while during the 1996 to 1997 season, it was 12.2% in Blenheim (New Zealand Government, 2000). This indicates that *E. amylovora* is present in orchards throughout the major production areas.

Varietal susceptibility

All commercial varieties of apple grown in New Zealand are susceptible to infection by *E. amylovora* (MAFNZ, 2002c). The use of susceptible dwarfing rootstocks (for example, M.9 and M.26) currently used for high-density plantings would increase the susceptibility of scions grafted on to the rootstock (van der Zwet and Beer, 1991). Therefore, high-density plantings in New Zealand would be prone to damage by *E. amylovora*.

Environmental conditions

Average rainfall and temperature data for Auckland, Gisborne, Napier (Hawke's Bay), Nelson, Blenheim, Christchurch and Alexandra (Otago region) indicate that climatic conditions are ideal for the occurrence of fire blight in the northern and eastern parts of the North Island and the northern part of the South Island, with conditions less favourable in eastern and central parts of the South Island.[9]

Orchard management

According to Fact Sheet 7 of the Integrated Fruit Production Program Manual (Anonymous, 2004a), a combination of measures is recommended for management of fire blight in New Zealand, including:

- pruning out infected shoots and cankers in the winter
- spraying one or more rounds of copper fungicides as bactericides in the winter program from leaf fall as necessary
- frequently inspecting the orchard; especially from blossoming to mid-summer for signs of infected blooms or shoots, pruning and burning any infected material upon detection
- identifying and removing alternative hosts from within 100 m of the orchard block, and applying copper fungicides if hosts cannot be removed
- applying streptomycin 24 to 48 hours before an infection event but no later than 24 hours after
- selecting rootstock and scion combinations that are not highly susceptible to *E. amylovora*
- where possible, obtaining nursery stock from areas free of fire blight
- avoid overhead irrigation
- assessment of fire blight infection periods
- avoid fertiliser programs that encourage succulent shoot growth.

In 2004, an average of 25% of blocks were treated for fire blight, of which 10% used streptomycin, 5% used Blossom Bless™ and 10% used copper. In 2002 and 2003 the average proportion of blocks treated for fire blight was 39% and 22% respectively (MAFNZ, 2005a). This indicates that although *E. amylovora* may be widely present, environmental factors are not always conducive to disease development (MAFNZ, 2005a).

MAFNZ (2005a) has stated that 61% to 75% of growers in any one year did not consider that production would be sufficiently affected by fire blight to warrant any control measure.

Summary

There is no scientific literature that indicates that any area of New Zealand is free of the fire blight bacteria and MAFNZ has not provided any information in support of freedom for any apple producing areas in New Zealand. Therefore the IRA team decided to represent Imp1 as 1.

Importation step 2: Likelihood that picked fruit is infested/infected with *E. amylovora*: triangular distribution with a minimum value of 10^{-3}, a maximum value of 5×10^{-2}, and a most likely value of 3×10^{-2}. $T(10^{-3}, 3 \times 10^{-2}, 5 \times 10^{-2})$

There is a large volume of published technical information relating to this step in the pathway. Information presented here focuses on data relevant to mature fruit. The available literature in

[9] National Institute of Water and Atmospheric Research (NIWA, 2003) http://www.niwa.cri.nz/edu/resources/climate/overview/climate_rainfall (NIWA, 2005). Accessed on 20/06/05

the context of this assessment is divided – some data supports the presence of *E. amylovora* as infestation (external) or infection (internal), while other data supports its absence from fruit.

With a view to providing a clear and balanced representation, the following presents the available data that supports:

- infestation of mature fruit
- no infestation of mature fruit
- infection of mature fruit
- no infection of mature fruit.

The responses to significant technical issues raised by stakeholders involving this step are incorporated in the discussion.

Infestation of mature fruit

Hale et al. (1987) studied the proportion of fruit carrying *E. amylovora* over a 100-day period from immature fruitlet stage to harvest (day 1 = 21 November 1984 and day 100 = 28 February 1985), from a severely infected orchard (75 infections per tree). They took washings from the calyx-end and main portion of each infested fruit in bacteriological saline and determined the number of *E. amylovora* cells present by directly plating onto semi-selective media. A logistic plot of the data presented in Table 1 of their publication was used to estimate the proportional decrease in the number of infested fruit over time. For day 1, the mean is 0.533 and the 95% confidence limits are 0.408 and 0.654. For day 100, the mean is 0.035 with 95% confidence limits of 0.02 and 0.06. On that basis, the proportional decrease from day 1 to day 100 can be estimated as follows:

- The expected proportional decrease is 1–(0.035/0.533) = 0.93. A conservative proportional decrease is 1–(0.06/0.408) = 0.85.

This value was used when considering some of the data in the literature discussed below.

The use of data from a single study reported by Hale et al. (1987) to derive the expected proportions and applying these across other studies was an approach questioned by stakeholders. The Hale et al. (1987) study was conducted in New Zealand and is the only one to examine *E. amylovora* infestation from fruitlet stage right through to maturity.

Bacteria predominantly colonise flowers (Thomson, 1986; Thomson, 2000) and only relatively low bacterial numbers are present on dried remnant flower parts subsumed into the calyx sinus of mature fruit (van der Zwet et al., 1990; Sholberg et al., 1988). Although it is acknowledged that conditions vary from season to season and between orchards, the 85% proportional decrease provides a guide to the reduction in calyx infestation that may be expected as fruit matures. Reductions of this magnitude are also consistent with other observations reported in the literature (see later discussion in this step). Under these circumstances it is reasonable to use data from different experiments to estimate trends for calyx infestation in mature fruit.

Hale and Clark (1990) reported calyx infestation in 8.7% of fruitlets sampled from orchards in New Zealand free from fire blight but with alternative hosts within the orchard (distance unspecified). If the 85% proportional decrease in the level of infestation is applied to this 8.7%, the final expected rate of calyx infestation in mature fruit would be 1.3%. If this same decrease of 85% is applied to 21.8% of calyx infestation in immature fruit sourced from orchards with 1 to 2 infections per tree (Clark et al., 1993) and 14.7% of immature fruit (Clark et al., 1993) from orchards with no fire blight symptoms, the expected rate of calyx infestation in mature fruit would be 3.3% and 2.2% respectively. The DNA hybridisation technique used for these assays was sensitive enough to detect 100 cells of *E. amylovora* in calyces of apple (Hale and Clark, 1990).

The isolation of *E. amylovora* from calyces of less than 1% of 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 fire blight symptoms (Hale and Taylor, 1999) has also been reported in New Zealand. This is consistent with the above data.

Recovery of *E. amylovora* from calyces of 5% of immature fruit harvested from a healthy orchard in West Virginia, USA, located 30 km from infected orchards was reported (van der Zwet et al., 1990). Applying the 85% proportional reduction to the above 5% figure would result in a value equivalent to 0.8% calyx infestation in mature fruit.

The presence of *E. amylovora* in 75% of calyces of mature fruit taken from symptomless trees in a severely infected orchard was reported by McManus and Jones (1995), using a nested PCR test capable of detecting less than one bacterial cell. They 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*.

In the USA, van der Zwet et al. (1990) showed that approximately 4% of non-infested mature 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.

In Canada, Sholberg et al. (1988) isolated epiphytic bacteria on naturally contaminated, blemish-free and apparently healthy apple fruit collected at harvest from an orchard severely infected by fire blight 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 isolation of the pathogen was done using bulked samples, which would have recorded a positive result even if one fruit was contaminated. They used three bulked fruit per assay, with three replications and six treatments. The number of fruit assayed was 54 (the actual number tested for *E. amylovora* was not specified) and the possible number of fruit testing positive for *E. amylovora* would be in the range of 18 to 54. This study did not distinguish between surface- and calyx-infested bacteria. It also reported isolation of an average of $10^{3.3}$ cfu per mL of viable *E. amylovora* from a bulked sample of harvested fruit which were naturally infested.

Van der Zwet et al. (1990) isolated *E. amylovora* populations exceeding 1000 cfu per fruit from calyces of mature apples in West Virginia, USA, taken from a blight-free orchard when severe fire blight was present in the area during that year.

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.

Temple et al. (2004), using cells from solidified medium freeze-dried cells and cells in air-dried ooze taken from diseased fruits, inoculated apple fruit to runoff with 10^5 to 10^7 cfu per mL and harvested them periodically for up to 35 days. Fruit washings were passed through membrane filters to trap the bacteria and the filters incubated on a growth medium. 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 inoculum 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* from two fruits were recovered from 330 fruit. Fire blight symptoms were not observed on inoculated trees or fruit.

Several stakeholders asserted that detection methods play a significant role in determining the pathogen population. Geenen et al. (1981) testing epiphytic populations on leaves of disease free hosts, detected *E. amylovora* on 1% of samples using the agglutination method in 1978 and 18.7% of samples using immunofluorescence microscopy in 1980. While epiphytic populations may have increased over the three years, the difference was partly attributed to the increasing sensitivity of techniques. More recently, Hale and Clark (1990) have demonstrated greater sensitivity of DNA hybridisation over plating techniques. Bereswill et al. (1992; 1993) and McManus and Jones (1995) reported the use of PCR technology to further increase the sensitivity of *E. amylovora* assays, but this technique does not differentiate between live and dead cells.

There are instances where culture techniques detect equally as well as other more sensitive techniques, and often extremely sensitive techniques such as PCR are of limited use as they are unable to distinguish between dead and live bacteria (McManus and Jones, 1995). The DNA hybridisation method is claimed to detect 100 cells (Hale and Clark, 1990). The sonication–membrane filtration technique detected as few as 19 bacterial cells. It was claimed that this method was more sensitive than immunofluorescent assays using monoclonal antibodies (Roberts et al., 1989). There is no justification or evidence to show that the bacterial numbers reported in the scientific papers cited above were systematically underestimated because of lack of sensitivity.

Several stakeholders indicated that *E. amylovora* can enter into a viable but non-culturable (VBNC) state and as a result can contribute to an underestimation of the pathogen numbers when only culture methods are used. Preliminary studies indicate that *E. amylovora* can enter into a VBNC state (Biosca et al., 2004; Ordax et al., 2004). 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., 2005). *E. amylovora* can be induced to enter into a VBNC state by nutrient starvation (Biosca et al., 2004) or in the presence of copper (Ordax et al., 2004). The ability of *E. amylovora* to survive and remain infective for six months in sterile irrigation water (Biosca et al., 2004) and the restoration of culturability and pathogenicity of copper-induced VBNC *E. amylovora* (Ordax et al., 2004) under sterile conditions has been reported.

The studies of Biosca et al. (2004) and Ordax et al. (2004) 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 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 70 days after exposure to copper including bacteria considered to be in the VBNC state. Given the low numbers of bacteria likely to be present on apples when 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., 2005) was unable to demonstrate recovery of cells to a culturable state suggesting that the VBNC state may be an irreversible stage towards cell death. Furthermore, the ability of *E. amylovora* to enter into a VBNC state in or on any apple tissue is yet to be demonstrated.

Bacteria occur either as independent single cells (planktonic) or as complex multicellular communities attached to surfaces embedded in polysaccharides (biofilms or slime). Biofilm formation is widespread among enterobacterial species (Charkowski et al., 2005). The importance of exopolysaccharides (EPS) on the survival of *E. amylovora* has been highlighted by stakeholders. EPS are thought to play a role in protecting the bacterial cell against desiccation, in adhesion to solid surfaces and biofilm formation, and also in cellular recognition. *E. amylovora* produces amylovoran and levan (Geider, 2000). 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 by preventing loss of residual water (Geider, 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 known that EPS contributes 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 EPS on the survival of low bacterial numbers in calyces but if EPS did support survival in calyces then this would already be accounted for by the consideration of the bacterial numbers actually found on mature healthy apples. Two types of biofilms which are chemically and genetically distinct have been recognised in *Erwinia chrysanthemi*. However, the contribution of biofilm related genes to pathogenicity is still unknown (Charkowski et al., 2005).

At least one stakeholder indicated that sigma factor enhances the survival of *E. amylovora* during periods of stress. It is known that alternative sigma factor RpoS regulates a panel of genes which serve to maintain viability of bacteria during periods of starvation and environmental stress (Kolter et al., 1993). However, Anderson et al. (1998) demonstrated that RpoS plays no role in the survival of *E. amylovora* during overwintering in mature tissue. Cesbron et al. (2004) showed that sigma factor *hrp*L negatively affected flagella synthesis in *E. amylovora* within plant tissues. Genes of the *hrp* region are essential for infection. Host-released chemical signals can initiate diverse interactions between hosts and microbes. Detection of these signals leads to altered patterns of gene expression that would result in changes in bacterial physiology required for these associations (Brencic and Winans, 2005). The complex nature of the plant-microbe interactions makes it difficult to understand the precise nature of the mechanisms involved. 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.

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 and symptomless orchards (van der Zwet et al., 1990) or alternative hosts (Momol and Aldwinckle, 2000). 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. 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, but Steiner (2000a) considers it to be a competent epiphyte capable of colonising and multiplying on plant surfaces. 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). It is also known that populations of *E. amylovora* are affected by exposure to solar radiation and high humidity (Maas Geesteranus and de Vries, 1984). However, as discussed by Lindow and Brandl (2003) in the review of phyllosphere microbiology, micro-habitats on plant surfaces in relation to factors such as fluctuating temperature and humidity, the presence or absence of moisture, exposure to ultraviolet (UV) radiation, availability of nutrients, aggregate formation, or biofilm influence the bacterial population levels. Further, Burnett et al. (2000), in a study concerning attachment of artificially inoculated *Escherichia coli* to apple fruit, detected bacteria on the surface, wounds, calyx tube and seed loculi. The rare detection of *E. amylovora* in the core of naturally infested apple fruit (van der Zwet et al., 1990) and on the seeds by Mundt and Hinkle (1976) may explain that such events could occur under exceptional circumstances.

Dueck and Morand (1975) studied seasonal changes in the epiphytic population of *E. amylovora* on apples and pears in Ontario, Canada. The highest frequency of epiphytic occurrence was observed during July and August. July is generally regarded as the period of maximum rainfall in Ontario, whereas harvesting of most apple varieties is done during September and October when, according to their data, epiphytic populations are extremely small.

No Infestation of mature fruit

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 mature fruit (173) 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 naturally infested 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).

Erwinia amylovora was not detected in aqueous sonicates of 1555 mature symptomless fruit harvested from blighted trees of seven cultivars grown at five locations in Washington state, USA (Roberts et al., 1989). The detection sensitivity level averaged 19 cfu, using a sensitive sonication–membrane filtration technique, which is more sensitive than the immunofluorescent assay using monoclonal antibodies.

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).

In Canada, Dueck (1974a) did not isolate *E. amylovora* from tissues of the stem-end and calyx-end of 60 mature fruit harvested from severely infected apple trees.

Infection of mature fruit

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. 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 July and August) 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 from apparently symptomless trees of four cultivars.

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 [WT/DS245/R, 4.94; WTO (2003)].

One stakeholder has suggested that all reference to the van der Zwet et al. (1990) publication should be removed. It is acknowledged that there are deficiencies in the way some data have been interpreted in this paper. Notwithstanding this, some observations reported in this paper concern mature fruit harvested from orchards that were naturally infested. Hence, at least some of the data presented in this publication provide useful technical information that cannot be ignored.

In Canada, mature apples were infected only when high inoculum doses were injected into the cortex of fruit. However, 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, *E. amylovora* was not isolated from any whole or split apple seeds tested in the USA (van der Zwet et al., 1990).

Several stakeholders have cited work on *E. coli* and extrapolate these findings to *E. amylovora,* as both species belong to the family Enterobacteriaceae. The 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.

The occurrence of *E. amylovora* 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 has been reported. The persistence of *E. amylovora* in xylem vessels seems to be limited because the salts and water contained within might lack elements required for rapid bacterial multiplication (Gowda and Goodman, 1970; Momol et al., 1998) but *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).

Some stakeholders considered that 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 lack of evidence of endophytic infection in mature fruit suggests that if endophytic infection does take place it must be a rare event.

No infection of mature fruit

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).

In one experiment, fruit in varying stages of maturity (immature, possibly mature and mature) was harvested from three different locations over two years in USA and one location in Canada (van der Zwet et al., 1990). *E. amylovora* was not recovered from internal tissues of the total number of 160 fruit sourced from both healthy and blighted orchards in West Virginia, USA and Ontario, Canada. Also, bacteria were not detected in 80 fruit harvested from both healthy and blighted orchards in Washington State, USA.

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. No bacteria were 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. No internal symptoms were detected in 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 was not isolated using a selective medium, in internal tissue of symptomless fruit harvested from blighted trees, where 20% of the wood on the trees from which apples were harvested had symptoms of fire blight (Dueck, 1974a).

Several stakeholders raised the issue of *E. amylovora*'s potential to cause internal infection of apple fruit in the same way as *Salmonella* spp. and *E. coli* cause internal infection in tomato. For example, Guo et al. (2001) brush-inoculated *Salmonella* spp. to tomato flowers or injected into tomato stems before or after fruit set, using a high inoculum dose (about 7.5 $\log_{10}$ cfu). The bacterium was detected in tomato fruit and survived during maturation. However, it would be incorrect to directly apply *Salmonella* studies to *E. amylovora* and tomato studies to apple, as these experiments bear very little relationship to the field situation for apple fruit.

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. This is confirmed by pulsed-field gel electrophoresis (PFGE) patterns of *E. amylovora* strains in Europe and the Mediterranean region (Jock et al., 2002). Significant differences in the patterns were detected in different areas. The authors concluded that in spite of unrestricted trade with host plants and fruit, the patterns of distribution of strains suggested 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.

Summary

In considering the appropriate value that should be assigned to Imp2, the IRA team assessed the relevance of the information reviewed above. It should be noted that, at this stage, only the unrestricted risk is being assessed. As such, this evaluation (of Imp2) needs to take into account the fact that apples could be sourced from anywhere in New Zealand irrespective of the fire blight status of orchards. For example, mature, symptomless apples could be sourced from, among other things, orchards:

- with active fire blight, including many fire blight strikes on each tree; or
- that show few or no symptoms, but are very close to active fire blight in hedgerow plants (such as cotoneaster); or

- that show no symptoms and are some distance from an active fire blight host.

Given the widespread distribution of fire blight in New Zealand, the IRA team concluded that more weight should be given to those studies on apples sourced from orchards that were showing symptoms of fire blight disease.

The IRA team acknowledged that there are several studies that found no evidence of the presence of fire blight bacteria on mature symptomless apples and that some of these studies were carried out on orchards showing symptoms of fire blight. However, given that there are a number of studies that confirm the presence of fire blight bacteria on such fruit, studies that found no evidence of fire blight bacteria on mature symptomless apples were given much less weight.

Turning to the studies that detected fire blight bacteria on mature, symptomless apples, there is a considerable amount of variation on the infestation rates reported. Roberts et al. (1998) reviewed the literature concluded that the average infestation rate for apples sourced from orchards:

- with symptoms was around 4.9%
- with no consideration of orchard symptoms was approximately 0.35%.

This review took into account those studies carried out in North America and New Zealand. The IRA team concluded that it was appropriate to choose a value for Imp2 that adequately took into account the range of variation that was reported in this literature and therefore decided to represent Imp2 as a triangular distribution, with a minimum value of 10^{-3}, a maximum value of 5×10^{-2}, and a most likely value of 3×10^{-2}.

Importation step 3: Likelihood that clean fruit is contaminated by *E. amylovora* during picking and transport to the packing house: triangular distribution with a minimum value of 10^{-3}, a maximum value of 3×10^{-2}, and a most likely value of 10^{-2}. T(10^{-3}, 10^{-2}, 3×10^{-2})

Bacteria on the plant surface (epiphytic or ooze from cankers and other infections) and any bacteria in the soil, on harvesting bins or picking bags are possible sources for contamination during picking and transport.

Bacteria on the plant surface

Epiphytic bacteria

Likelihood of bacteria surviving epiphytically on mature fruit was considered under Imp2. Further aspects of possible epiphytic survival on other plant parts, such as leaves, twigs or buds, which may be present as trash during harvesting and could act as a source of inoculum for contaminating clean fruit, are discussed below.

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 as an epiphyte 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.

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 20ºC, 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.

Recently, 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.

Few studies have tested *E. amylovora* populations on leaves around the time apples are harvested. 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}, air drying and then placing a further 30µL of this bacterial suspension in the calyx cavity. After just one day, no bacteria could be detected on the surface, indicating that the pear fruit surface is not a favourable environment for bacterial survival. Bacterial numbers in the calyx (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. Bacterial numbers in calyces of mature orchard fruit are likely to be similar to these and such small numbers in the calyx are unlikely to be physically accessible to allow contamination to occur during picking and transport. Further, 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. All of the above studies demonstrate poor epiphytic survival of *E. amylovora,* except occasionally in small numbers in the calyx.

Stakeholders have cited Steiner (1998), Calzolari et al. (1982), Crepel et al. (1996), van der Zwet et al. (1988), Geenen et al. (1981) and Persson (1999) as evidence supporting epiphytic survival of *E. amylovora*.

The Steiner (1998) report that claims *E. amylovora* is a competent epiphyte is a paper presented at an Annual General Meeting of West Virginia Horticultural Societies. However, this paper provides no supporting data for epiphytic survival of the pathogen.

Calzolari et al. (1982) examined 104 samples of dormant buds from plants being imported into Italy. They detected a positive only in one sample. While their observation may have some relevance to spread of the disease 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, 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 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.

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 method and 23 using immunofluorescence. In total they detected 3.8% positives in 1979 and 18.7% in 1980, presumably using immunofluorescence. Such epiphytic detections are possible only during the blossom period, if inoculum is nearby. 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 as *E. amylovora* following other 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. Hence, the identifications of Geenen et al. (1981) above are 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. However, the number of leaves infested declined 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. Further, their measurements appear to have been taken mostly during early season. The number of leaves with bacteria present are likely to be lower during the early autumn harvest period.

Stakeholders have also cited Wei et al. (1992), Wei and Beer (1995) and Wei et al. (2000) as studies supporting the ability of *E. amylovora* to survive nutrient-poor conditions. 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). What we consider here is the ability of *E. amylovora* to survive as an epiphyte or infestation outside the cuticle which is the outer limit of apoplast, and without contact with plant cells, for which the above studies do not provide any supporting evidence. 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 we can consider apoplast to be a low nutrient environment is questionable. 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 solutions containing high doses of the bacterium. They observed the bacterium attaching to the cuticle, wax plates, clefts, lenticels, etc. Stakeholders have used these studies to argue in favour of epiphytic survival of *E. amylovora* on fruit. 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 solutions 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*.

Overall, the indication is that likelihood of the presence of epiphytic bacteria on leaves and mature fruit surface (except calyx) at the time of apple picking is very small, and the likelihood of transfer of bacteria to clean fruit during picking and transport would be even lower.

Cankers and ooze

With all export orchards required to adhere to a pest and disease management program, thereby maintaining good orchard hygiene, there will be extremely small numbers of cankers, infected shoots and fruitlets present on trees. Further, during the picking period in late summer there will be less chance of ooze production by any infected parts left on the tree, this process being most likely to happen in early spring. Any ooze present in summer would be dry with most surface bacteria dead. Canker blight occurs during the green tip stage of bud development, coinciding with the flower bud stage, presumably triggered by the mobilisation of soluble carbohydrate reserves in response to early vegetative growth (Steiner, 2000b). Therefore, the likelihood that a picker touching a canker or an infected part would then transfer bacteria to a clean fruit would be very small.

Bacteria in soil

Thomson (1969) recovered *E. amylovora* from soil collected beneath blighted trees during spring in an orchard in the USA. Hildebrand et al. (2001) showed that *E. amylovora* was not recovered from soil five weeks after inoculation. Reviewing the reports on this topic, Thomson (2000) was of the opinion that soil is of little epidemiological significance in the spread of fire blight in orchards.

Bacteria on bins

Erwinia amylovora has been recovered from contaminated wood one month (McLarty, 1927), four months (Keck et al., 1996) and 11 months (Nachtigall et al., 1985) after inoculation. *E. amylovora* has survived on oak and poplar wood for up to 77 days in cold storage, but only up to 27 and 55 days respectively outdoors (Ceroni et al., 2004). Keck et al. (1996) found that hydrophobic surfaces (for example, plastic bins) appear to favour survival of the pathogen for four months but, conversely, Ceroni et al. (2004) showed that plastic surfaces were not suitable for survival of *E. amylovora*.

Transfer from contaminated sources to clean fruit

Transfer of bacteria from contaminated sources to clean fruit may happen primarily by contact/touch but also to some extent through rain.

Stakeholders have cited Ceroni et al. (2004) as a paper providing data on the rate of inoculum transfer from contaminated surfaces to fruit during handling. These authors used a simple model to demonstrate the possibility of transfer and the critical time of survival after transfer or contamination risk period. They assumed the ID_{50} (inoculum dose) for *E. amylovora* inoculation to be 38 cells, based on Crosse et al. (1972), the contact area of a fingertip to be 3.3 cm^2 and thus, the ID_{50} per cm^2 as 11.5 cells. They then used plots of percentage survival (cfu per cm^2) after artificial infestation against storage time in days for different materials to estimate the number of days corresponding to cfu per cm^2 = 11.5, calling this the contamination risk period. The model assumed that all contaminated sites on fruits, bins, trays and packaging papers would come into contact with the hands of the pickers or storage personnel, all bacterial cells at the contamination site would be transferred to the fingertips of the workers, and that workers would transfer the bacteria to viable infection sites on clean fruit every time. In these experiments, either entire fruits or sections (7 x 7 x 300mm) of container material were initially contaminated by immersing them in a bacterial suspension of 10^8 cfu mL^{-1}. Under these conditions, the phytosanitary risk periods for oak-wood bins and poplar-wood trays kept outdoors after infestation were found to be 1.3 and 6.9 days respectively, as well as 45 days for both when held in cold storage. For skin of pear fruit held in cold storage it was 1.5 days. The assumptions made above are extreme or worst case ones. If realistic probabilities were allocated to the assumed steps and to the numbers of bacteria and sites likely to be available for cross contamination under natural conditions, the phytosanitary risk periods would be much lower. As such, these data are not particularly useful in estimating the likelihood of contamination of clean fruit during picking and transport. An additional problem is that this work was done on pears and is difficult to extrapolate to apples. However, even if we consider the figures of 1.3 and 6.9 days risk days for bins and trays kept outdoors (more realistic than bins and trays continuously kept in cold storage), in terms of number of risk days per year these equate to probabilities of 0.003 and 1.9×10^{-2}.

Any damage to the fruit surface during picking and transport could provide sites for infection from low populations of epiphytic bacteria. Van der Zwet et al. (1990) provide some useful information to assess this possibility. These authors wounded with a nail puncture 72 visibly clean, non-disinfested fruit harvested from orchards where fire blight had been present and found that three fruits (4%) developed blight symptoms, presumably through epiphytic bacteria being present on the surface. The 4% infection rate therefore occurs when 100% of the fruit is wounded. Hetzroni et al. (2004) provide some information on the percentages of apples wounded or bruised during picking and transport. They tested the damage to 3000 Golden Delicious apples during harvesting and transport under four treatments that represented four different stages in the harvesting and transporting process: (a) on the tree – careful picking, (b) a whole container on the loading platform in the orchard, (c) a whole container in the packing house, and (d) half a container in the packing house. The percentage of damage was lowest (8%) for the careful picking treatment compared with 37% in the whole container in the packing house. Applying the van der Zwet et al. (1990) figure of 4% infection when all fruits were damaged to the more appropriate value of 37%, the likely contamination through damage to fruit surface would be 1.5%. Hailstorms can also cause injuries to leaves and fruit and such injuries may play a role in infections and outbreaks (Brooks, 1926). However, the likelihood of these events occurring during the harvesting and transport period in late summer and increased chances for contamination would be highly unlikely.

Wind-driven rain carrying bacteria can also be a source of contamination for clean fruit during harvesting and transport. Bacteria can be found in 80% to 100% of air samples collected during rain storms near active shoot infections with conspicuous ooze (Thomson, 2000). Rain storms as a factor influencing the likelihood of picked fruit being infested or infected have been considered in Imp2.

Summary

On the basis of the review of the literature and stakeholder comments and using the data of van der Zwet et al. (1990) and Hetzroni et al. (2004) and taking into account that the unrestricted risk was being assessed, the IRA team decided to represent Imp3 as a triangular distribution, with a minimum value of 10^{-3}, a maximum value of 3 x 10^{-2} and a most likely value of 10^{-2}. This range allows for fruit to be infected at picking through wounds as well as surface contamination that may occur by contact with contaminated bins, pickers' hands, leaves, twigs, etc.

Importation step 4: Likelihood that *E. amylovora* survives routine processing procedures in the packing house: triangular distribution with a minimum value of 0.3, a maximum value of 0.7, and a most likely value of 0.65. T(0.3, 0.65, 0.7)

The effect of the following packing house operations on the survival of *E. amylovora* is discussed below.

Pre-cooling

The pulp temperature of fruit at harvest is relatively high. To lower this pulp temperature, fruit is normally subjected to 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). A stakeholder raised the issue that during pre-cooling, fruit will be exposed to higher relative humidity. If *E. amylovora* were present in internal tissues, their numbers would not be reduced during pre-cooling storage or in the packing house. Maas Geesteranus and de Vries (1984) reported that *E. amylovora* (10^9 cells per mL) survived only hours when exposed to 75% humidity at 15ºC, whereas at low humidity (32% at 15ºC) it survived for several days. *E. amylovora* bacteria are short-lived when exposed to fluctuating temperatures and high humidity in the laboratory, and die rapidly when exposed to outdoor conditions at 75% and 90% relative humidity (Rosen, 1938). These conditions may occur during pre-cooling and packing house operations, which will reduce epiphytic populations of bacteria but not those in internal tissues.

Washing

Epiphytic bacteria, especially those in the protected calyx cavity, would not be removed in the dump tank, at least in closed-calyx cultivars, possibly because of the formation of air pockets. However, bacteria outside the calyx that are not attached to the fruit surface may be washed off.

There is no experimental evidence that bacteria infesting fruit, particularly those in protected sites, will be reduced by washing the fruit with high-volume high-pressure water, but it is expected that those present on fruit surfaces would be. The majority (73%) of export packing houses have adopted this procedure (MAFNZ, 2005a). Roberts and Reymond (1989) showed that the average number of *E. amylovora* recovered after treatment with water was 4 to 5 log units less than the average number applied to the fruit, suggesting that some bacteria can be removed by water. Beuchat (1999) reported a 10 to 100 fold reduction (data not given) in the number of microorganisms by vigorously washing fruits and vegetables with water, which is often as effective as treatment with 200 ppm chlorine. Therefore, bacteria present externally on the fruit surface or the stem-end are likely to be removed if a high-volume high-pressure water wash system is applied. As some stakeholders have pointed out, washing will have no effect on bacteria present in internal fruit tissues (endophytic infections) or the calyx cavity.

Goodman (1983) showed that the survival time of suspensions of *E. amylovora* in distilled water is very short, indicating that it might be connected with some osmotic damage to the outer membrane of the bacterial cell. Crosse et al. (1972) observed loss of viability of *E. amylovora* in aqueous suspensions at low concentrations, necessitating the use of

0.05 M potassium phosphate buffer. Maas Geesteranus and de Vries (1984) have suggested that the polysaccharide layer is readily dispersed by water and that bacteria treated in this way are killed by desiccation within 24 hours. However, it should be noted that water is essential for the spread of bacteria from stigmas to the hypanthium (floral cup).

Disinfection

In New Zealand 37% of packing houses in the export program use chlorine in the dump tank. The concentration of chlorine used varies between 5 and 50 ppm. Another 16% used peroxyacetic acid (Tsunami®), and bromo-chloro-dimethylhydantoin (Nylate®), as alternatives to chlorine, as per label instructions. Monitoring of disinfectants is done manually or automatically each day of operation or at specific times on each day. Chlorine or alternatives were not used by 47% of the packing house operators procedure (MAFNZ, 2005a).

Several stakeholders commented that chlorine is ineffective in disinfesting fruit. Chlorine-based chemicals are perhaps the most widely used sanitiser (Walker and LaGrange, 1991; Cherry, 1999). Chlorine is often used to sanitise produce and processing facilities and to reduce microbial populations in water used during cleaning and packing operations (Parish et al., 2003). Chlorine is also used to reduce populations of microorganisms on fruits and vegetables (Beuchat, 1992). The most common forms of free chlorine include liquid chlorine and hypochlorites. Although some bacterial populations are killed at 5 ppm of residual chlorine (Somers, 1963), a 50 to 200 ppm concentration range with a contact time of 1 to 2 min is generally used to sanitise produce surfaces and processing equipment (Parish et al., 2003). Toivonen *et al*. (2001) showed that sodium hypochlorite (100 µg per litre) or peroxyacetic acid at 80 ppm was fully effective in eliminating micro-organisms from the surface of apples. They showed that peroxyacetic acid eliminated microbes from the calyx while sodium hypochlorite did not, and that it was difficult to remove or kill micro-organisms present in the stem-end of the fruit using both chemicals. Both chemicals are used in some packing houses in New Zealand, but no experimental data is available that is directly relevant to fire blight. Nguyen-the and Carlin (1994) showed that cross-contamination of produce will occur if this concentration of chlorine is not maintained.

Naturally-contaminated mature apples infested with an average of $10^{3.3}$ cfu per mL (from bulked samples) when treated with 100 µg per mL of chlorine were not effectively sanitised, because chlorine did not reach bacteria in the protected calyx cavity (Sholberg et al., 1988) probably because of formation of air pockets. However, a 10 min dip in a solution of 1.0 M acetic acid and 1.0 M propionic acid was effective in completely eliminating bacteria from fruit inoculated with 6.4×10^7 cfu per mL of *E. amylovora* by spraying. Dueck (1974b) also observed that when *E. amylovora* suspended in distilled water (about 8.2×10^6 cell per mL) was artificially inoculated by swabbing on apples, bacterial numbers were reduced but not completely eliminated by chlorine. However, a 10 minute dip in 1.0 M solution of acetic acid completely eliminated *E. amylovora* from the fruit surface. Janisiewicz and van der Zwet (1988) reported that 12 mg per L of sodium hypochlorite in vitro totally eradicated *E. amylovora* in 5 minutes, but, with addition of a surfactant (X-77) at 0.25% and 0.5%, the amount of sodium hypochlorite required to totally eliminate bacteria in 5 minutes increased to 50 and 100 mg per litre respectively. However, Janisiewicz and van der Zwet (1988) showed that when artificially inoculated (10^8 cfu per mL) apple fruit was treated with 450 and 500 ppm sodium hypochlorite plus 0.25% of surfactant, *E. amylovora* was reduced but not completely killed.

Roberts and Reymond (1989) artificially inoculated mature apple fruit with *E. amylovora* aerosol solutions (8.0×10^6 to 1.3×10^8 per fruit) and immersed fruit in different concentrations (250, 300, 400, 500 ppm) of sodium hypochlorite or 1.0 M acetic acid. The reduction in the *E. amylovora* population averaged 6 to 7 log units less than the number applied to the fruit, but significant differences between treatments were not observed. Roberts and Reymond (1989) also reported that low pH 0.1 M citrate buffer was effective against *E. amylovora* but because of its incompatibility with sodium hypochlorite, this could not be used in the dump tank. They reported that treatment with 250 ppm sodium hypochlorite in 500 ppm dodecylbenzenesulphonic acid (DBSA) for 10 min significantly reduced *E. amylovora* on apple fruit. These reports indicate that chlorine at different concentrations is effective in reducing but not eliminating the bacterial population. While alternatives such as acetic acid or propionic acid are more effective than chlorine, the associated strong pungent vapour which is noxious in closed environments might cause worker discomfort.

Some stakeholders raised the issue of aggregate and biofilm formation and the impacts this may have on disinfection. A biofilm may be described as an assemblage of bacterial cells that are both enclosed by and attached to each other and/or to wetted surfaces by means of an extracellular fibrous polysaccharide-containing matrix. This matrix, termed a glycocalyx (Costeron et al., 1981), is synthesised by bacteria, and serves in part to permanently anchor bacterial cells adsorbed to a substratum (Fletcher and Floodgate, 1973). The existence in *E. amylovora* of virulence factors such as Type 111 pilus (Hrp pilus) and the ability to form EPS may help this pathogen to survive adverse conditions. The spatial distribution of cells in different physiological states may exist within the biofilm. Such inherent variability would help maintain cells at different metabolic rates, thus increasing their chances of survival (Gilbert et al., 1990). Biofilms of a single species form in multiple steps (Watnick and Kolter, 1999) require intercellular signalling (Davies et al., 1998) and demonstrate a profile of gene transcription distinct from that of planktonic bacteria (Prigent-Combaret et al., 1999). However, in natural environments the biofilm is invariably the product of multi-species microbial communities (Watnick and Kolter, 2000). Stabilisation of the biofilm structure is achieved by repressing the synthesis of flagella and producing exopolysaccharide (Watnick and Kolter, 2000). Once bacteria are encased in exopolysaccharides, detachment of cells occurs as a result of polysaccharide lyase production (Allison et al., 1998). Biofilm-specific exopolysacharides (Yildiz and Schoolnik, 1999) and quorum-sensing effects (Davies et al., 1998) may increase resistance to penetration by substances such as chlorine (Costeron et al., 1987).

Although currently there is no direct evidence to support the formation of aggregates or biofilms on apple fruit by *E. amylovora*, the potential for aggregates to be attached to discontinuities in the waxy surface of fruit and other structures may exist, especially when a temperature differential occurs between fruit and the external environment (Burnett et al., 2000; Kenney et al., 2001). Under these circumstances, bacterial aggregates or biofilms are unlikely to be removed by washing. It would seem that undisturbed bacteria in water biofilms are well-protected but the possibility exists for some to be released into water as planktonic bacteria. Caldwell (1990) showed that low levels of sodium hypochlorite (0.5 and 5 ppm available chlorine) were inhibitory to biofilms and their cells, but that these reactivated immediately after the chlorine solution was removed. When re-exposed to chlorine, these biofilms and their cells stopped growing. However, exposure at 50 ppm resulted in reduction of the biofilm and temporarily stopped cell growth even after the chlorine solution was no longer in contact. It should be noted that the above comments are based on work done on species other than *E. amylovora* for which information is lacking.

Bacteria determine cell population density through cell-to-cell communication. This bacterial network is termed 'quorum sensing', another issue raised by stakeholders. Several important traits regulated by quorum sensing are implicated in pathogenicity and colonisations of hosts (von Bodman et al., 2003). Among them is a cell-density dependent regulatory response which involves the production of N-acyl homoserine lactone (AHL) signal molecules (Bertani and Venturi, 2003). Although several bacterial pathogens of plants have been intensively studied, little information is available on quorum sensing of *E. amylovora*. Production of AHL by *E. amylovora* has also been reported for the first time (Venturi et al., 2004; Friscina et al., 2004). Production of *E. amylovora* EPS, amylovoran and levansucran was dependent on cell density (Molina et al., 2004). Given that AHL is involved in plant pathogenesis, it is speculated that AHL-dependent quorum sensing could have a role in coordinating the expression of virulence genes in *E. amylovora*. Quorum sensing also affects some properties of biofilms (Watnick and Kolter, 2000). Given the paucity of work on these aspects of *E. amylovora* it is difficult to assess the significance of this concept. However, if this mechanism affected survival of bacteria on mature apple fruit, this would already be implicitly accounted for in studies relating to the number of bacteria on mature fruit.

Disinfection of packing lines was undertaken by 93% of export packing houses in New Zealand manually or using high pressure water blasters and disinfectant. It was done before the season started and continued at varying intervals (daily, weekly, monthly) during and after the season. Organic exporters (7%) used only water to clean the lines (MAFNZ, 2005a).

Brushing

Brushing would not remove bacteria present in internal tissues or at the stem and calyx-ends of fruit, as these areas are inaccessible.

Waxing

Bacteria will survive low-temperature waxing, as the thermal death point of *E. amylovora* ranges from 45º to 50ºC (van der Zwet and Keil, 1979).

Sealing of *E. coli* within wax cutin platelets because of contact between apples has been demonstrated (Beuchat, 2001). These bacteria may be released as a result of breakdown in tissue that is embedding bacteria (Kenney et al., 2001). However, whether *E. amylovora* undergoes similar processes on apples is unknown.

Sorting and grading

Infected fruit that shows discolouration or rotting symptoms would be removed during this operation.

Damaged fruit could have been infected during picking and transport. Sorting and grading to remove visibly damaged fruit would reduce the number of apples potentially carrying infections initiated during the picking and transport stage.

Bacteria infesting the surface or stem- and calyx-end, as well as internal infections of fruit will not be detected during visual inspection.

Internal infection of immature fruit has been recorded (van der Zwet et al., 1990) but not in mature fruit. If such infections do occur on mature fruit they are unlikely to be detected during sorting and grading.

Packaging

Packaging, which aims to minimise moisture loss and maximise heat dissipation, will not reduce the bacterial population in protected sites or on the surface of fruit.

Cold storage

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.

Sholberg et al. (1988) inoculated fruit by swabbing calyces of apples with an average of 10^7 cfu per mL of *E. amylovora*. These authors demonstrated that the initial population decreased to an undetectable level after 6 months in cold storage.

Some stakeholders indicated that it was difficult to comprehend the data from Hale and Taylor (1999) presented in the revised draft IRA. Therefore, the decision was made to reproduce the results presented in Table 1 of their paper (see Table 17) for reasons of clarity. Hale and Taylor (1999) inoculated 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 (2ºC ± 0.5ºC) for 25 days or cool-stored them for 25 days before incubating at room temperature (about 20ºC) 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 (data not shown in table). 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.

Table 17 Percentage of inoculated apple calyces infested with *Erwinia amylovora* after cool storage, or cool storage and incubation in laboratory conditions, after Hale and Taylor (1999)

E. amylovora cfu	Time after inoculation and fruit treatment		
	Nil	Cool storage 25 days	Cool storage 25 days Room Temp. 14 days
10^7	100	90	35
10^5	100	20	3
10^4	100	20	0
10^3	100	<8	0
10^2	40	<8	0
10^1	20	<8	0
10^0	1	0	0
Saline	0	0	0

In another experiment, fruit inoculated with the various concentrations of *E. amylovora* were subjected to cool storage alone or alternatively, cool storage and incubation under commercial conditions. The results (see Table 2 of Hale and Taylor (1999)) reproduced in Table 18 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 and incubation *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 (data not shown in table). These results show that bacterial populations on cool-stored fruit incubated at room temperature (about 20ºC) for 14 days did not increase to levels detectable by PCR.

Table 18 Percentage of apple calyces inoculated at harvest infested with *E. amylovora* after cool storage, or cool storage and incubation in commercial conditions, after Hale and Taylor (1999)

E. amylovora cfu	Time after inoculation and fruit treatments		
	At harvest	Cool storage 25 days	Cool storage 25 days Room temp. 14 days
10^7	77	66	36
10^5	75	28	6
10^3	25	10	0
10^1	10	3	0
Saline	0	0	0

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 cool storage or cool storage and incubation. *E. amylovora* was not isolated from any 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 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 and then cold-stored for two to three months, none of the fruit developed external symptoms. A total of 1500 fruit was 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*.

Only early season fruit would be stored for a short period. Most harvested fruit would be in long-term storage (either cold storage or controlled atmosphere storage). While there is data on the efficacy of cold storage on survival of *E. amylovora* populations, there is no evidence concerning the effect of controlled atmosphere storage.

Summary

The operations listed above are routine procedures that occur in New Zealand packing houses and therefore have to be considered in the unrestricted risk assessment. None of the processes undertaken at this stage would have a large influence on the survival of *E. amylovora* on apple fruit. However, depending on individual packing house procedures some reduction in the number of fruit carrying bacteria would be expected because of factors such as the use of disinfectants and grading out of damaged fruit. After considering the technical information and the stakeholder comments the IRA team decided to represent Imp4 as a triangular distribution, with a minimum value of 0.3, a maximum value of 0.7, and a most likely value of 0.65.

Importation step 5: Likelihood that clean fruit is contaminated by *E. amylovora* during processing in the packing house: triangular distribution with a minimum value of 10^{-3}, a maximum value of 5×10^{-2}, and a most likely value of 2.5×10^{-2}. T(10^{-3}, 2.5×10^{-2}, 5×10^{-2})

Any bacteria present on fruit, trash (leaves and twigs), harvesting bins and soil adhering to bottom of bins may get into the dump tank and potentially contaminate clean fruit. Epiphytic presence of bacteria on these materials at the harvesting period was reviewed against literature under Imp2 and Imp3 above.

The largest surface area presented to wash water is that of fruit. Even a small amount of soil can have a large surface area for bacteria to bind to, but as discussed under Imp3 the likelihood of bacterial survival in soil is very small. General fruit surface is unlikely to carry significant amounts of epiphytic bacteria, with any present being in the calyx (Hale et al., 1987; Ceroni et al., 2004). The entrapment of a large air bubble in the calyx-end depression as apples float in the dump tank may prevent wetting of the calyx in some fruit. However, the calyx of at least some fruits would be expected to be wetted, allowing some bacteria inside to get into the dump tank water. Similarly, small numbers of epiphytic bacteria surviving on trash and bins may also get into the water. However, there will be a very high dilution factor in the dump tank water. There are also indications that *E. amylovora* has difficulty surviving in water. In their studies Crosse et al. (1972) had to change the suspension medium of bacteria from water to 0.05 M potassium phosphate buffer (pH 6.5) because of loss of bacterium viability in aqueous suspensions at lower inoculum concentrations, a factor relevant to dump tanks. Currently, 37% of New Zealand apple packing houses use chlorine at 5 to 50 ppm with 16% using an alternative such as peroxyacetic acid or bromo-chloro-dimethylhydantoin, while the remaining 47% do not use any disinfesting agents in the dump tank (MAFNZ, 2005a). Those using disinfestation agents monitor concentrations every few hours, or on a daily basis using manual/automatic systems. In addition, the dump tank water is generally replenished every 600 bins. Further, 73% of packing houses use high-pressure and high-volume washing with jets of clean water to rinse apples after washing in the dump tank (MAFNZ, 2005a). This means that any surface contamination of clean fruit in the dump tank will be removed to a high degree during the high-pressure water wash or post-dump tank rinse.

Compared to the dump tank, the rest of the packing line is considered to be a less significant contamination source. Packing houses in New Zealand maintain graders and conveyors in good hygienic condition, and up to 93% use high pressure water blasters with disinfectant to clean these areas. Disinfection/cleaning is first done preseason, then at varying periods (daily, weekly, monthly) throughout, and again at the end of season. Under these conditions, the likelihood of contamination of clean fruit through *E. amylovora* surviving on graders and conveyors appears to be extremely low. McLarty (1927), Keck et al. (1996), Nachtigall et al. (1985) and Ceroni et al. (2004) have shown survival of *E. amylovora* on wood and plastic for some weeks when these materials are dipped in high concentrations of bacterial suspensions and then kept without being subjected to washing or cleaning. Wooden or metal structures in the packing line will not be exposed to such high bacterial concentrations and as explained above, are regularly washed and cleaned.

New Zealand does not wax most of its apples, but many packing houses can do so if necessary to meet market requirements. Any bacteria encapsulated in wax are unlikely to be able to initiate infection.

The possibility of any bacteria in the dump tank infecting the fruit through minute damage and bruising to fruit surface requires some consideration, while noting that one of the aims of a flotation dump is to minimize such damage. Van der Zwet et al. (1990) observed that when fruits are artificially bruised or punctured and immediately immersed for 1 min in a bacterial suspension of 10^8 cfu/mL buffer, there was an average infection rate of 75%, with bruised treatment showing up to 80 to 90% infection. Applying the worse case figure of 37% damage for apples in a whole container in the packing house during harvesting and transport (Hetzroni et al., 2004), expected fruit infection rates could be around 30–33%, if dipped in a solution of 10^8 cfu/mL. There is no information available concerning *E. amylovora* concentrations in dump tanks, but these are likely to be at least 10^6 to 10^7 folds lower than the high concentration of 10^8 cfu/mL used in artificial inoculations. Infection rates at such lower bacterial concentrations could be at least 10 fold lower.

Van der Zwet et al. (1990) indicate up to 5% fruit that appear not fully mature may carry epiphytic bacteria. Stakeholders have claimed data in this paper show an increase from 4% to 14% of contamination in fruit following sanitation and cold storage. This conclusion was probably reached by comparing samples labelled A1 and A2 in Table 2 (not shown) of the above paper. However, this comparison and the above conclusion are not valid as apple samples for A1 and A2 were taken different distances from inoculum sources.

Sholberg et al. (1988) found an average of $10^{3.3}$ cfu/mL in washings of fruit from an orchard severely damaged by fire blight after a hail storm, with every tree heavily infected with blighted shoots and many oozing fruitlets. There is no doubt that washings of such fruits would have high bacterial numbers, but such situations in well-managed New Zealand export orchards would be extremely rare. Özakman and Maden (1999) observed 2.3 x 10^4 cfu/shoot in pear in late June/early July; however, numbers of bacteria washed from shoots during fruit harvest at least 8 to 10 weeks later are likely to be significantly lower.

Burnett et al. (2000), Kenney et al. (2001) and Seeman et al. (2002) have shown surface adherence and internalisation of *E. coli* cells in apples rinsed with bacterial solutions, and stakeholders have suggested the same may happen with *E. amylovora* in the dump tank. However, Ceroni et al. (2004) immersed pear fruit for 15 min in a suspension of *E. amylovora* with 10^8 cfu/mL and could not detect bacteria on the surface after just a few days, with small numbers remaining for longer periods only in the calyx. These authors concluded that bacterial survival on the fruit surface is very short and has a negligible epidemiological role. If *E. amylovora* gets into the core in the dump tank, one would expect some internal infection to develop but this has never been reported. Sapers (1999) carried out some apple washing trials in a commercial cider mill and found that for apples inoculated by dipping in *E. coli* solutions, bacteria were not washed out into the dump tank, the dump tank water did not get contaminated and no cross contamination took place in the dump tank. This behaviour of *E. coli* is different to *E. amylovora,* which has been shown in several studies to be easily washed from contaminated surfaces. This clearly demonstrates the differing behaviours of the two bacteria and the dangers of extrapolating from one to the other. In contrast to observations of Sapers (1999) for *E. coli,* we have concluded that a very small level of cross contamination as infestation in the dump tank may be possible for *E. amylovora*.

Summary

After consideration of the available information and the stakeholder comments the IRA team decided to represent Imp5 as a triangular distribution, with a minimum value of 10^{-3}, a maximum value of 5 x 10^{-2}, and a most likely value of 2.5 x 10^{-2}. This conclusion was based on the potential for the fruit dump tank to become contaminated by bacteria and the fact that disinfection of the dump tank water is not a routine practice in a significant number of New Zealand packing houses. This also takes into account that unrestricted risk is being assessed and therefore fruit from orchards with active symptoms could be carrying bacteria that wash off into the dump tanks.

Importation step 6: Likelihood that *E. amylovora* survives palletisation, quality inspection, containerisation and transportation to Australia: triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.8. T(0.7, 0.8, 1)

Bacteria are not visible and will survive quality inspection and palletisation.

Transportation of fruit in containers from New Zealand to Australia may take a minimum of 10 days. Several studies (Ceroni et al., 2004; Hale and Taylor, 1999) show that bacteria can survive on fruit for periods longer than 10 days. However, some reduction in numbers of bacteria and number of infested fruit would be expected. The effect of storage is discussed in more detail at Imp4 above and also again in the later section on risk management.

Summary

After consideration of the technical information and stakeholders' comments, the IRA team decided to represent Imp6 as a triangular distribution, with a minimum value of 0.7, a maximum value of 1 and a most likely value of 0.8. This is based on the conclusion that a small reduction in the number of fruit infested would occur simply because of the passage of time from packing house to arrival in Australia.

Importation step 7: Likelihood that clean fruit is contaminated by *E. amylovora* during palletisation, quality inspection, containerisation and transportation: triangular distribution with a minimum value of 0, a maximum value of 10^{-6}, and a most likely value of 5×10^{-7}. T(0, 5×10^{-7}, 10^{-6})

Surface contamination of clean fruit can occur only if bacteria ooze out from internally infected fruit. Such fruit are rarely found (van der Zwet et al., 1990), as rotten fruit is not harvested. If harvested, such fruit is rejected before entering the packing line. If rotten fruit is present after cold storage, it is discarded at quality inspection.

Packed fruit is kept under secure conditions, not exposed to elements and therefore not exposed to bacterial inoculum.

Summary

After consideration of the technical information the IRA team concluded that there was little opportunity for fruit to be contaminated at this state. The IRA team decided to represent Imp7 as a triangular distribution, with a minimum value of 0, a maximum value of 10^{-6}, and a most likely value of 5×10^{-7}.

Importation step 8: Likelihood that *E. amylovora* survives and remains with the fruit after on-arrival minimum border procedures is 1.

Bacteria present on the surface, in the calyx or internally will not be detected at on-arrival border procedures. Standard on-arrival inspection procedures would not be able to detect the presence of bacteria. Fruit carrying bacteria would not show any symptoms of fire blight.

Summary

The IRA team concluded that the likelihood of Imp8 should be represented as a value of 1.

Conclusion – probability of importation

When the above likelihoods were inserted into the risk simulation model, the probability of importation of *E. amylovora* was estimated as being 3.9 x 10^{-2} (mean), 2.2 x 10^{-2} (5th percentile) and 5.6 x 10^{-2} (95th percentile). Therefore, the infestation rate for *E. amylovora* was estimated to be 3.9% (mean) of the total proposed number of apples imported from New Zealand annually.

Probability of entry, establishment and spread

The factors relevant to the estimation of the probability of entry, establishment and spread are discussed below. These include:

- Probability of importation (discussed in previous section)
- The proportion of utility points near host plants susceptible to the pest in each exposure group (titled *Proximity* below)
- The probability of exposure of a susceptible host plant in the exposure group to the pest by an infested/infected apple discarded near it (titled *Exposure* below)
- The probability of establishment
- The probability of spread

These factors are combined using the approach set out in the methodology section to provide an estimate of the annual probability of entry, establishment and spread.

Proximity

The term 'proximity' expressed in this report refers to the likelihood that a utility point is sufficiently close to a host plant in a particular exposure group, for the likelihood of transfer of bacteria to a host to be greater than zero.

General issues specific to each utility point are discussed below, followed by a justification of the proximity ratings for each utility point by exposure group combination as set out in Table 19.

1. Orchard wholesalers

This group includes packing and storage facilities based in non-urban areas that might be expected to pack bulk New Zealand fruit, repack fruit needing culling or re-grading, or act as a storage and distribution facility for New Zealand fruit. The IRA team considered that the facilities undertaking these types of operations would be the same ones involved with domestic apple fruit and therefore would be located in areas close to apple and/or pear orchards. Workers and equipment packing New Zealand fruit may be contaminated by fire blight bacteria if they are present on apples. In addition, waste fruit may be discarded very close to host plants of fire blight.

Industry sources suggested that about seven facilities of this type could have some involvement with New Zealand apple fruit. One stakeholder also suggested that citrus packing houses may sometimes deal with apples. However, an industry source indicated that this was most unlikely, as the handling arrangements for citrus are quite different from those for apples. Even if this did occur, citrus packing houses are unlikely to be close to apple and pear orchards and therefore would not constitute a significant risk.

2. Urban wholesalers

This group includes packing, storage and distribution centres located in major cities. These are generally located in industrial areas, sometimes at fruit and vegetable markets where there are very few hosts of fire blight.

3. Retailers

This group includes supermarkets, fruit and vegetable shops, retail markets and roadside stalls. The numbers and distribution of these largely follow consumer population density, with the majority in large cities, often in shopping complexes or malls well separated from susceptible hosts. However, in some cases, apple retailers may be co-located with nurseries where some hosts of fire blight may be present.

4. Food services

This group includes restaurants, sandwich bars, cafeterias and hotels where apples may be used or consumed. The numbers and distribution of these largely follow consumer population density, with the majority in large cities, often in shopping complexes, malls or central business districts, well separated from susceptible hosts.

5. Consumers

This group includes all final consumers of apples. 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, fire blight host plants are present in many home gardens, parks and roadsides in large cities. In estimating proximity, the IRA team considered the proportion of the population in areas where hosts would not be present or occur at a very low frequency. An estimate based on ABS data is that approximately 85% of the Australian population live in areas where the climate is suitable for fire blight hosts. This puts an upper limit of 0.85 on the proportion of consumers located near susceptible hosts. This proportion is also relevant to retail and food service utility points.

There are several routes for disposal of waste. Most consumers dispose of their waste into landfills via the domestic garbage collection. Such waste is unlikely to constitute a risk for exposure to *E. amylovora*. However, apple cores are discarded directly into the environment, evidenced by the presence of volunteer apple plants along roadsides and near recreation areas. Such infested or infected waste could act as a potential source of inoculum. Local authorities encourage the recycling of waste. Consequently a large proportion of consumers not living in metropolitan areas dispose of their waste into backyard compost pits/heaps, which may be close to susceptible host plants.

An additional factor is the potential for consumers to be close to host plants. For example, the opportunities for apples to be exposed to hosts are significantly fewer for consumers living in flats or apartments, compared to consumers living in houses with gardens. ABS figures indicate that about 30% of the dwellings in major cities are flats, apartments or townhouses where there are unlikely to be any hosts of fire blight. Another factor to be considered is the occurrence of hosts in home gardens. This would vary considerably depending on the area and the climatic conditions. For example, hosts of fire blight are much more common in gardens in southern Australia, than in areas further north. Many hosts of fire blight have been identified as undesirable plants, and in some areas there are active campaigns to remove them and discourage further plantings. For example, large numbers of cotoneasters and pyracanthas have been removed in Canberra. It has been assumed that 50% of Australian home gardens would contain hosts of fire blight.

Care must be exercised to avoid ‘double counting’ when estimating proximity values. For example, an apple eaten and discarded by a consumer in a public park close to wild and amenity hosts cannot simultaneously be close to household and garden plants. When the model was being checked in response to stakeholder concerns about double counting, it was realised that some of the proximity values had been significantly overestimated in the previous draft because of this problem.

Commercial fruit crops near utility points

Major commercial fruit crops susceptible to *E. amylovora* are apple (*Malus* spp.) and pear (*Pyrus* spp.). Other fruit trees are quince (*Cydonia* spp.) and loquat (*Eriobotrya japonica*) and rarely, Japanese plum (*Prunus salicina*).

The proportion of **orchard wholesalers** near **commercial fruit crops**: 1

- All orchard wholesalers would be in proximity of commercial fruit crops. Most of them will dispose of waste to places within the orchard. Occasionally, some may dispose of waste to landfills or general waste disposal sites several kilometres away but still close to orchards. Before the waste is finally disposed of, it could remain open to the elements in a skip near the packing house.
- Occasionally orchard workers and visitors could discard apple cores in the orchard itself.
- The packing of New Zealand fruit from bulk bins and the repacking of New Zealand fruit originally imported in boxes would be in close proximity to host trees. Equipment and packing house workers exposed to New Zealand apples and associated waste would be in very close proximity to host trees.

The proportion of **urban wholesalers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are in metropolitan areas. Their waste goes to landfills. Both the utility point and the final waste are away from commercial fruit crops.
- Some urban wholesalers may be within apple production areas, such as Shepparton. The waste may be disposed of in close proximity to the orchard or into landfills away from production sites. The value decided by the IRA team allows for this possibility.

The proportion of **retailers** near **commercial fruit crops**: Uniform (10^{-4}, 10^{-2})

- Some retailers (up to 1%) and their waste could be near commercial fruit crops. This allows for retailers based in towns near orchards. However, most retailers are based in large urban centres significant distances from commercial fruit crops.

The proportion of **food services** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Major food services are extremely unlikely to be near commercial fruit crops.

The proportion of **consumers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Only a small proportion of the Australian population is estimated to be near commercial fruit crops, as the majority of the population is located in urban areas.

Nursery plants near utility points

Common nursery plants that are hosts of *E. amylovora* include apple (*Malus* spp. including crab-apples), cultivated and wild species of pear (*Pyrus* spp.), quince (*Cydonia* spp.), loquat (*Eriobotrya japonica*), Japanese plum (*Prunus salicina*) and potato rose (*Rosa rugosa*).

The proportion of **orchard wholesalers** near **nursery plants**: Uniform (10^{-3}, 5×10^{-2})

- Some orchardists may raise their own nursery plants or run a parallel wholesale business. Also, pome fruit nurseries may be located near orchards.

The proportion of **urban wholesalers** near **nursery plants**: Uniform (10^{-3}, 5×10^{-2})

- Urban wholesalers are in metropolitan areas and some may be close to garden centres selling nursery plants. Although their waste may finally end up in landfills, it could be kept temporarily in proximity of these garden centres.

The proportion of **retailers** near **nursery plants**: Uniform (10^{-3}, 5×10^{-2})

- Up to 5% of major retail outlets may sell nursery plants that are hosts such as apple, pear and/or ornamentals.

The proportion of **food services** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Major food services such as airlines caterers are extremely unlikely to be near nursery plants.

The proportion of **consumers** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Although some consumers may come in proximity to nursery plants susceptible to fire blight this is likely to be only for brief periods, and it is extremely unlikely that they would be discarding significant amounts of apple waste material in nurseries.

Household and garden plants near utility points

The most common household and garden plants susceptible to fire blight would be apple (*Malus* spp.), pear (*Pyrus* spp.) and potato rose (*Rosa rugosa*); less common host plants would be quince (*Cydonia* spp.) and loquat (*Eriobotrya japonica*).

The proportion of **orchard wholesalers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesalers and their waste disposal sites are located in an isolated area within the orchard premises, but some household and garden plants may be near them.

The proportion of **urban wholesalers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesalers are located in metropolitan areas and their waste is disposed of in landfill sites. Household and garden plants are unlikely to be near these sites, because residential properties would be located away from them.

The proportion of **retailers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Most retailers are in larger cities and their waste would be disposed of in landfill sites, which are generally not near residential properties.
- Major retailers may have hosts susceptible to *E. amylovora* near apple fruit displayed for sale.
- Retail nurseries may be sometimes found near fresh food markets.

The proportion of **food services** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Major food service industries are in cities, not near residential areas and their waste is disposed to landfill sites.
- Some restaurants may have a few *E. amylovora* hosts within their premises.

The proportion of **consumers** near **household and garden plants**: Uniform (10^{-2}, 0.15)

- Most consumers are in metropolitan and suburban areas, and their waste is disposed of in landfills with household and garden plants susceptible to *E. amylovora* unlikely to be near these sites.
- Some proportion of metropolitan consumers and most suburban consumers may have a few *E. amylovora* hosts present as household and garden plants.
- Local authorities encourage recycling of waste to make compost, and this is becoming a common practice in some rural areas. Pome fruit trees are common horticultural plants in back gardens in some parts of Australia. These may be found near compost heaps.

Wild and amenity plants near utility points

Host plants of *E. amylovora* in this category include several ornamental species of hawthorn (*Crataegus* spp.), firethorn (*Pyracantha* spp.), cotoneaster (*Cotoneaster* spp.), serviceberries (*Amelanchier* spp.), mountain ash (*Sorbus* spp.) and *Photinia* spp. Apart from these species, crab-apples (*Malus* spp.) and wild species of pear (*Pyrus* spp.) may also be present.

The proportion of **orchard wholesalers** near **wild and amenity plants**:
Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesale waste sites are mostly located within orchard premises and are not near wild and amenity plants. However, some amenity plants (e.g. cotoneaster) may be present as hedgerows in the orchard boundary.
- Orchard wholesalers will not allow feral plants and volunteer apple seedlings to grow near these waste disposal sites.
- No information on the susceptibility of Australian native plants to *E. amylovora* is available.

The proportion of **urban wholesalers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesaler waste is disposed of in landfills. Susceptible hosts may grow in the wild near these sites as a result of dispersal of seeds by birds (for example, crab-apple trees, apple seedlings, firethorn, cotoneaster etc.).
- Some susceptible host plants (for example, Manchurian pear) may be near urban wholesalers.

The proportion of **retailers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Retailer waste would be disposed of in landfills. Susceptible hosts may grow in the wild near these sites, as a consequence of dispersal of seeds of susceptible plants by birds.

The proportion of **food services** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Food services would dispose of their waste in landfills. Seedlings originating from seeds dispersed by birds would be present.

The proportion of **consumers** near **wild and amenity plants**: Uniform (5 x 10^{-3}, 5 x 10^{-2})

- Most consumers in metropolitan and suburban areas dispose of their waste in landfills. Susceptible hosts may grow from seeds in the wild near these sites as result of dispersal by birds.
- Some consumers may discard apple cores, rotten fruit or partially eaten fruit into the environment. This is likely to occur near parks, gardens, recreation sites and along roadsides where susceptible plants may be found. Usually the density of host plants near these sites would be low. However, there could be situations where the density of alternative hosts is high and occurs in a wide area. For example, hawthorn and cotoneasters are found along many country roads and in some instances stretch for several hundred kilometres.
- Local authorities encourage recycling of waste to make compost, and this is becoming a common practice in some rural areas. Garden hedgerows and the neighbourhoods of some localities may have susceptible amenity plants (for example, cotoneaster and hawthorn).

Table 19 Summary of proximity values for all utility point and exposure group combinations for *E. amylovora*

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	1	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Urban wholesalers	U(10^{-6}, 10^{-3})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Retailers	U(10^{-4}, 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Food services	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Consumers	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-2}, 0.15)	U(5 x 10^{-3}, 5 x 10^{-2})

Exposure

The term exposure is applied to the likelihood of transfer of the pathogen from infested or infected apples (waste) to a susceptible host plant. This is a complex variable dependent on a number of critical factors. A sequence of events needs to be completed for successful exposure of host plants to *E. amylovora* from infested or infected apples, in order for *E. amylovora* to establish in Australia. An analysis of key steps in the sequence of events that would need to occur in order for successful transfer of fire blight to take place is summarised below.

Location of bacteria

In mature harvested fruit, cells of *E. amylovora* occur predominantly in remnant flower parts in the calyces (Hale et al., 1987). Bacteria can also be present on the stem-end or surface of fruit. The occurrence of fire blight bacteria on fruit is discussed in detail in the earlier section on Imp2.

Viability

Bacteria, especially those present in the calyx, may survive cold storage and transport. Spoiled whole fruit, partially consumed fruit and fruit peels and cores infested or infected with *E. amylovora* will enter the Australian environment through the disposal of waste. *E. amylovora* is known to survive in calyces of mature apple fruit at harvest, from severely blighted orchards or when severe fire blight was present in the area (van der Zwet et al., 1990; Sholberg et al., 1988). Bacteria must survive in discarded waste or soil and retain their viability until exposure to susceptible host plants. 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). *E. amylovora* does not produce resting cells (Roberts et al., 1998). It is vulnerable to desiccation (Maas Geesteranus and de Vries, 1984) and dry conditions (Jock et al., 2005). Viability of *E. amylovora* is adversely affected by high temperature and low relative humidity (Maas Geesteranus and de Vries, 1984). *E. amylovora* cells can survive in the dark for considerable periods, but are killed rapidly when exposed to ultraviolet light/full sunlight. However, bacteria in the calyces would be protected to some extent and are likely to survive longer periods when exposed. While some reports indicate that short periods of cool storage reduce the bacterial population

(Taylor and Hale, 2003), other reports indicate that bacteria survived in a viable state in cool storage for at least several months (Sholberg et al., 1988).

Survival

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 viable bacteria in the calyx to multiply. The availability of nutrients could also encourage other saprophytic micro-organisms to multiply at the same time. When cores are discarded into the general soil environment, *E. amylovora* can survive for a limited period (Ark, 1932; Hildebrand et al., 2001; Thomson, 1969). Waste discarded into landfills or compost heaps would be colonised by other saprophytic micro-organisms causing rapid decay, and may be consumed by insects, mammals or birds, or destroyed by bacteriophages in the soil. 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). *E. 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 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 amylorova* cells slowly dispersed and could still be recovered after several weeks of storage at room temperature.

Transfer mechanism

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 a sufficient concentration 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 is a situation with ooze on active cankers and not as vectors from the calyx of fruit. *E. amylovora* does not have specific vectors or mechanism to allow transmission from an apple to a suitable host. Birds, particularly starlings have been implicated in fire blight transmission, based on circumstantial evidence (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.

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). Discarded apples are attractive to a wide range of insects and this attraction may be increased by rotting. For example, Figure 4 shows bees attracted to windfall fruit in an apple orchard. Bees are known to be involved in the secondary spread of fire blight disease (Thomson, 2000). Rotting of the apple could involve multiplication of fire blight bacteria resulting in the production of bacterial ooze.

Figure 4 Bees visiting rotting apple

Transmission of fire blight by insects attracted to ooze has been reported (van der Zwet and Keil, 1979). Taylor et al. (2003b) artificially inoculated apple calyces with a marked strain of *E. amylovora*. The infested apples were hung in apple orchards near flowers for a 20-day period over two consecutive seasons. *E. amylovora* was not detected by either culture or PCR tests on apple flowers and leaves, or trapped insects. However, given the replication and sampling methods used in this experiment, it is unlikely that lower probability events that could be of significance for fire blight spread would have been detected. 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 could also be 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 fire blight bacteria. Initiation of disease could then occur by transfer of bacteria to wounds caused by normal orchard operations such as pruning.

Availability of points of entry

Infection can also be initiated 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 means.

Inoculum dose

There is no accepted threshold number of bacteria required to initiate an infection, and this may vary with environmental and host factors. Hildebrand (1939) reported that a single bacterium 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. Van der Zwet et al. (1994) showed that five bacteria 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. Low populations of *E. amylovora* inoculated on to healthy stigmas can multiply rapidly to high populations (Thomson, 1986; Thomson et al., 1999).

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, there were no disease symptoms and *E. amylovora* was not detected. Fire blight symptoms were only observed when the inoculum dose of *E. amylovora* exceeded 10^6 cfu (Taylor et al., 2003b). Such populations may exist in fruit from heavily infected orchards, but not in fruit from lightly infected or symptomless orchards (Hale and Taylor, 1999). Similar observations were made by Beer and Norelli (1975), who reported that infections are likely to occur when epiphytic populations of *E. amylovora* reached 10^6 to 10^7 cfu under high relative humidity, and not at 10^2 cfu. However, the nature of these experiments makes it difficult to provide a high level of replication, so lower probability events that could have been significant in disease establishment may not have been detected.

Host receptivity

Finally, sufficient inoculum must be transferred to a receptive site in a susceptible host, mainly confined to the sub-family Maloideae of the family Rosaceae. There are at least 16 host genera susceptible to *E. amylovora*, each containing several species (AQIS, 1998a). There are species not belonging to the sub-family Maloideae (for example, *Prunus* spp.) which are also hosts of *E. amylovora*. In addition, epiphytic growth of *E. amylovora* has been detected in non-hosts of fire blight (Johnson, 2004). 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 at other times 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*.

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. A large number of alternative hosts are also present in apple growing areas. 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 but dry 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). There are also several amenity trees that are sparsely distributed but able to produce flowers almost throughout the year (Merriman, 1996).

Environmental factors

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 3ºC to 37ºC, with optimum temperature conditions spanning 25ºC to 27ºC (Billing et al., 1961). 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.

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 low likelihood of the entire chain of events being completed, then there is a 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.

Roberts et al. (1998) relied on published data and data derived from the biology of *E. amylovora* to develop a simple linear model to calculate the risk of the introduction of the bacterium on commercial apple fruit. A similar study was done by AQIS (1998a). The value used for the probability that a host is at the receptive stage was 5 x 10^{-2} and the probability that *E. amylovora* is transferred to a new host and infection takes place was 10^{-3} to 10^{-5}. The product of these two factors gives a range of 5 x 10^{-5} to 5 x 10^{-7}.

In reaching a conclusion on the value for exposure the IRA team noted that although there were some differences in the conditions at the five utility point by exposure group combinations the potential transmission modes in all cases was either mechanical transfer of bacteria from the apple to a suitable host, or insect mediated transfer of bacteria from the fruit to the host. The IRA team further noted that very low exposure values expressed on a per apple basis could be highly significant when the potential volume of trade is taken into account. The IRA team concluded that very little of the experimental work is directly relevant to this situation. It is just not possible to do experimental work with a robust experimental design and sufficient replication to assess events where the probabilities are potentially so low. Most of the work has been done under highly artificial conditions with experimental designs that have very little chance of detecting very low probability but significant events.

Conclusion – exposure

The IRA team concluded that the exposure value for an individual apple for all five utility points by four exposure group combinations should be in the range of Uniform (0, 10^{-6}). This range is based on the IRA team’s views on both mechanical and insect mediated transmission and explicitly acknowledges that in some circumstances the chances of exposure would be zero.

Probability of establishment

Availability of suitable hosts, alternate hosts and vectors 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* 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). Most of these hosts are present in Australia.

Some stakeholders have raised the issue of *Rubus* spp. serving 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).

In Australia, the majority of 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.

Stakeholders have commented on the distribution of some highly susceptible alternative hosts for example, cotoneaster and hawthorn which are commonly grown as hedgerows in home gardens, along roadsides and in parks. In Tasmania, alternative hosts, for example, 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 et al., 2005).

Detailed information on exact flowering times for pome fruit production areas is not available. Flowering patterns vary with latitude and altitude. 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 *E. amylovora* is unknown. However, none of the few native plants in the Rosaceae are closely related to any known hosts of fire blight.

Van der Zwet and Keil (1979), lists 77 genera of arthropods that have been associated with fire blight spread. Australia has at least 27 of these species or closely related species. 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.

Suitability of the environment

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 conditions occur in the spring and summer in most locations where pome fruit is grown.

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 (PIDs) and multiple infection periods (MIPs) 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).

The potential for adaptation of the pest

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.[10]

The 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 as suggested by some stakeholders.

Stable differences in virulence of some strains have been found on different genotypes of varieties of apple (Norelli et al., 1984).

The reproductive strategy of the pest

Under favourable conditions, *E. amylovora* bacteria may divide approximately every 20 minutes by binary fission (dividing the cytoplasm into two approximately equal parts with a transverse membrane). At this rate, one bacterium could produce one million bacteria in 10 hours (Agrios, 1997), provided there is no competition from other microorganisms and nutrient, temperature, humidity as well as moisture levels are optimal. 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).

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). However, blossom infection occurs only when bacteria reach the hypanthium (floral cup) under favourable conditions (Thomson, 2000).

Minimum population needed for establishment

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).

Hale et al. (1996) found that when blossoms were inoculated with 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 per flower four days after inoculation.

The method of pest survival

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, 1972). 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). *E. amylovora* can

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

remain viable on fruit spurs following blossom infection until bud burst the following spring (Dye, 1949).

Populations of *E. amylovora* can survive in soil over winter (Thomson, 1969) and could act as a source of primary inoculum. Ark (1932) demonstrated that the pathogen survived under natural conditions for about 3 months. However, a more recent study showed that *E. amylovora* declined rapidly in untreated soil collected from a field, and the pathogen was no longer detected 5 weeks after inoculation (Hildebrand et al., 2001). Bacteriophages that destroy *E. amylovora* have been readily isolated from soil beneath apple and pear trees (Baldwin and Goodman, 1963; Hendry et al., 1967).

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 this 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).

Several stakeholders have raised issues relevant to the effects of VBNC state, biofilm/aggregates and sigma factor on the survival of *E. amylovora*. These have been discussed under Imp2. Preliminary evidence suggests that the above factors may have a role to play in the survival of *E. amylovora*, but are not completely understood as yet.

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, oxyterracycline, 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 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). 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).

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).

Probability of spread

Suitability of the natural and/or managed environment

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). 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).

Presence of natural barriers

The major apple production areas are confined to six states in Australia. 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 not between them, unless simultaneous infections occur in each area or infected plants are transported to new areas across these natural barriers.

There is circumstantial evidence that *E. amylovora* can be spread long distances over land or sea by birds (Meijneke, 1974; Billing, 1974b) or aerosols transported by high altitude air currents (Meijneke, 1974).

Potential movement of pest with commodities or conveyances

Erwinia amylovora has been isolated from the calyces of apple fruit at harvest (Hale et al., 1987; van der Zwet et al., 1990). The pathogen could be spread via fruit, but its spread through this pathway has not been demonstrated (Taylor et al., 2003a). 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 PFGE patterns would have been similar in different areas if *E. amylovora* was introduced via trade in apple fruit.

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).

Intended use of the commodity

The intended use of imported mature apple fruit would be for human consumption.

Potential vectors of the pest

Seventy-seven genera of arthropods have been implicated in the secondary spread of *E. amylovora*. These include honeybees, aphids, pear psylla (*Psylla pyricola*), tarnished plant bug (*Lygus pratensis*), leafhoppers and numerous flies (van der Zwet and Keil, 1979).

Of the 27 insect vectors listed for the USA (van der Zwet and Keil, 1979), Australia has either the same species or a closely related species (AQIS, 1998a).

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).

Apple leafcurling midge (*Dasineura mali*) causes damage to leaves, predisposing them to infection by *E. amylovora*. However, there is no evidence to implicate the adult midge as a vector for dissemination of *E. amylovora* (Gouk and Boyd, 1999). Apple leafcurling midge is a quarantine pest for Australia and is considered in this IRA.

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 apples could unknowingly transfer the inoculum to susceptible host plants.

Potential natural enemies of the pest

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).

Partial probability of establishment and spread

Additional evidence considered in estimating the partial probabilities of establishment and spread and the values for specific exposure groups is provided below.

Commercial fruit crops

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.7, 1)

All apple varieties grown in Australia are susceptible to *E. amylovora*. Australian pome fruit production areas have climatic conditions conducive to fire blight development. Orchards are now planted at a higher density, which requires smaller trees. This is accomplished using dwarfing rootstocks (for example, M.26, M.9) and tree training techniques. Budding a susceptible scion to a highly susceptible rootstock makes the plants more vulnerable to *E. amylovora*. Streptomycin, which is effective against *E. amylovora*, is currently not registered in Australia.

Nursery plants

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.7, 1)

Nurseries produce apple varieties and other amenity plants highly susceptible to *E. amylovora* for commercial planting in orchards. These high-density plantings provide easy access to susceptible tissues for propagules of the pathogen, and favourable micro-climatic conditions created by high-density planting would enable disease establishment and spread. However, use of some copper formulations, which act as bactericides, may prevent the spread of the pathogen if it were to establish. The use of infected scion wood has been identified as the major route for introduction of the pathogen to areas free from the disease. Infected (but symptomless) plants could be distributed before it was realised that the disease was present, resulting in widespread distribution of the disease.

Household and garden plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (0.3, 0.7)

Several fruit trees and hedgerow plants are highly susceptible to *E. amylovora*. The variety and number of fruit trees that can be grown in backyards will depend on the availability of space. Many households may have a few fruit trees susceptible to *E. amylovora* (for example, apple and pear) and/or other susceptible plants such as firethorn or cotoneaster. However, it is unlikely that garden plantings would be contiguous, and therefore spread from household to household may be quite slow. The frequency of host plants also decreases substantially in warmer areas of Australia. Successful eradication of the disease would depend on the ability of householders to recognise it early and take timely action. If abnormal symptoms are detected in household plants, there is a reasonable chance that a diagnosis would be undertaken, followed by an appropriate control measure.

Wild and amenity plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (5×10^{-2}, 0.3)

Susceptibility of native plants to *E. amylovora* is unknown. It is likely that some introduced wild and amenity host plants established from seeds dispersed by birds (for example, cotoneaster and firethorn) or apple cores discarded by consumers near parks and along roads, and these may serve as sources of inoculum. The density of these plants is likely to be low and randomly distributed over a wide area. However, in certain locations, amenity plants may be present in high density covering a large area, for example the presence of hawthorn or cotoneaster along some roads in Tasmania.

Conclusion

The IRA team considered the information presented above in reaching the conclusions on the partial probabilities of establishment and spread for each exposure group, shown in Table 20.

Table 20 Partial probabilities of establishment and spread of *E. amylovora*

	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Partial probabilities of establishment (PPE)	U(0.7, 1)	U(0.7, 1)	U(0.3, 0.7)	U(0.3, 0.7)
Partial probabilities of spread (PPS)	U(0.7, 1)	U(0.7, 1)	U(0.3, 0.7)	U(5 x 10^{-2}, 0.3)

Conclusion – entry, establishment and spread

The model combines the probability of importation, the estimated volume of apples and the partial probability of establishment and spread to give an overall value for the annual probability of entry, establishment and spread (PEES). Table 21 below shows distribution values given by the @RISK model and were based on the two scenarios for utilisation of apple fruit:

Table 21 Unrestricted probability of entry, establishment and spread

Percentile	Probability of entry establishment and spread: P1 = Uniform (0.7, 1)	Probability of entry establishment and spread: P1 = Uniform (10^{-3}, 5 x 10^{-2})	Qualitative description
5^{th} percentile	1.3 x 10^{-2}	1.2 x 10^{-2}	Very low
Median simulated value	5.8 x 10^{-2}	5.7 x 10^{-2}	Low
95^{th} percentile	0.21	0.21	Low

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are given in Table 22. Available supporting evidence is provided in the text below.

Table 22 Impact scores for *E. amylovora*

Direct impact	Impact scores
Plant life or health	F
Human life or health	A
Any other aspects of the environment	A
Indirect impact	
Control or eradication	E
Domestic trade or industry	E
International trade	D
Environment	A
Communities	D

Direct impact

Plant life or health – F

Consequences affecting plant life or health would be significant at the national level and highly significant at a regional level. A rating of '**F**' was assigned to this criterion.

Fire blight, caused by *E. amylovora* is the most serious disease of pome fruit trees worldwide (Schroth et al., 1974).

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 the USA, annual damage from fire blight is estimated at US$200–500 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, with

US$23 million in crop losses expected until new plantings become established (Longstroth, 2001; Longstroth, 2002).

The loss of production in a worst-case scenario, for all production areas in Australia, was estimated at 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 pear fruit production in Australia.

If fire blight had occurred, the value of lost production between 1997 and 2002 would have been $424 million in Victoria, $141 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 (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).

The average farm gate value of apple and pear crops in South Australia is estimated at $36 million, which represents approximately 8% of the total field crop value of $542 million. A 10% loss of yield was estimated to cost growers about $3.5 million or at least $11.1 million of gross South Australian food revenue (AAPGA, 2000).

The Western Australian pome fruit industry has an estimated farm-gate value of $47.1 million (AAPGA, 2000).

Stanthorpe in Queensland produces approximately 45,000 t of apples at a gross value of around $35 million. 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).

The New South Wales Apple and Pear Industry is worth $66.2 million in gross value of production (NSWFA, 2000; Oliver et al., 1997).

In Victoria, in a worst-case scenario, the potential losses in pear and apple production in Goulburn Valley were estimated at 40% and 1%, respectively (Roberts, 1991). 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.

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.

Human life or health – A

There are no known direct impacts of *E. amylovora* on human life or health, and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There are no known other direct impacts of *E. amylovora* on the environment, and the rating assigned to this criterion was therefore '**A**'.

Indirect impact

Control or eradication – E

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies would be minor at the national level, significant at a regional level and highly significant at the district level. The rating assigned to this criterion was therefore '**E**'.

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, the Australian Commonwealth and State Governments would incur substantial costs, associated with regulatory enforcement and implementation of the contingency plan (control/eradication and surveillance/monitoring).

The *E. amylovora* eradication program carried out in and around Melbourne, Victoria, cost the Australian Government and the Victorian Government about $2.8 million (ANAO, 2000).

Payment of compensation for growers affected by fire blight could also involve large sums of money.

Replanting a hectare of apples in the Batlow region of NSW is estimated to cost at least $10,000 (Commonwealth of Australia, 2001).

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.

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).

Domestic trade or industry – E

The indirect impact on domestic trade or industry would be minor at the national level, significant at a 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 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).

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 – D

The indirect impacts on international trade are unlikely to be discernible at the national level, and would be of minor significance at a regional level, significant at the district level and highly significant at the local level. The rating assigned to this criterion was '**D**'.

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 markets in countries free from *E. amylovora* would 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 by about two years pending the outcome of disease surveys, after detection of *E. amylovora* in the Royal Botanic Gardens, Melbourne.

Australia will lose market share in fresh fruit exports as a result of the shortage of export quality fruit and the high cost of production. This would result in other countries entering the markets which Australia traditionally supplied. If this occurred, Australia would lose further export markets and/or be forced to reduce margins to ensure export orders are maintained (Kilminster, 1989).

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.

Environment – A

Any indirect impacts of fire blight on the environment are unlikely to be discernible. 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. Copper and antibiotic sprays (mainly streptomycin) are used to control fire blight overseas.

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 and therefore could not be used to control fire blight. Registration 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.

Communities – D

The indirect impacts on communities are unlikely to be discernable at the national level. They would be of minor significance at the regional level, significant at the district level and highly significant at a local level. A rating of '**D**' was assigned to this criterion.

In Australia, the pome fruit industry employs 3200 workers at base level and 16,000 at peak level (Street, 1996). The estimated national job losses would have been 2484 from 1997 to 2002 (Oliver et al., 1997).

The combined permanent work force in SPC Ltd, Ardmona Foods Ltd (now amalgamated) together with Henry Jones Foods (IXL) was estimated at 760. During peak fruit processing months, they employ an additional 2350 staff (Oliver et al., 1997). A shortage of fruit would result in reduced staffing requirements, thereby increasing the unemployment rate in these communities.

A fire blight outbreak would have a very significant impact on orchardists, processors and their employees. It would also affect regional economies and their social fabric (Kilminster, 1989).

Flow-on effects arising from a fire blight outbreak in regional pome fruit growing areas would seriously affect these local economies, through loss of employment in the pome fruit industry and associated service industries.

A fire blight outbreak would threaten the economic viability of around 330 growers in the Goulburn Valley, Victoria. This pome fruit growing area covers about 7000 ha, with individual orchards of 5 to 200 ha. The Goulburn Valley accounts for 14% of apple and 86% of pear production in Australia (Oliver et al., 1997). It is estimated that around 272 growers have orchards larger than 30 hectares, which represent 85% of the total number of orchards in the Goulburn Valley (Oliver et al., 1997). These are most likely family-operated orchards and, if these became commercially non-viable, there would be significant social and financial impacts. In the Goulburn Valley alone, the estimated total loss of full-time jobs would have been 1102 over the period 1997–2002 (Oliver et al., 1997). Youth unemployment increased from 13% to 24% over the period 1986–1991. Employment opportunities would diminish alongside the reduction in growing and processing activities, and might even lead to a net outflow of people, especially youth (Oliver et al., 1997).

Stanthorpe, Queensland, potentially supports a total workforce of about 450 and around 2200 during the peak season. An outbreak of fire blight would cause loss of jobs (Street, 1996).

Conclusion—consequences

Based on the decision rule described in the method section – that is, where the consequences of a pest with respect to a single criterion is '**F**' and the consequences of a pest with respect to remaining criteria are not unanimously '**E**' – the overall consequences are considered to be 'high'. Therefore, the overall consequence of *E. amylovora* is '**high'**.

Unrestricted risk

The model estimates the unrestricted annual risk by calculating the value for the annual probability of entry, establishment and spread and then combining this with the outcome of overall consequences, according to the risk estimation matrix in the method section. The unrestricted annual risk estimation for *E. amylovora* is shown in Table 23. Two estimates are given, based on a 'very low' proportion where P1 = Uniform (10^{-3}, 5 x 10^{-2}), and a high proportion where P1 = Uniform (0.7, 1), of imported apples being handled through orchard based wholesalers.

Table 23 Unrestricted risk estimation for *E. amylovora*

	P1 Uniform (0.7, 1)	**P1 Uniform (10^{-3}, 5 x 10^{-2})**
Overall probability of entry, establishment and spread[11] (median value)	5.8 x 10^{-2} (Low)	5.7 x 10^{-2} (Low)
Consequences	High	High
Unrestricted annual risk	Moderate	Moderate

As indicated in Table 23 above, the overall unrestricted risk for *E. amylovora* varies slightly depending on the value of P1. Irrespective of the P1 value used, the unrestricted risk estimate exceeds Australia's ALOP of 'very low'; risk management is therefore required for this pest.

Risk management for fire blight

The scope of this risk analysis is the importation of mature New Zealand apples free from trash. Given that much of the key information available in the literature and provided by New Zealand is based on standard commercial agronomic practice this forms the basis for consideration of risk management measures. Some aspects of standard commercial agronomic practice are discussed further in the section on operational requirements but one of the features of standard commercial agronomic practice is that fruit be free of fire blight

[11] Calculated by @RISK.

symptoms. Production procedures and pest management practices in apple orchards, as well as packing house processes used in New Zealand are intended to ensure that apples for export are free from visible symptoms of fire blight and trash and meet commercial export standards. Therefore this forms the starting point for the consideration of risk management measures.

The risk pathway of concern for fire blight with regard to apples for export is epiphytic infestation of fruit with *E. amylovora*. Such fruit rarely express symptoms. Therefore inspection at Imp6 or Imp8 cannot be used in the evaluation of options to reduce the likelihood of entry, establishment and spread.

An analysis of the unrestricted risk scenario for fire blight found that the number of infested/infected fruits likely to be imported was influenced by the following elements:

- Imp2—the likelihood that picked fruit is infested/infected with *E. amylovora*
- Imp3—the likelihood that clean fruit is contaminated by *E. amylovora* during picking and transport to the packing house
- Imp4—the likelihood that *E. amylovora* survives the routine processing procedures in the packing house
- Imp5—the likelihood that clean fruit is contaminated by *E. amylovora* during processing in the packing house.

Therefore, measures that could reduce the likelihood allocated to these steps were sought.

Sourcing apples for export from areas established, maintained and verified free from *E. amylovora* ('pest free areas'), in accordance with the guidelines outlined in ISPM No. 4: *Requirements for the establishment of pest free areas* (FAO, 1996b) would reduce the likelihood of several of these steps to 'negligible' and thereby mitigate the risks. However, this option was not considered feasible, given that *E. amylovora* is widely distributed in apple-growing areas of New Zealand and there is no feasible way to verify if bacteria are present in orchards or not.

However, individual apple orchards in New Zealand can be maintained free from fire blight disease symptoms ('areas free from disease symptoms') through the use of various management practices. Such orchards are known to have lower levels of bacteria associated with fruit than orchards where symptoms are evident. Similarly, treatments with chlorine and cold storage of apples have been reported to reduce bacterial numbers. Therefore the following options were evaluated to mitigate the risk of fire blight:

- Source apples for export from individual orchards free from fire blight disease symptoms (areas free from disease symptoms)
- Disinfest apples for export with 100 ppm chlorine for one minute at pH 5–6 (chlorine treatment) or other suitable disinfection treatment.
- Store apples for export at a temperature of 0°–4°C for six weeks (storage)
- Combinations of areas free from disease symptoms, chlorine treatment or storage (systems approach).

The analysis presented below is based on modelling carried out with P1 set to a uniform range from 0.7 to 1. This represents the scenario where a high proportion of the imported fruit is handled through orchard-based wholesalers. The choice of this scenario is based on advice provided by industry sources on the distribution and marketing system for apples in Australia and discussion with New Zealand on the possible modes of trade (bulk vs. packed fruit). However, the differences between this scenario and the scenario based on most apples being handled through urban wholesalers are quite small, therefore the conclusions on the various risk management measures are equally valid for both.

Areas free from disease symptoms

Areas free from disease symptoms, as distinct from pest free areas, could be established and maintained following the guidelines described in ISPM No. 4: *Requirements for the establishment of pest free areas* (FAO, 1996b) and ISPM No. 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999). An area free from disease symptoms could be a place of production (an orchard managed as a single unit) or a production site (a designated block within an orchard), for which freedom from fire blight symptoms is established, maintained and verified by MAFNZ.

The literature on infestation and infection of fruit with *E. amylovora* has been reviewed extensively in the section on Imp2 above. Endophytic infection of fruit has been recorded in immature fruit sourced from infected orchards (van der Zwet et al., 1990), but it has not been recorded in orchards free from symptoms of fire blight in New Zealand. Endophytic populations of *E. amylovora* were not recovered from mature fruit at harvest (Dueck, 1974a; Roberts et al., 1989; Roberts, 2002). On the basis of the work reviewed in Imp2 the IRA team concluded that endophytic infection was not a risk factor for fruit sourced from orchards free from symptoms.

In assessing the risk of calyx and surface infestation the IRA team took note of the literature on infestation rates for apples sourced from orchards with few or no symptoms. For example, studies conducted in New Zealand by Clark et al. (1993), using a specific DNA hybridisation method with a detection level of about 10^2 cfu per calyx, 60,000 immature apple fruit were tested from orchards free of fire blight symptoms, but *E. amylovora* was not detected. Such fruit, when mature would not have bacteria present in the calyces but may carry *E. amylovora* on the surface if the disease has been active in the orchard near to harvest time. There are many other studies that show that infestation of fruit is undetectable or the number of fruit infested is very small when fruit is sourced from orchards with few or no visible symptoms of fire blight (see Imp2 above). The IRA team concluded that ‘freedom from visible symptoms’ provided a firm basis for risk reduction by substantially reducing the likelihood that picked fruit is infected or infested.

The IRA team acknowledged that it would be extremely difficult to confirm absolute freedom from symptoms using visual inspection of orchards. The IRA team concluded that a practical inspection regime should be specified as free from visual symptoms at an inspection intensity that would, at a 95% confidence level, detect visual symptoms if shown by 1% of the trees. This inspection should take place between 4 to 7 weeks after flowering when conditions for fire blight disease development are likely to be optimal.

With lower bacterial populations in areas free from disease symptoms, the likelihood that clean fruit is contaminated during picking or transport to the packing house (Imp3) could be expected to be significantly reduced. This is because the orchard would be free from cankers and infected leaves, which could otherwise provide bacterial ooze for contamination of fruit. Similarly, the likelihood that clean fruit is contaminated during processing in the packing house (Imp5) would also be reduced for export apples sourced from symptom-free areas assuming that the packing house equipment was cleaned to remove potential contamination from previous lots and that only fruit sourced from symptom free areas was processed.

The values agreed by the IRA team for Imp2, Imp3 and Imp5 are shown in Table 24 below. In agreeing on these values the team took into account the relevant literature. For example, Roberts et al. (1998) reported that the average number of apples carrying fire blight bacteria was 10 times greater among apples from orchards with fire blight symptoms than from orchards in general. The proposal goes further than this in requiring all apples to be sourced from orchards free of fire blight symptoms and therefore justifying a greater reduction in Imp2. The reductions in Imp3 and Imp5 largely follow from this. For example, the adjusted value chosen for Imp3 is the same as Imp2. This means that, for every apple picked carrying fire blight, another apple could be contaminated at Imp3. In making such a conservative assumption the IRA team took into account the possibility that the teams of pickers and equipment may also be used to pick fruit from orchards with fire blight. The IRA team concluded that the reduction in Imp5 because of this measure should be less to account for the possibility that a few heavily infested apples could contaminate the water dump tank and the packing line with bacteria and therefore result in contamination of apples that are free from bacteria.

The modified values for Imp2, Imp3 and Imp5 are shown in Table 24. These values represent the conclusions of the IRA team, taking into account all the factors discussed above including the inspection regime that does not provide absolute freedom from symptoms. When these values were placed in the model and the assessment for fire blight was repeated, the restricted annual likelihood of entry, establishment and spread was found to fall in the 'very low' range (Table 24). When these values are combined with the estimate of consequences of 'high' for fire blight, the restricted risk for this pest was found to be 'low', which still exceeds Australia's ALOP. Therefore, the use of areas free from visible fire blight symptoms for sourcing export apples would not be a sufficient risk management measure by itself.

Table 24 Effect of orchards free from fire blight symptoms

Step	Unrestricted likelihood	Restricted likelihood
Imp2	T(10^{-3}, 3 x 10^{-2}, 5 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp3	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(10^{-3}, 2 x 10^{-3})
PEES (median)	5.8 x 10^{-2} (Low)	2.7 x 10^{-3} (Very low)
Consequences	High	High
Risk estimate	Moderate	Low

Disinfection treatment

The following discussion focuses on the use of chlorine for disinfection. Chlorine at various concentrations is already used in approximately 37% of New Zealand apple packing houses (MAFNZ, 2005a) and the principles and practices of application relating to this agent are well understood. However, it is acknowledged that there are several other bactericidal agents (Ecowise Environmental, 2005) that may be equally effective in this application. Some of these, such as Tsunami® or Nylate® are also used in some New Zealand packing houses (MAFNZ, 2005a).

Chlorine is known to have strong biocidal properties against a wide range of organisms (Dychdala, 1991). It is used as a disinfectant in drinking water and washing applications, for reducing microbial contamination of food products and for general surface disinfestation. In relation to post-harvest handling of fruit and vegetables, chlorine treatments are usually targeted against organisms that cause spoilage and affect human health. Chlorine is highly effective against non-spore-forming bacteria, but also to a lesser extent against spore-forming-bacteria, fungi, algae, protozoa and viruses. Bacteria in suspension are killed very quickly by concentrations of chlorine as low as 5 ppm (Somers, 1963), with 50 to 200 ppm used with a contact time of 1 to 2 minutes for sanitization of produce for food safety (Parish et al., 2003). However, it is recognised that chlorine has poor penetrating powers and is less effective in situations where there are high organic matter loads (Ecowise Environmental, 2005). Low temperatures when treating apples from cold storage may also reduce the effectiveness of chlorine. Nevertheless, even in these situations, if chlorine concentration and pH levels are maintained correctly, at least a 10 to 100 fold reductions in the bacterial numbers in solution can be expected.

Chlorine treatment could be applied in the routine packing house process by incorporating chlorine in the floatation tanks and maintaining its concentration at a minimum of 100 ppm. The system of application would need to ensure that fruit is fully exposed to this active concentration for the full time period and prevent subsequent contamination after treatment. A level of 100 ppm would help ensure that there are always sufficient levels of available chlorine to cope with the organic matter loads that could be present.

If all packing houses were to use minimum of 100 ppm chlorine treatment, then the risk of *E. amylovora* being present in or on apples for export would be reduced. Bacteria occurring as surface contaminants on the fruit and associated soil, trash, etc. would mostly be killed when exposed for one minute to 100 ppm chlorine treatment in the packing house. However, the chlorine treatment would not be fully effective against bacteria protected in the tissue, including those occurring in infested calyces or in symptomless infected fruit.

Therefore, chlorine treatment would reduce the likelihood allocated to steps Imp4 and Imp5. Because chlorine treatment would kill *E. amylovora* on the fruit surface and to some extent in the calyx (particularly in the open calyx varieties), the likelihood that the pest would survive on apples following the treatment at the Imp4 step would be reduced compared to the unrestricted risk. The application of chlorine at Imp4 would almost completely eliminate surface infestation of fruit that results from the processes included in Imp3. It is acknowledged that chlorine may not fully penetrate the calyx of fruit, and therefore would only slightly reduce the number of apples carrying fire blight bacteria in the calyx. Chlorine treatment would also have a significant effect on the likelihood of contamination of clean fruit in the packing house (Imp5), given that the treatment would kill *E. amylovora* on the surface of fruit and in the dump tank. Any bacteria surviving the chlorine treatment, particularly those in infested calyces or within symptomless fruit, would generally not be a source of contamination of other clean fruit at this step.

Based on a consideration of all the evidence, the IRA team concluded that chlorine applied at 100 ppm for one minute would lead to the following reductions compared to the unrestricted values:

- Reduction of surface contamination present at Imp4 by a factor of 0.66
- Reduction in calyx infestation present at Imp4 by a factor of 0.15
- Reduction by contamination at Imp5 by a factor of 0.95.

These values were used in the model to estimate the effect of chlorine. It is convenient to model the reduction of surface contamination by adjusting Imp3 appropriately, as most surface contamination is considered to occur at Imp3. This is a conservative approach, as it effectively ignores the effect of chlorine treatment on any surface contamination present on the apples before picking.

When the modified likelihoods were placed in the model, and the assessment for fire blight was repeated, the restricted annual likelihood of entry, establishment and spread was found to be in the ‘very low’ range (Table 25). When this was combined with the estimate of consequences of ‘high’ for fire blight, the restricted risk for this pest was found to be ‘low’ which still exceeds Australia’s ALOP. The use of the chlorine treatment alone would therefore not be a sufficient risk management measure.

Table 25 Effect of chlorine treatment on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp3	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	T(3.3 x 10^{-4}, 3.3 x 10^{-3}, 10^{-2})**
Imp4	T(0.3, 0.65, 0.7)	T(0.255, 0.55, 0.6)
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(5 x 10^{-5}, 2.5 x 10^{-3})
PEES (median)	5.8 x 10^{-2} (Low)	2 x 10^{-2} (Very low)
Consequences	High	High
Risk estimate	Moderate	Low

***Imp3 was adjusted to simulate the effect of chlorine killing surface contamination of apple fruit at Imp4.*

Storage

The level of infection and infestation of apple fruit by *E. amylovora* declines over time during storage, normally at low temperatures of 0ºC–4ºC (Sholberg et al., 1988; Hale and Taylor, 1999; Roberts, 2002; Taylor and Hale, 2003). Other data, see for example, Jock et al. (2005), indicates that the number of bacteria decreased over time where nutrients are lacking. This is the situation that would exist for *E. amylovora* on the surface of fruit or in the calyx. Although the literature supports the conclusion that bacterial numbers decline over time, very few of these studies were carried out in apples under conditions approximating those in commercial apple production. Given this problem, the IRA team has decided to take a conservative view of the effect of storage and has used a two-fold reduction factor for infested apples as a result of six weeks storage. This factor is used to assess the potential usefulness of storage as a risk management measure.

Apples could be stored before packing and/or after packing. However, if they are stored before packing there is a risk that they would be freshly contaminated in dump tanks and also down the packing line after storage. Therefore, the analysis of the effect of storage was based on application of the storage measure at the pre-export and transport step (Imp6). This means that this measure would be applied after all opportunities for further infection/infestation of fruit had passed. This simplifies the analysis and provides a good guide to the potential usefulness of this proposed measure, but it is acknowledged that it could also be appropriate to apply storage at the processing of fruit in the packing house stage (Imp4), provided adequate arrangements are in place to prevent contamination during subsequent handling.

When the modified likelihood for Imp6 was placed in the model, and the assessment for fire blight was repeated, the restricted annual likelihood of entry, establishment and spread was found to be in the 'very low' range (Table 26). When this was combined with the estimate of consequences of 'high' for fire blight, the restricted risk for this pest was found to be 'low', which still exceeds Australia's ALOP. The use of cold storage alone would therefore not be a sufficient risk management measure.

Table 26 Effect of storage on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp6	T(0.7, 0.8, 1)	T(0.35, 0.4, 0.5)
PEES (median)	5.8×10^{-2} (Low)	2.9×10^{-2} (Very low)
Consequences	High	High
Risk estimate	Moderate	Low

Systems approaches

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve an ALOP, as described in ISPM No. 14: *The use of integrated measures in a systems approach for pest risk management* (FAO, 2002). An advantage of the systems approach is the ability to address variability and uncertainty by modifying the number and strength of measures to provide the desired level of protection and confidence. Because none of the measures discussed above on their own reduced the risk of fire blight to within Australia's ALOP, the following systems approaches were examined.

- Areas free from disease symptoms and chlorine treatment: source apples for export from orchards free from fire blight disease symptoms and disinfest for export with chlorine.
- Areas free from disease symptoms and storage: source apples for export from orchards free from fire blight disease symptoms and store for 6 weeks.
- Chlorine treatment and storage: disinfest apples for export with chlorine (chlorine treatment) and store for 6 weeks.
- Areas free from disease symptoms and chlorine treatment and storage: source apples for export from orchards free from fire blight disease symptoms (areas free from disease symptoms), disinfest apples for export with chlorine and store for 6 weeks.

In assessing the combined effects of various treatments using the model, care was taken to ensure that risk management measures were applied in an appropriate sequence and to avoid double counting. In most cases, reduction factors were used rather than simply reducing likelihood categories. For example, when orchard inspection was combined with chlorine treatment, inspection was applied first as shown above, then the chlorine reduction factors were applied to these new values obtained from the application of inspection.

Areas free from disease symptoms and chlorine treatment

The effect of combining areas free from disease symptoms was assessed by first applying the effect of inspection to the appropriate Imp steps as shown above then applying the reduction factors for chlorine shown above to the appropriate Imp steps.

This systems approach using these measures reduced the restricted risk estimate to 'very low', which meets Australia's ALOP (Table 27).

Table 27 Effect of areas free from disease symptoms and chlorine treatment on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp2	T(10^{-3}, 3 x 10^{-2}, 5 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp3	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	U(3 x 10^{-7}, 3 x 10^{-4})**
Imp4	T(0.3, 0.65, 0.7)	T(0.255, 0.55, 0.6)
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(5 x 10^{-5}, 10^{-4})
PEES (median)	5.8 x 10^{-2} (Low)	4.7 x 10^{-4} (Extremely low)
Consequences	High	High
Risk estimate	Moderate	Very low

***Imp3 was adjusted to simulate the effect of chlorine killing surface contamination of apple fruit at Imp4.*

Areas free from disease symptoms and storage

The combination of these two measures was examined to reduce the risk of fire blight at steps Imp2, Imp3, Imp5 and Imp6 as described above. Imp2, Imp3 and Imp5 would not be altered by storage, and sourcing fruit for export from areas free from disease symptoms would not alter Imp6.

This systems approach reduced the restricted risk estimate to ‘low’, which still exceeds Australia’s ALOP (Table 28).

Table 28 Effect of areas free from disease symptoms and storage on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp2	T(10^{-3}, 3 x 10^{-2}, 5 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp3	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(10^{-3}, 2 x 10^{-3})
Imp6	T(0.7, 0.8, 1)	T(0.35, 0.4, 0.5)
PEES (median)	5.8 x 10^{-2} (Low)	1.3 x 10^{-3} (Very low)
Consequences	High	High
Risk estimate	Moderate	Low

Chlorine treatment and storage

The combination of these two measures was examined to reduce the risk of fire blight at steps Imp4, Imp5 and Imp6. The restricted values for the various steps are shown in Table 29. The combination of these two treatments did not reduce the risk estimate to the ALOP.

Table 29 Effect of chlorine treatment and storage on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp3 **	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	T(3.3 x 10^{-4}, 3.3 x 10^{-3}, 10^{-2})
Imp4	T(0.3, 0.65, 0.7)	T(0.255, 0.55, 0.6)
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(5 x 10^{-5}, 2.5 x 10^{-3})
Imp6	T(0.7, 0.8, 1)	T(0.35, 0.4, 0.5)
PEES (median)	5.8 x 10^{-2} (Low)	9.9 x 10^{-3} (Very low)
Consequences	High	High
Risk estimate	Moderate	Low

***Imp3 was adjusted to simulate the effect of chlorine killing surface contamination of apple fruit at Imp4.*

Areas free of disease symptoms and chlorine treatment and storage

This systems approach would reduce the restricted risk estimate to 'very low', which meets Australia's ALOP.

Table 30 shows the results obtained when all three approaches were combined. The restricted risk value for PEES falls in the 'extremely low' range and when combined with the consequences it results in a restricted risk estimate of 'very low.' This meets Australia's ALOP.

Table 30 Effect of areas free from disease symptoms and chlorine treatment and storage on *E. amylovora*

Step	Unrestricted likelihood	Restricted likelihood
Imp2	T(10^{-3}, 3 x 10^{-2}, 5 x 10^{-2})	U(10^{-6}, 10^{-3})
Imp3	T(10^{-3}, 10^{-2}, 3 x 10^{-2})	U(3 x 10^{-7}, 3 x 10^{-4})**
Imp4	T(0.3, 0.65, 0.7)	T(0.255, 0.55, 0.6)
Imp5	T(10^{-3}, 2.5 x 10^{-2}, 5 x 10^{-2})	U(5 x 10^{-5}, 10^{-4})
Imp6	T(0.7, 0.8, 1)	T(0.35, 0.4, 0.5)
PEES (median)	5.8 x 10^{-2} (Low)	2.4 x 10^{-4} (Extremely low)
Consequences	High	High
Risk estimate	Moderate	Very low

***Imp3 was adjusted to simulate the effect of chlorine killing surface contamination of apple fruit at Imp4.*

Other potential risk management measures

The IRA team considered other possible risk management measures including irradiation, fumigation and treatments with different bactericidal agents, vacuum infiltration of disinfectants and the use of pest free places of production. There was insufficient data relevant to fire blight for the IRA team to adequately assess the efficacy of these alternatives. However, the proposed measures are always open to review if additional relevant information is forthcoming that suggests alternative measures may be capable of reducing the risks to Australia’s ALOP.

Discussion

A summary of the risk estimates for all combinations of the three measures is provided in Table 31. There were no individual measures identified that would by themselves reduce the risk associated with fire blight to Australia’s ALOP. However, it was found that the risk associated with *E. amylovora* would be reduced to Australia’s ALOP by the combination of orchards being free from symptoms and disinfection by chlorine.

The IRA team considered other possible risk management measures such as alternative disinfection agents, much longer storage times, treatments such as fumigation and the possible requirement that fruit could only be imported packed in boxes.

The IRA team concluded that there are alternatives to chlorine that may be as effective as chlorine in disinfection of fruit. The IRA team considers that the use of any suitable disinfection agent should be allowed, provided there is data indicating that it is at least as effective as chlorine.

Apples are frequently stored for long periods before being sold. Long storage periods (greater than 3 months) may be an effective risk reduction measure, as the number of apples carrying fire blight bacteria and the number of bacteria on infested apples would be expected to reduce over time. However, the IRA team concluded that there was insufficient evidence on the efficacy of long term storage in reducing the risk of fire blight. The use of long storage periods could be reconsidered if further relevant data on efficacy was forthcoming.

There are various treatments available for the reduction or elimination of pests on fruit. These include chemical sprays or dips, fumigation and heat treatment. However, in considering possible treatments, the IRA team concluded that none of them would be effective against fire blight bacteria under conditions not overly restrictive to trade.

The risk assessment concluded that the handling of bulk fruit from New Zealand in orchard based packing houses posed a significant risk. The IRA team considered the requirement that fruit only be imported packed in boxes as a risk management measure. However, it concluded that such a requirement could be overly trade restrictive, and given the common practice of repacking and regrading fruit, it would not provide a sufficient reduction in risk to meet Australia’s ALOP.

Table 31 Risk management options for fire blight showing effect of areas free of disease symptoms, chlorine treatment and storage

Areas free of disease symptoms	Chlorine treatment	Storage	Risk estimate
+	–	–	Low
–	+	–	Low
–	–	+	Low
+	+	–	Very Low
+	–	+	Low
–	+	+	Low
+	+	+	Very low

+ = measure applied.

– = *measure not applied.*

Conclusion

The IRA team concluded that a combination of inspection for freedom from symptoms and chlorine treatment as specified above would be sufficient to manage the risks associated with fire blight disease.

Introduction

European canker caused by the fungus *Neonectria galligena* (Bres.) Rossman & Samuels, is an important disease affecting apples, pears and many species of hardwood forest trees (Swinburne, 1975). The disease was present in six blocks within four orchards in Spreyton, Tasmania, from about 1954 but it was eradicated by 1991 (Ransom, 1997). The disease is not known to occur in Australia (APPD, 2005).

Biology

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). Rose (*Rosa* spp.) is cited as a host (CABI, 2005), however, there is a lack of information in the literature on this host and there may be confusion with black cherry (*Prunus serotina*), a member of the Rosaceae family. If ornamental rose is a host, it is only infected rarely and is not considered a primary host.

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 (Brook and Bailey, 1965; Swinburne, 1975). The most serious cankers are those that develop at the crotch, which can cause the death of several branches or the entire tree (Butler, 1949).

In apple and pear species, fruit is also infected and develops rot. Foliage is not affected (Butler, 1949). Typically, infection of fruit occurs at the blossom end, through either 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 observed to spread to the seed cavity of the fruit, 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, infection of the fruit generally leads to the development of rot before harvest (Swinburne, 1964; Swinburne, 1971a; Swinburne, 1975), but infection can sometimes remain latent and develop only during storage (Bondoux and Bulit, 1959). In cooking varieties, rot rarely becomes apparent until after fruit has been stored for 3–7 months (Swinburne, 1975).

Apple varieties vary greatly in their susceptibility to the disease, but no variety is immune (McKay, 1947).

The fungus has several strains that differ in cultural characteristics but appear to be largely non-specific in their pathogenicity to different hosts (Flack and Swinburne, 1977; Ng and Roberts, 1974). 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, and possibly by insects and birds (Agrios, 1997; Butler, 1949). Spores germinate over a range of temperatures between 2°C and 30°C, the optimum being 20°–25°C (Munson, 1939).The disease can be severe enough to necessitate the replacement of trees, ranging from 10% of trees (Lovelidge, 1995) to the whole plantation (Grove, 1990a). Losses of 10–60% of fruit crops caused by rot from European canker have been recorded in various parts of the world (Swinburne, 1975). Damage to host species used for timber, through reduction in the quality and quantity of marketable logs, particularly in North America has been reported (CABI, 2005) although there is no estimate of the magnitude of this loss.

Sanitation (that is, removal and burning of cankered limbs or trees and spraying with fungicides) is the only feasible control measure.

Other information relevant to the biology of *N. galligena* is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario in respect to *N. galligena,* when importing apple fruit, is primarily any latent infection in fruit that would not have been detected at harvesting or during processing in the packing house. In dessert apple varieties, any infection of fruit generally develops in the orchard. Because New Zealand mostly exports dessert varieties, this risk of latent infection is reduced. However, the time an infection in fruit can remain latent is a function of the acidity. This means that infection could remain latent in dessert varieties with relatively higher acidity, especially if infection occurred late in the season. Any infestation on the surface of the fruit that later gains entry into the fruit and causes infection may also be of concern.

Neonectria galligena does not affect leaves, so leaf material in trash is not a concern. Small twigs in trash are of concern because the disease occurs on branches, but the likelihood of this happening in export quality apples would be remote. The likelihood of the pest entering through packing material contaminated with fungal spores would also be remote.

Probability of importation

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry. The importation scenario is divided into eight steps. The available evidence supporting the likelihood assessments for each step is provided in the text that follows.

Importation step 1: Likelihood that *N. galligena* is present in the source orchards in New Zealand: triangular distribution with a minimum value of 10^{-2}, a maximum value of 6×10^{-2}, and a most likely value of 3×10^{-2}. $T(10^{-2}, 3 \times 10^{-2}, 6 \times 10^{-2})$

Pathogen/disease distribution

European canker is reported in several districts where source orchards are located, and the rating in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) was queried by two stakeholders on the basis of the disease's uncertain distribution in New Zealand orchards. Atkinson (1971) reports that European canker is not regarded as a major disease in New Zealand outside the Auckland province where the disease has spread considerably over the last 40 years. In New Zealand, *N. galligena* is reported in Auckland, the Waikato, Coromandel, Northland, Taranaki, Westland, Gisborne, Bay of Plenty, Hawke's Bay and Nelson.[12] Wilton (2002a) reports the disease has been established in Auckland, the Waikato,

[12] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.

Bay of Plenty and Taranaki for many years and is now established in some orchards in the wetter parts of the Nelson district, with isolated instances of infection in the Gisborne area. The incidence and severity of the disease in these districts varies between seasons, depending on environmental conditions and orchard practices.

A survey of apple sites throughout New Zealand in 1990 found 2% of sites were infected with *N. galligena* (Braithwaite, 1996). A further survey conducted in 1999 across 52 orchards in the apple exporting areas of the North Island (central Hawke's Bay) and the South Island (Nelson, Marlborough and Central Otago) found the disease to be present in only one tree in Nelson, which 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 Walmea orchards of Nelson (Murdoch, 2002). MAFNZ (2004) indicates the establishment and spread of the disease in these areas occurred largely because of extraordinarily wet springs and autumns during 1998, 2000 and 2001 and coincided with large-scale introductions of planting material. Murdoch (2002) and Wilton (2002a) report that disease spread out of the Auckland and Waikato areas has been through the movement of infected nursery plants or graft wood. 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. A study in the United Kingdom called the 'Millennium project' (McCraken et al., 2003b) concluded that approximately 6% of canker infection in new orchards could be associated with movement of infected nursery plants, although this figure increased significantly under favourable climatic conditions. *N. galligena* can remain latent in infected plants for up to 3 to 4 years, expressing only when climatic conditions are conducive for disease development (McCraken et al., 2003b). MAFNZ (2003a) states that one of the larger nurseries in the Waikato area routinely applies fortnightly copper sprays to stock plants and dip tools, and applies carbendazim (benzimidazole) and captan to some cuttings. In spite of these measures, the disease is thought to have arrived in Nelson on trees imported from Waikato (Murdoch, 2002). Therefore, there is a continual threat of new pathogen inoculum being introduced into disease-free districts and remaining latent for up to 3 to 4 years.

Wilton (2002b) indicated the disease is absent from Hawke's Bay, Wairarapa, Marlborough, Canterbury and Otago, but lesions of the disease have been reported three times in Hawke's Bay on samples collected between 1967 and 1975.[13] Wilton (2004) indicated the records in Hawke's Bay were reported over 20 years ago, on 4- to 5-year-old orchard trees that had been brought into the district from the Auckland area. MAFNZ (2004) states that there was no evidence to indicate any subsequent spread of the disease from these initial lesions, and there have been no further reports of European canker symptoms in the Hawke's Bay area.

The disease is established in the Waikato and Auckland districts, with these two areas contributing about 3% of New Zealand's total apple export trade. The other districts, namely Gisborne and Nelson, where the disease occurs sporadically in wet seasons, produce about 40% of the total export trade. The rest of the apple export trade is supplied from the Hawke's Bay, Otago and Marlborough areas (about 55%) where the disease is either uncommon or has never been recorded.

Environmental conditions

One stakeholder indicated the rating in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) was too high, stating that recent outbreaks of disease in New Zealand orchards were largely caused by extraordinarily wet springs and autumns, and coincided with large-scale introductions of new planting material. 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. galligena* (Munson, 1939; Dubin and

[13] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.

English, 1974). McCraken et al. (2003b) state that sporulation, dispersal and infection of *N. galligena* are strongly encouraged by mild, wet conditions.

Temperature and duration of wetness have been shown to be the critical factors contributing to infection (Swinburne, 1975; Latorre et al., 2002). *N. galligena* readily survives at temperatures between 2°C and 30°C with the optimum temperature for disease development being 20°–25°C (Munson, 1939; Butler, 1949). Latorre et al. (2002) demonstrated, under controlled environmental conditions using high fungal inoculum levels (10^6 conidia per millilitre) and performing inoculations less than 1 hour after leaf abscission, that conidia germinate in a temperature range of 6°–32°C with no infection occurring at 5°C regardless of the wetness duration. 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).

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 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). The same authors report that the disease is only problematic in California where mean annual rainfall exceeds 1000 mm.

One stakeholder reported a study (McCraken et al., 2003b) which demonstrated that European canker could be a problem in areas with rainfall significantly less than 1000 mm. The annual rainfall in this study varied from 653 mm to 791 mm, with average summer temperatures between 8°C (minimum) and 21°C (maximum). Two out of the three trial orchards developed high levels of canker and were planted close to old orchards known to have high incidences of canker. The cool summer and autumn temperatures would have allowed for longer wetness periods, and McCraken et al. (2003b) reports aerial spread of conidia from actively sporulating cankers on trees nearby contributed to the numbers of cankers. Based on the annual rainfall in New Zealand, the distribution of European canker correlates with the 1000 mm estimation. In New Zealand, European canker is established in the wetter districts of the Waikato region (average annual rainfall 1190 mm) and Auckland (1240 mm), where mean annual rainfall regularly exceeds 1000 mm and has restricted distribution in the Nelson (970 mm) and Gisborne (1051 mm) regions, where rainfall varies around 1000 mm, depending on the year (Atkinson, 1971; MAFNZ, 2004). The disease has been recorded in Hawke's Bay (803 mm) but MAFNZ (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) where annual rainfall is well below 1000 mm.[14]

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp1 as a triangular distribution with a minimum value of 10^{-2}, a maximum value of 6×10^{-2}, and a most likely value of 3×10^{-2}. This range takes into account the variations in climatic conditions across New Zealand, and the information indicating that about 95% of the apple export production in New Zealand comes from orchards in areas where the disease has either never been recorded or the disease occurs only sporadically in very wet seasons.

[14] http://www.niwa.cri.nz/edu/resources/climate/summary/summary.xls. Checked on 15 November 2005.

Importation step 2: Likelihood that picked fruit is infested/infected with *N. galligena*: uniform distribution with a minimum value of 10^{-6} and a maximum value of 10^{-3}. U(10^{-6}, 10^{-3}).

Orchard management

The widespread adoption of integrated fruit production (IFP) by 85–90% of New Zealand export orchards (MAFNZ, 2003e; Wiltshire, 2003) including surveillance, pruning out of infected cankers and active fungicide programs against diseases such as black spot (*V. inaequalis*) largely controls the establishment and spread of European canker (Swinburne and Cartwright, 1973; Cooke, 1999; Anonymous, 2004a).

The New Zealand IFP Manual recommends a combination of systemic fungicides including benzimidazoles (for example, carbendazim), demethylation inhibitors (for example, dodine) and the use of protectant fungicides including copper, thiram, captan, euparen multi (tolyfluanid), dithiocarbamates (e.g. mancozeb, metiram, ziram) and dithianon for control of European canker (Anonymous, 2004a). Cooke (1999) reported the above fungicides reduce cankers by 65–90%, but suggested spray treatments alone cannot eradicate existing infections and must be supplemented by cutting out cankers and treating wounds with a fungicide paint.

The effectiveness against European canker of new fungicides like the strobilurins has been queried by stakeholders, but evidence indicates that these fungicides are effective against *N. galligena* infections (Lolas and Latorre, 1997; Creemers and Vanmechelen, 1998). Lolas and Latorre (1997) reported that strobilurins provided up to 97% control of European canker. The sterol biosynthesis inhibitors (SBI) including hexaconoazole and triflumizole are much less effective, providing less than 46% control of European canker at levels suggested for controlling other diseases of apple, but these chemicals are not widely used in the IFP program. A stakeholder claims that reduction in pesticide use as a result of adoption of IFP programs would increase the risks of European canker infections. The IFP program in New Zealand and other countries has resulted in significant reductions in the use of pesticides for insect control, but the use of fungicides has not substantially altered (Gildemacher et al., 2001; Wiltshire, 2003).

In New Zealand, European canker is primarily a disease of trees, with fruit only occasionally being attacked (Atkinson, 1971). Wilton (2002b) indicates leaf scar tissue is the main infection site in New Zealand orchards, particularly during the establishment phase of infection. Similarly, Clarke and Brook (1975) demonstrated that fruit spurs and leaf scars in autumn present the main infection sites for the disease in New Zealand apple orchards.

Foliage is not affected (Butler, 1949) and leaf trash is unlikely to present a significant threat, unless twigs with active cankers are picked with the fruit. Fruit infection will only occur when the disease is present on the tree or within the orchard (Bondoux and Bulit, 1959) and conditions of temperature and free moisture are suitable (Latorre et al., 2002). In Europe, where rainfall in summer coincides with spore release and flower/fruit production, fruit rot can be a major problem (Swinburne, 1975). By contrast, in the United States rainfall and infection generally occur in winter and 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. Fruit rot caused by *N. galligena* has been reported in New Zealand (Brook and Bailey, 1965; Braithwaite, 1996), but limited data is available on the incidence of fruit infection in New Zealand. Information presented in correspondence from MAFNZ (2005a) indicated 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. galligena*.

A search on New Zealand's Hortnet[15] found no literature on fruit rot caused by *N. galligena,* whereas there was extensive information available on other apple fruit rots in New Zealand including apple scab (*V. inaequalis),* bitter rot (*Glomerella cingulate),* black rot *(Botryosphaeria obtusa),* ripe rot *(Pezicula* spp.) and various core rots.

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 (Anonymous, 2004a) would greatly reduce the likelihood of *N. galligena* infections being present. These diseases are reported to be a problem only in high rainfall areas of Auckland and the Waikato as well as periodically in Nelson and Hawke's Bay during wet years (Anonymous, 2004a).

Fruit infection will only occur if cankers are present in the orchard (Bondoux and Bulit, 1959). Almost 90% of export orchards in New Zealand use disease management programs and fungicide programs to control apple scab and other apple diseases, and this would minimise the possibility of European canker (Anonymous, 2004a; Wiltshire, 2003) being present during fruit development and the harvest period. Given that climatic conditions typically reported for Hawke's Bay and Nelson during the harvest periods are normally dry and not conducive to spore release, fruit infection is very 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 spore production, 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. Braithwaite (1996), in a report to MAFNZ, acknowledged the possibility that European canker could go unnoticed at harvest or during the early part of storage, and therefore could be transmitted in fruit as latent infections.

Stakeholders raised the issue of latency in fruit infection. In mature dessert apple varieties, fruit infected with European canker typically 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 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). Latency of infection is reported to be associated with accumulation of benzoic acid, a substance toxic to fungi in young and immature fruit (Swinburne, 1975). An infection occurring in young, immature fruit will not grow because of high benzoic acid levels. However, as acidity decreases and sugar levels increase with ripening, the toxicity of benzoic acid decreases and the fungus resumes growth. The likelihood of latent infections occurring in mature fruit is reduced, except when infection occurs just before harvesting. New Zealand does not export significant volumes of immature or cooking varieties.

Fungicidal dips before storage of fruit are not used in New Zealand (MAFNZ, 2003a).

From 1988 to 2003, more than 450 fresh apple fruit were intercepted at the barrier by AQIS staff from countries where European canker is present, including 53 apple fruit from New Zealand. Common fruit rotting fungi were isolated and identified on about 30% of the fruit but there were no records of *N. galligena* being isolated (Anonymous, 2005a).

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp2 as a uniform distribution, with a minimum value of 10^{-6} and a maximum of 10^{-3}. In reaching this conclusion the IRA team focused on the fact that under New

[15] http://www.hortnet.co.nz. Checked on 15 November 2005.

Zealand conditions fruit is only occasionally attacked and this generally results in rotting of the fruit. Rotted fruit would not be picked or would be culled in the grading process.

Importation step 3: Likelihood that clean fruit is contaminated by *N. galligena* during picking and transport to the packing house: triangular distribution with a minimum value of 10^{-6}, a maximum value of 10^{-4}, and a most likely value of 10^{-5}. $T(10^{-6}, 10^{-5}, 10^{-4})$

Fungi from cankers

Clean fruit could be surface-contaminated by:

- pickers' hands or gloves contaminated with spores through accidentally touching cankers or infected fruit
- spores carried in rain splash or wind currents during harvesting and transport, although this requires actively sporulating cankers to be present in the orchard (Bondoux and Bulit, 1959; McCartney, 1967)
- trash with actively sporulating fungus and spores making contact with fruit in bins.

Clean fruit displaying no obvious rot symptoms and recently infected but symptomless fruit would be extremely unlikely to contaminate other fruit during the picking or transport process because the fungus does not actively sporulate until fruit becomes badly rotted or mummified (Dillon-Weston, 1927). Infected fruit that drops before harvest, or that remains on trees and becomes mummified during winter can develop perithecia in spring, producing ascospores that could contaminate other fruit. Dillon-Weston (1927) reported that only three apples collected from a total of 700 mummified fruit in an English orchard infected with *N. galligena* cankers developed perithecia, although this number increased to 49 when the fruit were incubated under laboratory conditions more favourable than those present in the field.

Foliage is not affected and trash presents an extremely small likelihood of contamination unless twigs with active cankers are picked along with fruit (Butler, 1949). Infected twigs or branches that have been cut and left on the orchard floor can sustain cankers for long periods and produce abundant spores (Atkinson, 1971). Swinburne (1971a) found spore production continues for over two years on excised wood left on the orchard floor.

Fungi on bins

Spores contaminating bins are unlikely to present a significant likelihood for infection as conidia and ascospores are sensitive to desiccation even at high relative humidity. Dubin and English (1975a) 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.

Transfer of fungi from hosts to clean fruit

Because *N. galligena* has a large host range, contamination could come from canker infections on susceptible hosts planted near export orchards. The rating in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) report was queried by several stakeholders, mainly on the basis of contamination of spores from outside the orchard from alternative host plants (for example, hedgerows) and the dispersal potential of spores in stormy climatic conditions. Although fungicides are widely used in orchards, alternative hosts planted as hedgerows and infected with *N. galligena* could produce conidia during the harvest period and, under the right climatic conditions, could contaminate clean fruit during picking and transport. Conidia can be dispersed up to 125 m in wet and windy storm conditions (Swinburne, 1975; CABI, 2005) and if cankers were present on alternative hosts, fruit could become contaminated.

In New Zealand, there are 54 records of *N. galligena* occurring primarily on *Malus* and *Pyrus* hosts[16], but the fungus has also been recorded on loquats (*Eriobotrya japonica*), coprosma (*Coprosma areolate*) and kowhai (*Sophora microphylla*). Kowhai is the national flower of New Zealand and is a common feature in New Zealand gardens.[17] Any of these hosts may be close to commercial orchards and could have active cankers.

Braun (1997) reported that European canker was well established in hedgerows 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. Climatic conditions typically experienced during harvest periods in most New Zealand orchards are not conducive to spore release and infection, but in the wetter districts of Auckland and the Waikato region, conditions favour these processes.

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp3 as a triangular distribution, with a minimum value of 10^{-6}, a maximum value of 10^{-4}, and a most likely value of 10^{-5}. This range allows for a small number of fruit to be contaminated but recognises that conditions in most areas of New Zealand during the harvesting season are not favourable for spore production.

Importation step 4: Likelihood that *N. galligena* survives routine processing procedures in the packing house: triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.85. T(0.7, 0.85, 1)

Pre-cooling

Most apple exporters in New Zealand routinely use a pre-cooling step in the packing house process (MAFNZ, 2005a). Rapid cooling after harvest reduces the incidence of decay in storage because low temperatures slow both the rate of fungal growth and the aging processes in the fruit (Anonymous, 1993). However, the short period of pre-cooling would not significantly affect the survival of latent infections, and the number of infected fruit would not be significantly reduced.

Washing

Initial washing of fruit in a dump tank and subsequent high-volume, high-pressure water washing (if available) may remove surface spores but will have no effect on internal infections, and the fungus will survive these procedures.

Several export packing houses in New Zealand use chlorine or other disinfectants, for example, peroxyacetic acid or bromo-chloro-dimethylhydantoin, in the dump tanks to reduce microbial populations (MAFNZ, 2005a). Although there is no specific data to indicate their effectiveness against *N. galligena*, it is likely these chemicals used at the correct dosage rates (concentration and time) would have varying degrees of effectiveness. However, internal infections will not be affected by such treatments (Holmes, 1993) and the fungus will survive these procedures.

[16] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.
[17] http://www.rhizobia.co.nz/taxonomy/legume.html. Checked on 15 November 2005.

Brushing

Brushing would not remove fungi present in internal tissues or at the stem and calyx-ends of fruit, as these areas are inaccessible.

Waxing

Conidia will survive low temperature waxing and waxing could help hold conidia or hyphae onto the fruit.

Sorting and grading

Sorting and grading will remove fruit with visible rots and blemishes, but latent infections or surface contamination will not be detected by visual examination.

Cold Storage

Post-harvest fungicide treatments are not used in New Zealand before cold storage (MAFNZ, 2003a).

Neonectria galligena can survive at temperatures between 2°C and 30°C (Munson, 1939; Butler, 1949) and would readily tolerate cool storage temperatures. The ability of this pathogen to survive low temperatures is a major reason for its ability to infect even dormant trees (Marsh, 1940). Any temporary cold storage soon after harvest and before processing begins is likely to be very short, a few days at the most, and this period of storage will be too short for significant expression of latent infections. Latorre et al. (2002) reported conidia did not germinate at temperatures below 5°C, but mycelia can grow at temperatures near 0°C (Lortie and Kuntz, 1963). Fruit becomes more susceptible to rotting from latent infections as storage times increase (Snowdon, 1990a). Any infection or infestation that remains at the end of packing house procedures will survive cold storage.

In France, Bondoux and Bulit (1959) estimated that *N. galligena* caused 0.5–2% losses of fruit in storage. In Northern Ireland, European canker was reported to have caused storage losses of about 30% on Bramley’s seedlings (Swinburne, 1964), but cooking varieties such as Bramley’s are more susceptible to long-term storage rot (Swinburne, 1975; Snowdon, 1990a).

Summary

After considering the technical information given above and stakeholders’ comments, the IRA team decided to represent Imp4 as a triangular distribution, with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.85. This range largely reflects the fact that internal and latent infections are unlikely to be visible and none of the processes in the packing house are likely to substantially reduce infections.

Importation step 5: Likelihood that clean fruit is contaminated by *N. galligena* during processing in the packing house: triangular distribution with a minimum value of 10^{-5}, a maximum value of 10^{-4}, and a most likely value of 5×10^{-5}. $T(10^{-5}, 5 \times 10^{-5}, 10^{-4})$

Several stakeholders agreed with the rating given in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004), although one stakeholder claimed the rating should have been higher because of contamination occurring in dump water. Holmes (1993) showed conidia from epiphytic infections of other fungi can be washed off into the dump water, thereby potentially contaminating clean fruit. Given the extremely small likelihood of fruit being infested/infected with *N. galligena*, the probability of surface spores being present on fruit and contaminating the dump water is similarly extremely small. Foliage is not affected and leaf trash presents an insignificant contamination pathway unless fruit is picked along with twigs that have small cankers (Butler, 1949). Severely rotted fruit and twigs are largely eliminated during the sorting and grading process.

Swinburne (1971a) reported that *N. galligena* spores are not able to penetrate intact apple fruit cuticle, although conidial contamination could take place through the calyx, lenticels, scab lesions or wounds caused by bruising. Polishing could create minute damage on the surfaces of fruit, and this could assist the spread of infection.

The use of chlorine and other disinfectants in dump tanks and high-pressure apple washers when applied would remove epiphytic microbes to varying degrees.

Latent fruit infections present a minimal likelihood of contamination in the processing pathway because spores do not develop on infected fruit until they become severely rotted or mummified (Dillon-Weston, 1927).

The remainder of the processing in the packing house presents an insignificant likelihood of fruit contamination.

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp5 as a triangular distribution, with a minimum value of 10^{-5}, a maximum value of 10^{-4}, and a most likely value of 5 x 10^{-5}. This allows for the presence of a small number of spores in the packing processes that could contaminate fruit.

Importation step 6: Likelihood that *N. galligena* survives palletisation, quality inspection, containerisation and transportation to Australia is 1.

Two stakeholders questioned the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004) rating on the basis that none of the steps in this process would significantly reduce the presence of latent infections. Some infected fruit not detected during sorting may be identified at quality inspection. However, quality inspection will not detect latent infections or any surface infestation, and these will survive palletisation, containerisation and transport because there are no mechanisms in these procedures to remove them.

The time between Imp4 and Imp6 will not be long enough for latent infection to express itself to a significant level. Because spores are microscopic, any remaining surface infestation will also remain undetected and survive.

Summary

After considering the technical information given above and stakeholders' comments, the IRA team concluded that the likelihood for Imp6 should be a value of 1.

Importation step 7: Likelihood that clean fruit is contaminated by *N. galligena* during palletisation, quality inspection, containerisation and transportation: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Packed fruit would be securely stored and would present a 'negligible' likelihood of becoming contaminated during the palletisation, quality inspection and transportation. The short period of storage and temperatures maintained during transportation would not be conducive to spore production.

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp7 as a uniform distribution, with a minimum value of 0 and a maximum value of 10^{-6}.

Importation step 8: Likelihood that *N. galligena* remains with the fruit after on-arrival minimum border procedures is 1.

On-arrival inspections of documentation would fail to detect fruit rot symptoms or latent infections, and these would remain when the fruit arrives in Australia. The likelihood rating for this importation step would not be significantly reduced by any normal on-arrival procedure.

Summary

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp8 as a value of 1.

Conclusion – probability of importation

When the above likelihoods were inserted into the risk simulation model, the probability of importation of *N. galligena* was estimated as being 6.9 x 10^{-5} (mean), 3.6 x 10^{-5} (5th percentile) and 10^{-4} (95th percentile). Therefore, the infestation/infection rate for *N. galligena* was estimated to be 0.0069% (mean) of the total proposed number of apples imported from New Zealand annually.

Probability of entry, establishment and spread

The factors relevant to the estimation of the probability of entry, establishment and spread are discussed below. These include:

- The probability of importation (discussed in previous section)
- The proportion of utility points near host plants susceptible to the pest in each exposure group (titled *Proximity* below)
- The probability of exposure of a susceptible host plant in the exposure group to the pest by an infested/infected apple discarded near it (titled *Exposure* below).
- The probability of establishment
- The probability of spread

These factors are combined using the approach set out in the methodology section to provide an estimate of the annual probability of entry, establishment and spread.

Proximity

The term 'proximity' expressed in this report refers to the likelihood that a utility point is sufficiently close to a host plant in a particular exposure group, to allow for a non-zero likelihood of transfer of bacteria to a host to occur.

General issues specific to each utility point are discussed below, followed by a justification of the proximity ratings for each utility point by exposure group combinations as set out in Table 32.

1. Orchard wholesalers

This group includes packing and storage facilities in non-urban areas that might be expected to pack bulk New Zealand fruit, repack fruit needing culling and re-grading, or act as a storage and distribution facility for New Zealand fruit. The IRA team considered that facilities undertaking these types of operations would be the same ones involved with domestic apple fruit and therefore be located close to apple and/or pear orchards. Industry sources suggested that about seven facilities of this type could have some involvement with New Zealand apple fruit. One stakeholder suggested that citrus packing houses may also sometimes deal with apples. However, an industry source indicated this was most unlikely, as the handling arrangements for citrus are quite different from those for apples. Even if this did occur, citrus packing houses are unlikely to be close to apple and pear orchards and therefore would not constitute a significant risk.

2. Urban wholesalers

This group includes packing, storage and distribution centres located in major cities. These are generally located in industrial areas and sometimes at fruit and vegetable markets where very few hosts of European canker would be present.

3. Retailers

This group includes supermarkets, fruit and vegetable shops, retail markets and roadside stalls. The numbers and distribution of these largely follow consumer population density, with the majority in large cities, often in shopping complexes or malls well separated from potential host plants. However, in some cases, apple retailers may be co-located with nurseries where hosts of European canker may be present.

4. Food services

This group includes restaurants, sandwich bars, cafeterias and hotels where apples may be used or consumed. The numbers and distribution of these largely follow consumer population density, with the majority in large cities, often in shopping complexes, malls or central business districts well separated from potential hosts.

5. Consumers

This group includes all final consumers of apples. 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 European canker are present in many home gardens, parks and roadsides in large cities. In estimating proximity, the IRA team considered the proportion of the population in areas where hosts would not be present or occur at a very low frequency. An estimate based on ABS data is that approximately 85% of the Australian population live in areas where suitable hosts could be present. This puts an upper limit of 0.85 on the proportion of consumers located near susceptible hosts. This proportion is also relevant to retail and food service utility points.

An additional factor is the potential for consumers to be close to host plants. For example, the opportunities for hosts to be exposed to apples are significantly fewer for consumers living in flats or apartments compared to those living in houses with gardens. ABS figures indicate that about 30% of dwellings in major cities are flats, apartments or townhouses where there are unlikely to be any hosts of European canker. Another factor to be considered is the occurrence of suitable host species in home gardens. This would vary considerably depending on the area and the climatic conditions. For example, hosts of European canker are much more common in gardens in southern Australia than in areas further north. It has been assumed that 50% of Australian home gardens would contain hosts of European canker.

Care must be exercised to avoid ‘double counting’ when estimating proximity values. For example, an apple eaten and discarded by a consumer in a public park close to wild and amenity hosts cannot simultaneously be close to household and garden plants. When the model was being checked in response to stakeholder concerns about double counting, it was realised that some of the proximity values had been significantly overestimated because of this problem.

Stakeholders generally agreed with the probability ratings assigned to the proportion of utility points near host plants susceptible to *N. galligena* in the four exposure groups. The exceptions were the ratings assigned for i) household and garden plants and ii) wild and amenity plants. Stakeholders suggested that the assigned ratings had been underestimated and should be increased. The IRA team considered all stakeholder comments in reviewing the proximity values.

Commercial fruit crops near utility points

Apple (*Malus* spp.) and pear (*Pyrus* spp.) are major commercial fruit crops susceptible to *N. galligena* and these crops are grown in large monocultures in commercial orchards. Black cherry (*Prunus serotina*) is cited as being a host (CABI, 2005), however, this species is not grown commercially.

The proportion of **orchard wholesalers** near **commercial fruit crops**: 1

- All orchard wholesalers 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.

The proportion of **urban wholesalers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are predominantly located in metropolitan areas, with waste typically going to landfill. Both the utility point and the waste are located well away from commercial fruit crops.
- Some urban wholesalers may be found within apple production areas for example, Shepparton. The waste may be disposed in close proximity to the orchard or in landfill away from production sites.

The proportion of **retailers** near **commercial fruit crops**: Uniform (10^{-4}, 10^{-2}).

- Almost all waste from retailers will end up in landfill. Up to 1% of retailers (including nurseries) and their waste could be located near commercial fruit crops and this waste could remain exposed to the elements in a skip before disposal.

The proportion of **food services** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Major food services are extremely unlikely to be near commercial fruit crops.

The proportion of **consumers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Only a small proportion of the Australian population is estimated to be located near commercial fruit crops. Waste typically goes to landfill, although consumers living near commercial fruit crops may compost their apple waste in close proximity to host plants.
- Consumers may dispose of fruit waste from vehicles in the vicinity of commercial orchards.

Nursery plants near utility points

Hosts of *N. galligena* commonly found in nurseries include apple (*Malus* spp.), pear (*Pyrus* spp.), poplar (*Populus* spp.), maples (*Acer* spp.), birch (*Betula* spp.), beech (*Fagus* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.) and elm (*Ulmus* spp.) trees.

The proportion of **orchard wholesalers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Although pome fruit growers and nurseries are largely two different industries, some orchard wholesalers may raise their own nursery plants or operate a parallel wholesale business.
- A new orchard being established or replanted may contain large numbers of nursery plants packed in one place and the orchardist may undertake re-packing of imported fruit at a significant scale until the orchard comes into production.

The proportion of **urban wholesalers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesalers are located in metropolitan areas and some may be close to garden centres selling nursery plants. Although waste is normally disposed in landfill, it could be kept temporarily, thus staying in close proximity to these garden centres.

The proportion of **retailers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Pome fruit nurseries may be located near orchards (for example, the Monbulk region in Victoria). Up to 5% of Australia's retail outlets sell nursery plants that are hosts of *N. galligena* including fruit trees (for example apple and pear) and ornamental plants (for example, elms, birch and maples).
- Retail nurseries are sometimes found near fresh food markets.

The proportion of **food services** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Waste originating from major food services is extremely unlikely to be disposed of near nursery plants.

The proportion of **consumers** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Fruit waste from consumers may be disposed of near nurseries although this event would be extremely infrequent.

Household and garden plants near utility points

Common household and garden plants that are hosts of *N. galligena* include apple (*Malus* spp.) and pear (*Pyrus* spp.). Maples (*Acer* spp.), poplars (*Populus* spp.), birch (*Betula* spp.), beech (*Fagus* spp.), ash (*Fraxinus* spp.), oak (*Quercus* spp.) and elm (*Ulmus* spp.) are also hosts of *N. galligena* (CABI, 2005; Flack and Swinburne, 1977) and are common household and garden plants in the temperate zones of Australia, although they are usually sparsely distributed.

The proportion of **orchard wholesalers** near **household and garden plants**:
Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesalers and their waste disposal sites are located in isolated areas within the orchard premises but some household and garden plants may be located near them.

The proportion of **urban wholesalers** near **household and garden plants**:
Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesalers are located in metropolitan areas and their waste is disposed of in landfill sites. Household and garden plants are unlikely to be in close proximity to these sites because residential properties would be located away from them.

The proportion of **retailers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Most retailers are located in larger cities and their waste would be disposed of in landfill sites, which are generally not near residential properties.
- Retail nurseries are sometimes found near fresh food markets. Major retailers may have hosts susceptible to *N. galligena* near apple fruit that is displayed for sale.

The proportion of **food services** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Major food service industries are located in cities and their waste is disposed to landfill sites although they may store their waste temporarily near household and garden hosts within their premise.

The proportion of **consumers** near **household and garden plants**: Uniform (10^{-2}, 0.15)

- Most consumers are located in metropolitan and suburban areas and their waste is typically disposed of in landfills, with household and garden plants susceptible to *N. galligena* unlikely to be near these sites.
- Composting and recycling of waste is becoming a common practice in both metropolitan and rural areas and some consumers may have a few *N. galligena* host plants present as household and garden plants. Pome fruit trees and other hosts are commonly located in some back gardens throughout southern Australia and apple waste disposed of in compost may be in close proximity to these plants.
- Consumers may dispose of fruit waste near residential dwellings and along roadsides in the vicinity of garden and household plants. Although the density of susceptible host plants near these sites would be low, there could be situations where alternate hosts occur over a wide area.

Wild and amenity plants near utility points

Host plants of *N. galligena* present in this category include crab-apple (*Malus* spp.), wild species of pear (*Pyrus* spp.), willow (*Salix* spp.) and several common ornamental species of oak (*Quercus* spp.) and elm (*Ulmus* spp.) that grow wild. No reports are available on the susceptibility of Australian native plants to infection by *N. galligena*. Birch (*Betula* spp.) and other primary forest hosts of *N. galligena* are limited in their distribution in Australia.

The proportion of **orchard wholesalers** near **wild and amenity plants**
Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesale waste sites are mostly located within the orchard premises and are not located near wild and amenity plants. *N. galligena* host plants are not normally grown as hedgerow plantings in commercial orchards although some wild and amenity plants (for example, crab-apple, poplars and oaks) may be present within the premises or along orchard boundaries.
- Orchard wholesalers typically manage feral plants and volunteer apple seedlings in commercial orchards, and it would be very unlikely these would grow near waste disposal sites.

The proportion of **urban wholesalers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesaler waste is disposed of in landfills. Susceptible wild and amenity hosts may grow wild near these sites as a result of dispersal of their seeds by birds (for example, crab-apple seedlings) or the disposal of viable plant cuttings.

The proportion of **retailers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Retailer waste would be disposed of in landfills. Susceptible wild and amenity hosts may grow wild near these sites as a consequence of dispersal of susceptible plant seeds by birds or the disposal of viable plant cuttings.

The proportion of **food services** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Food services would dispose of their waste in landfills. Susceptible wild and amenity hosts may grow wild near these sites as a consequence of dispersal of seeds by birds or the disposal of viable plant cuttings.

The proportion of **consumers** near **wild and amenity plants**: Uniform (5 x 10^{-3}, 5 x 10^{-2})

- Most consumers in metropolitan and suburban areas dispose of their waste in landfills. Susceptible hosts may grow from seeds in the wild near these sites as a result of dispersal by birds or disposal of viable plant cuttings.
- Some consumers may discard apple cores, rotten fruit or partially eaten fruit into the environment. This is likely to occur near parks, gardens, recreation sites and from vehicles along roadsides where susceptible wild and amenity plants may be found. The density of host plants near these sites would be very low but there could be situations where alternate hosts for example, willow may occur over a wide area.
- Local authorities encourage the recycling of household waste to make compost and this is becoming a common practice in metropolitan and rural areas. Susceptible wild and amenity plants may be in close proximity to compost heaps where apple waste may be disposed.

Table 32 Summary of proximity values for all utility point and exposure group combinations for *N. galligena.*

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	1	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Urban wholesalers	U(10^{-6}, 10^{-3})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Retailers	U(10^{-4}, 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Food services	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Consumers	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-2}, 0.15)	U(5 x 10^{-3}, 5 x 10^{-2})

Exposure

The term exposure refers to the likelihood of transfer of the pathogen from infested or infected apples to a susceptible host plant. This is a complex variable dependent on several critical factors. A sequence of events needs to be completed, and there must be successful exposure of host plants to *N. galligena* from infested or infected apples in order for European canker to establish in Australia. The pathogen must be able to survive in a viable state in or on fruit waste and must be transferred to a host plant receptive to infection, with environmental conditions conducive to infection being present. An analysis of the sequence of events that has to occur in order for successful exposure and transfer of *N. galligena* is summarised below.

Waste disposal

Most consumer waste is disposed into landfills, presenting a very small risk for subsequent exposure of *N. galligena*; however, an increasing amount is being disposed of in backyard compost heaps. Some waste is also disposed directly into the environment along roadsides and recreational areas, presenting potential inoculum sources for transfer to susceptible host plants.

Location of fungi

Fruit infection typically takes place at the blossom end of the fruit through the open calyx or stem end, as well as through lenticels and scab lesions (Swinburne, 1975; Bondoux and Bulit, 1959). This infection leads to the development of a rot and has been reported to spread to the seed cavity (Bondoux and Bulit, 1959), although this was not observed in California (McCartney, 1967). As the rot progresses, the fruit may become mummified followed by the development of perithecia in autumn, releasing ascospores in winter and spring (Munson, 1939; Grove, 1990a).

Survival and viability of the fungus in (or on) the fruit

Neonectria galligena can readily survive at temperatures between 2 to 30°C (Munson, 1939; Butler, 1949) although Latorre et al. (2002) demonstrated under controlled environmental conditions using high fungal inoculum levels (10^6 conidia/mL), that no infection occurred at 5°C regardless of wetness duration. The cool storage and transport process would not adversely affect the viability of the fungus. Latent infections could remain, with fungal growth and fruit rot resuming when fruit is removed from the cool chain, sold to consumers and stored at room temperature. Fruit discarded into the environment could further rot, become mummified and develop viable fungal inoculum, conidia or perithecia that could initiate new infection although perithecia rarely develop on infected fruit in waste dumps (Swinburne, 1964). Dillon-Weston (1927) reported only three apples collected from a total of 700 mummified fruit from an English orchard infected with *N. galligena* 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.

Apple waste disposed of in landfills and compost may be subjected to high temperatures (60°C), which would kill the fungus. 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 perithecia development. Similarly insects, mammals or birds could consume apple waste.

Neonectria galligena does not produce resting cells and spores are killed by prolonged desiccation from high temperature and low relative humidity (Dubin and English, 1975a). 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, 1975a).

Transfer mechanism

Neonectria galligena produces two types of spores: aerially dispersed ascospores and water-splashed conidia. No studies exist in the literature to demonstrate long-distance disease spread from fruit infections, but as indicated above, severely rotted or mummified fruit are capable of developing perithecia producing aerially disseminated ascospores. Wilson (1966) reports that ascospores forcibly discharged from perithecia are exposed to the dispersing effects of air currents and constitute the chief means of long-distance spread within orchards.

Transfer of European canker across borders or districts results from the movement of infected nursery stock (Cooke, 2003). Although wind disperses some conidia in the absence of rain (Swinburne, 1971b) they are mainly splash-dispersed (Munson, 1939). The most probable maximum distance for dispersal by rain splash is 10 m (Marsh, 1940) although one report suggests this might actually be as much as 125 m under stormy conditions (Swinburne, 1975). These studies relate to conidia produced from cankers on trees and the distances are likely to be far less for conidia originating from infected fruit on the ground.

Braun (1997) reported that European canker was present in hedgerows on maple and poplar trees around orchard blocks in Nova Scotia, but suggested that random distribution of the canker within the orchard indicated the inoculum originated from within the orchard rather than 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. Similarly McCraken et al. (2003b) reported that aerial spread of conidia from actively sporulating cankers in neighbouring trees contributed to the numbers of cankers recorded in a study in the United Kingdom.

Involvement of birds and insects as vectors is suspected, although transfer has not been demonstrated and *N. galligena* 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. They could get the spores on their feet or beaks while feeding on a discarded fruit and then transfer them to a branch of a susceptible plant, especially given that European canker is a disease specific to tree branches.

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. galligena* to a healthy tree.

Conidia of a similar pathogen of apple, *V. inaequalis,* have been observed on the legs of aphids (Dillon-Weston and Petherbridge, 1933).

Availability of entry points

Entry points for infection by *N. galligena* 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* and possibly woolly aphid injury present other entry points for infection (Swinburne, 1975; Brook and Bailey, 1965). Infection can also be initiated in the absence of wounds through natural openings for example, the calyx end of fruit or via lenticels (Swinburne, 1975; Bondoux and Bulit, 1959).

Inoculum dose

The number of conidia required to initiate an infection varies depending on environmental and host factors. CABI (2005) reports that approximately 1000 conidia are required for leaf scar infection; however, in artificial inoculations under optimal laboratory conditions as few as 10 or 12 conidia (McCraken et al., 2003b; Cooke, 2003) have produced infections and these numbers are considered to resemble natural situations (McCraken et al., 2003b). Dubin and English (1974) found that five conidia were insufficient to initiate infection, while 50 to 500 did so readily. Latorre et al. (2002) suggested that European canker is more aggressive in areas where abundant ascospores are produced during leaf fall.

Host plant receptivity

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. In addition there are more than 20 other genera susceptible to *N. galligena,* each containing several species (refer to data sheet Appendix 3 in Part C). Entry sites are available throughout most of the year, although the age of leaf scars and wound sites is of importance to infection. According to Crowdy (1952) leaf scars are highly susceptible to infection within the first hour after leaf fall and become much less susceptible over the next hour. Tests in California (Dubin and English, 1974) indicated that up to 5% of leaf scars can remain susceptible to infection for 10 days while Wilson (1966) found infection could occur up to 4 weeks post leaf fall. Seaby and Swinburne (1976) showed the susceptibility of pruning cuts to infection decreased considerably after a seven-day period.

Environmental factors

Climatic conditions are critical for disease development, both for inoculum production and infection by *N. galligena* (Dubin and English, 1974). Temperature and duration of wetness are critical factors contributing to transfer and successful infection (Swinburne, 1975; Latorre et al., 2002). *N. galligena* readily survives at temperatures from 2ºC to 30°C (Munson, 1939; Butler, 1949) with the optimum temperature for disease development being between 20ºC to 25ºC. These conditions are quite common in temperate and subtropical parts of Australia. A minimum 2 to 6 h wetness duration is required at the optimum temperature (20°C) with a longer wetting period required at lower temperatures (Latorre et al., 2002; Grove, 1990a). Swinburne (1975) reported that a minimum of 6 h free moisture duration was required for significant infection to take place. Under artificial conditions, Latorre et al. (2002) demonstrated that 2 h wetness duration was sufficient for disease development at 20°C when inoculations were performed within 1 h of leaf abscission and 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. galligena* 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. The same authors report that the disease is only problematic in California where mean annual rainfall exceeds 1000 mm. McCraken et al. (2003b) in a study in the UK reported that European canker could be a problem under high disease pressure with significantly less rainfall than 1000 mm, although this may be because of cooler temperatures allowing longer wetness periods. Some regions in Australia (including the Adelaide Hills, Manjimup and Perth) experience annual rainfall over 1000 mm[18] and this may be conducive to infection periods. Environmental conditions in nurseries, including use of overhead irrigation, may create favourable microclimates and be conducive to disease infection.

Some features specific to each exposure group are discussed below.

Commercial fruit crops

Most commercial apple fruit cultivars are susceptible to *N. galligena* (Anonymous, 1988; CABI, 2005).

Fruit trees in commercial orchards are planted in high-density monocultures and suitable wound sites would be available in commercial orchards all year round (Swinburne, 1975). In spring and autumn, natural infection sites include leaf scars and, in winter, pruning cuts would present an entry point for the fungus. In summer, *N. galligena* can infect fruit through the calyx-end or through lesions caused by pathogens such as *V. inaequalis*. On this basis the IRA concluded that the exposure value of an individual apple for orchard wholesaler waste is Uniform (10^{-6}, 10^{-3}) while the exposure value of an individual apple for urban wholesaler, retailer, food service and consumer waste is Uniform (0, 10^{-6}).

[18] http://www.bom.gov.au/climate/averages/. Checked on 15 November 2005.

Nursery plants

Most nurseries maintain high standards of hygiene, including use of fungicides, to produce high quality plants and apple fruit waste disposed of in such locations would be collected frequently.

The IRA team also considered that a further exposure source could result from nursery workers handling an infected fruit and then touching a suitable nursery host, particularly during pruning activities; however, this would almost never occur, so the IRA team concluded that the exposure value of an individual apple for all utility points is Uniform (0, 10^{-6}).

Household and garden plants

Most apple waste from the four utility points (orchards, urban wholesalers, retailers, food service) would be disposed of in waste sites or dump bins away from household and garden plants, and on the basis of this the IRA team concluded that the exposure value of an individual apple for orchard wholesaler, urban wholesaler, retailer and food service waste is Uniform (0, 10^{-6}).

Since most of the fruit goes to the consumers combined with the increased opportunity for expression of latent infections, there is an increased possibility that infected/infested apples may be present in their waste. Fruit trees and ornamental plants that are hosts of *N. galligena* may be found in household gardens, although their density would be low. Consumers disposing of fruit waste into a backyard compost heap may present an opportunity for exposure of conidia spores to host plants in the garden. High temperatures (up to 60°C) inside compost heaps (Anonymous, 2004b) would be expected to inactivate *N. galligena.* However, survival of the pathogen on fruit under incomplete composting, especially in domestic backyards, is possible although this event would be extremely unlikely.

Fruit waste disposed of by consumers from vehicles in the vicinity of household and garden plants may increase the likelihood of exposure, although fruit decay and competition from other saprophytic organisms would minimise this likelihood.

The lack of disease control and the use of irrigation may create climatic conditions more conducive for exposure and transfer of infection to household and garden plants.

On the basis of the available information, the IRA concluded that the exposure value of an individual apple for consumer waste is Uniform (10^{-6}, 10^{-3}) and the exposure value of an individual apple for orchard wholesaler, urban wholesaler, retailer and food service waste is Uniform (0, 10^{-6}).

Wild and amenity 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

The waste from other four utility points is disposed of mostly into landfill sites. Some consumers particularly in suburban and rural areas utilise waste for compost making. Consumers may also occasionally discarded fruit waste along roadsides and recreation areas. Retailer and food services waste would be disposed of into landfills. At waste disposal sites of the remaining four utility points there could be several hosts of *N. galligena*. There is a greater likelihood of exposure of the hosts to the pathogen at these sites. Further, European canker is primarily a disease affecting branches and stems. Birds commonly feeding at waste disposal sites could transfer spores from infected/infested apple cores to branches of susceptible hosts in the immediate surrounds, where they could gain entry through wounds.

On the basis of the available information, the IRA concluded that the exposure value of an individual apple for orchard wholesaler waste is Uniform (0, 10^{-6}) and the exposure value of an individual apple for urban wholesaler, retailer, food service and consumer waste is Uniform (10^{-6}, 10^{-3}).

Conclusion – exposure

The probabilities of exposure for all utility point–exposure group combinations for *N. galligena* are summarised in Table 33. These values are based on the IRA team's view taking into account all the factors discussed above. A significant exposure factor for *N. galligena* is the fact that the fungus has a specific mechanism for spore dispersal.

Table 33 The probability of exposure of *N. galligena* to susceptible host plants near exposure groups by utility points discarding a single infested/infected apple.

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesaler waste[19]	U(10^{-6}, 10^{-3})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Urban wholesaler waste	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})
Retailer waste	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})
Food service waste	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})
Consumer waste	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})

Probability of establishment

Availability of suitable hosts, alternate hosts and vectors 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, 2005).

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

[19] As indicated in the method section, for pathogens, waste includes discarded infested/infected apples.

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), however, reported that European canker in apple trees was more numerous in rows adjacent to hedges infected with European canker.

Suitable entry sites for infection by *N. galligena* are available most of the year with wound sites caused by leaf fall in autumn and leaf cracks from onset of spring bud burst presenting natural infection sites. Winter pruning cuts and lesions caused by other pathogens such as *V. inaequalis* and possibly woolly aphid injury present other entry points for infection (Swinburne, 1975; Brook and Bailey, 1965). Infection can also be initiated in the absence of wounds through natural openings, for example, the calyx-end of fruit and lenticels (Swinburne, 1975; Bondoux and Bulit, 1959).

Involvement of insects and birds as vectors is suspected (Butler, 1949). In particular, the possible role of woolly aphid as a vector has been mentioned (Brook and Bailey, 1965), although infection through this route has not been demonstrated and its involvement is doubted by some (McKay, 1947). Conidia of a similar pathogen of apple, *V. inaequalis*, have also been observed on the legs of aphids (Dillon-Weston and Petherbridge, 1933).

Suitability of the environment

Areas where average annual rainfall is greater than 1000 mm favour establishment of the disease (Grove, 1990a). Annual rainfall is close to, or more than, 1000 mm in several apple growing areas in Australia, for example, the Adelaide Hills (1118 mm), Perth Hills (1069 mm), Manjimup (1022 mm) and Batlow (949 mm). Similarly, a number of areas within temperate Australia and the coastal zone receive similar annual rainfall where alternative hosts may be found. Nursery plantings as well as household and garden plants are not solely dependent on natural rainfall, as they are regularly irrigated throughout the growing period. This means that wetness and humidity around these plants could be favourable for establishment of the disease.

Neonectria galligena can readily survive at temperatures between 2 to 30°C (Munson, 1939; Butler, 1949). Maximum and minimum temperatures, particularly in the temperate regions of Australia, are favourable for establishment of the disease and comparable to those of the Auckland and Waikato areas of New Zealand where the disease is well established.

In Europe the disease is more prevalent in waterlogged acid soils and those rich in nitrogen but deficient in other minerals compared to moderately fertile, non-acid permeable soils (Butler, 1949). Such soil conditions are quite common in Australia.

The potential for adaptation of the pest

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.

The reproductive strategy of the pest

Under suitable environmental conditions, production of conidia and ascospores can occur throughout the year and their tolerance of low temperatures are considered special adaptations that *N. galligena* 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).

Minimum population needed for establishment

The number of conidia required to initiate an infection varies depending on environmental and host factors. CABI (2005) reports that approximately 1000 conidia are required for leaf scar infection, however, in artificial inoculations under optimal laboratory conditions as few as 10 to 12 conidia have produced infections and these numbers are considered to resemble natural situations (McCraken et al., 2003b).

The method of pest survival

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 galligena can survive as a latent and symptomless infection in susceptible apple hosts for up to 3 to 4 years (Berrie et al., 2000; Lovelidge, 2003; McCraken et al., 2003a; McCraken et al., 2003b), resuming growth during more conducive climatic conditions.

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

Apple fruit remaining on the tree or on the orchard floor could become mummified and produce perithecia and ascospores, although Swinburne (1964) reported that perithecia rarely develop on infected fruit left in a waste dump.

Cultural practices and control measures

Integrated pest management programs used in Australia, including fungicide applications to control apple scab (except for Western Australia) and other fungal pests, will assist in reducing opportunities for the establishment of the pest.

Less use of disease control and heavy pruning practices in garden and household situations may favour establishment of the disease.

Probability of spread

Suitability of the natural and/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. galligena* is recorded on three alternative hosts, namely, loquat (*Eriobotrya japonica*), kowhai (*Sophora microphylla*) and coprosma (*Coprosoma areolate*) trees.[20] Australia has areas with similar environments to these countries. 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.

The fact the disease spread to a few orchards in Spreyton, Tasmania, probably after a single entry point indicates that the managed environment of Australia can be favourable for spread, although the extent of dispersal was quite limited despite being present for many years. This may have been because of the absence of air borne ascospores better suited to long-distance dispersal than conidia (Ransom, 1997), combined with unfavourable climatic conditions (Spreyton receives less than 900 mm annual rainfall) and the use of chemicals to control apple scab may also have limited disease spread. There were no reports of the disease spreading to

[20] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.

wild and amenity plants, including forest plants or household and garden plants during the 40-year eradication program (Ransom, 1997).

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.

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 the commodities or conveyances

CABI (2005) lists fruit (including pods), bark and stems (above-ground shoots, trunks and branches) as host plant parts that can carry spores and hyphae of the pathogen both internally and externally. Therefore, in addition to the fruit trade, 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.

Long-distance movement of European canker is primarily the result of movement of infected nursery stock. A study in the UK, called the 'Millennium project' 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). This type of infection can be significant in low rainfall areas and 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, movement of inoculum from neighbouring sources is of more concern than nursery infection.

There is no evidence in the literature that indicates that long-distance spread of disease is due to movement of fruit. Conidia and perithecia can develop in rotted or mummified fruit and contribute to local spread.

Intended use of the commodity

Apples would be used mostly for consumption by humans and would be widely consumed around the states and territories.

Potential vectors of the pest

Involvement of insects and birds as vectors is suspected (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).

People (for example, consumers, orchard and nursery workers) handling infected apples could potentially spread inoculum to susceptible host plants.

Partial probability of establishment and spread

Additional evidence to support the partial probabilities of establishment and spread for specific exposure groups is provided in the text below and the results are provided in Table 34.

Commercial fruit crops

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.3, 0.7)

Most apple cultivars grown commercially in Australia are susceptible to *N. galligena*. Climatic conditions in approximately 40% of Australian commercial fruit growing areas are conducive for infection (Adelaide Hills, Perth Hills and Manjinup have annual mean rainfalls greater than 1000 mm and Orange and Batlow in New South Wales have annual mean rainfalls close to 1000 mm). The Goulburn Valley and Bacchus Marsh in Victoria, Stanthorpe in Queensland and the Huon Valley in Tasmania, which together account for about 60% of Australian apple production receive annual rainfall significantly less than 1000 mm; these areas are unlikely to favour establishment of European canker.

Maximum, minimum and mean temperatures in commercial pome fruit growing areas are well within the temperature range of 2°C to 30°C suitable for germination of spores and fungal growth.

Monoculture and high density planting in commercial orchards with numerous entry sites favour establishment and spread of European canker, especially through rain splash and wind, the key methods of spread for this disease.

Apple scab (caused by *V. inaequalis*), thought to provide entry points for the European canker fungus (Swinburne, 1975) is present in pome fruit orchards, except in Western Australia. Woolly aphid is suspected to be involved in establishment and spread of the disease and is common in commercial orchards throughout Australia (Swinburne, 1975).

The disease was eradicated from commercial orchards in Spreyton, Tasmania in 1991. It was not in the major growing area of the Huon Valley.

Nursery plants

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.7, 1)

Spread of disease in nurseries, particularly in damp and cool districts can be high and is the main method of introducing the disease to new areas (Murdoch, 2002; Wilton, 2002a; Wilton, 2002b). Frequent watering and maintenance of high humidity conditions in nurseries, the spread of the pest through pruning/tools and the presence of a range of densely packed host plants are all factors encouraging disease establishment.

CABI (2005) reports that trees can be infected in the nursery shortly after, or during, propagation and may not express disease symptoms for up to three or four years (Berrie et al., 2000; Lovelidge, 2003; McCraken et al., 2003a; McCraken et al., 2003b).

Infected host plants from nurseries could be widely distributed around Australia and rapidly spread the disease to new districts.

Household and garden plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (0.3, 0.7)

Host species such as apple (*Malus domestica*), pear (*Pyrus communis*) and ornamental hosts (poplars, elms, beech) are common in many households and gardens. Others such as staghorn sumac (*Rhus typhina*) are listed as potential new host species in Australia.[21]

Household and garden plants are not solely dependent on natural rainfall as they are frequently watered, and the levels and duration of humidity around these plants could be favourable for establishment of the disease. Less use of pest control and heavy pruning practices may also

[21] www.newcrops.uq.edu.au/listing/listingindexd.htm. Checked 22 November 2005.

favour establishment and spread however, the scattered distribution of host plants would restrict spread.

When Tasmania had the disease there were no reports of it occurring on household and garden plants. The average annual rainfall in Spreyton where the disease was found is less than 900 mm and this may have restricted its spread.[22]

Wild and amenity plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (5 x 10^{-2}, 0.3)

Wild and amenity plants would not be sprayed with fungicides, meaning that the disease could remain undetected and easily establish, although spread would be restricted within that plant community.

Considerable damage to hardwood timber species is reported in the USA in addition to damage to commercial crops.

The scattered distribution of wild species means that rates of establishment and spread are lower compared with commercial crop and nurseries.

When the disease existed in Tasmania from 1954 to 1991, it was found only in some commercial orchards (Ransom, 1997) and did not spread to trees in the wild.

There are 54 records of *N. galligena* on the national website of New Zealand Fungi, the majority of which are recorded on apple and pear trees although the fungus has also been recorded on loquat (*Eriobotrya japonica*), kowhai (*Sophora microphylla*) and coprosma (*Coprosoma areolate*).[23] These species are not widely grown in Australia.[24]

Conclusion

The IRA team considered the information presented above in reaching the conclusions on the partial probability of establishment and spread for each exposure group, shown in Table 34.

Table 34 Partial probabilities of establishment and spread of *N. galligena*

	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Partial probabilities of establishment (PPE)	U(0.7, 1)	U(0.7, 1)	U(0.3, 0.7)	U(0.3, 0.7)
Partial probabilities of spread (PPS)	U(0.3, 0.7)	U(0.7, 1)	U(0.3, 0.7)	U(5 x 10^{-2}, 0.3)

Conclusion – entry, establishment and spread

Estimates of the partial probabilities of entry, establishment and spread for each of the utility points and susceptible host plants were combined by @RISK, as outlined in the method section, to give a combined annual probability of entry, establishment and spread as shown in Table 35.

[22] http://www.bom.gov.au/climate/averages/tables/cw_091232.shtml. Checked on 15 November 2005.
[23] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.
[24] http://www.chah.gov.au. Checked on 15 November 2005.

Table 35 Unrestricted probability of entry, establishment and spread[25]

Percentile	Probability of entry, establishment and spread: P1 = Uniform (0.7, 1)	Probability of entry, establishment and spread: P1 = Uniform (10^{-3}, 5 x 10^{-2})	Qualitative description
5th percentile	1.5 x 10^{-2}	1.4 x 10^{-2}	Very low
Median simulated value	9.1 x 10^{-2}	9 x 10^{-2}	Low
95th percentile	0.33	0.33	Moderate

Table 35 shows that the median value was within the qualitative likelihood of 'low'.

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are shown in Table 36. Available supporting evidence is provided in the text below.

Table 36 Impact scores for *N. galligena*

Direct impact	Impact scores
Plant life or health	E
Human life or Health	A
Impact on the environment	D
Indirect impact	
Control or eradication	D
Domestic trade or industry	D
International trade	B
Environment	C
Communities	C

Direct impact

Plant life or health – E

The direct consequences on plant life are expected to be minor at the national level, significant at the regional level and highly significant at the district level. A rating of '**E**' was assigned to this criterion.

[25] calculated by @RISK

Climatic conditions in approximately 40% of Australian commercial fruit growing areas are conducive to infection. The Adelaide Hills, Perth and Manjimup areas have annual mean rainfalls greater than 1000 mm, and Orange and Batlow in New South Wales have annual mean rainfalls close to 1000 mm.[26] Establishment of European canker in these districts could be highly significant with reduced yields and additional orchard practices required (see below). The rating assigned to this criterion was '**E**' indicating that the impact of an outbreak on plant life or health would be minor at the national level, significant at the regional level and highly significant at the district level.

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). 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.

In some apple cultivars under favourable environmental conditions, 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).

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, at least 30% of the trees with infected limbs removed subsequently developed further infection with entire trees requiring removal (Ransom, 1997).

Neonectria galligena 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. 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. *N. galligena* has not been reported to infect *Eucalyptus* spp. (Keane et al., 2000).

Human life or health – A

The impact on human life and health are unlikely to be discernible at local level and was assigned a rating of '**A**'.

There are no known direct impacts of *N. galligena* on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – D

Other environmental effects are unlikely to be discernible at a national level and would be of minor significance at the regional level, but would be significant at the district level and highly significant locally. A rating of '**D**' was assigned to this criterion.

Most stakeholders agreed with this rating, although one rated the impact as being too low on the basis that the Australian community greatly values its garden and forest environments. Another

[26] http://www.bom.gov.au/climate/averages/. Checked on 15 November 2005.

stakeholder rated it as being too high, on the basis that amenity plants are not significantly affected.

The Australian community places a high value on its forest and garden environments and several hosts of *N. galligena* 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 local climatic conditions (Spreyton receives less than 900 mm annual rainfall) and the absence of airborne ascospores that are better suited to long-distance dispersal than conidia (Ransom, 1997).

Many host plants of *N. galligena* 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, 2005) 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 direct flow-on effects. 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 highly significant at the local level.

Indirect impact

Control or eradication – D

The costs of control and eradication of an outbreak of European canker is unlikely to be discernible at a national level and would be of minor significance at the regional level, but would be significant at the district level and highly significant locally. A rating of ‘**D**’ was assigned to this criterion.

Stakeholders were in general agreement with the ratings. One stakeholder claimed a higher rating as canker diseases are generally difficult to eradicate, with the European canker outbreak in Tasmania requiring 40 years. Another stakeholder claimed the rating was too high, suggesting control strategies for other apple diseases would readily manage an outbreak. Based on the available evidence the original rating has been retained, with an outbreak being of minor importance at the regional level but significant at the district level, particularly in a state like Western Australia where apple scab is not present and additional fungicides would be required.

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 (CABI, 2005). Implementing these measures would require a multifaceted and costly approach.

Cultural practices and chemical measures used to control apple scab (*V. inaequalis*) in most Australian apple growing regions (except Western Australia) 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 strobulirins provide effective control of European canker (Lolas and Latorre, 1997; Creemers and Vanmechelen, 1998). Given the absence of apple scab disease in Western

Australia (McKirdy et al., 2001), the impact of an outbreak of European canker would be significant at the district level as additional fungicides and orchard practices would be required for control.

A stakeholder claimed the reduction in pesticides as a result of adoption of IFP programs would increase the risks of European canker infections. The IFP program in New Zealand and other countries has resulted in significant reductions in the use of pesticides. However, the use of fungicides has not been substantially altered (Gildemacher et al., 2001; Wiltshire, 2003).

If the disease establishes in wild or amenity plant species (for example, crab-apple, elm and willow) control would be difficult, as they are not subject to any integrated pest management programs and application in an urban situation would be difficult.

Domestic trade or industry – D

The indirect consequences on domestic trade are unlikely to be discernible at a national level and would be of minor significance at the regional level, but would be significant at the district level and highly significant locally. A rating of '**D**' was assigned to this criterion.

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 fruit and 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).

International trade – B

The indirect consequences on international trade would not be discernible at the national level and would be of minor significance at the local level, with a rating of '**B**' assigned to this criterion.

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 United Kingdom and Japan are the two importing countries that possess both host species and favourable climates for the disease and the disease is already present in these two countries. An outbreak of European canker in Australia would not have a significant impact on the current apple export trade. However, Australia may need to put in place special management practices if it is to seek access to new markets in temperate countries free of the disease.

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. galligena* (Fukuda, 2005). Therefore, if the disease did become established in Australia it would not significantly affect the international export of fruit.

Environment – C

The indirect consequences on the environment are unlikely to be discernable at the regional level, of minor significance at the district level and significant at the local level. A rating of '**C**' was assigned to this criterion.

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 significantly impacting on the future placement of plant species (for example, elm trees) at the local level.

Communities – C

The indirect consequences on communities are unlikely to be discernable at the regional level, of minor significance at the district level and significant at the local level. A rating of '**C**' was assigned to this criterion.

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. In the event of establishment and spread of the disease in Melbourne's elm tree population, there could be indirect significant flow-on effects for tourism.

There could be significant social impacts at a local level if several orchards were affected by European canker, owing to reduced crop yields and potential quarantine restrictions.

Conclusion – consequences

Based on the decision rule described in the methodology – that is, where the consequences of a pest with respect to one or more criteria are '**E**'– the overall consequences are considered to be 'moderate'. Therefore the overall consequences of *N. galligena* are '**moderate'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the 'rules' shown in the risk estimation matrix in the method section. The unrestricted annual risk estimation for *N. galligena* is shown in Table 37.

Table 37 Unrestricted risk estimation of *N. galligena*

Overall probability of entry, establishment and spread[27] (median value)	9.1 x 10^{-2} (Low)
Consequences	Moderate
Unrestricted annual risk	Low

As indicated in Table 37 above the overall unrestricted risk for European canker exceeds Australia's ALOP of 'very low'; risk management is therefore required for this pest.

[27] Calculated by @RISK.

Risk management for European canker

The unrestricted annual risk of European canker has been assessed as ‘low’ when the overall probability of entry, establishment and spread was combined with consequence. This exceeds Australia’s ALOP and risk mitigation measures are proposed to lower this rating to maintain the ALOP.

The risk pathway of greatest concern to export with regard to European canker is symptomless infection and infestation of fruit that cannot be detected by inspection. Under suitable conditions the fungus could develop to produce spores that transmit the disease. An analysis of the unrestricted risk scenario for European canker found the number of infested/infected fruits imported was influenced by the following importation steps:

- Imp2 – the likelihood that picked fruit is infested/infected with *N. galligena*
- Imp4 – the likelihood that *N. galligena* survives routine processing procedures in the packing house
- Imp5 – the likelihood that clean fruit is contaminated by *N. galligena* during processing in the packing house

Inspection cannot detect symptomless infection and infestation. Therefore, inspection at Imp6 and Imp8 cannot be used in the evaluation of options to reduce the risk resulting from symptomless infection or infestation by *N. galligena*.

In the unrestricted risk assessment for European canker, Imp4 was assessed considering all procedures taking place in New Zealand’s packing houses. This includes the use of sanitisers and short-term cold storage by some packing houses. There is no evidence in the literature that suggests any of these procedures mitigate symptomless infection. Therefore, it is not feasible to seek measures to reduce the likelihood allocated to Imp4.

The following options were evaluated with a view to mitigating the annual risk by reducing the likelihood allocated to Imp2 and Imp5. Imp1 will also be influenced by these options.

- Pest free areas – ISPM No. 4: *Requirements for the establishment of pest free areas* (FAO, 1996b).
- Establishment of pest free places of production – ISPM No.10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999).

Pest free area

A pest free area, as described in ISPM No. 4: *Requirements for the establishment of pest free areas* (FAO, 1996b) and ISPM No.10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999), would require systems to be put in place by MAFNZ to establish, maintain and verify that *N. galligena* does not occur within that area. Freedom from *N. galligena* in an area would influence likelihoods for Imp2 and Imp5 in the importation pathway. Fruit infection will only occur when the disease is present on the tree or within the orchard. Therefore, in pest free areas, the likelihood that picked fruit will be infected/infested with the pest (Imp2) is 0 and the likelihood that clean fruit is contaminated during processing in the packing house (Imp5) is a uniform distribution between 0 and 10^{-6}. This assumes that apples may be processed in packing houses in areas where European canker is present. If this was not the case then Imp5 would be 0. When these modified likelihoods were placed in the risk simulation model and the assessment for European canker repeated, the median of the restricted annual probability of entry, establishment and spread was found to be 3.7×10^{-3}, which is within the qualitative range of ‘very low’. When this was combined with the ‘moderate’ estimate of consequences for European canker, the restricted risk for European canker was below Australia’s ALOP.

The efficacy of pest free areas as a risk management option for European canker is summarised in Table 38.

Table 38 European canker: Effect of pest free area

Step	Unrestricted likelihood	Restricted likelihood
Imp2	U(10^{-6}, 10^{-3})	0
Imp5	T(10^{-5}, 5 x 10^{-5}, 10^{-4})	U(0, 10^{-6})
PEES (median)	9.1 x 10^{-2} (Low)	3.7 x 10^{-3} (Very low)
Consequence	Moderate	Moderate
Risk estimate	Low	Very low

While the option of a pest free area is available, *N. galligena* has been reported in Auckland, the Waikato region, Coromandel, Northland, Taranaki, Westland, Gisborne, Bay of Plenty, Hawke's Bay and Nelson.[28] Extensive detection and delineating surveys, including inspection of alternative host plants would be required to confirm pest free areas. Similarly, the establishment and maintenance of pest free areas would need to be relevant to the biology of *N. galligena,* including its means of spread. Infected nursery stock presents a pathway for establishment and spread of European canker in New Zealand. Recent detections in Nelson (Murdoch, 2002) and previous reports in Hawke's Bay (Wilton, 2002b; MAFNZ, 2003a) are considered to have occurred as a result of this pathway. Studies in the United Kingdom have confirmed that infection entering orchards through nursery stock can remain symptomless for up to four years (Lovelidge, 2003; McCraken et al., 2003b).

As there are no restrictions on the movement of planting stock within New Zealand, maintenance of pest free areas may not be a technically feasible option except with continuous inspection and verification of freedom.

Establish pest free places of production

A second option to mitigate the annual risk is to source apples from export orchards free of the disease, that is, establish pest free places of production, ISPM No.10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999). This measure would require the place of production, under the supervision and responsibility of MAFNZ, to establish, maintain and verify freedom from European canker disease symptoms supported by the appropriate documentation.

In the unrestricted risk assessment for European canker, the likelihood of *N. galligena* infection occurring on picked apple fruit (Imp2) was considered to be a uniform distribution between 10^{-6} and 10^{-3} in commercial orchards in New Zealand. Fruit infection will only occur when the disease is present on the tree or within the orchard (Bondoux and Bulit, 1959). Apples sourced from orchards free of cankers would therefore be relatively less likely to be infected or infested with *N. galligena,* when compared with apples produced under the unrestricted risk scenario. The likelihood that picked fruit is infected or infested with *N. galligena* (Imp2) was considered to be a uniform distribution between 0 and 10^{-6} for fruit sourced from orchards which were kept free of European canker symptoms in the current growing season. Similarly the likelihood that

[28] http://nzfungi.landcareresearch.co.nz/html/mycology.asp. Checked on 15 November 2005.

clean fruit is contaminated during processing in the packing house (Imp5) from orchards free of disease symptoms would be a uniform distribution between 0 and 10^{-6}.

When the modified likelihoods for Imp2 and Imp5 were used in the model and the assessment for European canker was repeated, the median of the restricted annual likelihood of entry, establishment and spread was found to be 3.7 x 10^{-3}, which is within the qualitative range of 'very low' (Table 39). When this was combined with the 'moderate' estimate of consequences for European canker, the restricted risk for this pest was found to be 'very low', which is below Australia's ALOP. Therefore, the use of areas free from disease symptoms for sourcing export apples would be an effective risk management measure for *N. galligena*.

Table 39 European canker: Effect of establishment of pest free places of production

Step	Unrestricted likelihood	Restricted likelihood
Imp2	U(10^{-6}, 10^{-3})	U(0, 10^{-6})
Imp5	T(10^{-5}, 5 x 10^{-5}, 10^{-4})	U(0, 10^{-6})
PEES (median)	9.1 x 10^{-2} (Low)	3.7 x 10^{-3} (Very low)
Consequence	Moderate	Moderate
Risk estimate	Low	Very low

Orchard inspections

Orchard freedom from European canker is established by conducting growing season inspections for European canker symptoms, combined with appropriate cultural practices and chemical control treatments to maintain disease freedom. All trees in the export orchard would be visually inspected annually in winter, after leaf fall and before winter pruning. In areas where climatic conditions are less favourable for disease establishment and spread (for example, Hawke's Bay and Otago), orchard freedom from European canker would be assessed by walking down every row and visually examining all trees on both sides of each row for symptoms.

In areas where environmental conditions are more conducive to disease establishment and spread, for example the Waikato region and Auckland, the use of ladders to inspect tree limbs, combined with the inter-row inspections would be necessary. This is consistent with the approach adopted during the eradication program in Tasmania, where annual inspections of the affected orchards were conducted after leaf fall and before winter pruning to verify canker freedom (Ransom, 1997). If European canker were present, the orchard would be ineligible to export fruit during that season. To be eligible for re-registration, cankers must be removed and follow-up fungicides applied, followed by re-inspection of the orchard for canker symptoms the following season.

Infected nursery stock presents a pathway for the establishment and spread of European canker into places of production. All new planting stock must be intensively examined, and appropriate cultural practices and fungicide sprays used to minimise the likelihood of canker infections.

Conclusions

The risk of *N. galligena* could be managed to an acceptable level below Australia's ALOP by sourcing apples for export from orchards free of disease symptoms. This risk management strategy would be technically feasible in New Zealand. It is proposed that orchards free of disease symptoms would be established and maintained by MAFNZ.

Introduction

The apple leafcurling midge, *Dasineura mali* (Kieffer), is a fly with four life stages: adult, egg, larva (or maggot) and pupa. Apple trees (including crab-apple) are the only hosts of apple leafcurling midge. This species occurs in northern Europe, North America and New Zealand.

Biology

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. Larvae are legless red maggots when they first hatch from the eggs, and change to clear white until the final instar when they become bright orange-red in colour (HortResearch, 1999b). Fully grown larvae are 1.5–2.5 mm long (CABI, 2004). Pupation takes place in a white silken cocoon 2–2.5 mm in length. The pre-pupal stage is orange and clearly visible inside the cocoon, whereas mature pupae are brown (Tomkins, 1998).

Apple leafcurling midge reproduces sexually. Laboratory evidence indicates that adults live for only 2–6 days and they must mate within this period. Swarming of adults has been observed to precede egg laying by females, and mating is assumed to occur in these swarms. Virgin females produce a sex pheromone that attracts males, and swarming of males has been observed around these females (Harris et al., 1996). Males are not attracted to mated females, including those that have mated just 1–2 hours previously. Females mate once or rarely twice, whereas males may mate many times. Some males are capable of mating on average 11 times in 30 minutes (HortResearch, 1999b). Males emerge from their pupae earlier than females, and peak male emergence (eclosion) occurs 1–2.5 hours before peak female emergence (Harris et al., 1996).

Apple leafcurling midge may produce up to seven generations over the summer depending on latitude and temperature, and individuals survive the New Zealand winter by overwintering as cocooned larvae (Tomkins, 1998). Mated females are attracted to volatile chemicals released by actively growing apple shoots on which they lay their eggs. Unlike the females, male apple leafcurling midges do not respond to the odour of apple foliage. The female has a strong preference for vigorous undamaged shoots on which to lay her eggs (HortResearch, 1999b) and lays several eggs on each leaf. Each female is capable of laying up to 200 eggs over about three days (CABI, 2002).

Apple leafcurling midge is reported to have arrived in New Zealand's North Island on East Malling IX apple stock shipped from the Netherlands in 1950 (Morrison, 1953), and was probably transported to other parts of New Zealand on nursery trees in the years following its introduction. By 1956, it was already present in many North Island locations (Berry and Walker, 1989). The most probable means of dispersal would be as cocooned larvae either in soil or associated with nursery plants (Berry and Walker, 1989).

Some responses to the *Draft import risk analysis on the importation of apples (*Malus x domestica *Borkh) from New Zealand* (BA, 2000)[29] on New Zealand apples incorrectly cite Gouk and Boyd (1999) as the authority behind the assertion that apple leafcurling midge is a

[29] Available at http://www.daff.gov.au

vector of fire blight. The authors clearly state that apple leafcurling midge infestations only cause leaf damage necessary for fire blight infections to occur and ‘there is currently no evidence to implicate the adult midge as a vector for dissemination of *E. amylovora*’ (Gouk and Boyd, 1999).

Other information relevant to the biology of apple leafcurling midge is available in the data sheet in Appendix 3 of Part C.

Risk scenario

The risk scenario of concern for apple leafcurling midge in this draft IRA involves mature larvae and pupae on apple fruit. The larvae of apple leafcurling midge prefer to pupate in the ground but some larvae falling from leaves become caught on apples, where they pupate (HortResearch, 1999b). The pupal cocoon would be firmly attached to the apple at either the stalk-or calyx-end of the fruit.

The potential for viable apple leafcurling midge larvae or pupae to be associated with trash after harvesting, packing house processing and transport would be minimal. Fully developed apple leafcurling midge larvae can remain trapped in their tightly rolled leaf galls under drought conditions, preventing them from completing their development until rainfall softens the leaf roll sufficiently to allow mature larvae to escape. It is likely that older leaves closer to the developing apple such as the flag leaves, which are not infested with apple leafcurling midge, would be picked accidentally.

Probability of entry, establishment and spread

The probability of entry, establishment and spread was calculated by undertaking a series of assessments including the:

- estimation of the probability of importation (mean infestation rate)
- estimation of the distribution of infested apples at utility points
- estimation of the partial probabilities of entry, establishment and spread at each of the utility points for each exposure group based on the distribution of infested apples to the utility points
- combination of all partial probabilities of entry, establishment and spread.

Entry comprises importation and distribution. The likelihood of importation was based upon the scenario of eight import steps and a likelihood for each step was assessed. These likelihoods, combined with the total expected trade in apples, were used to provide an estimate of the number of infested fruit imported into Australia and distributed at each utility point.

Distribution involves the release of imported apples from the port of entry and distribution to various utility points where susceptible hosts are present. Information relevant to distribution, establishment and spread is provided separately below. The partial probabilities of entry, establishment and spread were assessed for each utility point exposure group combination. All of the partial probabilities were then combined using the formula provided in the methods section to provide a single probability of entry, establishment and spread.

Importation

The initiating step for the apple fruit importation scenario is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry. The importation scenario is divided into eight steps and the available evidence supporting the likelihood of apple leafcurling midge being present at each step is provided in the text below.

Importation step 1: Likelihood that apple leafcurling midge is present in the source orchards in New Zealand is 1.

Apple leafcurling midge is common in New Zealand apple orchards ranging from Clyde to Auckland, and is probably found wherever apple trees are grown in New Zealand (Tomkins, 1998).

Chapman and Evans (1995) note that during the 1990s the incidence of apple leafcurling midge in commercial apple orchards in the Auckland, Waikato, Hawke's Bay and Nelson districts has increased noticeably.

Apple leafcurling midge infestation levels can differ between apple cultivars, although this can vary through the season depending on the availability of shoots suitable for egg laying. Gala types and cultivars with Gala parentage (for example, Braeburn, Gala, Royal Gala and Pacific Rose™) are particularly prone to infestation, because of the differing phenologies of the individual apple cultivars (Smith and Chapman, 1997).

No apple cultivar has been identified that is free from infestation (HortResearch, 1999b).

A stakeholder's submission gives this step a rating of 'certain' [1] because apple leafcurling midge has been found in all New Zealand apple orchards surveyed.

Summary

Based on evidence that apple leafcurling midge is common in New Zealand orchards and is probably found wherever apple trees are grown, the IRA team decided to represent Imp1 as 1.

Importation step 2: Likelihood that picked apple fruit is infested with Apple leafcurling midge: triangular distribution with a minimum value of 1.5×10^{-2}, a maximum value of 0.115, and a most likely value of 5×10^{-2}. $T(1.5 \times 10^{-2}, 5 \times 10^{-2}, 0.115)$

Apple leafcurling midge larvae usually exit leafrolls and fall to the ground to pupate at maturity. Some larvae are caught in the stalk-end or calyx-end of fruit as they try to reach the soil. These larvae pupate on the fruit, with the pupal cocoon firmly attached to the fruit skin (HortResearch, 1999b).

Most contaminated fruit have only a single cocoon attached, although up to 40 cocoons per fruit have been found on unsprayed trees (Tomkins, 1998; Tomkins et al., 1994).

A survey of 30 orchard blocks in the Waikato region and one in the Bay of Plenty during the 1993–94 season recorded up to 11.5% of apples as being contaminated with apple leafcurling midge pupae or larvae in the Waikato region, and around 1 to 2% in the Bay of Plenty. However, 63% of the cocoons contained no pupae, indicating that adults had already emerged from their cocoons before fruit was harvested (Tomkins et al., 1994).

Lowe (1993) reported that 10% of harvested apples were contaminated with pupae or larvae during the 1993–94 season in the Waikato region, with up to 1% being contaminated in Hawke's Bay.

A submission from a stakeholder rates this step as 'moderate' [Uniform (0.3, 0.7)], based on the following evidence: apple leafcurling midge occurs throughout New Zealand and can produce up to seven generations annually; large populations of midges are likely to be present when apples are harvested and the number of fruit contaminated with cocoons could be high; standard packing house procedures would remove few cocoons and apple leafcurling midge is commonly detected at pre-clearance of apples exported to the United States.

Another stakeholder also rates this step as ‘moderate’ [Uniform (0.3, 0.7)] since the 10–11.5% contamination rate is not indicative of apple leafcurling midge abundance, which is affected by rainfall leading to small levels of contamination in dry districts or seasons and higher levels in wet districts or seasons.

Another stakeholder’s submission asserts that this step should be rated ‘very low’ [Uniform (10^{-3}, 5 x 10^{-2})], because Lowe (1993) was reporting on an exceptional year in the Waikato region when apple leafcurling midge incidence was atypically high. At this time, growers were moving away from intensive use of organophosphate insecticides towards a new regime based on selective insecticides. This situation was overcome by implementing the IFP program.

The same stakeholder also contends that the Waikato region’s mild climate, regular high rainfall and moderate temperatures make it more conducive to the development of high midge populations, when compared with the primary production regions of Hawke’s Bay, Nelson and Otago. They further state that comprehensive pest management outcome data is now collected annually from apple packing houses, as part of a national program for monitoring the success of the IFP program. It is claimed that recent comprehensive data collected by Dr J. Walker of HortResearch (MAFNZ, 2005b) shows infestation levels of less than 1% to slightly more than 5% in inspected lines of mature export apples. It is not clear whether this data relates to fruit handling stages just after the initial water dump or after the apples have gone through the packing house procedure of washing, waxing, sorting and grading. In any case, Imp2 assesses the likelihood that picked apple fruit is infested with apple leafcurling midge, not the likelihood that apple leafcurling midge survives routine processing procedures in the packing house (Imp4).

Summary

The IRA team decided to represent Imp2 as a triangular distribution with a minimum of 1.5 x 10^{-2}, a maximum of 0.115 and a most likely value of 5 x 10^{-2}. This was based on the evidence that contamination rates for pupae or larvae of apple leafcurling midge range from 1–2% to 11.5% of apples in the Bay of Plenty and the Waikato region respectively, and taking into account that these rates are not indicative of apple leafcurling midge abundance which is affected by rainfall leading to higher levels in wet districts or lower levels in dry districts.

Importation step 3: Likelihood that clean fruit is contaminated by apple leafcurling midge during picking and transport to the packing house: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}. U(10^{-3}, 5 x 10^{-2})

Fruit is picked by hand into picking bags, and then transferred into bins kept on the ground in the orchard before transportation to the packing house.

Contamination may occur when infested leaves are picked during harvest along with the fruit.

If larvae are present on infested leaf material, they could move onto clean fruit to pupate in the stem-end or calyx-end of apple fruit.

Typically a leafroll contains 20–30 larvae, but numbers of up to 500 have been observed (Tomkins, 1998). However, the number of leaves picked is relatively small; a typical figure of up to 200 leaves per bin has been estimated by informed industry sources.

A stakeholder considers this step should be rated as ‘moderate’ [Uniform (0.3, 0.7)], asserting that the likelihood of infested leaves being picked along with the fruit during harvest has been underestimated. However, no other further information was provided to support this claim.

Another stakeholder claims that the numbers of apple leafcurling midge larvae reported by Tomkins (1998) are only found during spring and early summer (October to mid December), when eggs laid on new shoot tips hatched into larvae. These growing tips are not adjacent to fruit at harvest time and leaf growth is largely terminated by late December in New Zealand. This same stakeholder also claims that the only leaves growing close to the fruit at harvest are the flag leaves, and these are not infested with apple leafcurling midge. Since it has already been taken into account that a minimal number of leaves will be picked with the fruit, it is not necessary to change Imp3.

Summary

Based on the information that the contamination only occurs when infested leaves are picked and that the number of leaves picked along with fruit is very small, the IRA team decided to represent Imp3 as a uniform distribution with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}.

Importation step 4: Likelihood that apple leafcurling midge survives routine processing procedures in the packing house: triangular distribution with a minimum value of 0.5, a maximum value of 0.8, and a most likely value of 0.67. T(0.5, 0.67, 0.8)

The following packing house operations can influence the viability of apple leafcurling midge.

Washing

There is no evidence that the transfer of fruit through a flotation dump will affect the survival of apple leafcurling midge. The mature larvae pupate in a tough, white silken cocoon that can protect the pupae while immersed in the water dump tank.

If cocoons are firmly attached to the fruit skin at the stalk-end or calyx-end, washing is less likely to dislodge them.

Brushing

There is no evidence that a brushing process would affect the survival of apple leafcurling midge. The pupal cocoon is attached to the stem-end or calyx-end of fruit, so brushing would not easily dislodge them.

Waxing

There is no evidence that low temperature waxing would affect the survival of apple leafcurling midge pupae enclosed in cocoons.

Sorting and grading

Sorting and grading would remove fruit contaminated with pupae. However, given the volume of fruit passing through the grading areas, it is expected that some infested fruit would not be detected and removed.

A stakeholder submission rates Imp4 as ‘high’ [Uniform (0.7, 1)] since apple leafcurling midge pupae are small and hidden in the calyx or stem base and would be nearly impossible to see as the fruit moves quickly along the grading line. Another stakeholder contends that it would be difficult to detect apple leafcurling midge cocoons in the stalk and calyx end of apple fruit at sorting and grading.

However, data showing infestation levels of less than 1% to slightly more than 5% in inspected lines of mature export apples (MAFNZ, 2004) indicates that graders are intercepting apple leafcurling midge in apples after the routine washing process. However, this stakeholder states that there is limited unpublished data available demonstrating that routine packing house procedures have a significant effect on the numbers of apple leafcurling midge cocoons attached to mature apple fruit. It is claimed that up to 20% of cocoons present are washed off and a high percentage of the remainder are sufficiently damaged to render them non-viable.

Packaging

Packaging would have little effect on the survival of apple leafcurling midge. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while also minimising moisture loss. This environment is favourable for the survival of apple leafcurling midge.

Cold Storage

There is no evidence to suggest that cold storage would significantly reduce the viability of apple leafcurling midge pupae. The summer generation pupal stage lasts 13–18 days. However, the overwintering generation remains as pre-pupae or pupae inside the pupal cocoon for much longer. The adult stage lasts only 2–6 days. Apple leafcurling midge larvae overwinter in cocoons in northern Europe and north-east USA, suggesting that temporary cold storage would not significantly reduce viability of this pest.

Another stakeholder also questions the statement that cold storage would not significantly reduce the viability of apple leafcurling midge pupae, asserting that cold storage would be a significant mortality factor for the majority of insects contaminating consignments, but provided no further supporting evidence.

Interception data

Apple leafcurling midge has been detected on exports of New Zealand apples in several USA ports (USDA-APHIS, 2003), which indicates that some individuals of apple leafcurling midge will survive the packing house process.

Summary

Based on the lack of evidence that packing house procedures and cold storage are detrimental to the survival of apple leafcurling midge and USDA-APHIS interception data that indicates that some apple leafcurling midges have survived the packing house process, the IRA team decided to represent Imp4 as a triangular distribution with a minimum value of 0.5, a maximum value of 0.8, and a most likely value of 0.67.

Importation step 5: Likelihood that clean fruit is contaminated by apple leafcurling midge during processing in the packing house: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Some fruit arriving at the packing house would have pupae firmly attached to the fruit skin at the stem- or calyx-end (HortResearch, 1999b).

Dislodged apple leafcurling midge pupae would not be able to move about and attach to other fruit.

Apple leafcurling midge larvae would not persist inside the packing house, because there are no immature apple leaves to feed on.

Apple leafcurling midge adults, if present, would not lay eggs within the packing house because of the absence of immature apple leaves.

A stakeholder claims that leaf material introduced to the packing house would have at least a moderate chance of containing apple leafcurling midge; however, this factor has already been considered in Imp2. The submission also suggests that this step should be rated as ‘very low’ [Uniform (10^{-3}, 5 x 10^{-2})], asserting that mature larvae dislodged after immersion in the dip tank may attach themselves to an apple stem or calyx to pupate, but provides no further evidence to support this claim. However, even if this is the case, there is no net increase in the numbers of viable apple leafcurling midge already present in the packing house.

Another stakeholder contends that this step should be rated as ‘moderate’ [Uniform (0.3, 0.7)], claiming that washing and brushing could trigger mature larvae to move from fruit to fruit, but provides no further evidence to support this claim. This stakeholder also disputes the assertion that larvae would not persist inside the packing house because of the lack of immature leaves to feed on, as mature larvae could pupate on fruit. However, once again it should be noted that there is no net increase in the numbers of apple leafcurling midge already present in the packing house.

Summary

Based on the evidence that dislodged pupae or larvae washed off apple fruit during processing in the packing house would not subsequently result in a net increase in the number of infested fruit, larvae would not persist in the packing house, and adults would be unable to successfully find and lay their eggs on freshly developing leaves in the packing house, the IRA team decided to represent Imp5 as a uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}.

Importation step 6: Likelihood that apple leafcurling midge survives palletisation, quality inspection, containerisation and transportation to Australia: uniform distribution with a minimum value of 0.7 and a maximum value of 1. U(0.7, 1)

Some remaining viable pupae at the stem-end or calyx-end of fruit would survive palletisation, quality inspection, containerisation and refrigerated transport to Australia.

Apple leafcurling midge has been detected in several USA ports on New Zealand apples exported to the USA (USDA-APHIS, 2003).

A stakeholder’s submission gives this step a rating of ‘certain’ [1]. However, the IRA team considered that not all apple leafcurling midges would survive this step, since some natural mortality is expected to occur during the time it remains in cold storage during transportation.

Summary

Based on the evidence that some apple leafcurling midge pupae at the stem-end or calyx-end of fruit would be expected to survive palletisation, quality inspection, containerisation and transportation to Australia and apple leafcurling midge has been detected in several USA ports on New Zealand export apples, the IRA team decided to represent Imp6 as a uniform distribution with a minimum value of 0.7 and a maximum value of 1.

Importation step 7: Likelihood that clean fruit is contaminated by apple leafcurling midge during palletisation, quality inspection, containerisation and transportation: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Apple leafcurling midge pupae firmly attached to the fruit skin at the stem-end or calyx-end would not be easily dislodged, and if dislodged would not move about to attach to other fruit (HortResearch, 1999b). Thus, contamination of fruit by apple leafcurling midge during palletisation, quality inspection, containerisation and refrigerated transport to Australia would not occur.

A stakeholder assesses the likelihood of this step as being 'extremely low' [Uniform (10^{-6}, 10^{-3})] to 'very low' [Uniform (10^{-3}, 5 x 10^{-2})], stating that it is possible for mature larvae to move about and attach to fruit for pupation. However, there is no net increase in the numbers of apple leafcurling midge already present on apples.

Summary

Based on the evidence that apple leafcurling midge would not be easily dislodged from the apple fruit during palletisation, quality inspection and transportation, and there would ultimately be no net increase in the number of apple leafcurling midge on the apple fruit, the IRA team decided to represent Imp7 as a uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}.

Importation step 8: Likelihood that apple leafcurling midge survives and remains with the fruit after on-arrival minimum border procedures: triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.9. T(0.7, 0.9, 1)

The minimum border procedures described in the method section would not be effective in detecting apple leafcurling midge.

A stakeholder's submission gives this step a rating of 'certain' [1]. After consideration of this comment, it is reasonable to reassess this step as having a likelihood close to 1.

Summary

Based on the fact that on-arrival minimum border procedures would not be effective in detecting or destroying apple leafcurling midge, the IRA team decided to represent Imp8 as a triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.9.

Results – importation

When the above likelihoods were inserted into the risk simulation model, the probability of importation of apple leafcurling midge was estimated as being 4.1 x 10^{-2} (mean), 2 x 10^{-2} (5th percentile) and 6.5 x 10^{-2} (95th percentile). Therefore the infestation rate for apple leafcurling midge was estimated to be 4.1% (mean) of the total proposed number of apples imported from New Zealand annually.

On 3 August 2005 following many requests New Zealand provided some additional data on leafcurling midge. This data was generated from endpoint inspections during the 2001–2004 seasons and therefore should be a good estimate of the probability of importation. The information as provided by New Zealand is reproduced in Table 40.

Using the information from,Table 40 the probability of importation for apple leafcurling midge could be approximated as a triangular distribution with a minimum value of 10^{-3} a most likely value of 1.3×10^{-3} and a maximum value of 3.8×10^{-3}. These values are considerably lower than the results based on data previously available from New Zealand on apple leafcurling midge.

In the following analysis and in the discussion on risk management both sets of data are considered. The later data is referred to in the following analysis as 'August 2005' to differentiate it from the analysis based on the earlier published data.

Table 40 August 2005 data on apple leafcurling midge interceptions from endpoint inspections 2001–2004[30]

Year	Number of cartons inspected	Number of cartons pest free	Percentage of cartons pest free	Number of fruit inspected	Number of pests found	Percentage of infested fruit
2001	14,516	13,090	89.6%	1,620,801	1638	0.10%
2002	5544	4478	80.7%	593,691	2257	0.38%
2003	8673	7512	86.6%	1,011,823	1352	0.13%
2004	11,679	10,516	90.0%	1,330,249	2050	0.15%
Total	40,412	35596	88.1%	4,556,564	7297	0.16%

Probability of entry, establishment and spread

The initiating step for estimating the probability of entry, establishment and spread is the release of imported apples from the port of entry, and the final step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host resulting in pest establishment and spread. Entry, establishment and spread of a pest in a new area involves a complex set of interacting factors. Factors relevant to apple leafcurling midge are discussed in this section. For convenience the discussion has been broken up into several sub-sections:

- Discussion of the proportions of utility points near susceptible hosts (proximity). Utility points are orchard wholesalers, urban wholesalers, retailers, food services, and consumers. Susceptible host plants are grouped into four exposure groups; commercial fruit crops, nursery plants, household and garden plants and finally, wild and amenity plants.
- Discussion of factors relevant to the transfer of a pest to susceptible host plants from the utility point.
- Estimation of the number of infested fruit arriving at each utility point by exposure group combination.
- Discussion of factors relevant to establishment based on ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).
- Discussion of factors relevant to spread based on ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).

[30] based on standard 600-fruit inspection of a significant number of lines of fruit (Pipfruit NZ 2005)

- Estimation of the partial probabilities of entry, establishment and spread for each utility point exposure group combination taking into account all relevant information (PPEES).
- Estimation of the combined probability of entry, establishment and spread (PEES).

Several stakeholders have indicated that the methods employed in assessing the exposure of host plants from a single infested waste apple in the last draft are not appropriate for apple leafcurling midge. After consideration of their comments the assessment of exposure has been revised, taking into account the estimated number of infested apples.

Some stakeholders provide different ratings for the probability of exposure of apple leafcurling midge to susceptible hosts, but this is based upon calculations using a single infested fruit as the unit. However, since the method for analysis is based upon the number of infested fruit at a particular utility point, this comment is no longer applicable.

Proximity

The proximity of insect pest to its host(s) considers its dispersal characteristics, its host range, and the proximity of utility points in relation to its host(s).

Apple, including crab-apple is the only susceptible host to apple leafcurling midge. Leaves are the preferred site for egg-laying although eggs may also be laid under the bracts of buds and on developing flowers in spring, when fewer leaves are available. Studies have shown that volatile chemicals released by apple foliage are important in the host-finding behaviour of female apple leafcurling midges. The female apple leafcurling midge selects very young leaves for egg laying, normally only those which are just beginning to unfold in the shoot tips, or are about two-thirds unfolded. The adult female also prefers undamaged shoots that are growing vigorously.

Table 41 provides the estimated likelihoods of utility points near susceptible host plants for apple leafcurling midge. The estimated likelihoods were determined by expert judgement taking into consideration relevant stakeholder comments provided for the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004).

Table 41 The proportions of utility points near host plants susceptible to apple leafcurling midge in the four exposure groups

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	1	U(10^{-3}, 5 x 10^{-2})*	U(10^{-3}, 5 x 10^{-2})	U(5 x 10^{-2}, 0.3)
Urban wholesalers	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})
Retailers	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})
Food services	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})
Consumers	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(5 x 10^{-2}, 0.3)	U(10^{-3}, 5 x 10^{-2})

* *U(10^{-3}, 5 x 10^{-2}) should be read as the value is distributed uniformly between 0.001 and 0.05*

It should be noted that the risk assessment is based on a national perspective, therefore the ranges shown in Table 41 reflect the 'average' ranges for all of Australia. However, it is acknowledged that there are some districts (for example, apple growing areas) where a higher number of apple trees are in close proximity to a particular utility point.

Commercial fruit crops near utility points

The only commercial fruit crop susceptible to apple leafcurling midge is apple (*Malus* x *domestica*).

The proportion of **orchard wholesalers** near **commercial fruit crops**: 1

- All orchard wholesalers would be in proximity of commercial fruit crops.
- A stakeholder has raised the scenario of a citrus orchard wholesaler repackaging New Zealand apples during the 'off' season to provide for continuity of operation. In such a situation, the orchard wholesaler would not be surrounded by susceptible apple plants and the suggested rating would be 'high' [Uniform (0.7, 1)] instead of 'certain' [1]. The 'high' rating has also been suggested by another stakeholder. However, in discussions with industry experts it was not considered feasible or even likely that citrus orchard wholesalers would repack apples during the 'off' season. Therefore, a rating of 1 applies.

The proportion of **urban wholesalers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are generally located in metropolitan areas and commercial fruit crops are not grown within urban areas.
- Some urban wholesalers may be located within apple production regions, but the distance to these crops may be too far for the apple leafcurling midge to fly.

The proportion of **retailers** near **commercial fruit crops**: Uniform (10^{-3}, 5 x 10^{-2})

- Some retailers (up to 5%) and their waste could be located near commercial fruit crops.

The proportion of **food services** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Major food services are extremely unlikely to be located near commercial fruit crops.

The proportion of **consumers** near **commercial fruit crops**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of the Australian population is estimated to be located near commercial fruit crops. The majority of the population is located in metropolitan areas.

Nursery plants near utility points

Possible host nursery plants only include apple (*Malus* spp. including crab-apples).

The proportion of **orchard wholesalers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Some orchardists may raise their own nursery plants or run a parallel wholesale business. Also, pome fruit nurseries may be located near orchards.

The proportion of **urban wholesalers** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are located in metropolitan areas and some may be close to garden centres selling nursery plants. Apples could be kept temporarily in proximity to garden centres when apple plants have actively growing leaves.

The proportion of **retailers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of major retail outlets may sell apple trees as nursery plants.

The proportion of **food services** near **nursery plants** Uniform (10^{-6}, 10^{-3})

- Major food services are unlikely to be located near nursery plants.

The proportion of **consumers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of consumers may come in proximity to nursery plants susceptible to apple leafcurling midge. This is likely to be only for brief periods but is more likely to occur when apples have actively growing leaves.

Household and garden plants near utility points

The only common household and garden plants able to act as a susceptible hosts is apple (*Malus* spp.).

The proportion of **orchard wholesalers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesalers and their waste disposal sites are located in an isolated area within the orchard premises, but some household and garden plants may be near them.

The proportion of **urban wholesalers** near **household and garden plants**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are mostly located in industrial areas. Household and garden apple plants are unlikely to be near these sites because residential properties would be located away from them.

The proportion of **retailers** near **household and garden plants**: Uniform (10^{-6}, 10^{-3})

- The majority of retailers are located in larger cities.
- Some residential properties with apples trees would be located near retail outlets.

The proportion of **food services** near **household and garden plants**: Uniform (10^{-6}, 10^{-3})

- Major food service industries are located in cities, not near residential areas and their waste is disposed to landfill sites.
- Some restaurants may have a few apple trees within their premises.

The proportion of **consumers** near **household and garden plants**: Uniform (5 x 10^{-2}, 0.3)

- A small proportion of metropolitan and suburban consumers may have apple trees as household and garden plants.
- A stakeholder contends that the proportion of consumers located near household and garden apple plants should be rated as ‘high’ [Uniform (0.7, 1)]. After consideration of this comment it is still considered reasonable to rate the proximity of consumers to household and garden plants as being Uniform (5 x 10^{-2}, 0.3). This indicates that up to 30% of households consuming purchased apples will have an apple or crab-apple tree in their own or neighbouring backyards.

Wild and amenity plants near utility points

Host plants of apple leafcurling midge in this category only include apples and crab-apples (*Malus* spp.).

The proportion of **orchard wholesalers** near **wild and amenity plants**: Uniform (5 x 10^{-2}, 0.3)

- Some amenity plants other than commercial crops may be present in the orchard area.
- Well managed orchard wholesalers in most cases will not allow feral plants and volunteer apple seedlings to grow in close proximity to these premises.
- A stakeholder suggested that the proportion of orchard wholesalers located near wild and amenity plants should also be rated as ‘high’ [Uniform (0.7, 1)] rather than ‘very low’ [Uniform (10^{-3}, 5 x 10^{-2})], as in the *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004). After consideration of this comment, the proportion of orchard wholesalers near susceptible wild and amenity plants has been

reassessed as Uniform (5 x 10^{-2}, 0.3). This is partly based on a case study reported by Primary Industries and Resources South Australia in the Adelaide Hills, where over 1300 feral, roadside and derelict orchard apple trees were found within a 1km radius of two managed apple orchards (Creeper et al., 2005). The range 5 x 10^{-2}, 0.3 allows for the situation as well as areas where there are no abandoned apple orchards.

The proportion of **urban wholesalers** near **wild and amenity plants**: Uniform (10^{-6}, 10^{-3})

- Susceptible hosts may grow in the wild near these sites as a result of seed dispersal by birds (for example, crab-apple trees and apple seedlings).

The proportion of **retailers** near **wild and amenity plants**: Uniform (10^{-6}, 10^{-3})

- Retailer waste would be disposed of in landfills. Apple trees may grow in the wild near these sites as a consequence of seed dispersal by birds.

The proportion of **food services** near **wild and amenity plants**: Uniform (10^{-6}, 10^{-3})

- Apple seedlings originating from seeds dispersed by birds or discarded fruit may be present.

The proportion of **consumers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Apple trees may grow from seeds in the wild near these sites as result of dispersal by birds and consumers.
- This is likely to occur near parks, gardens, recreation sites and along roadsides. Usually the density of host plants near these sites would be very low.

Transfer to hosts

The insect stage of apple leafcurling midge associated with apple fruit is mature larva or pupa in a cocoon, and most contaminated fruit have only one larva or single cocoon attached. The only means through which apple leafcurling midge is able to leave fruit or packaging and enter the environment surrounding the utility points is adult flight. If mature larvae or pupae survive cold storage or controlled atmosphere storage, adults would need to emerge from the pupal stage after the apples have been taken out of storage. They could emerge wherever the cold chain is broken, such as at unpacking and repacking facilities or retailers and during the transportation of purchased apples from retailers to households.

The adult lifespan of both sexes ranges from 2 to 6 days under laboratory conditions. Field observations indicate adults only live for a few days in the wild. Both the adult male and female have wings and are able to fly. Maximum flight activity has been observed under warm, calm conditions, although small numbers have been seen on the wing even when the weather is cool, overcast, and windy. Recent research on the response of apple leafcurling midge to apple midge sex pheromone has shown that ‘significant numbers of (male) midges were caught at all distances up to 50m and greater distances were not investigated’; however, ‘numbers caught at 50m were still significant (several per day)’ and ‘no experiments on the distances females can fly’ have been attempted (Cross, 2005). Nevertheless, some researchers consider apple leafcurling midge strong fliers able to disperse well with the wind.

Apple leafcurling midge reproduces sexually. A successful transfer of apple leafcurling midge from infested/infected fruit to a host means that an emerged female would need to attract a male with which to mate, and then lay her eggs on a susceptible host plant during the two to six days of her adult lifespan. A sufficient number of eggs would need to survive and hatch in order for successful transfer to occur. Estimation of the number of infested fruit arriving at each utility point by exposure group combination

Stakeholders provided varying views on how imported apples might be distributed. Some stakeholders suggested that a large proportion of apples would come in as bulk produce and be sent to orchard packing houses for regrading and repacking, while other stakeholders suggested that apples would be packed in market ready boxes and sent directly to urban wholesalers for distribution. Two possible scenarios were considered in detail as follows.

One scenario was estimated with a (0.1% –5%) of imported apples being distributed to orchard packing houses and the remainder (95% to 99.9%) being distributed to urban wholesalers. The other scenario was estimated with (70%–100%) of imported apples being distributed to orchard packing houses and the remainder (0 to 30%) being distributed to urban wholesalers. Estimates of the number of infested fruit were calculated by running a series of simulations. The distribution of the indicative numbers of infested apples arriving at each utility point was evaluated using results of importation and the apple utilisation proportions described in the section 'Method for Import Risk Analysis'. The following assumptions were used:

- most apple imports will arrive over a six-month period from March to August (other periods ranging from 1 week to 52 weeks were also run – data not shown)
- the number of orchard wholesalers that might process imported fruit is seven (it should be noted that there may be more than seven orchard wholesalers throughout Australia but only seven were assumed to repack imported fruit)
- the number of urban wholesalers that might process imported fruit is six. (It should be noted that there may be more than six urban wholesalers throughout Australia but only a limited number would be likely to repack imported fruit)
- the number of retail outlets is 5000 (IBISWorld, 2004; IBISWorld, 2005)
- the number of food service outlets is 5000. There are over 60,000 food service outlets in Australia although not all would serve apples (ABS, 2001)
- the number of households where apples are consumed is estimated to be 6 million. This figure is based on an estimated 7.4 million households in Australia (ABS, 2004) and percentages of households purchasing fruit are estimated as being 77 % in summer and 92 % in winter (HAL, 2004).

The analysis assumed that imported apples will be evenly distributed among the six urban wholesalers. However, it is possible that two of the major urban wholesalers may together take up to 50% of the imported apples. Similar situations could apply to orchard wholesalers retailers and food service industries. This possibility and other scenarios were analysed but in the interests of simplicity only the data based on the assumptions shown above are presented.

Table 42 and Table 43 show the estimated number of infested fruit per week distributed to individual utility points. Data on the mean, midpoint and two percentiles (5th and 95th) are presented based on the original estimates of importation in Table 42 and the August 2005 data for importation in Table 43. The tables show the scenario with a higher proportion of apples sent either to orchard wholesale and the urban wholesaler. Also shown within the brackets is the number of individual utility points that are considered to be in proximity to exposure groups based on the estimates provided in Table 41 above.

Table 42 Weekly indicative estimates of apple leafcurling midge infested apples per utility point (based on 26 weeks of trade[31]) from published data

UTILITY POINTS	PREDICTED NUMBER OF INFESTED FRUIT TO UTILITY POINTS[32] (predicted number of utility points near exposure groups)															
	Commercial fruit crops				Nursery plants				Household and garden plants				Wild and amenity plants			
	5th	Median	95th	**Mean**	5th	Median	95th	**Mean**	5th	Median	95th	**Mean**	5th	Median	95th	**Mean**
**Orchard wholesalers	137 (7) 17167 (7)	1233 (7) 41104 (7)	3015 (7) 75549 (7)	1236 (7) 41139 (7)	137 (<1) 17167 (<1)	1233 (<1) 41104 (<1)	3015 (<1) 75549 (<1)	1236 (<1) 41139 (<1)	137 (<1) 17167 (<1)	1233 (<1) 41104 (<1)	3015 (<1) 75549 (<1)	1236 (<1) 41139 (<1)	137 (<1) 17167 (<1)	1233 (1) 41104 (1)	3015 (2) 75549 (2)	1236 (1) 41139 (1)
**Urban wholesalers	23485 (<1) 709 (<1)	54979 (<1) 8463 (<1)	99022 (<1) 20765 (<1)	55003 (<1) 8450 (<1)	23485 (<1) 709 (<1)	54979 (<1) 8463 (<1)	99022 (<1) 20765 (<1)	55003 (<1) 8450 (<1)	23485 (<1) 709 (<1)	54979 (<1) 8463 (<1)	99022 (<1) 20765 (<1)	55003 (<1) 8450 (<1)	23485 (<1) 709 (<1)	54979 (<1) 8463 (<1)	99022 (<1) 20765 (<1)	55003 (<1) 8450 (<1)
Retailers	28 (17)	66 (128)	119 (238)	66 (128)	28 (17)	66 (128)	119 (238)	66 (128)	28 (<1)	66 (3)	119 (5)	66 (3)	28 (<1)	66 (3)	119 (5)	66 (3)
Food services	<1 (<1)	2 (3)	4(5)	2 (3)	<1 (<1)	2 (3)	4(5)	2 (3)	<1 (<1)	2 (3)	4(5)	2 (3)	<1 (<1)	2 (3)	4(5)	2 (3)
Consumers	<1 (20699)	<1 (153000)	<1 (285299)	<1 (153000)	<1 (20697)	<1 (153000)	<1 (285297)	<1 (153000)	<1 (374987)	<1 (1.1×10^6)	<1 (1.7×10^6)	<1 (1.1×10^6)	<1 (20697)	<1 (153000)	<1 (285300)	<1 (153000)

NOTE 150(7) should be read as 150 infested apples arriving on a weekly basis at 7 places which have susceptible host plants nearby

4429 (<1) should be read as 4429 infested apples arriving on a weekly basis at less than one place which has susceptible host plants nearby

<1 (1530000) should be read as less than one infested apple arriving on a weekly basis at 1,530,000 places that have susceptible host plants nearby

*** In each box, the top set of numbers is based on P1 = Uniform (10^{-3}, 5×10^{-2}) and the lower set is based on P1 = Uniform (0.7, 1)*

[31] other intervals were considered, including 52 weeks and one week periods of trade
[32] Actual numbers vary slightly in different simulation runs

Table 43 Weekly indicative estimates of apple leafcurling midge infested apples per utility point (based on 26 weeks of trade[33]) from August 2005 data

PREDICTED NUMBER OF INFESTED FRUIT TO UTILITY POINTS

(predicted number of utility point near exposure groups)

UTILITY POINTS	Commercial fruit crops				Nursery plants				Household and garden plants				Wild and amenity plants			
	5th	Median	95th	Mean	5th	Median	95th	Mean	5th	Median	95th	Mean	5th	Median	95th	Mean
**Orchard wholesalers	7 (7) 945 (7)	62 (7) 2058 (7)	149 (7) 3746 (7)	62 (7) 2058 (7)	7 (<1) 945 (<1)	62 (<1) 2058 (<1)	149 (<1) 3746 (<1)	62 (<1) 2058 (<1)	7 (<1) 945 (<1)	62 (<1) 2058 (<1)	149 (<1) 3746 (<1)	62 (<1) 2058 (<1)	7 (<1) 945 (<1)	62 (1) 2058 (1)	149 (2) 3746 (2)	62 (1) 2058 (1)
**Urban wholesalers	1299 (<1) 36 (<1)	2752 (<1) 424 (<1)	4918 (<1) 1028 (<1)	2752 (<1) 423 (<1)	1299 (<1) 36 (<1)	2752 (<1) 424 (<1)	4918 (<1) 1028 (<1)	2752 (<1) 423 (<1)	1299 (<1) 36 (<1)	2752 (<1) 424 (<1)	4918 (<1) 1028 (<1)	2752 (<1) 423 (<1)	1299 (<1) 36 (<1)	2752 (<1) 424 (<1)	4918 (<1) 1028 (<1)	2752 (<1) 423 (<1)
Retailers	2 (17)	3 (128)	6 (238)	3 (128)	2 (17)	3 (128)	6 (238)	3 (128)	2 (<1)	3 (3)	6 (5)	3 (3)	2 (<1)	3 (3)	6 (5)	3 (3)
Food services	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)
Consumers	<1 (20698)	<1 (153000)	<1 (285299)	<1 (153000)	<1 (20699)	<1 (153000)	<1 (285299)	<1 (153000)	<1 (374988)	<1 ($1.1x10^6$)	<1 ($1.7x10^6$)	<1 ($1.1x10^6$)	<1 (20697)	<1 (153000)	<1 (285298)	<1 (153000)

*** In each box, the top set of numbers is based on P1 = Uniform (10^{-3}, 5 x 10^{-2}) and the lower set is based on P1 = Uniform (0.7, 1)*

[33] other intervals were considered, including 52 weeks and one week periods of trade

Establishment

Establishment is defined in ISPM No.11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment, the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of that pest in the PRA area from the first colonising generation.

In this sub-section information for establishment is formally presented against the factors listed in ISPM No.11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).

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

Apple trees (including crab-apples) are the only host of apple leafcurling midge.

No apple cultivar has been found that is not susceptible to infestation (CABI, 2002; Todd, 1959; Tomkins, 1998).

Apples are grown in all States and Territories in Australia except in the northern tropical regions, and are also found in suburban backyards in temperate Australia.

Feral and roadside apple trees as well as derelict and abandoned apple orchards would provide a breeding ground for susceptible hosts for apple leafcurling midge.

The number of available healthy shoots has a major impact on the success of each generation. The surge of new leaf growth in early summer is particularly suitable for rapid population increase in the second and third generations, while the cessation of leaf growth in mid- to late-summer often helps to reduce late season populations. This effect is most pronounced in dry seasons and regions.

Suitability of the environment

Apple leafcurling midge is found in northern Europe, north east and north west North America and New Zealand where environmental conditions are similar to apple growing regions in Australia.

Apples are not normally grown in protected environments such as in glasshouses.

The potential for adaptation of the pest

It was thought that apple leafcurling midge increased its pest status in New Zealand in the 1990s because of resistance to chemicals (organophosphorus insecticides such as azinphos-methyl) used for its control. However, tests showed that this was not the case, and there are no reports of apple leafcurling midge in New Zealand developing resistance to insecticides (HortResearch, 1999b; Chapman and Evans, 1995).

Azinphos-methyl was used for the test because it had been used in New Zealand's apple orchards longer than any other organophosphate insecticide. As apple leafcurling midge had not developed resistance to azinphos-methyl, the species was considered not likely to have developed resistance to any other organophosphate insecticides.

The reproductive strategy of the pest

Apple leafcurling midge only reproduces sexually.

Successful mating between males and females must occur within the limited 2–6 day life of the adult.

Males are not usually attracted to mated females, including those mated just 1–2 hours previously.

Females mate once or rarely twice, whereas males mate many times, some on average 11 times in 30 minutes (HortResearch, 1999b).

Males emerge from their pupae earlier than females, peak male emergence occurring 1–2.5 hours before peak female emergence (Harris et al., 1996).

Apple leafcurling midge has up to seven generations over summer under wet summer conditions typical of the Waikato region (MAFNZ, 2004).

In the primary fruit producing districts of Hawke's Bay and Nelson respectively there are 3–4 and 4–5 generations of apple leafcurling midge, depending on summer rainfall (MAFNZ, 2004).

Apple leafcurling midge survives the winter in New Zealand by overwintering as a cocooned larva (Tomkins, 1998). It aestivates to protect itself from unfavourable circumstances in areas with low summer (December–February) rainfall (MAFNZ, 2004).

Minimum population needed for establishment

The mated female lays several eggs on each leaf, with each female laying up to 200 eggs over about three days (CABI, 2002). A population can be started from a small group of viable eggs.

Cultural practices and control measures

Apple leafcurling midge is partially controlled in New Zealand by a parasitic wasp, *Platygaster demades* (Walker), an introduced biological control agent (Todd, 1959; Tomkins et al., 2000). This parasitoid is not present in Australia (Evenhuis, 1989).

Some natural enemies of apple leafcurling midge present in New Zealand, such as the European or common earwig (*Forficula auricularia*), the mirid (*Sejanus albisignata*) and the whirligig mite (*Anystis baccarum*) are also present in Australia.

Spread

Spread is defined as the 'expansion of the geographical distribution of a pest within an area' ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

In this sub-section information for spread is formally presented against the factors listed in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).

Suitability of natural and/or managed environment

Apple leafcurling midge has spread all over New Zealand since its accidental introduction in about 1950. There are similar environments in Australia that would be suitable for its spread.

Presence of natural barriers

The main Australian commercial apple orchards are in six states of Australia with natural barriers including arid areas, climatic differentials and long geographic distances between these areas. It would be difficult for the adults to disperse from one area to another unaided.

However, apple leafcurling midge has some characteristics that assist in its short-range dispersal. Apple host plants are also available between the commercial apple orchards in different areas or states, and this would help the spread of apple leafcurling midge.

Apple leafcurling midge does not require a vector for its dispersal.

Both the adult male and female are winged and are capable of flight.

Pre-egg-laying flights and colonisation of host plants by females, as well as location of females by males accounts for much of the midge’s short-range dispersal.

Male dispersal is strongly affected by the location of females.

Mated females have been observed to fly for up to an hour around actively growing shoot tips on adjacent trees before landing on foliage and laying their first egg. Flights between egg-laying may last for 15 minutes.

The females are attracted by odours from apple foliage, particularly young foliage.

Potential for movement with commodities or conveyances

A mixture of adult flight and the transportation of infested apple trees have probably enabled the long-distance movement of apple leafcurling midge in New Zealand.

The most probable means of apple leafcurling midge dispersal would be as cocooned larvae, either in soil or associated with nursery plants (Berry and Walker, 1989). Midges could readily be associated with nursery trees being despatched for planting in winter, because nursery trees are a favoured overwintering site.

Existing interstate quarantine control on the movement of nursery stock would reduce the scope for spread of apple leafcurling midge.

A stakeholder contends that apple leafcurling midge ‘flight cannot be associated with long-distance movement; only distances of less than 50 metres are recognised.’ However, communication with Jerry Cross (Cross, 2005) at East Malling Research, Kent, UK on their research on the response of apple leafcurling midge to apple midge sex pheromone has shown that ‘significant numbers of (male) midges were caught at all distances up to 50m and greater distances were not investigated’; however, ‘numbers caught at 50m were still significant (several per day)’. It should also be noted that ‘no experiments on the distances females can fly’ have been attempted.

Intended use of the commodity

Apples would be used mostly for consumption by humans, and be widely distributed throughout Australia.

If larvae or pupae have contaminated the fruit, they will be distributed with the commodity around the country.

Potential vectors of the pest

Apple leafcurling midge does not require a vector for its spread because it is capable of independent flight.

Potential natural enemies

The parasitic wasp *Platygaster demades* (Walker), used as a biological control organism for apple leafcurling midge in New Zealand, is not present in Australia (Evenhuis, 1989).

Other natural enemies in the PRA area, especially generalist predators, may be able to attack apple leafcurling midge but there is no evidence that these would be effective.

A stakeholder has suggested that the rating for partial probability of spread for wild and amenity plants has been underestimated and should be raised to ‘moderate’ [Uniform (0.3, 0.7)] from the original rating of ‘low’ [Uniform (5×10^{-2}, 0.3)]. Another stakeholder states that the partial probability of spread for all exposure groups should be rated as ‘high’ [Uniform (0.7, 1)] because of apple leafcurling midge’s propensity for rapid spread. These comments have been considered in light of the changed methodology for insect pests as explained in the method section.

Partial probability of entry, establishment and spread

The estimations of the partial probability of entry, establishment and spread are provided in Table 44 and for the August 2005 data in Table 45 below. These estimates are based on expert opinion taking into account the sequence of events for successful transfer of the pest to a susceptible host, the estimated numbers of infested apples at each utility point, the availability and susceptibility of hosts at each utility point, information relevant to establishment and spread of the pest and all relevant information provided by stakeholders. A summary of the evidence to support these likelihoods for each of the utility points and exposure groups is discussed after the tables. This summary draws on information presented elsewhere in this section and is relevant to both sets of data.

Table 44 The partial probabilities of entry, establishment and spread of apple leafcurling midge on susceptible host plants from infested apples at different utility points (based on the expected trade of apples in a year)

UTILITY POINTS	LIKELIHOOD OF ENTRY, ESTABLISHMENT AND SPREAD			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	U(0.5, 0.9)†	U(10^{-6}, 5 x 10^{-2})	U(10^{-6}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Urban wholesalers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Retailers	U(10^{-3}, 10^{-2})	U(10^{-3}, 10^{-2})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})
Food services	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Consumers	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})	U(0, 10^{-6})

† U(0.5, 0.9) should be read as the likelihood is distributed uniformly between 0.5 and 0.9

Table 45 The August 2005 data[34] partial probabilities of entry, establishment and spread of apple leafcurling midge on susceptible host plants from infested apples at different utility points (based on the expected trade of apples in a year)

UTILITY POINTS	LIKELIHOOD OF ENTRY, ESTABLISHMENT AND SPREAD			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	U(0.3, 0.7)†	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 10^{-3})
Urban wholesalers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Retailers	U(10^{-3}, 10^{-2})	U(10^{-3}, 10^{-2})	U(0, 10^{-6})	U(0, 10^{-6})
Food services	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Consumers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})

† U (0.3, 0.7) should be read as the likelihood is distributed uniformly between 0.3 and 0.7

Several issues are relevant to all likelihoods presented in Table 44 and in Table 45. Specific issues are discussed under individual utility points following the discussion below.

It would be very difficult to predict precisely when the majority of New Zealand apples would be imported if trade starts. However, it has been suggested that most apple imports would be from late summer to winter (March to August). The assessments provided in the above tables were mainly based on the assumption that most imported apples will arrive in Australia over a half year period as suggested above. There is a possibility that the majority of New Zealand apple fruit could arrive over a very short period such as a couple of months or a longer period such as a whole year. The ratings presented in Table 44 and Table 45 allow for these possibilities.

Successful transfer of apple leafcurling midge to a susceptible host would depend on several insects escaping from a utility point. It would also depend on the cool chain being broken to allow any mature pupae to emerge as adults

Apple leafcurling midges reproduce sexually. Successful mating between males and females must occur within the limited 2–6 day life of the adult. The mated female lays several eggs on each leaf, with each female laying up to 200 eggs over about three days (CABI, 2002). A population can be started from a small group of viable eggs. Apple leafcurling midge prefers to lay its eggs on actively growing apple shoots. The period of availability of actively growing apple shoots is mainly limited to spring and early summer. Actively grown apples shoots are not available in Australia during the New Zealand export season of late summer to winter. However, apple leafcurling midge has up to seven generations over summer under wet summer conditions typical of the Waikato region. In the primary fruit producing districts of Hawke's Bay and Nelson there are 3–4 and 4–5 generations of ACLM respectively, depending on summer rainfall.

[34] Data in this table relate to a probability of importation with a triangular distribution minimum value of 10^{-3}, most likely value of 1.3×10^{-3} and maximum value of 3.8×10^{-3}.

The fact that apple leafcurling midge has multiple generations would imply that the midge may also be able to lay its eggs on leaves other than actively growing apple leaf shoots. The number of available healthy shoots has a major impact on the success of each generation. The surge of new leaf growth in early summer is particularly suitable for rapid population increase in the second and third generations, while the cessation of leaf growth in mid- to late-summer often helps to reduce late season populations. This effect is most pronounced in dry seasons and regions.

Apple leafcurling midge survive the winter in New Zealand by overwintering as cocooned larvae (Tomkins, 1998)

Apple leafcurling midge is partially controlled in New Zealand by a parasitic wasp, *Platygaster demades* (Walker), an introduced biological control agent (Todd, 1959; Tomkins et al., 2000). This parasitoid is not present in Australia (Evenhuis, 1989). However, some natural enemies of apple leafcurling midge present in New Zealand, such as the European or common earwig (*Forficula auricularia*), the mirid (*Sejanus albisignata*) and the whirligig mite (*Anystis baccarum*) are also present in Australia.

Probability of entry, establishment and spread – Orchard wholesalers

Apple trees are available around orchard wholesalers as commercial fruit crops, may be available as wild and amenity plants, but may not be available as nursery plants or household and garden plants.

Table 42 and Table 43 show that significant numbers of apple leafcurling midge could be distributed to orchard wholesalers near to commercial fruit crops on a weekly basis and therefore there is a greater chance of at least a male and female emerging together and successfully mating and this could be sufficient to initiate a sustainable population.

The partial probabilities of entry, establishment and spread for orchard wholesalers and each of the four exposure group combinations are provided in Table 44 for the original data and for later data in Table 45.

As indicated in the tables, the partial probability of entry, establishment and spread was rated highest for commercial fruit crops. This is because of the evidence that commercial fruit crops (apples) are available and in close proximity to all seven orchard wholesalers and thus higher number of susceptible host plants and higher number of available healthy shoots would be present. The likelihood would be towards the lower end of the assessment if the infested apples arrive at this utility point when there are no actively growing shoots available. The likelihood for wild and amenity plants was rated lower because of the lower number of orchard wholesalers near this exposure group. The likelihood for nursery and household and garden plants was rated with a lower minimum value because of the small number of orchards wholesalers near these exposure groups.

Probability of entry, establishment and spread – Urban wholesalers

Table 42 and Table 43 show that the indicative number of infested apples sent to urban wholesalers per week was significantly large. However, the tables also show that apple trees would not be available around urban wholesalers as commercial fruit crops, household and garden plants, nursery plants, or wild and amenity plants in sufficient numbers for a entry, establishment and spread event to occur.

The partial probabilities of entry, establishment and spread for urban wholesalers and each of the four exposure groups combinations in Table 44 for the original data and for later data in Table 45.

Probability of entry, establishment and spread – Retailers

Most retailers are located in urban areas. Apple trees are generally not available as commercial fruit crops around retailers (although some retailers, for example, the ones in the Goulburn Valley or Batlow could be near commercial fruit crops), and as nursery plants (although apple seedlings can be sold in some major retail outlets during the spring period), and may not be available as household and garden plants, or wild and amenity plants.

In retail outlets apples are displayed at ambient temperature resulting in the cool chain being broken, allowing any mature pupae to emerge as adults. In this situation, most emerged insects would be trapped indoors and need to escape into the surrounding environment before they could successfully find a mate and locate a susceptible host plant.

The partial probabilities of entry, establishment and spread for retailers and each of the four exposure group combinations are in Table 44 for the original data and for later data in Table 45. These likelihoods were assessed as higher than those for urban wholesalers, food services, and consumers but lower than those for orchard wholesalers. This was because only small numbers of apple leafcurling midge would be distributed to each of the retailers on a weekly basis (Table 42 and Table 43). The ratings for commercial fruit crops and nursery plants were slightly higher than those for household and garden plants or wild and amenity plants to take into account the retailers located in commercial fruit crop areas and apple seedlings that could be sold in retailers. There is a possibility that the majority of the infested fruit could all arrive at a few retail outlets rather than be evenly spread among all the Australian retail outlets over an extended period of time. In this case there would be a greater chance for adults to emerge together and successfully mate.

Probability of entry, establishment and spread – Food services

Most food services are in urban areas. Apple trees are generally not available around food services as commercial fruit crops, nursery plants, household and garden plants, or wild and amenity plants.

Table 42 and Table 43 show that the indicative number of infested apples per week was predicted to be significantly lower at this utility point. Therefore there is little chance of at least a male and female emerging together and successfully mating to initiate a sustainable population.

The partial probabilities of entry, establishment and spread for food services and each of the four exposure group combinations are provided in Table 44 for the original data and for later data in Table 45.

Probability of entry, establishment and spread – Consumers

Most consumers live in urban areas. Although apple trees could be available around consumers as household and garden plants, wild and amenity plants, commercial fruit crops and nursery plants. Table 42 and Table 43 show the indicative number of infested apples per week was predicted to be very small for each consumer.

The partial probabilities of entry, establishment and spread for consumers and each of the four exposure group combinations are in Table 44 for the original data and for later data in Table 45. The likelihood for consumers and household and garden plants combination was assessed as slightly higher because it was considered that consumers were in closer proximity to backyard garden plants than to other exposure groups.

Consumers usually purchase small quantities of apples, which are transported home under ambient temperatures. Some of this purchased fruit is usually kept under refrigeration until consumed, when the fruit will again warm to ambient temperature, resulting in the cool chain being broken and allowing any mature pupae to emerge as adults. Because of the small number of fruit involved, there is little chance for a male and female emerging together and successfully mating. There is a possibility that a consumer could purchase all of their fruit from an infested consignment. In this case there would be a greater chance for adults to emerge together and successfully mate.

Conclusion – probability of entry, establishment and spread

Estimates of the partial probabilities of entry, establishment and spread for each of the utility points and susceptible host plants were combined using the equation given in the method section, to give a combined annual probability of entry, establishment and spread as shown in Table 46.

Table 46 Unrestricted probability of entry, establishment and spread based on the published data[35]

Percentile	Probability of entry, establishment and spread	Qualitative description
5th percentile	0.56	Moderate
Median	0.73	High
95th percentile	0.89	High

Table 46 shows that distribution of probability of entry, establishment and spread estimated for the original data for the 5th percentile was within the qualitative likelihood interval of '**moderate'** and the 50th to the 95th percentiles were within the qualitative likelihood interval of '**high'**. Therefore, the overall unrestricted probability of entry, establishment and spread for the original data was assessed to be '**high'** for apple leafcurling midge.

Table 47 shows that the distribution of the probability of entry, establishment and spread estimated for the later data for the 5th to the 95th percentiles were all within the qualitative likelihood interval of '**moderate'**.

Table 47 Unrestricted probability of entry, establishment and spread based on the August 2005 data [36] [37]

Percentile	Probability of entry, establishment and spread	Qualitative description
5th percentile	0.33	Moderate
Median	0.51	Moderate
95th percentile	0.68	Moderate

35 calculated by @RISK using published data
36 The August 2005 data values relate to a probability of importation with a triangular distribution minimum value of 10^{-3}, most likely value of 1.3×10^{-3} and maximum value of 3.8×10^{-3}
37 calculated by @RISK using August 2005 data

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are shown in Table 48. Available supporting evidence is provided in the text below.

Table 48 Impact scores for apple leafcurling midge

Direct impact	Impact scores
Plant life or health	D
Human life or health	A
Any other aspects of the environment	A
Indirect impact	
Control or eradication	D
Domestic trade or industry	D
International trade	D
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are unlikely to be discernable at the national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Smith and Chapman (1995) conducted a survey of 30 apple orchards in the Nelson area in order to rank the most important arthropod pest and measure perceptions of the relative importance of apple leafcurling midge. The results indicted that 33% of growers ranked apple leafcurling midge alone, 17% ranked apple leafcurling midge and mites together, and 17% ranked apple leafcurling midge, leafroller and mites altogether as being the most serious arthropod pests, with the perception of 63% of the growers being that apple leafcurling midge adversely affects plant health.

Apple leafcurling midge is a specialist herbivore restricted to apple trees. It affects crown formation of young apple trees in the first stages of development, but mature trees are able to tolerate normal population levels. Damage to young leaves would provide opportunities for entry of plant pathogens.

Apple leafcurling midge spread rapidly in New Zealand after its introduction. Surveys of Apple leafcurling midge have shown it is a serious pest in most apple growing regions of New Zealand (Smith and Chapman, 1995; Tomkins et al., 1994). Smith and Chapman (1997) and Wilton (1994) report large increases in populations.

Apple leafcurling midge is capable of 4–7 overlapping generations in a growing season, resulting in rapid population build up.

A stakeholder's submission rates this impact as **'F',** implying that apple leafcurling midge will cause significant consequences to plant life or health at the national level, that is, this impact would threaten the economic viability of the nation. This is clearly not the case in New

Zealand where apple leafcurling midge has been introduced; however, it is accepted apple leafcurling midge could have a highly significant impact at a local level, with this already accommodated in the current rating of '**D**'.

On the other hand, another stakeholder claims that the current rating of '**D**' is excessive, suggesting that it should be reduced to '**B**' at most. However, Smith and Chapman (1995) have reported that 33% of growers in the Nelson area rank apple leafcurling midge as the most serious arthropod pest which would imply that apple leafcurling midge is highly significant at the local level, suggesting that this impact score of '**D**' is appropriate.

Human life or health – A

There are no known direct impacts of apple leafcurling midge on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There are no known direct impacts of apple leafcurling midge on any other aspects of the environment, and the rating assigned to this criterion was therefore '**A**'.

Indirect impact

Control or eradication – D

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies is unlikely to be discernable at a national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Indirect consequences of the eradication or control as a result of the introduction of apple leafcurling midge may be:

- an increase in the use of insecticides for control of apple leafcurling midge because of difficulties involved in estimating optimum times for insecticide application
- disruption to integrated pest management (IPM) programs because of the need to re-introduce or increase the use of organophosphate insecticides
- increases in control measures and impacts on existing production practices, as well as IPM/IFP programs already in place
- subsequent increases in costs of production to producers
- increased costs for crop monitoring and consultative advice to producers.

A stakeholder's submission rates this indirect impact as '**E**', implying an impact of minor significance at a national level and a significant impact at the regional level.

Another stakeholder considers that a rating of '**C**' is more appropriate. However, the IRA team decided to maintain the rating as '**D**' – minor significance at a regional level but unlikely to be discernible at the national level.

Domestic trade or industry – D

The indirect consequences on domestic trade are unlikely to be discernable at a national level and would be of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

The presence of apple leafcurling midge on commercial apple crops could result in:

- trade restrictions in the sale or movement of fruit within a district or region or between states
- fruit skin being distorted by bumps (Tomkins, 1998) caused by high populations of apple leafcurling midge affecting developing fruitlets

- consumer expectations and aesthetic considerations ranging from the acceptance of fruit that is slightly affected right through to outright rejection of imperfect fruit.

A stakeholder's submission rates this impact as being '**E**' while another stakeholder gives a rating of '**B**'. However, the IRA team decided to maintain the rating as '**D**' – minor impact at a regional level and highly significant impact at the local level.

International trade – D

The indirect consequences on international trade are unlikely to be discernable at a national level and would be of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

In the case of New Zealand, apple leafcurling 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 leafcurling midge became established in Australia, trading partners may reject consignments of apples infested with apple leafcurling midge.

A stakeholder gives this impact a rating of '**B**', citing that apple exports are a relatively small component of the Australian apple industry. However, the rejection of the consignment would have a highly significant impact at local level and this rating of '**D**' is considered to be appropriate.

Environment – B

The indirect consequences on the environment would not be discernible at a national level and would be of minor significance at the local level, and a rating of '**B**' was assigned to this criterion.

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 biocontrol agents could affect existing biological control programs.

The only hosts of apple leafcurling 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.

The indirect impact upon the environment has been assessed by a stakeholder as being '**A**', which indicates that the indirect impact on the environment would be unlikely to be discernible at the local level. However, as stated above, increased insecticide use and possible introduction of new biocontrol agents may have some impact on the environment.

Communities – B

The indirect consequences on communities would not be discernible at a national level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Two stakeholders rate this impact as '**C**', claiming that the indirect impact on communities would be significant at the local level. A significant impact is one that would threaten economic viability through a moderate increase in mortality/morbidity, or where a moderate decrease in production and effects may not be reversible. This has clearly not occurred in New Zealand or Ontario where apple leafcurling midge has been introduced, and after consideration of the stakeholder's comments it is considered realistic to reassess its impact on communities as being minor at a local level. Therefore a rating of '**B**' is considered more reasonable, since a minor impact is not expected to threaten economic viability, but would lead to a minor increase in mortality/morbidity or a minor decrease in production with the effects generally being reversible.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are rated '**D**', the overall consequences are considered to be 'low'. Therefore, the overall consequences of apple leafcurling midge are apple leafcurling midge rated as being '**low**'.

Unrestricted risk

Unrestricted annual risk is the result of combining the annual probability of entry, establishment and spread and the outcome of overall estimated consequences. Probabilities for entry, establishment and spread and associated consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for apple leafcurling midge is shown in Table 49.

Table 49 Unrestricted risk estimation for apple leafcurling midge

	Published data	August 2005 data
Probability of entry, establishment and spread[38]	High	Moderate
Consequences	Low	Low
Unrestricted annual risk	Low	Low

As indicated in Table 49, the unrestricted annual risk for apple leafcurling midge is 'low' which is above Australia's ALOP of 'very low'. Therefore, risk management would be required for this pest. The analysis of the later data shows that combining either a 'high' or 'moderate' probability of entry establishment and spread with a 'low' consequence will result in a 'low' risk. Therefore, risk management would be required for this pest even with the later data values provided by New Zealand.

Risk management for apple leafcurling midge

The risks associated with apple leafcurling midge were estimated to be above Australia's ALOP and therefore risk management is required. This section discusses possible risk management measures.

Inspection

In assessing this unrestricted risk, the effects of the standard AQIS 600-unit sampling and inspection protocols were not applied. This inspection protocol is used for a large range of exports with treatment only being applied if pests of quarantine concern are found. It represents one of the least trade restrictive approaches to managing the quarantine risks that may be associated with imports. The assessment of the restricted risk starts by first

[38] Calculated by @RISK.

considering the effect of a 600-unit inspection and any remedial action taken as a result of that inspection finding pests of quarantine concern.

Apple leafcurling midge pupae are highly visible, and if an infested apple was detected within the 600-unit inspection, the consignment would require remedial treatment. To test the efficacy of inspection and the subsequent fumigation and re-export/destruction of positively identified affected fruit consignments, a statistical analysis was conducted to modify the importation results. This analysis first considered the probability of infected fruit missing detection by the 600 unit sampling rate within lots/consignments of varying sizes based on the published data for apple leafcurling midge infestation levels. Fumigation was assumed to be 100% effective in killing the apple leafcurling midge present on fruit.

This analysis indicated that inspection of 600 fruit from each lot followed by treatment by fumigation of lots where apple leafcurling midge were found would be very effective in detecting apple leafcurling midge infestation rates at the level indicated by the published data. The analysis showed that the proportion of infested apples remaining infested after inspection followed by fumigation is 5.87×10^{-7} for a lot size of 20,000 apples. Variations in lot size made very little difference to these probabilities. This value was inserted into the model at Imp8 and the probability of importation recalculated and shown in Table 50.

Table 50 Recalculated probabilities of importation after inspection then fumigation with Imp8 = 5.87×10^{-7}

	Probability of importation
5th Percentile	1.4×10^{-8}
Mean	2.8×10^{-8}
95th percentile	4.3×10^{-8}

The reassessment of the probability of entry, establishment and spread after fumigation of an infested consignment is provided in Table 51 below. The likelihoods were assessed based on the sequence of events after fumigation for successful transfer of the pest to a susceptible host; the estimated numbers of infested apples at each utility point; the availability and susceptibility of hosts at each utility point; and any information relevant for establishment and spread of the pest.

Table 51 The partial probability of entry, establishment and spread of apple leafcurling midge on susceptible host plants from infested apples at different utility points after fumigation

UTILITY POINTS	LIKELIHOOD OF ENTRY, ESTABLISHMENT AND SPREAD			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Urban wholesalers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Retailers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Food services	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Consumers	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})

Estimates of the probabilities of entry, establishment and spread for each of the utility points and susceptible host plants were combined, using the equation given in the methodology section to give a combined annual probability of entry, establishment and spread as shown in Table 52.

Table 52 Combined restricted probability of entry, establishment and spread

Percentile	Probability of entry establishment and spread	Qualitative description
5th percentile	7.9 x10^{-6}	Extremely Low
Median	10^{-5}	Extremely Low
95th percentile	1.2 x 10^{-5}	Extremely Low

The table shows that the distribution from the 5th to the 95th percentile was within the qualitative likelihood interval of ‘extremely low’.

Therefore after risk mitigation measures have been applied, the restricted likelihood of entry, establishment and spread is ‘extremely low’.

When the probability of entry, establishment and spread was combined with the estimated consequences for apple leafcurling midge, the restricted risk for this pest was found to be ‘negligible’, which is within Australia’s ALOP. The restricted annual risk estimation for apple leafcurling midge is shown in Table 53.

Table 53 Restricted risk estimation for apple leafcurling midge

Probability of entry, establishment and spread	Extremely low
Consequences	Low
Restricted annual risk	Negligible

The analysis shown in Table 53 was based on the published set of data on the prevalence of apple leafcurling midge in New Zealand that resulted in a probability of importation of 4.1 x 10^{-2} (mean value). With an infestation rate of 4.1% apple leafcurling midge will be detected in practically every lot and therefore every lot will be fumigated. A 600 unit inspection is very effective in detecting lots carrying pests at this infestation rate. This combined with the high efficacy of a treatment results in a high degree of risk reduction. Clearly as the infestation rate decreases then the probability that a 600-unit inspection system will detect apple leafcurling midge in a lot decreases. Therefore some lots may not be treated but may still contain some apple leafcurling midge.

The efficacy of a 600 unit inspection/treatment system at different pest infestation rates was explored. It was found that the 'worst case' for the total number of apple leafcurling midge that would enter Australia undetected if a 600 fruit inspection/treatment system was used is with an infestation rate for apple fruit of about 0.17%. If the infestation rate was around 0.17% then inspection followed by treatment based on a 600 fruit sample would allow lots to pass without treatment resulting in a final importation rate for the total imports of around 0.06%. When placed in the model this importation rate was found to result in a restricted risk estimate that exceeded Australia's ALOP. This indicates that, at least for some infestation levels, an inspection/treatment system based on a 600 fruit sample may not be adequate to manage the risk for apple leafcurling midge.

This predicted 'worst case' prevalence of 0.17% falls into the range of the 'August 05 data' (0.1%–0.38%) on infestation provided by Pipfruit, New Zealand (ENZA, 2003). Table 49 shows that the unrestricted risk for infestation rates in this range would exceed Australia's ALOP. The relationship between sample sizes and the number of apple leafcurling midge that could be imported for infestation rates between 0.1% and 0.38% was explored. On the basis of this analysis it was concluded that a sample size of 3000 per lot was needed. With these infestation rates with a 3000 sample size the "worst case" infestation rate that could be present in imports after inspection and treatment was 0.005%. Table 54 and Table 55 show the recalculated probability of entry establishment and spread based on this infestation rate.

Table 54 The partial probability of entry, establishment and spread of apple leafcurling midge on susceptible host plants from infested apples at different utility points at 0.005% prevalence

UTILITY POINTS	LIKELIHOOD OF ENTRY, ESTABLISHMENT AND SPREAD			
	Commercial fruit crops	**Nursery plants**	**Household and garden plants**	**Wild and amenity plants**
Orchard wholesalers	$U(10^{-2}, 0.3)$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(10^{-6}, 10^{-3})$
Urban wholesalers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Retailers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Food services	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Consumers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$

Table 55 Combined restricted probability of entry, establishment and spread at 0.005% prevalence

Percentile	Probability of entry establishment and spread	Qualitative description
5th percentile	2.5×10^{-2}	Very Low
Median	0.16	Low
95th percentile	0.29	Low

Table 55 shows that the probability of entry, establishment and spread for the 5th percentile was 'very low' and the median was ‘low’ for the whole distribution. Therefore the restricted risk for this pest is 'very low', which is within Australia’s ALOP (Table 56).

Table 56 Restricted risk estimation for apple leafcurling midge at 0.005 % prevalence

Probability of entry, establishment and spread (median)	0.16 (Low)
Consequences	Low
Restricted annual risk	Very low

On the basis of this analysis the IRA team concluded that if infestation rates of export fruit were in the range of 0.1% to 0.38% then a 3000 fruit inspection would be effective in detecting apple leafcurling midge. Lots that failed this inspection would either need to be treated to kill apple leafcurling midge or withdrawn from export.

Mandatory treatment

An alternative to the inspection/treatment approach may be the routine use of a mandatory treatment such as fumigation to all export lots. This may be a less trade restrictive approach if the prevalence of apple leafcurling midge is such that most or all lots are likely to fail at inspection.

Pest free places of production and areas of low pest prevalence

An alternative risk management approach may be to source apples from orchards or blocks that are free of apple leafcurling midge. However, the insect is mobile and data available indicates that it is widespread in New Zealand and therefore measures based on orchard or export block freedom may not be feasible. These same issues would also suggest that the use of low pest prevalence may also not be feasible. However, alternative approaches to risk management could be considered further if New Zealand supplied detailed information on apple leafcurling midge prevalence.

Conclusion: risk management for apple leafcurling midge

On the basis of this analysis two risk management options have been identified:

1. Inspection of a random sample of 3000 fruit from each lot. Application of a suitable treatment (e.g. fumigation) or rejection of any lots where apple leafcurling midge is found; or

2. Treatment of all lots with a suitable treatment to kill apple leafcurling midge.

Further details on risk management and operational procedures are given in a later section.

Garden featherfoot

Introduction

The garden featherfoot, *Stathmopoda horticola* Dugdale, is a moth with four life stages: adult, egg, larva (or caterpillar) and pupa. The larvae are known to feed on the surface of the fruit from a silken shelter and occasionally pupate in a white silken cocoon on the fruit. Larvae diapause overwinter in a cocoon. Adults are sexually reproducing organisms and are capable of flight.

Biology

Mature larvae are approximately 8 mm in length and are a dark purplish brown in colour, with a dark reddish brown head and paler intersegmental divisions. The cocoon is often attached to the surface of the fruit (Landcare Research, 1999).

Very little has been published on the life history of this species but on orchard trees the larvae are known to feed on the surface of fruit from a silken shelter under the dying calyces (Landcare Research, 1999).

Other information relevant to the biology of garden featherfoot is available in the data sheet in Appendix 3 of Part C.

Risk scenario

The risk scenario of concern for garden featherfoot in this draft IRA is the presence of larvae and pupae on the surface of the fruit.

The potential for viable garden featherfoot larvae to be associated with trash after harvesting, packing house processing and transport would be minimal. The larvae are known to feed on the surface of fruit from a silken shelter under the dying calyces, while mature larvae only occasionally pupate in a cocoon on fruit. The majority of trash will be eliminated during the packing house process.

Probability of entry, establishment and spread

The probability of entry, establishment and spread was calculated by undertaking a series of assessments including the:

- estimation of the probability of importation (mean infestation rate)
- estimation of the distribution of infested apples at utility points
- estimation of the partial probabilities of entry, establishment and spread at each of the utility points for each exposure group based on the distribution of infested apples to the utility points
- combination of all partial probabilities of entry, establishment and spread.

Entry comprises importation and distribution. The likelihood of importation was based upon the scenario of eight import steps and a likelihood for each step was assessed. These likelihoods, combined with the total expected trade in apples were used to provide an estimate of the number of infested fruit imported into Australia and distributed at each utility point.

Distribution involves the release of imported apples from the port of entry and distribution to various utility points where susceptible hosts are present. Information relevant to distribution, establishment and spread is provided separately below. The partial probabilities of entry, establishment and spread were assessed for each utility point exposure group combination. All of the partial probabilities were then combined using the formula provided in the methods section to provide a single probability of entry, establishment and spread.

Importation

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry. The importation scenario is divided into eight steps and the available evidence supporting the likelihood of garden featherfoot being present at each step is provided in the text below.

Importation step 1: Likelihood that garden featherfoot is present in the source orchards in New Zealand: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}. U(10^{-3}, 5×10^{-2})

Garden featherfoot is a native New Zealand moth that is generally distributed throughout the country (HortResearch, 1999b).

There is no reference to garden featherfoot in HortResearch's internet BugKEY (HortResearch, 1999b), although unidentified species of *Stathmopoda* caterpillars (probably including garden featherfoot) are mentioned as occasional pests of apples in the north of New Zealand and they may be found feeding at the calyx or stem-end of apples.

The fruits of kiwifruit and stone fruits are more often attacked by garden featherfoot (HortResearch, 1999b).

A stakeholder contends that this step should be rated as 'high' [Uniform (0.7, 1)] based on an interpretation of the facts that garden featherfoot is a widespread polyphagous species and is highly likely to occur within, or in close proximity to apple orchards but no other further information was provided to support this claim. It should be noted that garden featherfoot more often attacks kiwifruit and stone fruit and *Stathmopoda* caterpillars (probably also including garden featherfoot) are only occasional pests of apple in the north of New Zealand (HortResearch, 1999b).

Summary

Based on the evidence that garden featherfoot is widely distributed throughout New Zealand and it prefers to attack kiwifruit and stone fruit but only occasionally attacks apples in the north of New Zealand, the IRA team decided to represent Imp1 as a uniform distribution, with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}.

Importation step 2: Likelihood that picked apple fruit is infested with garden featherfoot: uniform distribution with a minimum value of 10^{-6} and a maximum value of 10^{-3}. U(10^{-6}, 10^{-3})

Larvae feed on the surface of fruit from within a silken shelter at the dying calyx while pupation occurs in a white silken cocoon, often attached to the surface of the fruit (Landcare Research, 1999).

Stathmopoda species are occasional pests of apples in the north of New Zealand (HortResearch, 1999b).

A stakeholder states that, since 'the lack of references to this species in the New Zealand apple pest management literature strongly suggests it is never a serious pest and has not been intercepted by quarantine inspections of export fruit' and '[garden featherfoot] has been recorded as feeding on apples on the North Island', this step should be appropriately rated as 'very low' [Uniform (10^{-3}, 5 x 10^{-2})]. However, no other further information was provided to support this claim. The very fact that garden featherfoot has not been recorded as a serious pest of apples and has not been intercepted on export fruit would strongly suggest that a probability distribution of Uniform (10^{-3}, 5 x 10^{-2}) is not justified.

Summary

Based on the evidence that garden featherfoot larvae rarely feed on the outside of the apple fruit from within a silken shelter at the dying calyx and pupate in a cocoon often attached to the apple fruit, the IRA team decided to represent Imp2 as a uniform distribution, with a minimum value of 10^{-6} and a maximum value of 10^{-3}.

Importation step 3: Likelihood that clean fruit is contaminated by garden featherfoot during picking and transport of apples to the packing house: uniform distribution with a minimum value of 10^{-6} and a maximum value of 10^{-3}. U(10^{-6}, 10^{-3})

Fruit are picked into picking bags and then transferred into bins kept on the ground in the orchard before transportation to the packing house.

Garden featherfoot is only an occasional pest of apples in the North Island of New Zealand (HortResearch, 1999b).

Larvae are occasionally found underneath a silken shelter in the calyx or stem-end of apples (HortResearch, 1999b) suggesting that the larvae would not be dislodged during harvesting.

Taking into account stakeholders' comments it is reasonable to reassess the likelihood that garden featherfoot will contaminate harvested apples being transported to the packing house as no greater than the likelihood that picked apple fruit will be infested. The likelihood for this step was reassessed as Uniform (10^{-6}, 10^{-3}).

Summary

Based on the fact that garden featherfoot would not be dislodged from their silken shelters in the calyx or stem-end of apple fruit during harvesting thus preventing contamination of apples, the IRA team decided to represent Imp3 as a uniform distribution, with a minimum value of 10^{-6} and a maximum value of 10^{-3}.

Importation step 4: Likelihood that garden featherfoot survives routine processing procedures in the packing house: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}. U(10^{-3}, 5 x 10^{-2})

The following packing house operations may influence the survival of garden featherfoot.

Washing

Landcare Research (1999) indicates that the pupa is in a white silken cocoon on surface of the fruit or the larva feeds on the surface of fruit from a silken shelter under the dying calyx. Washing would be able to remove some pupae or larvae.

Brushing

Because of their large size, most pupae or larvae on surface of the fruit will be brushed off.

Waxing

Any remaining larvae and pupae would be able to survive the waxing.

Sorting and grading

Pupae in silken cocoons and the silken shelters of larvae are highly visible and are likely to be noticed and discarded during the sorting and grading process.

Packaging

Packaging would have little effect on the viability of the remaining pupae and larvae. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture. This environment is favourable for the survival of garden featherfoot.

Cold storage

Landcare Research (1999) states that larvae diapause overwinter in a cocoon and pupate in spring. This suggests that larvae are able to survive cold storage before transportation.

Additional considerations

A stakeholder's submission gives this step a rating of 'low' [Uniform (5 x 10^{-2}, 0.3)] claiming that a likelihood of 'very low' [Uniform (10^{-3}, 5 x 10^{-2})] is 'probably too great a reduction in the population for this step'. However, no other further information was provided to support this claim.

Another stakeholder's submission considers that the assessment for this step has been underestimated based upon the similarities of garden featherfoot pupae to apple leafcurling midge pupae and the fact that both occupy a similar niche namely, in the calyx-end and stem-end of apple fruit.

Summary

Based on the lack of evidence that packing house procedures and cold storage are detrimental to the survival of garden featherfoot and the large size and highly visible nature of larvae and pupae that makes them more likely to be noticed and discarded during the sorting and grading process, the IRA team decided to represent Imp4 as a uniform distribution with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}.

Importation step 5: Likelihood that clean fruit is contaminated by garden featherfoot during processing in the packing house: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Larvae or pupae dislodged during processing would not contaminate clean fruit.

Summary

Based on the fact that garden featherfoot larvae and pupae dislodged from the surface of apple fruit during processing would not contaminate other apple fruit or result in an increase in the infestation rate, the IRA team decided to represent Imp5 as a uniform distribution with a range from 0 to 10^{-6}.

Importation step 6: Likelihood that garden featherfoot survives palletisation, quality inspection, containerisation and transportation to Australia: uniform distribution with a minimum value of 0.7 and a maximum value of 1. U(0.7, 1)

The fact that larvae diapause over winter in a cocoon suggests that they are able to survive the cold conditions during transportation.

A stakeholder's submission gives this step a rating of 'certain' [1], contending that nothing [no process] has been identified that would reduce garden featherfoot infestation levels during palletisation, quality inspection, containerisation and transportation to Australia. However, it is likely that limited mortality will occur during this stage because of mechanical damage to the larvae and pupae, cold storage or controlled atmosphere storage.

Another stakeholder has pointed out that cold storage or controlled atmosphere storage will be a significant mortality factor for a majority of insects contaminating consignments of apples. Although cold storage is used as a disinfestation method for some insects it is thought that garden featherfoot will be able to survive the cold conditions during transportation, since garden featherfoot larvae diapause over winter to survive cold conditions in the wild. Therefore a rating of Uniform (0.7, 1) is a more appropriate estimate of risk.

Summary

The fact that garden featherfoot larvae diapause over winter in New Zealand suggests they would be able to survive cold conditions during transportation and thus survive palletisation, quality inspection, containerisation and transportation to Australia. The IRA team decided to represent Imp6 as a uniform distribution, with a minimum value of 0.7 and a maximum value of 1.

Importation step 7: Likelihood that clean fruit is contaminated by garden featherfoot during palletisation, quality inspection, containerisation and transportation: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Larvae that have spun their cocoons on apple fruit for pupation would not leave that fruit to contaminate other apple fruit.

Any pupae dislodged during quality inspection would be unable to attach to other fruit.

Summary

Based on the fact that garden featherfoot larvae that have already spun their cocoons on apple fruit for pupation would be unable to leave that fruit to contaminate other apple fruit and any pupae dislodged would be unable to re-attach to other apple fruit, there would be no net increase in the infestation rate. Therefore the IRA team decided to represent Imp7 as a uniform distribution, with a minimum value of 0 and a maximum value of 10^{-6}.

Importation step 8: Likelihood that garden featherfoot survives and remains with fruit after on-arrival minimum border procedures: triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.9. T(0.7, 0.9, 1)

The minimum border procedures as described in the method section would not be effective in detecting the larvae or pupae of garden featherfoot.

A stakeholder's submission gives this step a rating of 'certain' [1]. After consideration of this comment it is reasonable to reassess this step with a likelihood close to 1.

Summary

Based on the fact that on-arrival minimum border procedures would not be effective in detecting or destroying garden featherfoot, the IRA team decided to represent Imp8 as a triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.9.

Results – importation

When the above likelihoods were inserted into the risk simulation model, the probability of importation of garden featherfoot was estimated as 1.3×10^{-6} (mean), 4.7×10^{-7} (5^{th} percentile) and 2.4×10^{-6} (95^{th} percentile). Therefore the infestation rate for garden featherfoot was estimated to be 0.00013% (mean) of the total proposed number of apples imported from New Zealand annually.

Probability of entry, establishment and spread

The initiating step for estimating the probability of entry, establishment and spread is the release of imported apples from the port of entry, and the final step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host resulting in pest establishment and spread. Entry, establishment and spread of a pest in a new area involves a complex set of interacting factors. Factors relevant to garden featherfoot are discussed in this section. For convenience, the discussion has been broken up into sub-sections:

- Discussion of the proportions of utility points near susceptible hosts (proximity). Utility points are orchard wholesalers, urban wholesalers, retailers, food services and consumers. Susceptible host plants are grouped into four exposure groups: commercial fruit crops, nursery plants, household and garden plants, and wild and amenity plants.
- Discussion of factors relevant to the transfer of a pest to susceptible host plants from the utility point.
- Estimation of the number of infested fruit arriving at each utility point by exposure group combination.
- Discussion of factors relevant to establishment based on the ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).
- Discussion of factors relevant to spread based on the ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).
- Estimation of the partial probabilities of entry, establishment and spread for each utility point exposure group combination taking into account all relevant information (PPEES).
- Estimation of the combined probability of entry, establishment and spread (PEES).

Several stakeholders have indicated that the methods employed in assessing the exposure of host plants from a single infested waste apple in the last draft are not appropriate for arthropod pests including garden featherfoot. After consideration of their comments the assessment of exposure has been revised, taking into account the estimated number of infested apples

Proximity

The proximity of an insect pest to its host(s) considers its dispersal characteristics, its host range, and the proximity of utility points in relation to its host(s).

Garden featherfoot has been recorded feeding on apple, peach and kiwifruit.

Table 57 provides the estimated likelihoods of utility points near susceptible host plants for garden featherfoot. The estimated likelihoods were determined by expert judgement taking into consideration relevant stakeholder comments provided for the revised *Draft import risk analysis on the importation of apples from New Zealand* (BA, 2004).

Table 57 The proportions of utility points near host plants susceptible to garden featherfoot in the four exposure groups

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	1	U(10^{-3}, 5 x 10^{-2})	U(5 x 10^{-2}, 0.3)	U(5 x 10^{-2}, 0.3)
Urban wholesalers	U(10^{-6}, 10^{-3})*	U(10^{-6}, 10^{-3})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Retailers	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Food services	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})
Consumers	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(5 x 10^{-2}, 0.3)	U(5 x 10^{-2}, 0.3)

* *U(10^{-6}, 10^{-3}) should be read as the likelihood is distributed uniformly between 0.000001 and 0.001*

Commercial fruit crops near utility points

The commercial crops of garden featherfoot are apple, kiwifruit and peach.

The proportion of **orchard wholesalers** near **commercial fruit crops**: 1

- All orchard wholesalers would be in proximity of commercial fruit crops.

The proportion of **urban wholesalers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are generally located in metropolitan areas and commercial fruit crops are not grown within urban areas.

- Some urban wholesalers may be located within apple production regions but the distance to these crops may be too far for garden featherfoot to fly.

The proportion of **retailers** near **commercial fruit crops**: Uniform (10^{-3}, 5 x 10^{-2})

- Some retailers (up to 5%) and their waste could be near commercial fruit crops.

The proportion of **food services** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Major food services are extremely unlikely to be near commercial fruit crops.

The proportion of **consumers** near **commercial fruit crops**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of the Australian population is estimated to be near commercial fruit crops. The majority of the population is located in the metropolitan areas.

Nursery plants near utility points

Possible host nursery plants include apple, kiwifruit and peach.

The proportion of **orchard wholesalers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Some orchardists may raise their own nursery plants or run a parallel wholesale business. Also, pome fruit nurseries may be near orchards.

The proportion of **urban wholesalers** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are in metropolitan areas and some may be close to garden centres selling nursery plants. Apples could be kept temporarily in proximity to garden centres when apple plants have actively growing leaves.

The proportion of **retailers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of major retail outlets may sell nursery plants that are hosts such as apple, peach and kiwifruit.

The proportion of **food services** near **nursery plants**: Uniform (10^{-6}, 10^{-3})

- Major food services such as restaurants and airlines caterers are unlikely to be near nursery plants.

The proportion of **consumers** near **nursery plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Up to 5% of consumers may come in proximity to nursery plants susceptible to garden featherfoot. This is likely to be only for brief periods when susceptible hosts have actively growing leaves.

Household and garden plants near utility points

The household or garden plants susceptible to garden featherfoot are apple, kiwifruit and peach.

The proportion of **orchard wholesalers** near **household and garden plants**:
Uniform (5 x 10^{-2}, 0.3)

- Orchard wholesalers and their waste disposal sites are located in an isolated area within the orchard premises but some household and garden plants may be near them.

The proportion of **urban wholesalers** near **household and garden plants**:
Uniform (10^{-3}, 5 x 10^{-2})

- Urban wholesalers are mostly in industrial areas. Household and garden plants are unlikely to be near these sites because residential properties would be located away from them.

The proportion of **retailers** near **household and garden plants**: Uniform (10^{-3}, 5 x 10^{-2})

- The majority of retailers are in larger cities
- Some residential properties with apple or peach trees and/or kiwifruit vines would be near retail outlets.

The proportion of **food services** near **household and garden plants**: Uniform (10^{-6}, 10^{-3})

- Major food service industries are in cities, not near residential areas and their waste is disposed to landfill sites.
- Some restaurants may have a few host plants within their premises.

The proportion of **consumers** near **household and garden plants**: Uniform (5 x 10^{-2}, 0.3)

- A proportion of metropolitan and suburban consumers may have apple or peach trees and/or kiwifruit vines as household and garden plants.

Wild and amenity plants near utility points

Wild and amenity plants susceptible to garden featherfoot are feral apple and peach trees.

The proportion of **orchard wholesalers** near **wild and amenity plants**:
Uniform (5 x 10^{-2}, 0.3)

- Some amenity plants other than commercial crops may be present in the orchard area.
- Orchard wholesalers in most cases will not allow feral plants and volunteer apple or peach seedlings to grow near their sites.

The proportion of **urban wholesalers** near **wild and amenity plants**:
Uniform (10^{-3}, 5 x 10^{-2})

- Susceptible hosts may grow in the wild near these sites as a result of dispersal of seeds by birds (for example, apple trees, apple and seedlings).

The proportion of **retailers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2}).

- The majority of retailers are in large cities.
- Retailer waste would be disposed of in landfills. Susceptible hosts may grow in the wild near these sites as a consequence of dispersal of seeds of susceptible plants by birds.

The proportion of **food services** near **wild and amenity plants**: Uniform (10^{-6}, 10^{-3})

- Seedlings originating from seeds dispersed by birds or discarded fruit may be present.

The proportion of **consumers** near **wild and amenity plants**: Uniform (5 x 10^{-2}, 0.3)

- Susceptible hosts may grow from seeds in the wild near these sites as result of dispersal by birds and consumers.
- This is likely to occur near parks, gardens, recreation sites and along roadsides where susceptible plants may be found. Usually the density of host plants near these sites would be very low.

Transfer to hosts

The insect stage of garden featherfoot associated with apple fruit is the larvae or pupae on the surface of fruit. The only means for garden featherfoot to leave fruit or packaging and enter the environment of exposure groups is by adult flight after emergence from pupae. If mature larvae or pupae survive cold storage, adults would need to emerge from the pupal stage after the apples have been taken out of storage. The emergence could occur at unpacking and repacking facilities or retailers (utility points), on discarded fruit in waste, at landfills where the waste is disposed, and during transportation of purchased apples from retailers to households.

A successful transfer of garden featherfoot from infested fruit means that mature larvae need to pupate, pupa need to develop to become adults. Both the adult male and female have wings and are able to fly. Adult females need to locate a male to mate with, and to lay their eggs on a susceptible host plant. Successful mating between a male and a female must occur before viable eggs are produced. The chance for this to happen depends on several factors, including mortality of larvae and pupae, level of infestation and number of apples in the same utility points, availability and susceptibility of hosts and lifespan of the pest.

Estimation of the number of infested fruit arriving at each utility point by exposure group combination

Stakeholders provided varying views on how imported apples might be distributed. Some stakeholders suggested that a large proportion of apples would come in as bulk produce and be sent to orchard packing houses for regrading and repacking, while other stakeholders suggested that apples would be packed in market ready boxes and sent directly to urban wholesalers for distribution. Two possible scenarios were considered in detail as follows.

The first scenario was estimated with (0.1% –5%) of imported apples being distributed to orchard packing houses and the remainder (95% to 99.9%) being distributed to urban wholesalers. The second scenario was estimated with a (70%–100%) of imported apples being distributed to orchard packing houses and the remainder (0 to 30%) being distributed to urban wholesalers. Estimates of the number of infested fruit were calculated by running a series of simulations. The following assumptions were used:

- the distribution of the indicative numbers of infested apples arriving at each utility point was evaluated using results of importation and the apple utilisation proportions described in the section 'Method for Import Risk Analysis'
- most apple imports will arrive over a six month period from March to August (other periods ranging from 1 week to 52 weeks were also run – data not shown)
- the number of orchard wholesalers that might process imported fruit is seven (it should be noted that there may be more than seven orchard wholesalers throughout Australia but only seven were assumed to repack imported fruit)
- the number of urban wholesalers that might process imported fruit is six (it should be noted that there may be more than six urban wholesalers throughout Australia but only a limited number would be likely to repack imported fruit)
- the number of retail outlets is 5000 (IBISWorld, 2004; IBISWorld, 2005)
- the number of food service outlets is 5000. There are over 60,000 food service outlets in Australia although not all would serve apples (ABS, 2001)
- the number of households where apples are consumed is estimated to be 6 million. This figure is based on an estimated 7.4 million households in Australia (ABS, 2004) and percentages of households purchasing fruit are estimated as being 77 % in summer and 92 % in winter (HAL, 2004).

The analysis assumed that imported apples will be evenly distributed among the six urban wholesalers. However, it is possible that two of the major urban wholesalers may together take up to 50% of the imported apples. Similar situations could apply to orchard wholesalers, retailers and food service industries. This possibility and other scenarios were analysed but in the interests of simplicity only the data based on the assumptions shown above are presented.

Table 58 shows the indicative estimated number of infested fruit per week distributed to individual utility points. Data on the mean, midpoint and two percentiles (5^{th} and 95^{th}), is presented for the original estimates of importation. The table shows the scenario with a higher proportion of apples sent either to orchard wholesalers or urban wholesalers. Also shown within the brackets is the number of individual utility points that are considered to be in proximity to exposure groups based on the estimates provided in Table 57 above.

Table 58 Weekly indicative estimates of Garden featherfoot infested apples per utility point (based on 26 weeks of trade[39]) from published data

PREDICTED NUMBER OF INFESTED FRUIT TO UTILITY POINTS[40]

(predicted number of utility points near exposure groups)

UTILITY POINTS	Commercial fruit crops				Nursery plants				Household and garden plants				Wild and amenity plants			
	5^{th}	Median	95^{th}	Mean	5^{th}	Median	95^{th}	Mean	5^{th}	Median	95^{th}	Mean	5^{th}	Median	95^{th}	Mean
**Orchard wholesalers	<1 (7)	<1 (7)	<1 (7)	<1 (7)	<1 (<1)	<1 (<1)	<1 (<1)	<1 (<1)	<1 (<1)	<1 (1)	<1 (2)	<1 (1)	<1 (<1)	<1 (1)	<1 (2)	<1 (1)
	<1 (7)	1 (7)	3 (7)	1 (7)	<1 (<1)	1 (<1)	3 (<1)	1 (<1)	<1 (<1)	1 (1)	3 (2)	1 (1)	<1 (<1)	1 (1)	3 (2)	1 (1)
**Urban wholesalers	1 (<1)	2 (<1)	4 (<1)	2 (<1)	1 (<1)	2 (<1)	4 (<1)	2 (<1)	1 (<1)	2 (<1)	4 (<1)	2 (<1)	1 (<1)	2 (<1)	4 (<1)	2 (<1)
	<1 (<1)	<1 (<1)	1 (<1)	<1 (<1)	<1 (<1)	<1 (<1)	1 (<1)	<1 (<1)	<1 (<1)	<1 (<1)	1 (<1)	<1 (<1)	<1 (<1)	<1 (<1)	1 (<1)	<1 (<1)
Retailers	<1 (17)	<1 (128)	<1 (238)	<1 (128)	<1 (17)	<1 (128)	<1 (238)	<1 (128)	<1 (17)	<1 (128)	<1 (238)	<1 (128)	<1 (17)	<1 (128)	<1 (238)	<1 (128)
Food services	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)	<1 (<1)	<1 (3)	<1 (5)	<1 (3)
Consumers	<1 (20698)	<1 (153000)	<1 (285299)	<1 (153000)	<1 (20699)	<1 (153000)	<1 (285299)	<1 (153000)	<1 (374988)	<1 ($1.1x10^6$)	<1 ($1.7x10^6$)	<1 ($1.1x10^6$)	<1 (374986)	<1 ($1.1x10^6$)	<1 ($1.7x10^6$)	<1 ($1.1x10^6$)

NOTE: 34 (7) should be read as 34 infested apples arriving on a weekly basis at seven places which have susceptible host plants nearby

45 (<1) should be read as 45 infested apples arriving on a weekly basis at less than one place which has susceptible host plants nearby

<1 (128) should be read as less than one infested apple arriving on a weekly basis at 128 places that have susceptible host plants nearby

*** In each box, the top set of numbers is based on P1 = Uniform (10^{-3}, 5 x 10^{-2}) and the lower set is based on P1 = Uniform (0.7, 1)*

[39] other intervals were considered, including 52 weeks and one week periods of trade

[40] actual values vary slightly in different simulation runs

Establishment

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

The relevant information for establishment is presented below against the factors listed in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).

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

Apple, kiwifruit and peach are the only known hosts of garden featherfoot but it is probably polyphagous.

Commercial crops such as apples are grown in all States and Territories in Australia, except in the northern tropical regions. Apples are also found and grown in suburban backyards in temperate Australia.

Suitability of the environment

Garden featherfoot is native to New Zealand where climatic conditions are similar to those in Australia.

Apples are not grown in protected environments such as in glasshouses.

Potential for adaptation of the pest

The potential for adaptation of the pest is not known.

Reproductive strategy of the pest

There is limited information on the biology of garden featherfoot.

Successful mating between a male and a female must occur before eggs are produced.

Minimum population needed for establishment

A population can be established from eggs laid by a mated female.

Cultural practices and control measures

Integrated pest management (IPM) programs are utilised in the production of apples in Australia.

Spread

Spread is defined as the 'expansion of the geographical distribution of a pest within an area' (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

The relevant information for spread is presented below against the factors listed in ISPM No. 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO, 2004).

Suitability of natural and/or managed environment

Garden featherfoot is a native New Zealand moth that is generally distributed throughout the country (HortResearch, 1999b). There are similar environments in Australia that would be suitable for its spread.

Presence of natural barriers

The main Australian commercial apple, kiwifruit and peach orchards are located in six states of Australia with natural barriers including arid areas, climatic differentials and long distances existing between these areas. It would be difficult for the adults to disperse from one area to another unaided.

Other host plants available between the commercial apple orchards in different areas would help the spread of garden featherfoot.

Both the adult male and female are winged and are capable of flight.

Potential for movement with commodities or conveyances

A mixture of adult flight and the transportation of infested apple trees have probably aided the movement of garden featherfoot within orchards.

Dispersal of garden featherfoot would result from the movement of larvae or pupae on the surface of the fruit.

Existing interstate quarantine control on the movement of nursery stock would reduce the scope for spread of garden featherfoot.

Intended use of the commodity

Apples would be used mostly for consumption by humans and would be widely distributed around the states.

If larvae or pupae have contaminated the fruit, they will be distributed with the commodity around the country.

Potential vectors of the pest

Garden featherfoot does not require a vector for its spread since it is capable of independent flight.

Potential natural enemies

The relevance of potential natural enemies in Australia is not known.

Partial probability of entry, establishment and spread

The estimations of the partial probability of entry, establishment and spread are provided in Table 59 below. These estimates are based on expert opinion taking into account the sequence of events for successful transfer of the pest to a susceptible host, the estimated numbers of infested apples at each utility point, the availability and susceptibility of hosts at each utility point, information relevant to establishment and spread of the pest and all relevant information provided by stakeholders. A summary of the evidence to support these likelihoods for each of the utility points and exposure groups is discussed after the table. This summary draws on information presented elsewhere in this section.

Table 59 The partial probabilities of entry, establishment and spread of garden featherfoot on susceptible host plants from infested apples at different utility points (based on the expected trade of apples in a year)

UTILITY POINTS	LIKELIHOOD OF ENTRY, ESTABLISHMENT AND SPREAD			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	$U(10^{-6}, 10^{-2})$	$U(0, 10^{-6})$	$U(0, 10^{-3})$	$U(0, 10^{-3})$
Urban wholesalers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Retailers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Food services	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$
Consumers	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$	$U(0, 10^{-6})$

Several issues are relevant to all likelihoods presented in Table 59. Specific issues are discussed under individual utility points following the discussion below.

It would be very difficult to predict precisely when the majority of New Zealand apples would be imported if trade starts. However, it has been suggested that most apple imports would be from late summer to winter (March to August). The assessments provided in the above table were mainly based on the assumption that most imported apples will arrive in Australia over a half year period as suggested above. There is a possibility that the majority of New Zealand apple fruit could arrive over a very short period such as a couple of months or a longer period such as a whole year. The ratings presented in Table 59 allow for these possibilities.

Successful transfer of garden featherfoot to a susceptible host will depend on several insects escaping from utility points where significant volumes of infested fruit are stored for repacking. It would also depend on the cool chain being broken to allow any mature pupae to emerge as adults. Under such circumstances there is more chance of a male and female emerging together and successfully mating.

Both the adult male and female garden featherfoot are winged and are capable of flight and would be able to reach susceptible host plants. A mixture of adult flight and the transportation of infested apple fruit could aid the movement of garden featherfoot.

The recorded hosts of garden featherfoot include apple (*Malus x domestica*), kiwifruit (*Actinidia deliciosa*) and peach (*Prunus persica*) although it is considered to be probably polyphagous on fruits of a wide range of trees.

Probability of entry, establishment and spread – Orchard wholesalers

The host plants of garden featherfoot such as apple and peach are available around orchard wholesalers as commercial fruit crops, may be available as household and garden plants and wild and amenity plants, but may not be available as nursery plants.

Table 58 shows that small numbers of garden featherfoot could be distributed to orchard wholesalers on a weekly basis and therefore there is a small chance of at least a male and female emerging together and successfully mating but this may not be sufficient to initiate a sustainable population.

The partial probabilities of entry, establishment and spread for orchard wholesalers and each of the four exposure group combinations are provided in Table 59.

As indicated in the table, the partial probability of entry, establishment and spread was rated highest for commercial fruit crops. This was because of the fact that commercial fruit crops are available and in close proximity to all seven orchard wholesalers and thus higher number of susceptible host plants would be present. The range for the partial probability for nursery plants was rated narrower among the exposure groups because of the insignificant numbers of orchard wholesalers near nursery plants. The partial probabilities for household and garden plants and wild and amenity plants were rated the same but were lower than that for commercial fruit crops. This was because of smaller number of orchard wholesalers near these two exposure groups compared with the number of orchard wholesalers near commercial fruit crops. However, the range for the partial probability of entry, establishment and spread was assessed as wider than that for nursery plants. This is taking into account that some household and garden plants or wild and amenity plants may be available around orchard wholesalers.

Probability of entry, establishment and spread – Urban wholesalers

Table 58 shows that small numbers of garden featherfoot could be distributed to urban wholesalers on a weekly basis and therefore there is a small chance of at least a male and female emerging together and successfully mating, but this may not be sufficient to initiate a sustainable population. However, the table also shows that the host plants of garden featherfoot would not be available around urban wholesalers as commercial fruit crops, household and garden plants, nursery plants, or wild and amenity plants.

The partial probabilities of entry, establishment and spread for urban wholesalers and each of the four exposure group combinations are provided in Table 59.

Probability of entry, establishment and spread – Retailers, food services and consumers

Table 58 shows that the host plants of garden featherfoot would be available around these utility points as commercial fruit crops, household and garden plants, nursery plants, or wild and amenity plants. However, Table 58 also shows that insignificant numbers of garden featherfoot could be distributed to each retailer, food service or consumer on a weekly basis and therefore there is very little chance of at least a male and female emerging together and successfully mating and initiating a sustainable population.

The partial probabilities of entry, establishment and spread for retailers, food services and consumers and each of the four exposure group combinations were assessed as the same (see Table 59).

Probability of entry, establishment and spread – conclusion

Estimates of the partial probabilities of entry, establishment and spread for each of the utility points and susceptible host plants were combined using the equation given in the method section, to give a combined annual probability of entry, establishment and spread as shown in Table 60.

Table 60 Unrestricted probability of entry, establishment and spread[41]

Percentile	Probability of entry, establishment and spread	Qualitative description
5th percentile	1.5×10^{-3}	Very low
Median	6×10^{-3}	Very low
95th percentile	1.1×10^{-2}	Very low

Table 60 shows the distribution of probability of entry, establishment and spread from the 5th to the 95th percentiles was within the qualitative likelihood interval of 'very low'.

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are shown in Table 61. Available supporting evidence is provided in the text below.

Table 61 Impact scores for garden featherfoot

Direct impact	Impact scores
Plant life or health	D
Human life or health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	D
Domestic trade or industry	D
International trade	D
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are unlikely to be discernible at the national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Garden featherfoot attacks commercial crops such as apple, kiwifruit and peach.

[41] calculated by @RISK

Human life or health – A

There are no known direct impacts of garden featherfoot on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There is no known direct impact of garden featherfoot on any other aspects of the environment and a rating of '**A**' was assigned to this criterion.

Indirect impact

Control or eradication – D

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies is unlikely to be discernible at the national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Indirect consequences of the eradication or control as a result of the introduction of garden featherfoot may be:

- an increase in the use of insecticides for its control because of difficulties estimating the optimum time for insecticide application
- disruption to IPM programs because of the need to re-introduce or increase the use of organophosphate insecticides
- subsequent increase in cost of production to producers
- damage to leaves would provide entry courts for the entry of plant pathogens
- increased costs for crop monitoring and consultant's advice to the producer.

Domestic trade or industry – D

The indirect consequences on domestic trade are unlikely to be discernible at a national level and would be of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

The presence of garden featherfoot on commercial apple crops could result in:

- trade restrictions in the sale or movement of fruit within that district and region and between states
- consumer expectations and aesthetics ranging from the acceptance of fruit that is slightly affected to rejection of imperfect fruit.

International trade – D

The indirect consequences on international trade are unlikely to be discernible at a national level and would be of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

If garden featherfoot became established in Australia, our trading partners might reject or require risk management measures for consignments of apples infested with garden featherfoot.

Environment – B

The indirect consequences on the environment would not be discernible at the national level and would be of minor significance at the local level and a rating of '**B**' was assigned to this criterion.

Increased insecticide use could cause undesired effects on the environment.

The introduction of new biocontrol agents could affect existing biological control programs.

Host plants of the garden featherfoot are apple, kiwifruit and peach. Commercial apples are grown in six states in Australia under intensive cultivation, so there would be little effect on designated environmentally sensitive or protected areas because few apple or peach trees and kiwifruit vines grow or are allowed to continue to grow in such areas.

Communities – B

The indirect consequences on communities would not be discernible at the national level and would be of minor significance at the local level, thus a rating of '**B'** was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**D**', the overall consequences are considered to be 'low'. Therefore the overall consequences of garden featherfoot are '**low'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread and the outcome of overall estimated consequences. Probabilities for entry, establishment and spread, and the consequences rating are combined using the risk estimation matrix explained in the method section. The unrestricted annual risk estimation for garden featherfoot is shown in Table 62.

Table 62 Unrestricted risk estimation for garden featherfoot

Probability of entry, establishment and spread	Very low
Consequences	Low
Unrestricted annual risk	Negligible

As indicated in Table 62, the unrestricted annual risk for garden featherfoot is 'negligible' which is below Australia's ALOP. Therefore, risk management would not be required for this pest.

Introduction

The grey-brown cutworm, *Graphania mutans* (Walker), is a moth of the family Noctuidae. It has four life stages: adult, egg, larva (or caterpillar) and pupa. It is a native of New Zealand and is found in apple orchards throughout New Zealand.

Biology

Eggs are cream to yellow in colour, and are laid in batches on leaves or sometimes under the calyces of apple fruit. The hatching caterpillars disperse to feed on the foliage for a short time before descending to the orchard understorey. Egg batches are also sometimes laid on the fruit close to harvest (HortResearch, 1999b).

Newly hatched larvae are pale yellow in colour with distinct black spots and covered in stiff, erect hairs. Larvae continue to feed on foliage of host trees until fully grown (Landcare Research, 1999). However, HortResearch (1999b) states that most of the young caterpillars of *G. mutans* descend from the trees to the ground cover of the orchard after a short time, where they feed on a variety of pasture plants. *G. mutans* caterpillars, which were artificially prevented from their normal behaviour of descending to the orchard understorey, cause considerable damage to the surface of apple fruit (HortResearch, 1999b). Mature larvae are approximately 25 mm long, light to dark brown in colour with a broken, white longitudinal stripe down each side (Landcare Research, 1999).

Other information relevant to the biology of grey-brown cutworm is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of concern for grey-brown cutworm in this draft IRA is the presence of eggs and larvae on fruit. Adult females of the grey-brown cutworm sometimes lay eggs under the calyces of apple fruit close to harvest, and larvae are known to damage the surface of apple fruit (HortResearch, 1999b).

The potential for viable grey-brown cutworm eggs, larvae or pupae to be associated with trash after harvesting, packing house processing and transport would be minimal. Eggs, if laid on apples and then dislodged onto trash, would probably be damaged, as would larvae. Pupae would not contaminate trash because the insect pupates in the soil.

Probability of entry, establishment and spread

The following analysis examines the likelihoods of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk with respect to Australia's ALOP.

The probability of entry is obtained by considering the importation and distribution pathways for the commodity, and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed.

Importation

The likelihood that grey-brown cutworm will arrive in Australia with the importation of apple fruit from New Zealand: **Moderate**.

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry.

Supporting evidence for a 'moderate' probability of importation is provided in the text below.

Source orchards

Larval damage and egg deposition of grey-brown cutworm occurs in all New Zealand's apple growing regions, with varying frequency (Burnip et al., 1995).

Orchards surrounded by diverse land uses other than pasture land particularly irrigated pasture have the lowest incidence of grey-brown cutworm (Burnip et al., 1995).

This pest is primarily a pasture species, but sometimes it can also attack apples (HortResearch, 1999b).

Egg batches are laid on leaves and the hatching larvae disperse to feed on foliage for a short time in spring. Most of the young caterpillars then descend from the trees to the orchard understorey where they feed on a variety of ground cover plants.

Eggs can be laid on any convenient object in the orchard and sometimes on the fruits close to harvest, particularly under the calyx.

Larval damage to fruit is generally obvious, because tracks are eaten in the skin of the apple (HortResearch, 1999b).

In a comparison of three fruit production systems – organic production, integrated fruit production and biological fruit production – no significant difference was found in the overall level of damage (3–6 %) (Wearing, 1996).

Research from the late 1980s indicates that noctuid larval feeding damage immediately post-flowering accounted for 3–7% of fruit rejected at harvest in Canterbury, Nelson and Hawke's Bay (Burnip et al., 1995).

Grey-brown cutworm larvae can damage 2–6% of young fruitlets from late bloom in export orchards and this damage can increase to more than 10% when fruitlets are left unprotected for long periods in early summer (Wearing et al., 1994).

Harvesting fruit for export

Fruit are picked into picking bags and then transferred into bins which are kept on the ground in the orchard before transportation to the packing house.

Grey-brown cutworm larvae are only on the apple tree for a short time after flowering before descending to the orchard understorey to complete their development. Clean fruit picked at harvest would rarely be contaminated with larvae.

Eggs would not be able to move from contaminated to uncontaminated fruit.

Processing of fruit in the packing house

The larvae only feed on the surface of the fruit and would be washed off in the water dump or by the washing process.

Some eggs would be washed off but some eggs may survive the washing process if they are in the calyx.

Egg batches under the calyx are not likely to be brushed off.

Any remaining eggs under the calyx may be able to survive the waxing.

Larval damage to the fruit is considerable and unmistakable (HortResearch, 1999b). Damaged fruit would be noticed and discarded.

Egg batches under the calyx of apple can escape detection during the grading process.

Packaging would have little effect on the viability of the remaining eggs. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture, these conditions may favour egg survival.

There is no data available on the impact of cold storage on the viability of the eggs on apple fruit. However, Burnip et al. (1995) indicated that the interception of noctuid egg batches on fruit by quarantine inspectors has been of greater importance to the apple industry as this can result in the rejection of export consignments. This assertion implies that the eggs, if present on the apple fruit, can survive the packing house process including cold storage.

Grey-brown cutworm can survive stone fruit packing house procedures as AQIS inspectors intercepted grey-brown cutworm on plums in 1998 from New Zealand. New Zealand stone fruit does not undergo the rigorous brushing and waxing procedures used for export apple processing.

Eggs dislodged during packing house operations will not reattach to other clean fruit, as they are not capable of movement.

Post-harvest grading, washing and packing procedures are likely to remove the majority of this pest from the fruit.

Pre-export and transport to Australia

Palletisation, quality inspection and containerisation would have little impact on any egg batches although quality inspection may be able to detect the damaged fruit.

During the 1992–93 New Zealand apple export season, noctuid egg batches were detected on export fruit to USA from both Hawke’s Bay and Nelson (Burnip et al., 1995).

This species has been detected during pre-clearance of New Zealand apples to USA (MAFNZ, 2003b) at a rate of 0.37 insects per million fruit inspected.

There is no data available on the impact of cold storage during transportation on the viability of grey-brown cutworm eggs on apple fruit.

Remaining eggs are not likely to hatch at transportation temperature.

On-arrival procedures

The minimum border procedures as described in the method section would not be effective in detecting the eggs of grey-brown cutworm.

Distribution

The likelihood that grey-brown cutworm will be distributed to the endangered area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Moderate**.

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The sequence of events that has to be completed for a successful transfer of grey-brown cutworm pest to a susceptible host is summarised below.

The insect stage associated with the apple fruit are eggs laid under the fruit calyx or larvae on the fruit. Most fruit displaying obvious signs of grey-brown cutworm larval infestation would usually be discarded during the harvest, processing and quality inspection procedures. If the fruit was not discarded during this process, survival for both larvae and eggs would be limited.

If the eggs or larvae were to survive fruit harvesting, packing house processing, cold and/or controlled atmosphere storage and transport to Australia, eggs would have to hatch and larvae would have to move out from infested fruit to either feed or pupate. In the field, recently hatched larvae normally feed on apple foliage for a short time in spring (HortResearch, 1999b) before descending from the trees to the ground cover of the orchard, where they feed on a variety of pasture plants before pupating within a cell in the soil. In retailer premises and on waste, larvae would find it very difficult to find a suitable host to complete their development.

Grey-brown cutworm reproduces sexually. A successful transfer of grey-brown cutworm to a host plant means that an egg would have to hatch, and the larvae would need to find and crawl onto a susceptible host plant. All life stages would need to avoid mortality because of various reasons including predation or environmental stress.

In summary, a successful transfer leading to establishment of grey-brown cutworm from infested fruit to a suitable host requires several crucial steps. Eggs or larvae need to survive processing and transport, eggs need to hatch and larvae need to find suitable foliage to feed on before pupation. If pupation is successful adults need to emerge and disperse in sufficient numbers to ensure mating can occur and then the fertilised female needs to find a susceptible host on which to lay her eggs. Finally, environmental conditions need to be suitable to allow continued population development.

Supporting evidence for a '**moderate**' probability of distribution:

- Grey-brown cutworm is polyphagous on a wide range of host plants usually dicotyledonous herbaceous plants, occasionally trees or shrubs and rarely on grasses. Grey-brown cutworm hosts include cabbage (*Brassica rapa*), apple (*Malus* x *sylvestris*), garden pea (*Pisum sativum*), plantain (*Plantago* spp.) and wheat (*Triticum aestivum*).
- A successful transfer of grey-brown cutworm to susceptible host will depend on multiple insects escaping from utility points where large numbers of imported apple are stored for unpacking or packing because these points would have more infested fruits for males and females of grey-brown cutworm to emerge and successfully mate.
- The natural dispersal stage for grey-brown cutworm is the adult.
- Distribution of the commodity in the PRA area would be for wholesale and retail sale, processing and human consumption. Grey-brown cutworm has been intercepted on New Zealand produce, indicating that the larvae can survive cold storage during distribution.
- Waste material would be generated during distribution and consumption. Waste produced by apple retailers and processors may be disposed into landfills. Commercial host fruit crops would usually not be near these sites; however, wild and amenity host plants may be in the proximity of landfill areas and may be susceptible to grey-brown cutworm infestation if eggs and larvae were able to survive landfill processing procedures and reach maturity.
- Some households dispose of their organic waste as compost, host plants within the garden may be exposed to grey-brown cutworm larvae from infested apples if eggs and larvae are able to survive and transfer from the composting site.

Probability of entry

The likelihood that grey-brown cutworm will enter Australia as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Low**.

The overall probability of entry is determined by combining the probabilities of total importation and distribution using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that grey-brown cutworm will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

Establishment is defined as the 'perpetuation, for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a 'high' probability of establishment is provided in the text below.

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

Grey-brown cutworm attacks apples, garden pea, plantain (*Plantago* spp.), wheat and is polyphagous on a wide range of dicotyledonous herbaceous plants (HortResearch, 1999b).

Commercial crops such as apples and wheat are grown in all States and Territories in Australia, except in the northern tropical regions. Apples are also found and grown in suburban backyards in temperate Australia.

Some susceptible host plants of grey-brown cutworm for example, apple are planted as high density monocultures.

Susceptible host plants such as apple as well as common weeds such as plantain (*Plantago* spp.) and other pasture plants are readily available.

Suitability of the environment

Grey-brown cutworm is found in New Zealand where climatic conditions are similar to those in temperate Australia.

Potential for adaptation

The potential for adaptation of the pest is not known. However, grey-brown cutworm is polyphagous and host plants are present in Australia.

Reproductive strategy

Grey-brown cutworm reproduces sexually. Successful mating between a male and a female must occur before eggs are produced.

Minimum population needed for establishment

When the larvae hatched from eggs find a host, they need to develop, pupate, become adults and mate before laying their eggs to establish a new population while avoiding mortality because of predation and environmental stress.

Cultural practices and control measures

IPM programs are utilised for the control of other pests in the production of Australian apples, including apples grown in Western Australia. This may reduce the likelihood of establishment of grey-brown cutworm.

Probability of spread

The likelihood that grey-brown cutworm will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Spread is defined as the ‘expansion of the geographical distribution of a pest within an area’ (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia

The draft report *Extension of Existing Policy for Stone fruit from New Zealand into Western Australia* (BA, 2005) assigned a rating of 'moderate' for this pest. As a result of an initial review of stakeholder comments on this draft report it was concluded that the rating was underestimated. On this basis a ‘high’ probability of spread was considered appropriate. Supporting evidence for a ‘high’ probability of spread is provided below.

Suitability of natural and/or managed environment

Grey-brown cutworm is native to New Zealand. There are similar environments in Australia that would be suitable for its spread.

Presence of natural barriers

Both the adult male and female are winged and are capable of flight.

The main commercial fruit crops of grey-brown cutworm, including apple and wheat crops, are located in six states of Australia, with natural barriers including arid areas, climatic differences and long distances between these areas.

However, other host plants between the commercial apple orchards in different areas would help the spread of grey-brown cutworm over several generations.

Potential for movement with commodities or conveyances

A mixture of adult flight and the transportation of infested apple trees have probably aided the movement of grey-brown cutworm within orchards.

The means of dispersal would include eggs on fruit or crawling larvae.

Long-distance dispersal is through adult flight, as both males and females are winged. Short-distance dispersal is through the movement of active larvae to new host plants.

Existing interstate quarantine control on the movement of nursery stock would reduce the rate of spread.

Intended use of the commodity

Grey-brown cutworms have multiple hosts including nursery stock for planting and fruit for human consumption. Eggs contaminating the fruit may be distributed with apple fruit around the country. Consumption of fruit and limitations on nursery stock movement between states would limit spread.

Potential vectors of the pest

Grey-brown cutworm does not require a vector for its spread since it is capable of independent flight.

Potential natural enemies

The relevance of potential natural enemies in Australia is not known.

Conclusion – probability of entry, establishment and spread

The overall likelihood that grey-brown cutworm will enter Australia as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Low**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are shown in Table 63. Available supporting evidence is provided in the text below.

Table 63 Impact scores for grey-brown cutworm

Direct impact	Impact scores
Plant life or health	D
Human life or health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	D
Domestic trade or industry	D
International trade	D
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are unlikely to be discernible at the national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Grey-brown cutworm is a polyphagous insect that causes direct harm to a wide range of commercial crops. Feeding damage reduces marketability of produce.

Human life or health – A

There are no known direct impacts of grey-brown cutworm on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There is no known direct impact of grey-brown cutworm on any other aspects of the environment and a rating of '**A**' was assigned to this criterion.

Indirect impact

Control or eradication – D

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies is unlikely to be discernible at the national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

Attempts at control or eradication may lead to an increase in the use of insecticides because of difficulties in estimating the optimum time for insecticide application. Increased insecticide use may lead to a subsequent increase in cost of production to producers.

There may be increased costs for crop monitoring and consultant's advice to the producer.

Domestic trade or industry – D

The indirect consequences on domestic trade are unlikely to be discernible at a national level and would be of minor significance at a regional level. A rating of '**D**' was assigned to this criterion.

The presence of grey-brown cutworm could result in trade restrictions in the sale or movement of infested commodities within that district and region and between states and between different districts.

International trade – D

The indirect consequences on international trade are unlikely to be discernible at a national level and would be of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

If grey-brown cutworm became established in Australia, trading partners may require risk management measures for imported commodities.

Environment – B

The indirect consequences on the environment would not be discernible at the national level and would be of minor significance at the local level and a rating of '**B**' was assigned to this criterion.

Additional pesticide applications or other control activities may be required to control grey-brown cutworm and this increased insecticide use could cause undesired effects on the environment.

Communities – B

The indirect consequences on communities would not be discernable at national level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the methodology, that is, where the consequences of a pest with respect to one or more criteria are ‘**D**’, the overall consequences are considered to be ‘low’. Therefore the overall consequences of grey-brown cutworm are ‘**low’**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix (Table 11) in the method section. The unrestricted annual risk estimation for grey-brown cutworm is shown in Table 64.

Table 64 Unrestricted risk estimation for grey-brown cutworm

Overall probability of entry, establishment and spread	Low
Consequences	Low
Unrestricted annual risk	Very low

As indicated in Table 64, the unrestricted annual risk for grey-brown cutworm is ‘very low’, which meets Australia’s ALOP. Therefore, risk management would not be required for this pest.

Introduction

This assessment relates to five species of leafrollers:

Brownheaded leafroller, *Ctenopseustis herana* (Felder and Rogenhofer)

Brownheaded leafroller, *Ctenopseustis obliquana* (Walker)

Greenheaded leafroller, *Planotortrix excessana* (Walker)

Greenheaded leafroller, *Planotortrix octo* (Dugdale)

Native leafroller, *Pyrgotis plagiatana* (Walker).

These five species of tortricid moths were assessed together because they are classified in the same family and are predicted to have a similar biology.

Brownheaded and greenheaded leafrollers are considered of ‘primary’ economic importance (Wearing et al., 1991) while the native leafroller *Pyrgotis plagiatana* is considered an incidental species (Wearing et al., 1991) that is occasionally found attacking apples and pears (HortResearch, 1999b). More published biological information is available for the primary pest species and therefore these four species were used as the basis for the following risk assessment.

Biology

Leafrollers are the larval (caterpillar) stages of a number of species of moth of the family Tortricidae, which includes at least 5000 species worldwide. Leafrollers have four life stages: adult, egg, larva (caterpillar) and pupa. The larvae of leafrollers (*Planotortrix, Ctenopseustis*, and *Pyrgotis*) feed on leaves or fruit.

When the adult leafroller is at rest, only the forewings are visible, with one overlapping the other to form a bell-shaped outline. The body length of adult brownheaded leafroller moths ranges from 8 to12 mm for females and 8 to 11 mm for males. The wingspan of female brownheaded leafrollers ranges from 20 to 28 mm while that of the males ranges from 17 to 24 mm. Adult brownheaded leafrollers are extremely variable in colour and forewing pattern. In both sexes the forewings vary from dark brown (almost black) to a pale fawn. Both males and females have a characteristic darker oblique mark halfway down the edge of each forewing and males also have a characteristic dark transverse stripe (often black) across the front part of the folded wings.

Adult greenheaded leafroller moths have a body length ranging from 8 to 14 mm for females and 7 to 12 mm for males, and wingspans of 22–30 mm for females and 18–25 mm for males. Females are normally pale to dark brown, often with a series of broad darker brown variable zigzag markings on the forewing and a prominent, subapical dark brown spot. The forewings of the male are a uniform medium to dark coppery brown, sometimes with a distinct greyish surface sheen. Adults are not readily distinguishable from other, closely related leafroller moths.

Brownheaded and greenheaded leafrollers lay eggs in flat oval rafts or batches of between 2 and 216, usually on the upper surface of host plant leaves. The eggs are flat, with a pebbled surface and overlap each other within the raft to form a smooth mass. This makes it difficult to distinguish the eggs from the surrounding leaf surface. Eggs of greenheaded leafroller are approximately 1.3 × 1 mm and egg batches are densely coated with characteristic white particles that make it difficult to see individual eggs. They are initially blue-green and change to a paler yellow-green as they develop. brownheaded leafroller eggs are approximately 0.7 × 1.0 mm, with a sparse coating of particles over the surface of egg batches. They are initially pale green and change to a more yellow-green as they develop. Before hatching, the dark head of the developing caterpillar is visible through the egg wall, giving the egg batches a blotchy or speckled appearance (Anonymous, 1983; HortResearch, 1998).

Larvae of different leafroller species are very similar in appearance and it can be very difficult to distinguish between them. The first larval instar of brownheaded leafroller is about 1.5–2.0 mm long, has a pale brown head with a dark mark on each side, and the body is often pale green. The head becomes strikingly black in the second instar and changes again, through subsequent instars, from dark brown to reddish or pale brown. Body colour varies. The mature larva may have faint red or red-brown stripes on its head, and is up to 20 mm long. The two species of brownheaded leafroller are visually identical at all life stages, as are the two species of greenheaded leafroller. The first larval instar of the greenheaded leafroller is about 1.5–2.0 mm long and has a pale brown head with a dark mark on each side. During development, the head and the plate behind it become paler and almost transparent. The full-grown mature larva is about 25 mm in length and the head and the plate behind it are shining green. The body is pale bluish-green with diffuse, white longitudinal bands.

The pupa (chrysalis) of brownheaded and greenheaded leafrollers is at first green. It soon becomes brown after rapidly hardening, and then darkens during development. The pupa is typically found in a thin-walled silken cocoon between two leaves webbed together, and is usually 10–15 mm long; the female pupae are larger than those of the male. At the end of the abdomen, two prominent broad-based laterally projecting spines and several hooks support the pupa in its cocoon. Each abdominal segment also has a series of short, backward-projecting spines that are used by the pupa to move partially out of its cocoon before the moth emerges (HortResearch, 1999b).

Other information relevant to the biology of leafrollers is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of concern for leafrollers in this draft IRA is the presence of larvae on or inside the apple fruit. Leafroller larvae are known to enter the calyx and feed on the internal tissue of apple fruit as well as feeding externally on apple fruit from within a protective silken shelter between a leaf and the fruit (HortResearch, 1999b).

The potential for viable leafroller eggs or larvae to be associated with trash after harvesting, packing house processing and transport would be minimal. The majority of trash would be eliminated during apple processing in the packing house.

Probability of entry, establishment and spread

The following analysis examines the likelihoods of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk, with respect to Australia’s ALOP.

The probability of entry is obtained by considering the ‘importation’ and ‘distribution’ pathways for the commodity and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed.

Importation

The likelihood that leafrollers will arrive in Australia with the importation of apple fruit from New Zealand: **Moderate.**

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, while the end-point is the release of imported apples from the port of entry.

Supporting evidence for the 'moderate' probability of importation is provided in the text below.

Source orchards

Brownheaded leafrollers, *Ctenopseustis obliquana* and *C. herana* and greenheaded leafrollers, *Planotortrix excessana* and *P. octo,* occur only in New Zealand, including some offshore islands (Thomas, 1998).

C. obliquana is a major pest of apples in Hawke's Bay, Gisborne, the Waikato region and Nelson.

C. herana is a pest species in apple orchards mainly in Nelson, Canterbury and the Waikato (HortResearch, 1999b).

Greenheaded leafrollers inhabit most lowland forest margins and horticultural areas (Thomas, 1998).

P. excessana is rare or infrequent in the eastern regions of the country and it is a major pest of apples in Nelson and the Waikato (HortResearch, 1999b).

P. octo is found in both the North and South Islands and is particularly important in the eastern apple growing regions of Poverty Bay, Hawke's Bay, Marlborough, Canterbury and Central Otago. It is also a pest in the Waikato region (HortResearch, 1999b).

In the Auckland area there are four to six overlapping generations annually and every stage of the lifecycle is present throughout the year (Green, 1998).

Re-invasion of apple trees by the overwintering generation takes place during October–December (HortResearch, 1999b).

Walker et al. (1996) found the incidence of leafrollers ranged from nine larvae from 1200 shoots (cv Braeburn) to three larvae from 1200 shoots (cv. Fuji) at Twyford (Walker et al., 1996).

Harvesting fruit for export

Occasionally young larvae enter through the calyx and feed on the internal tissue of the apple. When this occurs, the apple fruit may show no sign of external damage (HortResearch, 1999b; Thomas, 1998).

Young and mature larvae occasionally attach ('web') leaves to the fruit as a shelter where they feed on the surface of the fruit.

Early instar caterpillars settle mainly on the lower surfaces of leaves where they construct silken shelters and feed near the main leaf veins or in shoot tips.

Internal damage to apple fruits caused by greenheaded leafrollers is much less common than surface damage (HortResearch, 1999b).

Egg-masses of greenheaded leafrollers are laid together on leaves while their larvae feed mainly on leaves by forming a protective shelter by spinning them together with silk (HortResearch, 1999b).

If disturbed during the day adults make a short flight or escape ‘jump’ into ground vegetation (Thomas, 1998).

Fruit are picked into picking bags and then transferred into bins kept on the ground in the orchard before transportation to the packing house.

- Larvae that have been dislodged from trees could contaminate harvest bins or containers used to transport apples to the packing house.
- Larvae feeding internally would not move into other fruit; they would remain in the fruit they are already feeding in.

Processing of fruit in the packing house

The following packing house operations may influence the viability of leafrollers.

Larvae feeding within the apple would not be removed by washing, although internal feeding is not common.

Larvae feeding externally in a protective silken shelter between the fruit and a leaf or two fruits are likely to be removed by brushing.

Larvae protected inside apple fruit may survive the waxing process, while external larvae would not survive the waxing process.

Sorting and grading would remove some fruit that are contaminated with external larvae and some fruit containing internal larvae as entrance holes or frass (droppings) outside the fruit would be noticeable (Thomas, 1998).

Larvae of greenheaded leafrollers overwinter as late instars in the cold Canterbury region in the South Island of New Zealand (Thomas, 1998), suggesting that they are able to survive cold conditions.

Larvae inside apple fruit would almost certainly be able to survive storage before transportation since they are able to feed in the fruit or alternatively survive as a resting stage in cool storage.

Larvae feeding internally in apple fruit (HortResearch, 1999b) would not move about to attach to other fruit.

Externally occurring larvae that have survived the packing house processes to this point would be able to move among the apples. However, the number of larvae would remain the same.

Pre-export and transport to Australia

Leafroller larvae should be able to survive the cold conditions experienced during refrigerated transport since greenheaded leafroller larvae overwinter as late instars in the Canterbury region of the South Island of New Zealand (Thomas, 1998).

Larvae inside the apple fruit may initially be provided with some protection from the cold and they may be able to survive by feeding internally on the fruit.

Planotortrix excessana has been intercepted on fresh avocados exported from New Zealand to Australia (DAFF-PDI, 2002), indicating that larvae can survive cold storage during transportation.

Brownheaded leafroller larvae have been detected several times on imported fresh apricots, peaches, nectarines, cherries and avocados (DAFF-PDI, 2002), indicating that larvae can survive cold storage (DAFF-PDI, 2002). Note that the above mentioned commodities do not undergo similar washing and packing house processing as for apple fruit.

HortResearch (1999b) indicates that the threshold temperature of development for brownheaded leafroller is 4.8°C and for greenheaded leafroller 6.1°C. This data indicate while leafrollers may survive colder conditions they are unlikely to develop.

Packaging would have little effect on the viability of the remaining larvae. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture providing ideal conditions for any surviving caterpillars.

On-arrival procedures

The minimum on-arrival border procedures as described in the method section would not be effective in detecting the larvae.

Distribution

The likelihood that leafrollers will be distributed to the endangered area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Moderate**.

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The sequence of events that has to be completed for a successful transfer of leafrollers to a susceptible host is summarised below.

Leafrollers are associated with apples in the larval life stage. If the larvae were to survive fruit harvesting, processing, cold and/or controlled atmosphere storage and transport to Australia it would then have to move out from the fruit to find a site to pupate.

Leafrollers are able to move to a host plant in either the larval or adult stage. The time since being removed from cold storage and proximity to susceptible host plants are important factors in the successful transfer of leafrollers to nearby host plants. For example, a larval leafroller developing soon after removal from cold storage would not be able to move far and the danger of mortality, including predation, is high for a young larva searching for a place to pupate. In contrast to this, if larvae spend longer developing and pupating in the apple consignment, they will emerge as adults that could fly quickly and in relative safety to hosts up to 400 metres away.

Winged adult leafrollers can escape from many points in the apple supply and waste pathways. Escape of adult leafrollers could occur at packing facilities, wholesalers, retailers, during the transportation, from discarded fruit in waste, and from landfills where the waste is disposed. Sexual reproduction is essential for leafrollers. Female pheromones are released in the evening and night, particularly around dusk, to attract males for mating.

In summary, a successful transfer of leafrollers from infested fruit to a suitable host requires several crucial steps. Larvae need to survive processing and transport, mature larvae need to emerge from fruit to pupate, pupae need to develop into adults in sufficient numbers and proximity to susceptible hosts to ensure adult females could locate a male to mate with and then find a susceptible host on which to lay their eggs. Finally, environmental conditions need to be suitable to allow continued population development.

Supporting evidence for a 'moderate' probability of distribution is provided in the text below.

- Larvae of greenheaded and brownheaded leafroller species are highly polyphagous and have a wide host plant range. Leafroller larvae have been found on more than 200 plant species. Some of the more important and common leafroller hosts are: kiwifruit, apples, pears, grapes, citrus varieties, stone fruit, walnut, lupin, ivy, *Camellia*, laurel, *Hebe*, *Polyanthus*, *Coprosma*, young conifers, *Feijoa*, and berries. Other host plants include pohutakawa, karaka, mahoe, poroporo, willow, honeysuckle, privet, poplar, *Eucalyptus*, *Cyclamen*, orchids, roses, and clover. Many of these leafroller host plants are common and widely available throughout Australia. These include native and naturalized wild plants, household and garden plants and horticultural crops.

- A successful transfer (mating and over position) of leafrollers to susceptible hosts multiple insects escaping from utility points where large numbers of imported apple are stored for unpacking or packing.
- Distribution of the fruit would be for retail sale, as the intended use of the commodity is human consumption.
- Waste material would be generated during distribution and consumption. Waste produced by apple retailers and processors may be disposed into landfills. Commercial host fruit crops would usually not be near these sites; however, wild and amenity host plants may be in the proximity of landfill areas and may be susceptible to leafroller infestation if they were able to survive landfill processing procedures and reach maturity.
- Some households dispose of their organic waste as compost, host plants within the garden may be exposed to leafrollers from infested apples if larvae are able to survive and transfer from the composting site, pupate and emerge as adults.
- Early instar larvae escaping detection are likely to survive cold storage and distribution to the endangered area where they could develop to pre-pupation within the fruit before fruit desiccation or decay. Provided a sheltered site is available, larvae that escape detection could pupate and emerge as adults.
- Consumption or discarding of the apple fruit and the search by the larvae for a suitable pupation site may increase mortality.
- Leafrollers are associated with apples in the larval life stage. Larvae of brownheaded leafroller and greenheaded leafroller species may be able to survive, but are unable to develop, below temperatures of 4.8˚C and 6.1˚C respectively. If the larvae survive cold storage and mature after the apples have been taken out of cold storage, they could pupate in the apple consignment or move into the PRA area for pupation.
- Leafroller adults are winged and can escape from many points in the apple supply, distribution and waste pathways if cold storage conditions are removed for a sufficient time period for larvae to mature, move to pupation sites and successfully pupate without mortality.
- Sexual reproduction is essential for leafrollers. Female pheromones are released in the evening and night, particularly around dusk, to attract males for mating.

Probability of entry (importation x distribution)

The likelihood that leafrollers will enter Australia as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Low**.

- The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of ‘rules’ for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that leafrollers will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High.**

Establishment is defined as the ‘perpetuation for the foreseeable future, of a pest within an area after entry’ (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a ‘high’ probability of establishment is provided in the text below.

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

Caterpillars of greenheaded and brownheaded leafrollers have been recorded on more than 200 plant species in 71 families. While many of these are true host plants, which enable the insect to complete its full lifecycle, others may be only temporary hosts for the caterpillars (HortResearch, 1999b).

Some of the more important and common hosts of leafrollers are: apples, pears, grapes, citrus, stone fruit, kiwifruit, *Feijoa*, berryfruits, walnut, lupin, tree lupin, ivy, *Camellia*, laurel, *Hebe, Polyanthus, Coprosma* and young conifers (HortResearch, 1999b).

Caterpillars of native leafroller have been recorded on apple, pear, *Cassinia*, *Coprosma*, *Hebe*, and *Pittosporum* (HortResearch, 1999b).

Many of these host plants are widely available in Australia.

Suitability of the environment

Brownheaded and greenheaded leafrollers are found throughout New Zealand and some offshore islands where climatic conditions are similar to those of Australia.

The environment (for example, suitability of climate, soil, pest and host competition) in Australia would therefore be suitable for the establishment of these leafrollers.

Leafrollers develop faster in the warmer areas of New Zealand and around Auckland can complete up to four overlapping generations per year. Since many areas of Australia are comparable in climatic temperatures to the warmer areas of New Zealand, leafrollers may also develop quickly and have continuously overlapping generations in Australia.

The potential for adaptation of the pest

The genetic adaptability of brownheaded and greenheaded leafroller populations has not been studied, but high host range and the potential for several generations per season may indicate potential for genetic adaptation.

Planotortrix octo has developed resistance to the organophosphate insecticide azinphos-methyl and cross resistance to several other insecticides in Central Otago (Wearing, 1995a) and Hawke’s Bay (Lo et al., 1997; Lo, 2003).

Ctenopseustis obliquana has developed resistance to the organophosphate insecticide azinphos-methyl and cross-resistance to the Insect Growth Regulator Mimic™ in Hawke’s Bay and resistance to a pyrethroid in the Bay of Plenty (Lo, 2003).

The reproductive strategy of the pest

Leafrollers only reproduce sexually and produce from two to six overlapping generations a year depending on latitude and climate.

Development is temperature driven with the threshold temperature for development determined to be 4.8ºC for brownheaded leafroller and 6.1ºC for greenheaded leafroller larval development is slowed considerably during the winter (HortResearch, 1999b).

In the central New Zealand region there is no winter resting stage (HortResearch, 1999b).

Development for greenheaded leafroller from egg to adult can be completed in 4 to 6 weeks in summer (Landcare Research, 1999).

Greenheaded and brownheaded leafrollers produce distinct female sex pheromones that are released in the evening and night, but particularly around dusk, to attract males over long distances.

Females are normally mated once, although both sexes are capable of mating more often. Most mating occurs 1 to 4 days after adult emergence.

Fecundity is highly variable between individual females and in one study ranged from 52–282 eggs/female for greenheaded leafroller and from 58–429 eggs/female for brownheaded leafroller when larvae were fed on apple foliage. Variation in fecundity is determined primarily by weather conditions, and probably the quality and succession of host plants.

Egg infertility in New Zealand under natural conditions is rare at less than 1%, as is egg mortality, which averages only 2% (HortResearch, 1999b).

Successful mating between a male and a female must occur within the limited lifespan of the adult.

Minimum population needed for establishment

Populations can start from a single mated female that is able to lay up to 216 eggs (HortResearch, 1999b).

After larvae have hatched from eggs they need to find a host, before they can develop, pupate and become adults and mate before laying their eggs to establish a new population.

Cultural practices and control measures

Pest control programs are similar between New Zealand and Australia. Integrated pest management (IPM) and integrated fruit production (IFP) programs are utilised in the production of Australian apples (APAL, 2003). Similarly New Zealand orchardists use IFP in the production of their fruit (ENZA, 2003; Anonymous, 2002). These existing programs may adversely affect the ability of leafrollers to establish.

Mating disruption is also being used for resistance management of these leafrollers in New Zealand (HortResearch, 1999b) and the bacterial spray *Bacillus thuringiensis* is frequently used for organic control of leafrollers (HortResearch, 1999b).

Some parasitoids introduced from Australia for the control of light brown apple moth in New Zealand have also attacked these leafrollers and are now found in their populations (HortResearch, 1999b). This may also adversely affect the ability of leafrollers to establish.

Probability of spread

The likelihood that leafrollers will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Spread is defined as the ‘expansion of the geographical distribution of a pest within an area’ (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed host plant, or group of host plants, to susceptible host plants in other parts of Australia.

Supporting evidence for a ‘high’ probability of spread is provided in the text below.

Suitability of natural and/or managed environment

These species have been reported from all over New Zealand. There are similar environments in Australia that would be suitable for their spread.

These leafroller species are able to survive in both cold and warmer areas of New Zealand, thriving in the warmer northern areas. Their potential for natural range expansion may not have been realised in the limited size and habitat availability of New Zealand. The Australian environment may provide a larger choice of suitable habitats for leafrollers to expand their range.

Presence of natural barriers

There is little information on the ability of these leafrollers to spread beyond natural barriers. The long distances existing between some of the main Australian commercial orchards may make it difficult for these leafrollers to disperse directly from one area to another unaided.

However, the highly polyphagous nature of these species may enable them to locate suitable hosts in the intervening areas.

Potential for movement with commodities or conveyances

A mixture of adult flight and the transportation of infested apple trees and fruit would probably aid the movement of the leafrollers within orchards.

Existing interstate quarantine control on the movement of nursery stock would reduce the scope for the spread.

Larvae that are in the calyx or feeding internally would be distributed through the wholesale or retail trade of apples.

Intended use of the commodity

Leafrollers have multiple hosts with multiple end uses. Limitations upon the movement of nursery stock and host fruit (if implemented) would slow the spread of leafrollers.

Potential vectors of the pest

Leafrollers do not require a vector for their spread because they are capable of independent flight.

Potential natural enemies

Some parasitoids present in Australia would be able to attack these leafrollers because several species (such as *Goniozus jacintae*, *Glabridorsum stokesii*, *Xanthopimpla rhopaloceros* and *Trigonospila brevifacies*) have been introduced from Australia for the control of light brown apple moth in New Zealand (HortResearch, 1999b) and have also been reported attacking these leafrollers in New Zealand.

Conclusion – probability of entry, establishment and spread

The overall likelihood that leafrollers will enter Australia as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Low**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of ‘rules’ for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are shown in Table 65. Available supporting evidence is provided in the text below.

Table 65 Impact scores for leafrollers

Direct impact	Impact scores
Plant life or health	D
Human life or Health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	E
Domestic trade or industry	D
International trade	E
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are unlikely to be discernible at national level and of minor significance at the regional level. Thus a rating of '**D**' was assigned for this criterion.

Wearing et al. (1991) rated brownheaded and greenheaded leafrollers as primary economic pests in New Zealand where they damage the leaves, buds and fruit of their hosts.

Brownheaded and greenheaded leafrollers are pests of apples, pears, stone fruit, berries, oaks, conifers, cotoneaster and ivy. Brownheaded and greenheaded leafrollers are highly polyphagous feeding on over 200 species of plant both economic (such as fruit trees, vines as well as apples) and non-economic in 71 families (HortResearch, 1999b).

Brownheaded and greenheaded leafrollers cause similar damage to foliage and fruits. Leaf feeding and shoot damage often includes leaf folding and rolling and shoot distortion. Buds of deciduous host plants are especially vulnerable to attack in the winter and early spring, when the interior of the buds may be eaten. Leaves are webbed to the fruit and feeding injury takes place under the protection of the leaf; or larvae spin web between fruits in a cluster.

Surface fruit damage is common in short-stemmed apple varieties such as Cox's Orange Pippin, Sturmer Pippin, which form compact fruit clusters.

Young larvae biting through the skin cause small circular 'stings'. In crops such as kiwifruit, plum, grapefruit and apple, the maturing fruit produces a layer of corky tissue over the damage by leafrollers. The fruit surface is eaten and some caterpillars bore into the fruit, particularly through the calyx. Internal damage to apple and pear fruits is much less common than surface damage. Leafrollers can also cause internal damage to apricots, peaches, and walnuts.

On *Pinus* species, greenheaded leafrollers web needles together and form them into a tube that kills the needles, which then turn brown and hard. Greenheaded leafroller larvae feed on foliage, stems, growing points, flowers and green cones, and, in winter, buds and stems are attacked resulting in malformation and retardation of growth of young stems (Anonymous, 1983).

All life stages are present throughout the year especially in the warmer regions around the Waikato and Auckland. Two to four overlapping generations occur annually depending on latitude and host plant.

Human life or health – A

There are no known direct impacts of greenheaded and brownheaded leafroller on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There are no known direct impacts of the leafrollers on any other aspects of the environment and a rating of '**A**' was assigned to this criterion.

Indirect impact

Control or eradication – E

The indirect impact of new or modified eradication, control, surveillance/monitoring and compensation strategies is and of minor significance at the national level and significant at the regional level. A rating of '**E'** was assigned to this criterion.

In New Zealand leafrollers are kept under control by the application of organophosphate insecticides and insect growth regulators, such as tebufenozide, that are also used for the control of other pests such as apple leafcurling midge and other leafrollers, in particular light brown apple moth (HortResearch, 1999b).

Planotortrix octo and *Ctenopseustis obliquana* have already developed resistance and cross-resistance to various organophosphates and insect growth regulators in New Zealand (Wearing, 1995a; Lo et al., 1997; Lo, 2003). Thus it would be more difficult to eradicate or control these pests if the resistant leafrollers were introduced into Australia.

The extremely wide range of host species for these species would also make it difficult to completely eradicate them from the natural environment.

Mating disruption, *Bacillus thuringiensis* and pyrethrum are being investigated but are not widely used (McLaren and Fraser, 1994). Despite the activity of natural enemies they are inadequate for commercial leafroller control (McLaren and Fraser, 1994).

Although the brownheaded and greenheaded leafrollers have been reasonably well studied in New Zealand it would be essential to provide resources to study the pest under Australian conditions should they become established in Australia.

An increase in the use of insecticides may occur for control because of difficulties estimating the optimum time for insecticide application.

Increased costs for crop monitoring and consultant's advice to the producer may be incurred.

Domestic trade or industry – D

The indirect consequences on domestic trade are unlikely to be discernable at national level and of minor significance at the regional level. A rating of '**D**' was assigned to this criterion.

The presence of leafrollers in commercial production areas may have a highly significant effect at the local level because of any resulting interstate trade restrictions on a wide range of commodities. These restrictions could lead to a loss of markets, which in turn would be likely to require industry adjustment

International trade – E

The indirect consequences on international trade are of minor significance at the national level and significant at the regional level. A rating of '**E'** was assigned to this criterion.

- These leafrollers are endemic in New Zealand and are treated as quarantine pests by many countries.
- If leafrollers become established in Australia trading partners may require phytosanitary measures for exported host commodities.

Environment – B

The indirect consequences on environment would not be discernible at the national level and of minor significance at the local level and a rating of '**B**' was assigned to this criterion.

The impact on environment by these leafrollers can result from chemical control, biological control and feeding damage on native plants.

Increased insecticide use may cause undesired effects on the environment.

Control of leafrollers primarily depends on the application of broad-spectrum insecticides such as organophosphates, carbamates, and, to a limited extent, synthetic pyrethroids, which are applied against other key apple pests in conventional New Zealand orchards. These products have provided very effective control of leafrollers and other pests but they have had the disadvantage of wider toxicity to many natural enemies.

Recently, the chemical industry has developed effective insect growth regulator compounds, which combine toxicity to leafrollers with safety to many important beneficial species.

The introduction of other biocontrol agents can affect existing biological control programs of other pests particularly light brown apple moth.

The introduction of new biocontrol agents for leafrollers would also affect the simplified orchard ecosystem as well as native ecosystems in the vicinity of orchards in the first instance, particularly if the biocontrol agents turn out to be not host specific in the wild.

A wide range of beneficial predators and parasitoids attack greenheaded and brownheaded leafrollers, but these have never been the primary method of control in commercial orchards.

Parasitoids introduced for control of light brown apple moth (an Australian species) have been found parasitising greenheaded and brownheaded leafroller. These include *Goniozus jacintae* and *Glabridorsum stokesii*, *Trigonospila brevifacies*, and *Xanthopimpla rhopaloceros* from Australia. These are contributing to reducing pest populations of greenheaded and brownheaded leafroller not only in orchards but also on their many host plants in the surrounding environment. This could minimise immigration of moths into orchards and reduce the need for chemical control (HortResearch, 1999b).

Biological control agents, such as *Bacillus thuringiensis* or viruses, may offer an alternative method of control (HortResearch, 1999b).

Native plant communities as well as crop species may be affected following the introduction of these leafrollers given the wide host range of these species that includes genera such as *Acacia*, *Acmena*, *Boronia*, *Eucalyptus* and *Leptospermum*, which are such dominant representatives of Australian flora.

Communities – B

The indirect consequences on communities would not be discernable at national level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**E**', the overall consequences are considered to be 'moderate'. Therefore, the overall consequences of leafrollers are '**moderate'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for leafrollers is shown in Table 66.

Table 66 Unrestricted risk estimation for leafrollers

Overall probability of entry, establishment and spread	Low
Consequences	Moderate
Unrestricted annual risk	Low

As indicated in Table 66 the unrestricted risk for leafrollers is 'low', which is above Australia's ALOP. Therefore, risk management would be required for these pests.

Risk management for leafrollers

Brownheaded and greenheaded leafrollers are quarantine pests for stone fruit. Inspection and remedial action, if leafrollers are detected, is proposed as adequate risk management for New Zealand stone fruit to Australia. The proposed risk management measure for leafrollers is inspection and remedial action based on a 600-fruit sample from each lot.

Information from New Zealand states that 'The calyx of various fruits, especially pip fruits, may be invaded by young larvae [of brownheaded leafrollers] but show no external damage' (HortResearch, 1998) and therefore visual inspection may not be appropriate for detecting the internal larvae in apple fruit. There are apparently no studies on the exact percentage of internal damage caused by brownheaded and greenheaded leafrollers. Nevertheless, HortResearch (1999b) indicates that internal damage to apple fruits by leafrollers is much less common than surface damage. The most important and common leafroller pest in New Zealand apple orchards, more than the brownheaded and greenheaded leafrollers, is the light brown apple moth, which can also bore into fruit.

Because of the uncertainty about the level of internal infestation of apple fruit by brownheaded and greenheaded leafrollers, New Zealand is requested to provide additional information that addresses these issues. One approach to providing additional data could be the examination of a 600 cut fruit sample the presence of internal larvae of brownheaded and greenheaded leafrollers at the beginning of the export season in all packing houses that export apples to Australia. If the results from all the inspections do not detect the presence of internal larvae of these leafrollers, fruit cutting will not be required in the future for the detection of leafrollers. If the sampling revealed the presence of larvae of brownheaded and greenheaded leafrollers, future inspection would require fruit cutting.

When a consignment is found to be infested with leafrollers in New Zealand or at on-arrival inspection in Australia, the following phytosanitary measures may be applied to maintain Australia's ALOP:

- withdrawing the consignment from export to Australia (pre-clearance)
- re-export of the consignment from Australia
- destruction of the consignment
- treatment of the consignment to ensure that the pest is no longer viable.

The objective of this measure is to ensure that consignments of apple fruit from New Zealand infested with leafrollers can be readily identified and subjected to appropriate remedial action. This measure is considered to reduce the risk associated with leafrollers to meet Australia's ALOP.

Pests assessed for Western Australia

Apple scab or black spot

Codling moth

Mealybugs

Oriental fruit moth

Oystershell scale

Introduction

Apple scab (referred to as black spot in New Zealand), caused by the fungus *Venturia inaequalis* (Cooke) G. Winter (1875), is the most economically important disease of apples worldwide (CABI, 2005). *V. inaequalis* occurs in Australia (APPD, 2005) except in Western Australia, where it has been eradicated (McKirdy et al., 2001).

Biology

According to Keitt (1953), *V. inaequalis* attacks only members of the genus *Malus*, which includes cultivated apple (*Malus* × *domestica*) and crab-apples (*M. coronaria* and *M. iowensis*). *V. inaequalis* has also been recorded on other hosts including arrow-wood (*Viburnum* spp.) and loquat (*Eriobotrya japonica*) (MacHardy, 1996; CABI, 2005). Although *Sarcocephalus esculentus* is listed as a host (MacHardy, 1996) and is identified as a potential new crop for Australia[42], the species is not currently known to occur widely in Australia.

In pear (*Pyrus* spp.), scab is caused by *Venturia pirina* (Shabi, 1990). Several host specific forms referred to as 'formae speciales' of *V. inaequalis* on mountain ash (*Sorbus aucuparia*), hawthorn (*Crataegus oxycantha*) and cotoneaster (*Cotoneaster integerrma*) have been designated (Menon, 1956). Similarly, firethorn (*Pyracantha* spp.) is also infected by another 'formae speciales' of *V. inaequalis* (Le Cam et al., 2002). These 'formae speciales' are not known to cause infection on *Malus* spp.

Venturia inaequalis attacks leaves, petioles, blossoms, sepals, fruits, pedicels and less frequently, young shoots and bud scales. However, the most obvious symptoms occur on leaves and fruit (Biggs, 1990). The fungus produces two distinct types of spores, conidia (asexual) and ascospores (sexual). Ascospores released from overwintered leaves and fruits on the orchard floor are the principal source of inoculum in the spring. The lesions resulting from these infections produce conidia throughout the spring and summer and serve as secondary inoculum. Under favourable conditions, the pathogen attacks the leaves and fruit to cause serious damage. Crop losses have been estimated at around 70% where cool and humid weather conditions occur during spring (Biggs, 1990). Direct losses are caused by the reduction of fruit quality because of scabby growth. Indirect losses are the result of yield reductions that occur as a result of impaired growth vigour caused by repeated defoliation (Biggs, 1990).

The lesions on infected immature fruit that survive abscission enlarge and become brown and corky. Sometimes these lesions may coalesce to form what is referred to as 'sheet scab' but commonly discrete lesions are found on fruit. As fruit matures cracks appear on the fruit surface and these may extend into the flesh. Fruit may even become deformed owing to uneven growth of meristematic tissue near the fruit surface (Biggs, 1990).

Apples become more resistant to scab when they mature (Keitt and Jones, 1926). Fruit infected late in the season before harvest is likely to have 'pin-point' or 'pin-head' lesions that may not be visible at harvest. Such infections may cause 'storage scab', after 8–12 weeks in cold storage (MacHardy, 1996). These lesions are typically black and sunken and may either show rupture of the cuticle or have concentric bands.

[42] http://www.newcrops.uq.edu.au/listing/commonnameslistingindexd.htm. Accessed on 14 September 2005.

The Potential Ascospore Dose (PAD) prediction system (MacHardy and Jeger, 1982) is used throughout major apple production areas, including New Zealand, to effectively manage inoculum and apple scab infection levels within orchards (MacHardy, 1998). Inoculum levels are maintained at levels that ensure fruit quality is not adversely affected by disease infection by focusing on the reduction of the incidence of black spot on leaves before leaf fall and reducing the density of leaf litter remaining in the following spring (Horner and Horner, 2002).

Other information relevant to the biology and epidemiology of *V. inaequalis* is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of particular relevance to *V. inaequalis* is that associated with scabby growth on the surface of mature fruit and 'pin-point' lesions that are not visible. The latter may cause rotting symptoms in cold storage. This PRA considers apple fruit grown under standard agronomic practices for the production of export quality fruit within New Zealand.

Importation of trash is another potential pathway for introduction of *V. inaequalis.* This pathway was not considered in detail in this analysis, because the scope of this assessment is limited to mature apple exports from New Zealand free from trash. However, leaves and small twigs taken from apple trees at the time of harvest are no more likely to be carrying *V. inaequalis* than fruit and therefore do not present a special risk over and above that presented by fruit.

Probability of Importation

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand while the end-point is the release of imported apples from the port of entry. The importation scenario is divided into eight steps and the available evidence supporting the likelihood assessments is provided in the text that follows.

Importation step 1: Likelihood that *V. inaequalis* is present in the source orchards in New Zealand is 1.

Pathogen/disease distribution

Apple scab is endemic in all pipfruit production areas in New Zealand (Manktelow and Beresford, 1995). In the main apple production area of Hawke's Bay, more than 20% of growers had problems with scab (Stewart et al., 1993).

The highest number of infection periods occurred in Auckland followed by Nelson, Hawke's Bay and Canterbury. These areas account for 86% of New Zealand exports. Ascospore release occurs later in the cooler southern regions (Beresford et al., 1989) resulting in a lower incidence of scab. Overall, scab is more prevalent in the orchards in the North Island than it is in the South Island.

The biology of the pathogen (see data sheet sheet in Appendix 3 in Part C) suggests that all orchards would have the disease to some level.

Varietal susceptibility

All commercial varieties grown in New Zealand are susceptible to scab (Manktelow and Beresford, 1995). These authors also showed that the three major commercial cultivars (Braeburn, Fuji and Gala) grown in Auckland, Hawke's Bay, Nelson, Canterbury and Central Otago and varieties derived from their parentage are susceptible to scab.

Environmental conditions

Climatic conditions in New Zealand are conducive for the establishment and spread of the pathogen.

Orchard management

In New Zealand, under standard agronomic production practices, primary inoculum is reduced by using the Potential Ascospore Dose (PAD) prediction system (MacHardy and Jeger, 1982). Fungicides are applied using the PAD system and weather-based infection period monitoring (Beresford and Spink, 1992). Inoculum levels are maintained to ensure that fruit quality is not adversely affected by the disease. This is done by focusing on the reduction of the incidence of black spot on leaves before leaf fall and reducing the density of leaf litter remaining in the following spring (Horner and Horner, 2002).

Summary

Apple scab caused by *V. inaequalis* is present in all pipfruit production areas in New Zealand where commercial varieties are susceptible and environmental conditions are favourable for disease development. Standard agronomic practices maintain inoculum at levels that ensure fruit quality is not adversely affected by the disease, however, the pathogen is likely to be present on leaf tissue in most New Zealand orchards. The IRA team decided to represent Imp1 as 1.

Importation step 2: Likelihood that picked fruit is infected with *V. inaequalis*: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}. U(10^{-3}, 5×10^{-2})

Pathogen/disease distribution

Autumn application of urea as a post-harvest spray to leaves on the ground reduced ascospore production in the spring (Beresford et al., 2000). This measure is used as part of New Zealand apple producers’ standard agronomic practices and lowers the availability of primary inoculum for scab infection of apple fruit.

Implementation of the PAD prediction system integrated in conjunction with weather based infection monitoring has reduced the incidence of orchard infection by scab (Batchelor et al., 1997).

Infection of mature fruit

Mature fruit is less prone to infection (Keitt and Jones, 1926). Should fruit become infected early in the growing season numerous scabby lesions would develop and would easily be detected and discarded during the thinning process before picking. However, small lesions such as those around the fruit stalk or on sepals may not be easily detected. Further, the fruit infected during the latter part of the season may produce small ‘pin-point’ lesions that are not visible at harvest (Bratley, 1937; MacHardy, 1996).

The low levels of scab infection post-harvest in New Zealand could be the reason for not using fungicides to prevent post-harvest rot (MAFNZ, 2003a).

Summary

Scab disease is well managed in New Zealand by employing preventive and curative measures. Several applications of fungicides based on monitoring scab infection periods, ascospore counts and scab incidence maintain minimal fruit infection levels. Additionally, mature fruit is less prone to infection. These factors indicate that only a small level of infection of mature fruit by *V. inaequalis* is likely to be present.

After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp2 as a uniform distribution, with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}.

Importation step 3: Likelihood that clean fruit is contaminated by *V. inaequalis* during picking and transport to the packing house: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}. U(10^{-3}, 5 x 10^{-2})

Contamination at picking

Conidia are formed on leaf lesions throughout the spring and summer. Leaves are capable of producing up to 100,000 conidia per lesion under high humidity (Biggs, 1990). However, standard agronomic practices maintain inoculum at levels that ensure fruit quality is not adversely affected.

Clean fruit may be susceptible to surface contamination by conidia during handling at harvest especially during wet weather.

Contamination in soil

The overwintered pseudothecia on leaves shed in the previous season would have released ascospores by harvest time in the current season. At this time leaves of the current season have not been shed and pseudothecia have not yet formed. Ascospores are unlikely to be present in the soil.

Contamination in bins

Storage bins kept on the orchard floor awaiting transportation to the packing house are unlikely to be contaminated by *V. inaequalis* in the soil. Fruit may be contaminated by conidia splashed from infected leaves in canopies during wet weather, however, standard agronomic practices within New Zealand apple orchards maintain conidia at levels that greatly reduce the likelihood of this event.

Contamination during transport

Contamination of the fruit may occur if actively sporulating lesions are present on trees at harvest. This may occur during wet weather if bins were not covered during transportation to the packing house through the orchard. Contamination may also occur from infected trash during transport, only if wet weather persists. However, standard agronomic practices within New Zealand apple orchards maintain conidia at levels that greatly reduce the likelihood of this event.

Summary

Contamination of fruit may occur if actively sporulating lesions are present in the orchard at time of harvest. Direct contamination from bins and soil would not occur. The fungicide program to control scab is designed to minimise fruit infection. Therefore, well-managed orchards would not have significant amounts of scab. Based on the above technical information and stakeholders' comments, the IRA team decided to represent Imp3 as a uniform distribution, with a minimum value of 10^{-3} and a maximum value of 5 x 10^{-2}.

Importation step 4: Likelihood that *V. inaequalis* survives routine processing procedures in the packing house: triangular distribution with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.85. T(0.7, 0.85, 1)

Pre-cooling

This treatment would not have any effect on the survival of conidia as they can survive at low temperatures (Biggs, 1990).

Washing

Conidia on fruit lesions tend to be easily detached upon wetting (Frey and Keitt, 1925) when the fruit is washed in the dump tank. However, infected lesions will remain unaffected. The same effect is likely to occur with the high-pressure high-volume water spray installed in some packing houses.

Brushing

Brushing would dislodge external conidia but not conidia present within tissues in fruit.

Disinfection

A proportion of packing houses in New Zealand use disinfection methods (see discussion under Imp5 below. However, even where disinfection is used it is unlikely to be effective in eliminating infected lesions in the fruit.

Waxing

Waxing would not dislodge any conidia present within tissues in fruit.

Sorting and grading

During packing house operations, scabby, blemished, misshapen, split or unripened fruit or those that do not meet the export quality standard would be rejected.

Fruit infected at maturity is unlikely to show discernable scabby lesions (MacHardy, 1996). These ‘pin-point’ lesions that are not visually detected or tiny scabby lesions that have escaped detection will survive the routine packing house operations.

Post-harvest fungicides

Post-harvest fungicides are not used before storage of fruit in New Zealand (MAFNZ, 2003a).

Cold storage

Any internal infections that survive the packing house operations will develop disease symptoms when cold-stored for 8–12 weeks (MacHardy, 1996). The minimum temperatures for conidial germination, sporulation and infection are 0ºC, 4ºC, 4ºC, respectively (MacHardy, 1996; Studt and Weltzien, 1975). This suggests that conidia are able to survive, germinate, sporulate and infect during or after cold storage.

Summary

Packing house operations would remove obviously blemished and scabby fruit. However, mature fruit infected with ‘pin-point’ lesions may not be detected during routine packing house operations unless they have developed rots in cold storage. The conidia in these lesions can survive cold storage and contaminate other fruit. After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp4 as a triangular distribution, with a minimum value of 0.7, a maximum value of 1, and a most likely value of 0.85.

Importation step 5: Likelihood that clean fruit is contaminated by *V. inaequalis* during processing in the packing house: uniform distribution with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}. U(10^{-3}, 5×10^{-2})

Some of the fruit and trash arriving at the packing house may be infected/infested with conidia. In New Zealand 37% of packing houses in the export program use chlorine in the dump tank. The concentration of chlorine used varies between 5 and 50 ppm. Another 16% used peroxyacetic acid (Tsunami®), and bromo-chloro-dimethylhydantoin (Nylate®), as alternatives to chlorine, as per label instructions. Monitoring of disinfectants is done manually or automatically each day of operation or at specific times on each day. Chlorine or alternatives were not used by 47% of the packing house operators procedure (MAFNZ, 2005a). These disinfection treatments are likely to reduce the possibility of contamination but not all packing houses use them. Therefore conidia dislodged in the water dump have the potential to contaminate clean fruit. Conidia that have contaminated clean fruit surfaces in the water dump are likely to be removed during brushing and washing.

The lesions, which appear as 'pin-points' on fruit, are subcuticular and protected by the cuticle. These lesions would not provide inoculum for contamination of clean fruit in the packing house (MacHardy, 1996).

Ascospore formation occurs in pseudothecia on leaves and fruit, only after a period of development and maturation over winter (Biggs, 1990). Ascospores would not be a source of inoculum for contamination of clean fruit during the packing house operations.

Summary

Conidia dislodged in the water dump have the potential to contaminate clean fruit. Conidia in 'pin-point' lesions on fruit would not provide inoculum for contamination of clean fruit in the packing house. Ascospores would not be present. After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp5 as a uniform distribution, with a minimum value of 10^{-3} and a maximum value of 5×10^{-2}.

Importation step 6: Likelihood that *V. inaequalis* survives palletisation, quality inspection, containerisation and transportation to Australia: uniform distribution with a minimum value of 0.7 and a maximum value of 1. U(0.7, 1)

Fruit with 'pin-point' scab lesions may not be detected during Imp6. Fruit with obvious symptoms that have not been previously detected are likely to be detected during quality inspection.

The pathogen is likely to survive this step especially on fruit with 'pin-point' lesions that have not been cold stored for at least 8–12 weeks (MacHardy, 1996).

Apple would be transported in refrigerated containers (0–2ºC) by sea or air. It takes only a few hours to reach Australia by air and the sea voyage from New Zealand would take about 7–10 days. Fruit with internal infection not stored for an adequate period before export has the potential to develop symptoms when cold-stored on arrival.

Summary

'Pin-point' lesions present on fruit are likely to survive if fruit spends only a short time in cold storage. After considering the technical information above and stakeholders' comments, the IRA team decided to represent Imp6 as a uniform distribution, with a minimum value of 0.7 and a maximum value of 1.

Importation step 7: Likelihood that clean fruit is contaminated by *V. inaequalis* during palletisation, quality inspection, containerisation and transportation: uniform distribution with a minimum value of 0 and a maximum value of 10^{-6}. U(0, 10^{-6})

Fruit with 'pin-point' lesions when cold stored for 8–12 weeks may develop disease symptoms (MacHardy, 1996). These may be discarded at quality inspection. The number of fruit with 'pin-point' lesions is likely to be small, as scab disease is managed well in export orchards.

Fruit that has been sorted, graded and inspected for quality will have few infected fruit present with spores that could contaminate clean fruit.

Summary

Contamination of fruit would not occur at this step because any rotting fruit would be rejected before and after cold storage. After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp7 as a uniform distribution, with a minimum value of 0, and a maximum value of 10^{-6}.

Importation step 8: Likelihood that *V. inaequalis* survives and remains with the fruit after on-arrival minimum border procedures: uniform distribution with a minimum value of 0.7 and a maximum value of 1. U(0.7, 1)

Symptoms on fruit infected with 'pin-point' lesions, where the fruit is not cold stored for 8–12 weeks (MacHardy, 1996), are unlikely to be detected.

Fruit with pseudothecia containing developing asci and ascospores are unlikely to be detected.

Summary

Fruit with 'pin-point' lesions that have not been cold stored for 8–12 weeks and fruit with mature pseudothecia will not be detected by on-arrival minimum border procedures. After considering the technical information given above and stakeholders' comments, the IRA team decided to represent Imp8 as a uniform distribution, with a minimum value of 0.7 and a maximum value
of 1.

Conclusions—probability of importation

When the above likelihoods were inserted into the risk simulation model, the probability of importation of apple scab was estimated as being 4.8 x 10^{-2} (mean), 2.2 x 10^{-2} (5th percentile) and 7.8 x 10^{-2} (95th percentile). Therefore the infection rate for apple scab was estimated to be 4.8% (mean) of the total proposed number of apples imported from New Zealand annually.

Probability of entry, establishment and spread

The factors relevant to the estimation of the probability of entry, establishment and spread are discussed below. These include:

- The probability of importation (discussed in previous section)
- The proportion of utility points near host plants susceptible to the pest in each exposure group (titled *Proximity* below)
- The probability of exposure of a susceptible host plant in the exposure group to the pest by an infested/infected apple discarded near it (titled *Exposure* below)
- The probability of establishment
- The probability of spread

These factors are combined using the approach set out in the methodology section to provide an estimate of the annual probability of entry, establishment and spread.

Proximity

The term 'proximity' as used in this report is the likelihood that a utility point is sufficiently close to a host plant in a particular exposure group for the likelihood of transfer of fungal spores to a host to be greater than zero.

General issues specific to each utility point are discussed below, followed by a justification of the proximity ratings for each utility point by exposure group combination as set out in Table 67.

1. Orchard wholesalers

This group includes packing and storage facilities based in non-urban areas that might be expected to pack bulk New Zealand fruit, repack fruit that needed culling or re-grading, or act as a storage and distribution facility for New Zealand fruit. The IRA team considered that the facilities undertaking these types of operations would be the same facilities involved with domestic apple fruit and therefore would be located in areas close to apple and/or pear orchards. In addition waste fruit may be discarded very close to host plants of apple scab.

2. Urban wholesalers

This group includes packing, storage and distribution centres located in major centres. These are generally located in industrial areas, sometimes at fruit and vegetable markets.

3. Retailers

This group includes supermarkets, fruit and vegetable shops, retail markets and roadside stalls. The numbers and distribution of these largely follows the population density (consumers) with the majority in large cities, often in shopping complexes or malls well separated from hosts. However, in some cases apple retailers may be co-located with nurseries where some hosts of apple scab may be present.

4. Food services

This group includes restaurants, sandwich bars, cafeterias and hotels and so on where apples may be used or consumed. The numbers and distribution of these largely follow the consumer population density with the majority in large centres, often in shopping complexes, malls or business districts, well separated from potential hosts.

5. Consumers

This group includes all the final consumers of apples. The majority of the population (and therefore the majority of apple consumption) is in the capital city, a significant distance from most commercial apple and pear orchards. However, hosts of apple scab are present in some home gardens and along roadsides. In estimating proximity, the IRA team considered the proportion of the population in areas where hosts would not be present or occur at a very low frequency. An estimate based on ABS data is that approximately 85% of the Western Australian population live in areas where apple scab hosts could grow. This proportion is also relevant to retail and food service utility points.

An additional factor is the potential for consumers to be close to host plants. For example, the opportunities for hosts to be exposed to apples are significantly less for those consumers living in flats or apartments compared to consumers living in houses with gardens. ABS figures indicate that about 30% of the dwellings in major cities are flats, apartments or townhouses where there are unlikely to be any hosts of apple scab. Another factor to be considered is the occurrence of hosts in home gardens. This would vary considerably, depending on the area and the climatic conditions. For example, hosts of apple scab are much more common in gardens in southern Western Australia than in areas further north. It has been assumed that 50% of home gardens would contain hosts of apple scab.

Care must be exercised to avoid ‘double counting’ when estimating proximity values. For example, an apple eaten and discarded by a consumer in a public park close to wild and amenity hosts cannot simultaneously be close to household and garden plants. When the model was being checked in response to stakeholder concerns about double counting, it was realised that some of the proximity values had been significantly overestimated in the previous draft because of this problem.

Commercial fruit crops near utility points

The commercial fruit hosts susceptible to *V. inaequalis* infection are mainly apple (*Malus* spp.), and to a lesser extent loquat (*Eriobotrya japonica*). Areas of apple are planted as monocultures within the PRA area.

The proportion of **orchard wholesalers** near **commercial fruit crops**: 1

- All orchard wholesalers would be in proximity of commercial fruit crops. Most of them will dispose of waste to places within the orchard. Occasionally a few may dispose of waste to landfills or general waste disposal sites several kilometres away but still close to orchards. Before the waste is finally disposed of, it could remain open to the elements in a skip near the packing house.
- Occasionally orchard 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 New Zealand fruit originally imported in boxes may contaminate equipment and packing house workers.

The proportion of **urban wholesalers** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Urban wholesalers are in metropolitan areas. Their waste goes to landfills. Both the utility point and the waste are away from commercial fruit crops.
- Occasionally an urban wholesaler may be located within apple production areas. The waste may be disposed of in close proximity to the orchard or into landfills away from production sites.

The proportion of **retailers** near **commercial fruit crops**: Uniform (10^{-3}, 10^{-2})

- It is estimated that up to 1% of retailers could be near commercial fruit crops.

The proportion of **food services** near **commercial fruit crops**: Uniform (10^{-6}, 10^{-3})

- Major food services are extremely unlikely to be near commercial fruit crops.

The proportion of **consumers** near **commercial fruit** crops: Uniform (10^{-6}, 10^{-3})

- Less than 0.1% of the West Australian population is estimated to be near commercial fruit crops. The majority of the population is located in the metropolitan areas.

Nursery plants near utility points

Common Australian nursery plants that are hosts of *V. inaequalis* are apple (*Malus* spp.), loquat (*Eriobotrya japonica*) and arrow–wood (*Viburnum* spp.). These are likely to be found in nurseries and some retail outlets.

The proportion of **orchard wholesalers** near **nursery plants**: Uniform (10^{-3}, 10^{-2})

- Some orchardists may raise their own nursery plants or run a parallel wholesale business. Also, apple fruit nurseries may be located near orchards.

The proportion of **urban wholesalers** near **nursery plants**: Uniform (10^{-3}, 10^{-2})

- Urban wholesalers are in metropolitan areas and some may be close to garden centres selling nursery plants. Although their waste may finally end up in landfills, it could be kept temporarily in proximity to these garden centres.
- In rare instances retail nurseries in Western Australia can be located near urban waste dumps, for example, Canning Vale tip.
- Rarely, flea markets selling nursery plants may be in proximity of urban wholesalers.

The proportion of **retailers** near **nursery plants**: Uniform (10^{-3}, 5×10^{-2})

- Nursery plants of apple and loquat are sold in major retail outlets.
- Up to 5% of major retail outlets are estimated to sell and have nursery plants in close proximity of hosts for apple scab.

The proportion of **food services** near **nursery plants**: Uniform (10^{-6}, 10^{-3}).

- Major food services are unlikely to be near nursery plants.

The proportion of **consumers** near **nursery plants**: Uniform (10^{-6}, 10^{-3}).

- Although considerable numbers of consumers may come in close proximity to nursery plants susceptible to apple scab it is extremely unlikely that they would discard significant amounts of apple waste material in nurseries.
- General consumer fruit waste goes to landfills but it is extremely unlikely that nurseries would be located near them.

Household and garden plants near utility points

The most common household and garden plants susceptible to *V. inaequalis* are apple and crab-apple (*Malus* spp.), loquat (*Eriobotrya japonica*) and arrow-wood (*Viburnum* spp.).

The proportion of **orchard wholesalers** near **household and garden plants**:
Uniform (10^{-3}, 5×10^{-2})

- Orchard wholesalers and their waste disposal sites are located in an isolated area within the orchard premises, but some household and garden plants may be near them.

The proportion of **urban wholesalers** near **household and garden plants**:
Uniform (10^{-3}, 10^{-2})

- Urban wholesalers are located in metropolitan areas and their waste is disposed of in landfill sites. Very few residential properties are likely to be located near urban wholesalers.

The proportion of **retailers** near **household and garden plants**: Uniform (10^{-3}, 5×10^{-2})

- Most retailers are in larger cities and their waste would be disposed of in landfill sites, which are generally not near residential properties.

- Major retailers may have hosts susceptible to *V. inaequalis* near apple fruit displayed for sale.
- Retail nurseries may be sometimes found near fresh food markets.

The proportion of **food services** near **household and garden plants**: Uniform (10^{-3}, 10^{-2})

- Major food service industries are in cities, not near residential areas and their waste is disposed to landfill sites.
- Some restaurants may have a few hosts susceptible to apple scab within their premises.

The proportion of **consumers** near **household and garden plants**: Uniform (10^{-2}, 0.15)

- Most consumers are in metropolitan and suburban areas, and their waste is disposed of in landfills with household and garden plants susceptible to apple scab unlikely to be near these sites.
- Some proportion of metropolitan consumers and most suburban consumers may have a few hosts of apple scab present as household and garden plants.
- Local authorities encourage recycling of waste to make compost, and this is becoming a common practice in some rural areas. Pome fruit trees are common horticultural plants in back gardens in some parts of Western Australia. These may be found near compost heaps.

Wild and amenity plants near utility points

In this category the relevant host plants for *V. inaequalis* are crab-apple (*Malus* spp.), arrow-wood (*Viburnum* spp.) and volunteer plants of apple and loquat (*Eriobotrya japonica*). Some of the volunteer plants may be present in the wild as a result of birds, other animals and humans spreading the seeds.

The proportion of **orchard wholesalers** near **wild and amenity plants**: Uniform (10^{-3}, 5 x 10^{-2})

- Orchard wholesale waste sites are mostly located within orchard premises and are not near wild and amenity plants. However, some amenity plants (for example, *Viburnum* spp.) may be present as hedgerows in the orchard boundary.
- Orchard wholesalers will not allow feral plants and volunteer apple seedlings to grow near these waste disposal sites.

The proportion of **urban wholesalers** near **wild and amenity plants**: Uniform (10^{-3}, 10^{-2})

- Urban wholesaler waste is disposed of in landfills. Susceptible hosts may grow in the wild near these sites as a result of dispersal of seeds by birds (for example, crab-apple trees, apple seedlings, etc.).

The proportion of **retailers** near **wild and amenity plants**: Uniform (10^{-3}, 10^{-2})

- Retailer waste would be disposed of in landfills. Susceptible hosts may grow in the wild near these sites, as a consequence of dispersal of seeds of susceptible plants by birds.

The proportion of **food services** near **wild and amenity plants**: Uniform (10^{-3}, 10^{-2})

- Food services would dispose of their waste in landfills. Seedlings originating from seeds dispersed by birds may be present.

The proportion of **consumers** near **wild and amenity plants**: Uniform (5 x 10^{-3}, 5 x 10^{-2})

- Most consumers in metropolitan and suburban areas dispose of their waste in landfills. Susceptible hosts may grow from seeds in the wild near these sites as result of dispersal by birds.
- Some consumers may discard apple cores, rotten fruit or partially eaten fruit into the environment. This is likely to occur near parks, gardens, recreation sites and along roadsides where susceptible plants may be found. Usually the density of host plants near these sites would be low.

- Local authorities encourage recycling of waste to make compost, and this is becoming a common practice in some rural areas.

Table 67 Summary of proximity values for all utility point and exposure group combinations for *V. inaequalis*

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesalers	1	U(10^{-3}, 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})
Urban wholesalers	U(10^{-6}, 10^{-3})	U(10^{-3}, 10^{-2})	U(10^{-3}, 10^{-2})	U(10^{-3}, 10^{-2})
Retailers	U(10^{-3}, 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 5 x 10^{-2})	U(10^{-3}, 10^{-2})
Food services	U(10^{-6}, 10^{-3})	U(10^{-6}, 10^{-3})	U(10^{-3}, 10^{-2})	U(10^{-3}, 10^{-2})
Consumers	U(10^{-6}, 10^{-3})	U(10^{-6},10^{-3})	U(10^{-2}, 0.15)	U(5 x 10^{-3}, 5 x 10^{-2})

Exposure

The term exposure is applied to the likelihood of transfer of the pathogen from infected apples or their waste to a susceptible host plant. This is a complex variable dependent on several critical factors. A sequence of events needs to be completed for successful exposure of host plants to *V. inaequalis* from infected apples, in order for *V. inaequalis* to establish in Western Australia. An analysis of key steps in the sequence of events that would need to occur in order for successful transfer of apple scab to take place is summarised below.

Presence of fungi upon or within fruit

Apple scab attacks predominantly the leaves and fruit. Fruit is highly susceptible to infection through petal fall and fruit set (MacHardy, 1996). Lesions on young fruit are darker with distinct margins and these eventually become corky spots. When fruits enlarge, cracks appear in the skin and fruit flesh, but early infected fruit usually drop prematurely. Apples become more resistant to scab as they approach maturity (Keitt and Jones, 1926). Lesions develop more slowly when infections occur late in the season particularly on the stem-end of fruit before cork formation restricts the fungal growth before harvest (Bratley, 1937). These ‘pin-head’ or ‘pin-point’ size lesions (0.1 to 4 mm diameter) appear shortly before harvest and they are frequently followed by storage scab, which may not appear until after 10 to 12 weeks in storage (MacHardy, 1996). ‘Storage scab’ is typically seen as shiny, black, sunken spots in contrast to the velvety-like appearance of lesions that develop on fruit in the orchard (MacHardy, 1996). Further, this author indicated that as lesions enlarge during cold storage, the cuticle is either broken or shows alternate concentric bands of smooth and rough ridges.

Survival and development of the fungus in (or on) the fruit

Bratley (1937) studied the conditions for scab development during fruit storage. He identified several important factors. Among these were:

- The presence of free moisture affected lesion size.
- Orchard conditions before picking influenced the number of lesions that developed in storage.
- Lesion size was smallest at 0°C but the lesion size and number increased at high temperature and high relative humidity.
- New lesions appeared at the stem-end of fruit.

An investigation of the relationship between scab development on mature fruit (cv. Granny Smith) and temperature (1–2°C and 20°C) during storage after inoculation was carried out (Schwabe, 1982). It took 80 days for apples stored at 1–2°C to develop lesions compared to 35–45 days for apples to develop lesions when stored at 20°C. It took 180 days for maximum lesion development for fruit stored at the lower temperature compared to about 100–120 days at the higher temperature. Lesions that appeared during storage developed from infections that occurred before harvest, and the number of infections that developed into lesions is directly related to temperature. At higher temperatures (and high relative humidity), lesions appear earlier and are more numerous.

Moisture is the most important factor affecting the size of lesions, particularly free moisture on apples packed tightly in storage cartons (Bratley, 1937). At a given temperature, increasing the relative humidity by 20% generally doubles the size of old lesions. He concluded that infections 1 to 2 weeks before harvest were unlikely to cause visible lesions during normal storage time (Bratley, 1937). Temperature determines how soon and at what rate lesions appear in storage. Apples were graded for scab severity before storage, at 0.5, 2.8°C or a cycle of 2.8 and 0.5°C in a room held at *c*.80% relative humidity (Tomerlin and Jones, 1983). The increase in lesion diameter from one orchard was significantly greater at 2.8°C than at 0.5°C regardless of scab severity. Most new lesions that developed in storage were on apples that had visible lesions when stored. Of apples graded initially as scab-free, none from one orchard and 7% of fruit from the second orchard developed new lesions during storage.

The apple scab fungus continues to grow inside the infected tissue with the initiation of pseudothecia. The rate of further development of pseudothecia depends on temperature and moisture levels (MacHardy and Sutton, 1997). At least 20 min of exposure to light is required for pseudothecia to develop normally and that low or no light will reduce the number of pseudothecia produced (Holz, 1939). Moisture is a limiting factor in pseudothecial development (James and Sutton, 1982). Summarising the work of several researchers (MacHardy, 1996) concluded that scabby apple tissue must be wetted occasionally by rain or dew after leaf fall for pseudothecia to be produced and develop, but prolonged or continuous moisture can result in fewer pseudothecia, retard their maturation or lead to abnormal development.

Transfer mechanism

When tissue infected with apple scab becomes wet in the spring, mature asci expand through the ostiole and forcibly discharge ascospores in the air (Biggs, 1990). Ascospores continue to mature and are discharged over a period of 5 to 9 weeks. The peak period of ascospore discharge usually occurs between the pink and full-bloom stages of bud development (Biggs, 1990). This period coincides with an abundance of susceptible leaves. At least 0.2 mm rainfall per hour, lasting one to several hours, uninterrupted or interrupted by a maximum of two dry hours is needed for distinct ascospore ejection (Rossi et al., 2001).

The airborne ascospores which serve as primary inoculum are disseminated by wind and carried to susceptible tissue on host apple trees that have begun growth and flowering in spring.

Most ascospores are deposited in close proximity to their inoculum (CABI, 2005). Ascospores were released over distances ranging from 0.1 to 8.1 mm (one reached 13.2 mm) from the source, inside small chambers in still air (Aylor and Anagnostakis, 1991). They also showed that 75% of the ascospores were projected less than 4.1 mm from the source and only 1% were projected as far as 6.6 mm. The aerial concentration of ascospores decreased rapidly with height above the ground. On average, values of ascospores at 3 m height were only approximately 6% of ascospores measured at 0.15 m. The decrease in spore numbers was attributed to rapid increase of wind speed and turbulent eddy diffusivity with height above the ground (Aylor, 1995).

Nearly all ascospores are ejected less than 6 mm into still air, and, with the water film on the leaf surface, the distance ascospores are propelled decreases to less than 0.25 mm. They are seldom carried into the tree canopy under windless conditions. Ascospores reaching the turbulent air must then pass through tree canopies and the surrounding boundary layer of the orchard (Frinking, 1993). It is generally accepted that most spores remain within a crop and fewer than 10% spores released in a crop are released beyond the crop boundary layer (Gregory, 1973).

After ascospores are ejected the temperature and moisture are the most critical determinants of ascospore viability and the rate at which ascospores germinate and grow. Germination and germ tube elongation occur over a wide temperature range (0.5°–32°C) but these two processes are reduced greatly below 11°C and above 26°C, the optimum being 17°C (MacHardy, 1996). The minimum number of hours of continuous leaf wetness required for infection at various temperatures has been examined in detail (Mills, 1944; MacHardy and Gadoury, 1989; Stensvand et al., 1997; Gadoury and Seem, 1997). In general, for infection to occur the ascospores must be continuously wet for 28 hours at 6ºC, for 14 hours at 10ºC, for 9 hours at 18°–24ºC or for 12 hours at 26ºC (Agrios, 1997).

Ascospore germination and first infection is mostly on apple leaf or fruit, but initial infection can occur on sepals at ‘bud break’ stage which can then be a source of secondary inoculum for developing fruits. On germination the ascospore germ tube pierces the cuticle and grows between the cuticle and the outer wall of the epidermal cells and the initial hypha ramifies to form a subcuticular stroma. The mycelium produces conidiophores and large numbers of conidia, which push outwards, rupture the cuticle, and within 8 to 15 days of inoculation, form olive-green, velvety scab lesions. Although, the mycelium remains mostly as a subcuticular stroma, first the epidermal cells and later the palisade and mesophyll cells of the leaves show a gradual depletion of their contents, eventually collapsing and drying (Agrios, 1997). The viability of ascospores can last up to 19 days at 5°C (Boríc, 1985).

Host plant receptivity

Suitable hosts for apple scab infection are distributed throughout Western Australia (refer to data sheet in Appendix 3 in Part C). Apple scab attacks predominantly the leaves and fruit. As the leaves emerge, the lower surface in particular, and the surface adjacent to the midrib gets infected first and then the upper surface as the leaves unfold. Infected leaves usually become distorted as scab lesions enlarge (CABI, 2005).

Some aspects specific to each exposure group are discussed below.

Commercial fruit crops

Most commercial apple fruit cultivars are susceptible to *V. inaequalis* (McKirdy, 2003) and different physiologic races differing in pathogenicity attack *Malus* species and varieties (Parisi et al., 1993; CABI, 2005). Pear, however, is affected by another species of *Venturia, V. pirina* (Shabi, 1990).

Fruit trees in commercial orchards are planted in high-density monocultures. In spring and summer, *V. inaequalis* could infect leaves, petioles, stems and fruit and hence, the IRA team concluded that the exposure value of an individual apple for orchard wholesaler waste is Uniform (10^{-6}, 2 x 10^{-4}).

The other four utility points would present a lower likelihood for exposure given that *V. inaequalis* infects only a narrow host range and on this basis the IRA team concluded that the exposure value of an individual apple for urban wholesaler, retailer, food service and consumer waste is Uniform (0, 10^{-6}).

Nursery plants

To produce high quality planting material nurseries maintain high hygienic standards by using fungicides to control diseases. Apple fruit waste disposed in such locations would be collected frequently and on this basis the IRA team concluded that the exposure value of an individual apple for orchard wholesaler, urban wholesaler, retailer and consumer waste is Uniform (0, 10^{-6}).

A slightly higher likelihood of exposure could result from a worker in a retail shop or a consumer handling an infected fruit and then touching a susceptible nursery host in the same shop and on this basis the IRA team concluded that the exposure value of an individual apple for retailer waste is Uniform (10^{-6}, 2 x 10^{-4}).

Household and garden plants

Most apple waste from the orchard wholesalers, urban wholesalers, retailers and food services would be disposed of in waste sites of dump bins away from household and garden plants and therefore the IRA team concluded that the exposure value of an individual apple for orchard wholesaler, urban wholesaler, retailer and food service waste is Uniform (0, 10^{-6}).

Consumers disposing of fruit waste into a backyard compost heap may present an opportunity for exposure of conidia to host plants in the garden. Apple and loquat trees and amenity plants like crab-apple and *Viburnum* that are hosts of *V. inaequalis* are commonly found in household gardens, although their density would be low. High temperatures (up to 60°C) inside compost heaps (Anonymous, 2004b) would be expected to inactivate *V. inaequalis*, however, survival of the pathogen on fruit under incomplete composting, especially in domestic backyards is possible. On this basis the IRA team concluded that the exposure value of an individual apple for consumer waste is Uniform (10^{-6}, 2 x 10^{-4}).

Wild and amenity plants

The hosts of *V. inaequalis* present as wild and amenity plants would be sparsely distributed. Exposure of such sparsely distributed hosts to conidia from a single waste fruit through rain splash or wind assisted rain would almost never occur. On this basis the IRA team concluded that the exposure value of an individual apple for all utility points is Uniform (0, 10^{-6}).

Conclusion

The probabilities of exposure for all utility point-exposure group combinations based on the discussion above for *V. inaequalis* are summarised in Table 68.

Table 68 The probability of exposure of *V. inaequalis* to susceptible host plants near exposure groups by the utility points discarding a single infested/infected apple.

UTILITY POINTS	EXPOSURE GROUPS			
	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Orchard wholesaler waste[43]	U(10^{-6}, 2 x 10^{-4})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Urban wholesaler waste	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Retailer waste	U(0, 10^{-6})	U(10^{-6}, 2 x 10^{-4})	U(0, 10^{-6})	U(0, 10^{-6})
Food service waste	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})	U(0, 10^{-6})
Consumer waste	U(0, 10^{-6})	U(0, 10^{-6})	U(10^{-6}, 2 x 10^{-4})	U(0, 10^{-6})

Probability of establishment

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

The apple production area in Western Australia covers 1874 hectares over four growing regions. Most of the recent plantings are medium to high-density populations, that is, closer plantings (Jarvis, 2000).

All cultivated *Malus* spp. are susceptible to scab. Most of the commercial varieties are susceptible to scab but Jonathan, Red Delicious and Golden Delicious show some resistance. Gala is moderately susceptible but Lady William, Granny Smith, Pink Lady™ and Sundowner™ are very susceptible (McKirdy, 2003). Wild and ornamental species of *Malus* are equally susceptible to scab, as well as abandoned orchards.

Compared to the density of plants in commercial orchards and nurseries the density of household and garden as well as wild and amenity plants would be relatively low and sparsely distributed.

Vectors are not required for establishment of this pathogen. However, conidia of *V. inaequalis* were found on the legs of aphids removed from severely infected trees (Dillon-Weston and Petherbridge, 1933). Therefore, aphids and other pests of apple have the potential to involuntarily disseminate conidia.

Suitability of the environment

There have been six previous outbreaks of scab in the south-west of Western Australia since the first detection in Manjimup in 1930 (MacHardy, 1996). This author showed that during recurrence of scab around Manjimup in 1989, 455 trees were infected at 10 locations between December and March. This shows that environmental conditions are suitable for development of the disease.

[43] As indicated in the method section, for pathogens waste includes discarded infested/infected apples.

The areas in Western Australia that experience spring and summer rains are more susceptible to scab but areas that have a Mediterranean-type climate are less prone to scab infection (MacHardy, 1996).

The mean annual rainfall in the Perth Hills and Manjimup exceeds 1000 mm per annum. These conditions are ideal for establishment of the disease.

The temperature, wetness and relative humidity have an effect on spore germination and infection (Studt and Weltzien, 1975). The temperature range in these areas is within the range favourable for ascospore and conidial germination. This has been demonstrated in previous scab outbreaks (MacHardy, 1996).

The optimum temperature range for ascogonial development and maturation is 8°–12ºC and 16°–18ºC, respectively (James and Sutton, 1982).

The potential for adaptation of the pest

The occurrence of fungicide tolerant strains (Köller et al., 1997; Lalancette et al., 1987) and strains with reduced sensitivity to sterol demethylation inhibitors (Stains and Jones, 1985; Whelan et al., 1992) has been demonstrated. Therefore, the scab pathogen can develop fungicide resistance.

The adaptation of this pathogen to overcome host resistance has also been reported. As a consequence, seven physiologic races have been identified (CABI, 2005). Race 1 of the pathogen has been reported from Australia (Heaton et al., 1991) and New Zealand (Patterson et al., 2003). Therefore, the scab pathogen has the potential to adapt to overcome host resistance.

The reproductive strategy of the pest

The scab fungus can reproduce sexually or asexually. Sexual reproduction occurs via ascospores produced in ascocarps (pseudothecia) in overwintered leaves or fruit on the orchard floor.

Ascospores released from pseudothecia overwintering on leaves and fruit provide the inoculum for new growth at bud break. The lesions developing from ascospores produce conidia (Biggs, 1990).

Conidia produced on leaves and fruit are the principal source of inoculum for the build up of the disease in the summer. Several secondary cycles may occur during the growing season. Each cycle takes about 9–17 days to show visible symptoms after conidia penetrate and ramify in the host tissues (Biggs, 1990).

Minimum population needed for establishment

Potentially a single ascospore or conidium can initiate an infection, provided environmental factors are favourable for germination.

Inoculum dose has a considerable influence on the amount of scab that develops on mature Granny Smith apples. Five-fold increases in inoculum dose (i.e. 118590, 2950, 14750, 73750 and 368750 viable conidia per cm^3) resulted in about one, 14, 48, 70, and 98% scabby fruit, respectively. The higher the inoculum dose the greater is the damage (MacHardy, 1996).

The method of pest survival

The pathogen survives from one season to another by pseudothecia where asci and ascospores continue to mature over the winter months (Biggs, 1990).

The fungus can also overwinter as mycelia in twig lesions in maritime climates, but this method of survival is unusual elsewhere (Biggs, 1990).

Cultural practices and control measures

Integrated pest and disease management (IPDM) programs are undertaken in commercial orchards in Australia. Commercial orchards have strategies in place for the management of chemical sprays to prevent development of resistant strains. In Orange and Batlow, NSW, Australia, apple scab is controlled by the application of protectant fungicides at 7 to 10 day intervals, supplemented by curative sprays when required following infection warnings (Penrose, 1992). These fungicides would be effective in controlling scab in Western Australia.

During the 1989–90 scab outbreaks in Western Australia, sanitation methods (stripping infected leaves from young trees, pruning and removal of infected shoots, mulching with leaf litter, ploughing to bury leaves, using sheep to graze the orchard floor), chemical methods (application of fungicides, spraying the ground with 5% urea at early leaf fall), and other methods (restriction of fruit movement, orchard inspections) were employed to successfully eradicate scab.

Probability of spread

Suitability of the natural and managed environment

Apple scab is widespread in the eastern states of Australia where the disease is managed. Occurrence of several small outbreaks of scab in Western Australia in the past indicates that the disease can spread in the natural environment when conditions are conducive for the spread of scab.

The disease management programs undertaken in orchards to maintain general hygiene may have reduced the spread potential during the previous outbreaks in Western Australia.

Spread of scab is likely to be rapid in commercial orchards and nurseries because of an abundance of susceptible tissues in a concentrated area whereas in wild and amenity plants susceptible hosts would be few and far between. The household and garden plant environment is also highly suitable for rapid spread of the pathogen.

Presence of natural barriers

Western Australia is isolated from the closest apple growing area in South Australia by a dry land mass. It is unlikely that the pathogen would disseminate by rain or wind over such long distances.

Physical barriers may prevent long-range spread of the pathogen but, if scab were to be introduced to Western Australia, physical barriers are unlikely to be a limiting factor for the spread of scab. The disease has the potential to gradually spread by expanding its foci of infection to all apple production areas in Western Australia.

Potential for movement with commodities or conveyances

The pathogen can infect most above ground parts but the most obvious sites of infection are leaves and fruit (Biggs, 1990).

The most likely mode of introduction of scab into Western Australia would be via infected planting material or contaminated fruit (MacHardy, 1996).

Inadvertent transmission on clothing by humans has also been suggested as a possible means of introducing the disease into Western Australia (MacHardy, 1996).

Intended use of the commodity

Apples would be used mainly for human consumption.

Potential vectors of the pest

There are no specific vectors but some insects coming into contact with ascospores or conidia of the pathogen have the potential to spread the spores, provided the viability is retained.

Potential natural enemies of the pest

Species antagonistic to pseudothecial formation and ascospore production of *V. inaequalis* have been reported under experimental conditions (Boudreau and Andrews, 1987; Cullen et al., 1984; Miedtke and Kennel, 1990; Philion et al., 1997). They include *Aureobasidium pullulans*, *Chaetomium globosum*, *Athelia bomacina*, *Coniothyrium* spp. and *Phoma* spp. Some of these species are likely to exist under natural conditions in orchards or waste dumps.

Partial probability of establishment and spread

The partial probabilities of establishment and spread are provided in Table 69. Additional evidence to support the combined partial probability of establishment and spread for specific exposure groups is provided in the text below.

Commercial fruit crops

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.7, 1)

Most apple cultivars grown in Western Australia are susceptible to scab. The environmental conditions are favourable for infection. Monoculture and high-density plantings also favour rapid spread of the disease. Existence of derelict and abandoned orchards in commercial apple production areas would also favour infection by *V. inaequalis*. In areas where Mediterranean-type climate occurs, conditions are not ideal for disease establishment and spread. However, occurrence of several small outbreaks in commercial orchards over some years indicates that scab has the potential to spread in Western Australia.

Nursery plants

Establishment – Uniform (0.7, 1)
Spread – Uniform (0.7, 1)

In nurseries, the micro-climatic effects created by close planting and overhead irrigation (if undertaken) can create environmental conditions suitable for rapid spread of the pathogen. Use of infected planting material has been attributed as one of the means of introduction and spread of scab in Western Australia. To ensure freedom from scab, nurseries would be sprayed with chemicals.

Household and garden plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (0.7, 1)

The backyard apple tree population in Western Australia is estimated to be approximately 145,000 trees but these would be widely dispersed and few in number at any one location. Loquat trees are also present both as backyard and wild/amenity trees. These trees are susceptible to apple scab infestation and not likely to be subjected to a regular regime of fungicide control. However, the number of susceptible host plants would be few and low in density. This would limit the availability of susceptible tissues. Some householders would attempt to control the disease either by sanitation methods or use of chemicals, but these measures are likely to be successful only if the disease is detected early and application of chemicals is timed properly. Most organic growers will not use chemical sprays.

Wild and amenity plants

Establishment – Uniform (0.3, 0.7)
Spread – Uniform (5 x 10^{-2}, 0.3)

Several host-specific forms of *V. inaequalis* infect amenity plants (Menon, 1956; Le Cam et al., 2002). Such plants are unlikely to serve as an alternative host for apple scab. Most susceptible wild and amenity plants are fewer in number and scattered over a wide area. It is almost certain that wild and amenity plants infected by scab would not be sprayed with fungicides to control the disease.

Conclusion

The IRA team considered the information presented above in reaching the conclusions on the partial probability of establishment and spread for each exposure group, shown in Table 69.

Table 69 Partial probabilities of establishment and spread of *V. inaequalis*

	Commercial fruit crops	Nursery plants	Household and garden plants	Wild and amenity plants
Partial probabilities of establishment (PPE)	U(0.7, 1)	U(0.7, 1)	U(0.3, 0.7)	U(0.3, 0.7)
Partial probabilities of spread (PPS)	U(0.7, 1)	U(0.7, 1)	U(0.7, 1)	U(5 x 10^{-2}, 0.3)

Conclusion – entry, establishment and spread

Estimates of the partial probabilities of entry, establishment and spread for each of the utility points and susceptible host plants were combined by @RISK, as outlined in the method section, to give a combined annual probability of entry, establishment and spread as shown in Table 70.

Table 70 Unrestricted probability of entry, establishment and spread[44]

Percentile	Probability of entry establishment and spread	Qualitative description
5th percentile	0.19	Low
Median simulated value	0.86	High
95th percentile	1.0	High

[44] calculated by @RISK

Table 70 shows that the distribution at the median value was within the qualitative likelihood interval of 'high'.

Assessment of consequences

Impact scores allocated for the direct and indirect criteria are given in Table 71. Available supporting evidence is provided in the text below.

Table 71 Impact scores for *V. inaequalis*

Direct impact	Impact scores
Plant life or health	E
Human life or health	B
Any other aspects of the environment	B
Indirect impact	
Control or eradication	E
Domestic trade or industry	E
International trade	D
Environment	B
Communities	C

Direct impact

Plant life or health – E

Consequences affecting plant life or health would be significant at the regional level and highly significant at the district level. The rating assigned to this criterion was therefore '**E**'.

The health of the plant is affected directly by lowering the fruit quality and indirectly by affecting the vigour of plant growth (Biggs, 1990). Fruit with scabby growth is not acceptable to consumers and is unsaleable, and mature fruit with 'pin-point' lesions may develop fruit rot symptoms after storage. Such fruit will be discarded.

Crop loss figures are not available for Australia, but large numbers of apple trees have been destroyed during previous outbreaks (MacHardy, 1996) and significant crop losses (70% or more) have been reported elsewhere when environmental conditions are favourable for the pathogen (Biggs, 1990).

In south-west Western Australia, there have been six outbreaks of scab since the first detection in Manjimup in 1930 (MacHardy, 1996). These outbreaks occurred around the Manjimup and Albany districts from 1930–1991 (MacHardy, 1996). This author showed that another unrelated attack occurred in Stoneville 30 km north to north-east of Perth in 1991–1992. At Mt. Baker in 1936–1939, more than 11000 trees were destroyed or returned to the nursery that supplied the plants. In 1947–1948, about 3700 young trees were destroyed and about 19000 trees or stocks were cut back (MacHardy, 1996). During the 1989 recurrence of scab around Manjimup, trees in 10 locations were infected between December and March. These outbreaks would have contributed to actual or potential yield reductions.

Manjimup in Western Australia experiences significantly more wet conditions than Gisborne or Hamilton in New Zealand, with an average of 15 wet days per month over the three-month period in the spring (Anonymous, 2004a) suggesting that environmental conditions in Western Australia may cause significant crop losses because of scab.

The direct impact of scab on other susceptible household plants or on wild plants is difficult to estimate. Direct impact is likely to be discernible only by commercial growers who are directly affected. Other species such as arrow-wood (*Viburnum* spp.), and loquat (*Eriobotrya japonica*) can succumb to the disease, (CABI, 2005; MacHardy, 1996), but during earlier outbreaks in Western Australia damage to these crops was not reported.

Previous outbreaks of scab in Western Australia have not caused collapse of the apple industry in Western Australia suggesting that the impact on plant life is not highly significant at regional level.

Human life or health – B

The rating assigned to this criterion was '**B**'.

The presence of apple scab in Western Australia will increase fungicide usage and may have an effect at the local level.

Any other aspects of environmental effects – B

Increased use of fungicides may have an impact on the environment and the rating assigned to it was therefore '**B**'.

Removal of large numbers of apple trees during previous outbreaks of scab in Western Australia (MacHardy, 1996) would have affected the environment at the local level in a minor way. During previous outbreaks of scab in Western Australia, there was no evidence that *V. inaequalis* infected native plant species or endangered biodiversity.

Indirect impact

Control or eradication – E

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies was considered significant at the regional level and highly significant at the district level. The rating assigned to this criterion was therefore '**E**'.

Scab is effectively controlled in the eastern states of Australia by using protective and curative fungicides. These applications are made when required following infection warnings (Penrose, 1992).

In areas where scab is a significant problem about 70% of the pesticides applied are used in relation to scab control (CABI, 2005).

During the 1989–1990 scab outbreak, several strategies were adopted to eradicate the disease including sanitation, chemical control and other methods. These programs were highly successful, but significant costs were incurred in controlling and eradicating scab in Western Australia. However, long-term economic viability of the majority of commercial orchards has not been threatened.

In the event of an incursion of scab in Western Australia, an eradication program would be initiated under the Western Australia scab plan (Kumar, 2002).

If scab occurs in Western Australia, additional costs would be incurred for eradicating or controlling scab. The cost is likely to depend on the severity and duration of the outbreak. Eradication programs can be very expensive if an outbreak is not detected early, and involve joint participation from all levels of government and industry.

Previous scab outbreaks in Western Australia have been contained and eradicated. Therefore, it would be feasible to control the disease with chemical sprays or even to eradicate it using several strategies as has been done previously.

However, additional resources may be required to provide assistance to growers either to control or eradicate the pathogen. If the eradication program were not successful, presence of scab in Western Australia would require minor modifications to horticultural practices such as removal of overhead irrigation, modification of tree canopies and changes to cultural practices.

Compensation has been paid to growers affected by scab during previous outbreaks.

Domestic trade or industry – E

The indirect consequences on domestic trade are likely to be significant at the regional level. A rating of '**E**' was assigned to this criterion.

Scab is primarily a disease affecting the quality of fruit. Australian consumers have a very low tolerance for blemished fruit. Such fruit is likely to be down graded or rejected at different points in the marketing chain.

The Western Australian apple industry enjoys a competitive production advantage not having to treat for apple scab. Implementation of control or eradication programs would have a significant negative effect on domestic trade.

Scab occurs in the eastern states in Australia. There is free movement of apple fruit between all States and Territories, except Western Australia.

Currently, there are trading restrictions on planting materials and a ban on the movement of fruit into Western Australia. Therefore, national marketing arrangements for movement of fruit are unlikely to change in the short-term.

However, if scab were to establish in Western Australia and it could not be eradicated, there may be scope to open up the market to Western Australia, subject to meeting quarantine requirements for other pests not in Western Australia.

International trade – D

The indirect consequences on international trade are likely to be minor at the regional level and significant at the district level. A rating of '**D**' was assigned to this criterion.

At present, Australia exports about 10% of the apples produced, valued at $21.6 million. Western Australia contributes a significant amount to the total exports.

Australia exports apples to ten major destinations. Japan imports only Fuji apples from Tasmania. Scab is present in Japan and the UK, which are two significant markets. None of the other markets, which are tropical countries, have recorded scab (CABI, 2005).

Apple producing countries are able to export their fruit to most markets around the world, regardless of the presence of scab in the export production areas. Occurrence of scab in the eastern states in Australia has not resulted in restrictions being imposed for the international trade in fruit.

Other countries are unlikely to introduce restrictions on trade in apples if scab were to be introduced into Western Australia, but apple fruit from Western Australia may then not be able to command premium prices.

Major markets in Europe demand the use of environmentally sustainable practices in fruit production. Excessive use of fungicides may lead to rejection of fruit. Currently, there are no disruptions in trade owing to failure to comply with changes in international consumer demand.

Environment – B

The indirect consequences on the environment are unlikely to be discernable at district level and would be minor at the local level. A rating of '**B**' was assigned to this criterion.

Currently, management of scab in Australia is based on an IPDM program, which includes application of fungicide.

The presence of apple scab in Western Australia will increase fungicide usage and may have an indirect impact on the environment at the local level although no such unacceptable effects have been reported during previous attempts to control scab in Western Australia. It is unlikely that scab would have an impact on ecological processes such as erosion, water table changes, increased fire hazards and nutrient cycling.

Communities – C

The indirect consequences on communities are unlikely to be discernable at the regional level, and would be of minor significance at the district level. A rating of '**C**' was assigned to this criterion.

There would be some social implications if several farms were infected by scab causing significant economic damage. The main effect would be discontinuing workers owing to reduced or lack of fruit production.

Previous outbreaks of scab in Western Australia could have had minor impacts on communities at district level and significant impacts at local level.

It is unlikely that there would be any effect on the tourist industry should scab occur in Western Australia.

Scab would have little or no effect on water quality, recreational uses, tourism and animal grazing, hunting or fishing.

Conclusion—consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**E**', the overall consequences are considered to be 'moderate'. Therefore the overall consequences of apple scab are '**moderate'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the 'rules' shown in the risk estimation matrix in the method section. The unrestricted annual risk estimation for apple scab is shown in Table 72.

Table 72 Unrestricted risk estimation of *V. inaequalis*

Overall probability of entry, establishment and spread[45] (median value)	0.86 (High)
Consequences	Moderate
Unrestricted annual risk	Moderate

[45] Calculated by @ RISK.

The unrestricted annual risk of apple scab has been assessed as 'moderate' when the overall probability of entry, establishment and spread was combined with consequence. This exceeds Australia's ALOP, and risk mitigation measures would be needed to lower this rating to an acceptable level if apples are to be imported into Western Australia.

Risk management for apple scab

Venturia inaequalis is a pest of concern only for Western Australia, as the disease is present throughout apple production areas of eastern Australia. The movement of mature apple fruit and apple nursery stock from eastern Australia into Western Australia is currently prohibited because of the lack of risk management measures that would maintain Australia's ALOP for the disease based on regional freedom.

The risk pathway of greatest concern to export with regard to apple scab is symptomless (latent) infection and infestation of fruit that cannot be detected by inspection. Under suitable conditions the fungus could develop to produce spores that transmit the disease. An analysis of the unrestricted risk scenario for apple scab found the number of infested/infected fruits imported was influenced by the following importation steps, including:

- Imp2—the likelihood that picked fruit is infested/infected with *V. inaequalis*
- Imp4—the likelihood that *V. inaequalis* survives routine processing procedures in the packing house
- Imp5—the likelihood that clean fruit is contaminated by *V. inaequalis* during processing in the packing house
- Imp6—the likelihood that *V. inaequalis* survives palletisation, quality inspection, containerisation and transportation to Australia
- Imp8—the likelihood that *V. inaequalis* survives and remains with fruit after on-arrival minimum border procedures.

Inspection cannot detect symptomless infection and infestation. Therefore inspection at Imp6 and Imp8 cannot be used in the evaluation of options to reduce the risk resulting from symptomless infection or infestation by *V. inaequalis*.

In the unrestricted risk assessment for apple scab, Imp4 was assessed considering all procedures taking place in New Zealand's packing houses. This includes the use of sanitisers and short-term cold storage by some packing houses. There is no evidence in the literature that suggests any of these procedures mitigate symptomless infection. Therefore, it is not feasible to seek measures to reduce the likelihood allocated to Imp4.

The following options were evaluated with a view to mitigating the annual risk by reducing the likelihood allocated to Imp2 and Imp5.

- Pest free areas ISPM No.4: *Requirements for the establishment of pest free areas* (FAO, 1996b).
- Establishment of pest free places of production and pest free production sites ISPM No. 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999).

Pest free areas

A pest free area, as described in ISPM No.4: *Requirements for the establishment of pest free areas* (FAO, 1996b) would require systems to be put in place by MAFNZ to establish, maintain and verify that *V. inaequalis* does not occur within that area.

Freedom from *V. inaequalis* in an area would influence likelihoods for steps Imp1, Imp2 and Imp5 in the importation pathway. Because Imp1 in the unrestricted analysis was 1, this likelihood is modified to Uniform (0, 10^{-6}) in the restricted analysis. Fruit infection will only occur when the disease is present on the tree or within the orchard, therefore, in pest free areas, the likelihood that picked fruit will be infected/infested with the pest (Imp2) and the likelihood that clean fruit is contaminated during processing in the packing house (Imp5) are both Uniform (0, 10^{-6}). When these modified (restricted) likelihoods were placed in the risk simulation model and the assessment for apple scab repeated, the restricted annual probability of entry, establishment and spread was found to be 2.3 x 10^{-4} which is within the qualitative interval of ‘extremely low’. When this was combined with the ‘moderate’ estimate of consequences for apple scab, the restricted risk for apple scab met Australia’s ALOP and apples could safely be imported into Western Australia from pest free areas.

While the option of a pest free area is available, in constrast to *N. galligena* (European canker), *V. inaequalis* has been reported throughout New Zealand apple production areas. Extensive detection and delineating surveys, including inspection of alternative host plants would be required to confirm pest free areas. Similarly, the establishment and maintenance of pest free areas would need to be relevant to the biology of *V. inaequalis*, including its means of spread.

Infected nursery stock and apple fruit presents a pathway for establishment and spread of apple scab in New Zealand. As there are no restrictions on the movement of planting stock or apple fruit within New Zealand, maintenance of pest free areas may not be a technically feasible option except with continuous inspection and verification of freedom.

MAFNZ has not indicated that this would be a preferred risk management option for apple scab. However, BA would consider any technical data forwarded by MAFNZ to support establishment of these pest free areas.

Table 73 Apple scab: Effect of pest free area

Step	Unrestricted likelihood	Restricted likelihood
Imp1	1	U(0, 10^{-6})
Imp2	U(10^{-3}, 5 x 10^{-2})	U(0, 10^{-6})
Imp5	U(10^{-3}, 5 x 10^{-2})	U(0, 10^{-6})
PEES (median)	0.86 (High)	2.3 x 10^{-4} (Extremely low)
Consequence	Moderate	Moderate
Risk estimate	Moderate	Negligible

Pest free places of production

An alternative option to mitigate the annual risk of apple scab is to source apples from export orchards free of the disease, that is, establish pest free places of production as outlined in ISPM No. 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999). A pest free place of production could be a place of production (an orchard managed as a single unit) or a production site (a designated block within an orchard), for which freedom from apple scab symptoms is established, maintained and verified by MAFNZ.

Orchard inspections would need to be conducted at peak apple scab infestation periods during the production season. Areas where apple scab symptoms were detected would be excluded from export for that season.

While the option of a pest free place of production is available, *V. inaequalis* has been reported throughout New Zealand apple production areas. Extensive detection and delineating surveys, including inspection of alternative host plants would be required to confirm pest free places of production. Similarly, the establishment and maintenance of pest free places of production would need to be relevant to the biology of *V. inaequalis,* including its means of spread.

Infected nursery stock and apple fruit presents a pathway for establishment and spread of apple scab in New Zealand. As there are no restrictions on the movement of planting stock or apple fruit within New Zealand, maintenance of pest free places of production may not be a technically feasible option except with continuous inspection and verification of freedom.

Conclusion – risk management

Biosecurity Australia has considered the risk management options but consider they would not adequately maintain Australia's ALOP for the disease based on regional freedom. MAFNZ has not provided any proposed risk management measures for apple scab. Biosecurity Australia would consider any data or alternative options for the management of apple scab if provided. Until suitable risk management measures for apple scab have been developed it is proposed that mature apple fruit from New Zealand (and eastern Australia) will be prohibited entry into Western Australia.

Introduction

This assessment relates to codling moth, *Cydia pomonella* (Linnaeus).

This species is not present in Western Australia and is a pest of regional quarantine concern for that state.

Biology

Codling moth, *Cydia pomonella* (Linnaeus), has four life stages: adult, egg, larva, and pupa.

The adult is a small grey-brown moth. Eggs are laid singly on developing fruits and nearby foliage. After hatching, the larva burrows immediately into a fruitlet. Larvae pass through five instars while feeding within the fruit, and then vacate it. Larvae then spin cocoons within cracks in the tree trunk or under loose pieces of bark or among debris on the ground (HortResearch, 1999b). Cocoons can also be found in fruit containers and other equipment (Hely et al., 1982).

Life cycle development varies seasonally but has an average of 68 days. The number of generations per year varies from 1 to 4 depending on the climate, and sometimes the host plant (CABI, 2005). In New Zealand, there is one full generation per year in the central and southern areas of New Zealand, and two generations in Hawke's Bay and the northern areas of the North Island (HortResearch, 1999b). The main hosts of this pest are pome fruit (apple and pear), stone fruit (apricot, cherry, plum, nectarine and peach), walnut chestnut, quince, persimmon, crab-apple and pomegranate.

Other information relevant to the biology of codling moth is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of concern for codling moth in this draft IRA is the presence of larvae inside apple fruit. Codling moth is a known internal feeder of pome fruit, including apples (HortResearch, 1999b).

The potential for viable codling moth eggs or larvae to be associated with trash after harvesting, packing house processing and transport would be minimal.

Probability of entry, establishment and spread

The following analysis examines the likelihoods of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk, with respect to Australia's ALOP.

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed

Importation

The likelihood that codling moth will arrive in Western Australia with the importation of apple fruit from New Zealand: **Moderate.**

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, while the end-point is the release of imported apples from the port of entry.

Supporting evidence for a ‘moderate’ probability of importation is provided in the text below.

Source orchards

Codling moth is common throughout New Zealand (HortResearch, 1999b), and apple is one of its main host plants (CABI, 2002);

Eggs are laid on or close to the developing fruit. The caterpillars hatch within about a week and enter the fruit within 24 hours. This may occur anywhere on the surface but is primarily on the ripe side and/or through the calyx.

The first stage caterpillar constructs a spiral gallery or mine just below the fruit surface; it then moults to second stage and begins radial penetration of the fruit; later stages consume some of the seeds and tunnels extensively in the fruit. Larvae pass through five instars while feeding within the fruit, and then vacate it to pupate.

After about four weeks, the mature larva leaves the fruit and spins a cocoon within cracks in the tree trunk or under loose pieces of bark or among debris on the ground.

In New Zealand during the apple production season, codling moth has one generation in the south, one and a partial second generation in Nelson, Canterbury, Otago and southern apart of North Island, and two generation in Hawke’s Bay and the northern part of North Island.

According to Rothschild and Vickers (1991), commercial orchards using broad-spectrum insecticides correctly can keep codling moth damage to below 2%.

In Nova Scotia, Canada, the degree of infestation under insecticide-free conditions varied from 6 to 10% of the entire crop in an orchard over 12 years, depending on the cultivar (MacLellan, 1977). In an orchard in Lake Ontario, USA, where there is one generation and a partial second during an apple production season, similar to those seen in southern England, damage ranged from 7 to 35% (Glass and Lienk, 1971). In warmer climates, where two or more generations occur in a single season, damage to apples has been reported as being as high as 84% in the Crimea (Tanskiy and Bulgak, 1981), or 65 to 100% in Australia (Geier, 1964).

Harvesting fruit for export

Fruit would not be contaminated by codling moth during picking.

Young larvae of codling moth usually do not leave infested fruit.

Mature larvae can leave fruit to seek sites in which to pupate.

A single larva will usually attack only one fruit, and fruits are seldom attacked by more than one larva (CABI, 2002).

Processing of fruit in the packing house

Codling moth larvae feed internally within the apple and they would not be removed by external washing or brushing.

There is no evidence to suggest that larvae protected inside apple fruit would not be able to survive the waxing process.

Sorting and grading would remove some damaged fruit since the presence of entry holes and frass (droppings) outside the fruit may be noticeable.

Packaging would have little effect on the survival of codling moth. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture, these conditions would favour survival of the larvae.

Diapausing codling moth larvae are cold hardy and can survive exposure of –20ºC for 3 days (Neven, 1998).

Cocooned larvae are likely to survive cold storage because codling moth overwinters as cocooned larvae on the host plant in cracks and under bark or under the soil.

Larvae inside apple fruit would be able to survive storage before transportation since they can feed inside the fruit.

As the larvae live inside the fruit, codling moth would not be able to contaminate uninfested fruit during processing in the packing house.

Pre-export and transport to Australia

Diapausing codling moth larvae are cold hardy and can survive exposure of – 20ºC for 3 days (Neven, 1998). The larvae inside the fruit would be able to survive the palletisation, quality inspection, containerisation and refrigerated transport to Australia.

On-arrival procedures

The minimum border procedures as described in the method section would not be effective in detecting larvae inside the fruit.

Distribution

The likelihood that codling moth will be distributed to the endangered area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Moderate.**

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The sequence of events that has to be completed for a successful transfer of codling moth to a susceptible host plant is summarised below.

The insect stage associated with the imported apple is the larva. There is usually only one larva per apple. If the larvae were to survive fruit harvesting, processing, cold or controlled atmosphere storage and transport to Western Australia they would then have to leave the fruit to find a site to pupate.

There may be mortality during the import or distribution phases or during the larva’s search for a pupation site. Pupae need time to develop and become mature. If the pupae were to survive and emerge as an adult it could occur at unpacking and repacking facilities or retailers, on discarded fruit in waste, at landfills where the waste is disposed, or during transportation of purchased apples from retailers to households.

Adult codling moths would leave a pupation site and fly into the PRA area. The adults are capable of flying for 300m for most females and 1 km for most males. Sexual reproduction is essential. Female codling moths produce a potent sex pheromone to enable long-range communication with males seeking a mate (HortResearch, 1999b). After mating, aromatic compounds produced by the host fruit stimulate egg laying in the female.

In summary, a successful transfer of codling moth from infested fruit to its hosts requires several crucial steps. Larvae need to survive processing and transport, mature larvae need to emerge from fruit to pupate, pupae need to develop into adults in sufficient numbers and proximities to ensure adult females could locate a male to mate with and then find a susceptible host on which to lay their eggs. Finally, environmental conditions need to be suitable to allow continued population development.

Supporting evidence for a 'moderate' probability of distribution is provided in the text below.

The host plants for codling moth include apple, pear, quince, walnuts, orange, persimmon, pomegranate, hawthorn, damson, chestnut, cherry, nectarines, peaches, apricot and plums (CABI, 2005). These host plants are grown in Western Australia.

A successful transfer of codling moth to a susceptible host would require multiple insects escaping from utility points where large numbers of imported apple are stored for unpacking or packing.

Distribution of the commodity in the PRA area would be for wholesale and retail sale, processing and human consumption.

Waste material would be generated during distribution and consumption. Waste produced by apple retailers, processors and consumers and may be disposed into landfills. Hosts in proximity to these sites may be susceptible to codling moth infestation if larvae were able to survive cold storage, distribution, landfill processing procedures and reach maturity.

Household and garden host trees may be exposed to codling moth from household apples such as an infected apple core or discarded apple that is composted in a garden. Although the host tree would have to be fruiting at the time of exposure for a successful transfer.

Aromatic compounds produced by the host fruit stimulates egg laying in the female codling moth.

Feral plants, for example, volunteer apple seedlings, crab-apple, present in Western Australia may be susceptible to codling moth infestation if discovered by the adult moth at a suitable fruit bearing stage.

Probability of entry (importation x distribution)

The likelihood that codling moth will enter the PRA area as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Low**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that codling moth will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High.**

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a 'high' probability of establishment is provided in the text below.

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

Apple (including crab-apple) and pear are the main host plants for codling moth and it can complete its lifecycle on these hosts. Other recorded hosts include quince, walnut, orange, persimmon, pomegranate, hawthorn, damson, chestnut, cherry, nectarine, peach, apricot and plum (CABI, 2005). These host plants are grown in Western Australia.

Suitability of the environment

Several codling moth outbreaks have occurred in Western Australia and have been successfully eradicated. This is clear indication that the Western Australia environment is suitable and establishment could occur if codling moth is introduced into Western Australia in sufficient numbers at a suitable period of host fruit availability.

The potential for adaptation of the pest

Genetic adaptability of codling moth is not known. However, it is likely to be able to adapt to the climatic conditions in Western Australian orchards since several outbreaks have already occurred there.

The reproductive strategy of the pest

The number of generations per year varies from 1 to 4 depending on the climate, and sometimes the host plant (CABI, 2005). Flight occurs at and after dusk, mainly on warm, still evenings. A female attracts a mate by releasing a pheromone (Ferro and Akre, 1975). Mating can take up to 80 minutes depending on whether the male has been previously mated.

Egg-laying usually takes place on warm evenings (12 to 30°C). Eggs are laid singly on developing fruits and foliage.

Adult females usually lay approximately 250-300 eggs, ovipositing for 4 to 7 days. They live for about 4 days after the last oviposition.

After hatching, the larva burrows immediately into a fruit. Larvae pass through five instars while feeding within the fruit, and then vacate it. Larvae then spin cocoons within cracks in the tree trunk or under loose pieces of bark or among debris on the ground.

Where the pest has more than one generation a year, pupation of a significant proportion of the population of the early generations starts immediately. For the last generation, larvae overwinter and pupate the following spring.

Minimum population needed for establishment

Population can start from a single mated female laying her eggs on the host plants.

After larvae hatched from these eggs, they would be able to develop, pupate and become adults and mate to establish a new generation.

Cultural practices and control measures

Integrated pest management (IPM) programs are utilised in the production of Australian apples including apples grown in Western Australia for the control of other pests. This may reduce the likelihood of establishment of codling moth.

Probability of spread

The likelihood that codling moth will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **High.**

Spread is defined as the 'expansion of the geographical distribution of a pest within an area' (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

Supporting evidence for a 'high' probability of spread is provided in the text below.

Suitability of natural or managed environment

Codling moth is thought to have originated in the Palaearctic region and has spread along with the cultivation of apples to most temperate regions of the world, including Europe, China, North and South America, South Africa, Australia and New Zealand (Bradley et al., 1979).

Codling moth has also spread in the eastern states of Australia and successfully entered Western Australia several times (successfully eradicated each time), indicating the environment in Western Australia would be suitable for its spread.

Presence of natural barriers

In Western Australia, apples and pears are grown in the south-west of the state. Many other hosts of codling moth are also grown there.

Studies indicate that most males (80%) can fly for one km from their point of release and some individuals have been recovered up to 4.8 km away, or even as far as 11 km. On the other hand, 90% of marked mated females have been captured within 300 m of their release point and maximum dispersal may be as low as 600 m (HortResearch, 1999b).

Potential for movement with commodities or conveyances

As the larvae of codling moth live inside the fruit, they would be dispersed into new areas with the movement of infested fruit. The historic records for introduction of *C. pomonella* throughout the world emphasise the dangers inherent in transporting infested plant material from country to country (CABI, 2005).

A mixture of adult flight and the transportation of infested apple trees have probably aided the movement of the insects within orchards.

The means of dispersal would include as eggs on fruit or crawling larvae.

Long-distance dispersal is through adult flights, as both males and females are winged. Short-distance dispersal is through the movement of active larvae to new host plants.

Intended use of the commodity

Apples would be used mostly for consumption by both humans and animals and would be widely distributed around Western Australia.

Potential vectors of the pest

Codling moth does not require a vector for its spread since it is capable of independent flight.

Potential natural enemies

Many natural enemies have been reported to attack codling moth larvae and pupae and some are present in Western Australia including the minute codling moth egg parasite *Trichogramma minutum* Riley (CABI, 2005).

Conclusion – probability of entry, establishment and spread

The overall likelihood that codling moth will enter Western Australia as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Western Australia: **Low.**

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Codling moth is a quarantine pest of regional concern for Western Australia. The following assessment of consequences applies only to the regional level (Western Australia) not the national level.

Impact scores allocated for the direct and indirect criteria are shown in Table 74. Available supporting evidence is provided in the text below.

Table 74 Impact scores for codling moth

Direct impact	Impact scores
Plant life or health	D
Human life or Health	A
Any other aspect of the environment	A
Indirect impact	
Control or eradication	E
Domestic trade or industry	B
International trade	D
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are of minor significance at the regional level and significant at the district level. Thus a rating of '**D**' was assigned for this criterion.

Codling moth is a major pest of apples and pears and is considered an important pest wherever it has established in Australia.

According to Rothschild and Vickers (1991), commercial orchards using broad-spectrum insecticides correctly can keep codling moth damage to below 2%.

In Nova Scotia, Canada, the degree of infestation under insecticide-free conditions varied from 6 to 10% of the entire crop in an orchard over 12 years, depending on the cultivar (MacLellan, 1977).

In an orchard in Lake Ontario, USA, where there is one generation and a partial second generation per year, similar to those seen in southern England, damage ranged from 7 to 35% (Glass and Lienk, 1971).

In warmer climates, where two or more generations occur in a year, damage to apples has been reported as being as high as 84% in the Crimea (Tanskiy and Bulgak, 1981), or 65 to 100% in Australia (Geier, 1964).

Human life or health – A

There are no known direct impacts of codling moth on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of the environment – A

There are no known impact of codling moth on any other aspects of the environment and the rating assigned to this criterion was therefore '**A**'.

Indirect impact

Control or eradication E

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies are significant at the regional level and highly significant at the district level. A rating of **'E'** was assigned to this criterion.

If codling moth enters Western Australia again, the eradication program will be very expensive. It has already cost the Western Australia Government and fruit growing industry several million dollars to eradicate three outbreaks since 1993, including a two-year eradication campaign to control an incursion at Dwellingup.

Insecticide usage within the Western Australian pome fruit industry would increase should codling moth become established and continue until such time as alternative control measures, such as pheromone disruption techniques, become established.

The economic consequences, as a result of eradication, control and management restructuring, would be significant to Western Australia.

Domestic trade or industry – B

The indirect consequences on domestic trade are unlikely to be discernable at the regional level and of minor significance at the local level. A rating of '**B**' was assigned to this criterion.

It is considered that the presence of codling moth in commercial production areas of Western Australia will not result in interstate trade restrictions as it is already established in the eastern states.

However, restrictions in the movement of fruit and other host material would need to be put in place to contain the pest if there is an outbreak in Western Australia.

International trade – D

The indirect consequences on international trade are of minor significance at the regional level. A rating of **'D'** was assigned to this criterion.

The presence of codling moth in commercial production areas in Western Australia would have an effect on Western Australia's access to overseas markets where this pest is absent.

Environment – B

The indirect consequences on the environment would be discernable at the local level and unlikely to be discernible at the district level and a rating of **'B'** was assigned to this criterion.

Chemical control or biological control would have some impact on the environment: increased insecticide use can cause undesired effects on the environment, introduction of new biocontrol agents can affect existing biological control programs or impact on biodiversity.

Communities – B

The indirect consequences on communities would not be discernable at the regional level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**E**', the overall consequences are considered to be 'moderate'. Therefore the overall consequences of codling moth are '**moderate'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for codling moth is shown in Table 75.

Table 75 Unrestricted risk estimation for codling moth

Overall probability of entry, establishment and spread	Low
Consequences	Moderate
Unrestricted risk	Low

As indicated in Table 75, the unrestricted annual risk for codling moth is 'low', which is above Australia's ALOP. Risk management measures for codling moth would be required only for imports of New Zealand apples into Western Australia. Imports of New Zealand apples into areas of Australia where codling moth is present would not require risk management measures.

Risk management for codling moth

Stakeholders have indicated that visual inspection of fruit may not be an appropriate risk management measure for codling moth because clear visual external signs of infestation may not be present. If infested fruit was not detected at inspection, codling moth may enter, establish or spread in Western Australia.

Biosecurity Australia has considered stakeholder comments and agrees that visual inspection of fruit alone may not be an appropriate risk management measure. Other identified options to manage risks associated with codling moth are either the use of disinfestation treatments or by sourcing fruit from areas of low pest prevalence or pest free areas, if fruit is to be imported into Western Australia.

Option 1: Sourcing fruit from pest free areas

Area freedom is a measure that might be applied to manage the risk posed by codling moth. If MAFNZ wishes to consider the option of pest free areas as a management measure for codling moth, Biosecurity Australia will assess any proposal from New Zealand.

The requirements for establishing pest free areas are set out in ISPM No. 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO, 1999) and ISPM No. 4: *Establishment of pest free areas* (FAO, 1996b).

MAFNZ will be responsible for the establishment of production area pest freedom by verification of pest free places of production or pest free production sites by official surveys and monitoring. These survey results must be submitted to Biosecurity Australia/AQIS before access can be considered.

The objective of this procedure is to provide a measure that will reduce the risk of the importation of the codling moth to a level that will maintain Australia's ALOP.

Option 2: Sourcing fruit from 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 No. 22 *Requirements for the establishment of areas of low pest prevalence* (FAO, 2002). MAFNZ currently 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 NZ apples to Western Australia may be applied to manage the risk posed by codling moth. Components of the program 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 will be responsible for the establishment of areas of low pest prevalence by official surveys and monitoring. These survey results must be submitted to Biosecurity Australia/AQIS before access can be considered.

The objective of this procedure is to provide a measure that will reduce the risk of the importation of the codling moth to a level that will maintain Australia's ALOP.

Option 3: Methyl bromide fumigation

Methyl bromide fumigation is a measure that might be applied to manage the risk posed by codling moth. It is proposed that the fumigation treatment could be performed either pre-shipment or on-arrival.

It is proposed that 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 21^0C or greater – minimum concentration time (CT) product of $47 g/m^3$;
- $40 g/m^3$ at a pulp temperature of 16^0C or greater – minimum concentration time (CT) product of $58 g/m^3$; or
- $48 g/m^3$ at a pulp temperature of 10^0C or greater – minimum concentration time (CT) product of $70 g/m^3$.

It is proposed that fruit should not be fumigated if the pulp temperature is below 10^0C and that fumigations should be carried out in accordance with AQIS fumigation standards.

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)
- CT product of methyl bromide achieved by the fumigation (g/m^3)
- the fumigation duration (hours)
- ambient air temperature during fumigation (°C)
- minimum fruit pulp temperature during fumigation (°C).

The objective of this procedure is to provide a measure that will reduce the risk of the importation of the codling moth to a level that will maintain Australia's ALOP.

Conclusion – risk management for codling moth

Consignments that have undergone Option 1 and Option 2 mandatory risk management measures for importation of apple fruit into Western Australia and have been inspected and found to be free of codling moth will not require additional risk management measures. Consignments that have undergone Option 3 (methyl bromide fumigation) will not require inspection.

When a consignment is inspected and found to be infested with codling moth at AQIS pre-clearance inspection in New Zealand, Australia's ALOP may be maintained by the following phytosanitary actions:

- withdrawal of the consignment from export to Western Australia; or
- treatment of the consignment to ensure that the pest is no longer viable.

Alternatively, when a consignment is found to be infested with codling moth at AQIS inspection on arrival in Western Australia, Australia's ALOP may be maintained by the following phytosanitary actions:

- re-export of the consignment from Western Australia; or
- destruction of the consignment; or
- treatment of the consignment to ensure that the pest is no longer viable.

Introduction

This assessment relates to two species of mealybugs:

Citrophilus mealybug, *Pseudococcus calceolariae* (Maskell)

Mealybug, *Planococcus mali* Ezzat and McConnell.

These species are not present in Western Australia and are pests of regional quarantine concern for that state.

In New Zealand, citrophilus mealybug *P. calceolariae* is considered a more important pest on apples as compared with *P. mali*. The biology of the two species was considered sufficiently similar to justify combining the two species into a single assessment.

In this assessment, the term 'mealybugs' is used to refer to these two species, unless otherwise specified.

Biology

Citrophilus mealybug (*Pseudococcus calceolariae*) is a widespread pest throughout the eastern states of Australia, and is a serious pest of citrus in South Australia (CABI, 2004). Citrophilus mealybug is commonly found throughout the major fruit-growing regions in New Zealand, and may be very common locally on some fruit crops (CABI, 2004).

Apart from taxonomy, information on *P. mali* is very limited. It was intercepted in Honolulu on *Olearia chathamica* from New Zealand in 1937, and intercepted on apple from Tasmania at Buffalo, New York and Boston, Massachusetts in 1946. Subsequently it was named and described by (Ezzat and McConnell, 1956). The mealybug is 'probably fairly common' in Tasmania on various plants, but has been found only once on mainland Australia (Williams, 1985). Cox (1987) also recorded the species from apple in New Zealand and stated it was 'fairly common' and widespread being found mainly on introduced plants. There is no recent information in relation to the occurrence of this species in apple orchards in New Zealand (HortResearch, 1999b), indicating it is a minor pest. It sometimes causes damage to blackcurrants in New Zealand (Cox, 1987; Cox, 1989).

Females of citrophilus mealybug develop through egg and three immature instars (nymphs) and undergo a final moult to become adult. The female is a slow-moving, oval-shaped insect approximately 3–4 mm in length. Males develop through egg, first and second feeding instars, and short-lived third (about 2 days) and longer-lived fourth (about 4 days) non-feeding instars before moulting into tiny, winged adults with a pair of stout wax terminal filaments.

Parthenogenesis has not been reported in citrophilus mealybug, suggesting that sexual reproduction is essential (CABI, 2002). Mature females produce a sex pheromone, which attracts crawling males from short distances or flying males from distances in excess of one metre.

Like other scale insects, mealybugs debilitate plant hosts by sucking sap during feeding and contaminating the plant with honeydew on which sooty mould can grow. Although mealybugs live mainly on the bark of apple trees (HortResearch, 1999b), they also can be found on fruit and tend to live either around or in the calyx of fruit.

Other information relevant to the biology of mealybugs is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of concern for the mealybugs in this draft IRA is that some nymphs and adults feed on or contaminate apple fruit. Citrophilus mealybug and *Planococcus mali* have been found around or in the calyx of apple fruit (HortResearch, 1999b).

The potential for viable mealybugs larvae to be associated with trash after harvesting, packing house processing and transport would be minimal. Both species of mealybugs live mainly on the bark of apple trees and occasionally around or in the calyx of apple fruit and are not usually associated with the leaves. Mealybugs are dependent on a source of sap, available through living plant material, which is not available from dead leaves.

Probability of entry, establishment and spread

The following analysis examines the likelihood of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk, with respect to Australia's ALOP.

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed.

Importation

The likelihood that mealybugs will arrive in Western Australia with the importation of apple fruit from New Zealand: **High**.

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, whereas the end-point is the release of imported apples from the port of entry.

Supporting evidence for a 'high' probability of importation is provided in the text below.

Source orchards

Citrophilus mealybug is common throughout the major fruit growing regions of the North Island and in Nelson on the South Island, but has not been recorded any further south (HortResearch, 1999b).

There is no specific information about the rate of citrophilus mealybug attack on apple fruit. However, mealybugs live mainly on the bark of apple and pear trees and small colonies of all stages may develop in the calyx of apples and among the fruit clusters (HortResearch, 1999b).

Three species of mealybugs are commonly found in apple orchards: longtailed mealybug, *Pseudococcus longispinus*, obscure mealybug, *P. viburni*, and citrophilus mealybug (HortResearch, 1999b). Several other species including *Planococcus mali* can also be found on apple.

Harvesting fruit for export

Mealybugs are mobile at all life stages. First instar nymphs are highly mobile in comparison to slow moving adults. Adults and nymphs would be able to infest the clean fruit from other infested fruit or leaves if present during harvesting.

Processing of fruit in the packing house

The washing process has been shown to significantly reduce the number of mealybugs on the fruit. However, those located beneath the calyx of apples with a closed calyx cavity may remain with the fruit (Whiting et al., 1998). Mealybugs located beneath the calyx of apples with a closed calyx cavity may remain with the fruit during brushing and waxing (Whiting et al., 1998).

Mealybugs may not be detected by sorters and graders, particularly those hidden in the calyx of apples with a closed calyx cavity.

Packaging would have little effect on the survival of mealybugs. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture. These conditions may favour survival of mealybugs.

Pre-export and transport to Australia

Citrophilus mealybug overwinter under the bark of deciduous pipfruit trees, and on a range of other host plants in the sward or surrounding shelter-belts or shrubs (HortResearch, 1999b) suggesting that temporary cold storage may not be effective in killing the mealybugs.

Citrophilus mealybug has been detected both at pre-clearance in New Zealand (MAFNZ, 2003b), and at on-arrival inspection in the USA on New Zealand apples exported to the USA (USDA-APHIS, 2003) indicating that mealybugs can survive this process.

On-arrival procedures

The minimum border procedures described in the method section would not be effective in detecting mealybugs.

Distribution

The likelihood that mealybugs will be distributed to the endangered area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Moderate**.

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of the apple fruit) in a viable state to an endangered area and subsequent transfer to a suitable host.

The sequence of events that has to be completed for a successful transfer of mealybugs to a susceptible host is summarised below.

The insect stages associated with the apple fruit are either nymphs or adults which hide within the calyx, around the stalk or under fruit sepals. Most fruit displaying obvious signs of mealybug infestation would usually be discarded during the harvest, processing and phytosanitary certification procedures.

If mealybugs were to survive fruit harvesting, processing, cold and/or controlled atmosphere storage and transport to Western Australia, they would then have to move out from infested fruit to find a suitable host and mate in order to establish.

The ability to disperse for mealybugs is limited as the only means for mealybugs to leave fruit or packaging and enter the environment is through the movement of nymphs or adults. Adults and nymphs would need to find to a susceptible host plant by crawling or wind dispersal. Unfertilised adult females would need to locate a male to mate with and lay their eggs, and the eggs would have to survive to maturity.

In summary, a successful transfer leading to establishment of mealybugs from infested fruit to a suitable host requires several crucial steps to be achieved without mortality. Nymphs and/or adults need to survive processing and transport, and they need to disperse in sufficient numbers and in proximity to susceptible hosts to ensure adult females can locate a male to mate with and then find a host on which to lay their eggs. Finally, environmental conditions need to be suitable for continued population development.

Supporting evidence for a ‘moderate’ probability of distribution is provided in the text below.

Commercial host plants such as apple and pear trees and grapevines are readily available within the PRA area.

The majority of apple retailers, processors and consumers are located in metropolitan and suburban areas.

Waste is produced by apple retailers and processors and may be disposed of in landfills. Commercial host fruit crops would usually not be near these sites; however, wild and amenity host plants may be near landfill areas and may be susceptible to mealybug infestation if they were able to survive landfill processing procedures.

Some households dispose of their organic waste as compost. Host plants within the garden may be exposed to mealybugs from infested apples if they are able to survive and transfer from the composting site.

The ability of mealybugs to disperse is limited. Adult females are slow-moving. Males are capable of crawling short distances or flying distances of over one metre when attracted to female sex pheromones.

Probability of entry (importation x distribution)

The likelihood that mealybugs will enter the PRA area as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Moderate**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of ‘rules’ for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that mealybugs will establish within the PRA area based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High.**

Establishment is defined as the ‘perpetuation for the foreseeable future, of a pest within an area after entry’ (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a ‘high’ probability of establishment is provided in the text below.

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

Citrophilus mealybug is highly polyphagous and has been recorded from hosts in 40 plant families (CABI, 2002), including many commercial and nursery plants such as apple, pear, grape, stone fruit, potato, hibiscus and roses.

Commercial host crops such as apple, pear and grape are grown in southern regions of Western Australia. Hosts are also found in suburban gardens in Western Australia.

Suitability of the environment

Citrophilus mealybug is reported in New South Wales, Queensland, Tasmania and Victoria. Western Australia has similar environmental conditions suitable for the establishment of mealybugs.

The potential for adaptation of the pest

For the past four decades, the citrophilus mealybug has been controlled by broad-spectrum contact or systemic insecticides in New Zealand and Australia. However, resistance to some organophosphates has been reported for other mealybug species such as *P. viburni* in New Zealand (Charles, 1993). Because of this, organophosphates are gradually being replaced by insect growth regulators. However, the insect growth regulators effective against mealybugs are persistent chemicals and there is a risk of mealybugs developing resistance to them (CABI, 2002).

The reproductive strategy of the pest

Successful mating between a male and a female must occur for viable eggs to be produced.

Mature females of the citrophilus mealybug produce a sex pheromone which attracts crawling males from short distances or flying males from distances in excess of one metre (CABI, 2002).

Newly emerged crawlers spend the first few days of their lives sheltering under the disintegrating egg sac before dispersing to feed (CABI, 2002). They usually do not move far from their feeding site for the first moult.

Minimum population needed for establishment

Mature females of the citrophilus mealybug may lay more than 700 eggs within a waxy egg sac (CABI, 2002). They commonly move to a protected site to lay eggs over a period of up to two weeks. They cease feeding before egg laying and die afterwards (CABI, 2002). A population may be established from these eggs.

Citrophilus mealybug is reported to have three to four generations per year, depending on the climate (CABI, 2002).

Cultural practices and control measures

Some success in control of mealybugs has been achieved using natural enemies to ensure biological control, especially with the development of IPM programs (CABI, 2002).

Probability of spread

The likelihood that mealybugs will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **High.**

Spread is defined as the ‘expansion of the geographical distribution of a pest within an area’ (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

Supporting evidence for a ‘high’ probability of spread is provided in the text below.

Suitability of natural and/or managed environment

Citrophilus mealybug is present in Queensland, New South Wales, Victoria, Tasmania and South Australia but is absent from Western Australia, although suitable environmental conditions for its spread exist in some areas of the state.

Presence of natural barriers

Imported infested apples would be used mostly for human consumption and distributed to the main population centres that may also have readily available host plants. However, unaided dispersal beyond these areas across large arid areas with very few host species would be difficult.

The commercial host fruit crops of mealybugs are grown in south-western part of Western Australia and there are natural barriers against spread between some districts. It would be difficult for the mealybugs to disperse from one district to another if unaided.

Potential for movement with commodities or conveyances

Wind dispersal and the transportation of infested nursery stock have probably achieved Long-distance movement of the citrophilus mealybug.

There is some intrastate quarantine control on the movement of nursery stock and various host commodities that may reduce the scope for spread.

Intended use of the commodity

Mealybugs have multiple hosts with multiple uses, including nursery stock for planting and fruit for human consumption. Limitations on nursery stock movement (if implemented) and consumption of fruit would limit spread.

Potential vectors of the pest

There is no reported vector for mealybugs.

Potential natural enemies

Natural enemies of the citrophilus mealybug such as the coccinellid *Cryptolaemus montrouzieri* and parasitoids *Tetracnemus pretisous* and *Coccophagus gurneyi* are present in Australia. However, only *Cryptolaemus montrouzieri* is known to be present in Western Australia.

Conclusion – probability of entry, establishment and spread

The overall likelihood that mealybugs will enter the PRA area as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Western Australia: **Moderate**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of ‘rules’ for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Citrophilus mealybug and *P. mali* are of regional quarantine concern to Western Australia. The following assessment of consequences applies only to the regional level (Western Australia) not the national level.

Impact scores allocated for the direct and indirect criteria are shown in Table 76. Available supporting evidence is provided in the text below.

Table 76 Impact scores for mealybugs

Direct impact	Impact scores
Plant life or health	D
Human life or health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	C
Domestic trade or industry	B
International trade	B
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are likely to be minor at the regional level and significant at the district level. A rating of ‘**D**’ was assigned to this criterion.

Mealybugs can infest a wide range of host plants and have also been reported as a vector of diseases. For example, *P. calceolariae* has been shown to be a vector of the closterovirus associated with grapevine leafroll disease (CABI, 2002).

Citrophilus mealybug is highly polyphagous and has been recorded from hosts in 40 plant families.

Damage to fruit consists of reduction in fruit quality because of the presence of secondary infection of sooty mould caused by mealybug exudate.

Human life or health – A

There are no known direct impacts of mealybugs on human life or health and the rating assigned to this criterion was therefore ‘**A**’.

Any other aspects of environmental effects – A

There is no known direct impact of mealybugs on any other aspects of the environment and a rating of ‘**A**’ was assigned to this criterion.

Indirect impact

Control or eradication – C

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies is unlikely to be discernible at the regional level and of minor significance at the district level. A rating of ‘**C**’ was assigned to this criterion.

Programs to minimise the impact of these pests on host plants may be costly and may include additional pesticide applications and crop monitoring.

Existing control strategies in place for other economically important mealybug species (eg. Longtailed mealybug, *Pseudococcus longispinus)* may be effective in minimising the impact of citrophilus mealybug in Western Australia.

Existing IPM programs may be disrupted because of the possible need to re-introduce or increase the use of organophosphate insecticides.

Costs for crop monitoring and consultant's advice regarding management of the pest may be incurred by the producer.

Domestic trade or industry – B

The indirect consequences on domestic trade are unlikely to be discernible at the regional and district level and of minor significance at the local level. A rating of '**B**' was assigned to this criterion.

Restriction of movement of plant material susceptible to mealybugs maybe put into place around the infested area if there is an outbreak of the mealybugs. Interstate trade restrictions would not be applied as the pests are present in eastern Australia.

International trade – B

The indirect consequences on international trade are unlikely to be discernible at the regional and district level and minor at the local level. A rating of '**B**' was assigned to this criterion.

If these species of mealybugs became established in Western Australia, it is unlikely that trading partners would require risk management measures for these pests as they are widespread throughout the world.

Environment – B

The indirect consequences on the environment would be unlikely to be discernible at the regional and district level and of minor significance at the local level. A rating of '**B**' was assigned to this criterion.

Mealybugs introduced into a new environment will compete for resources with the native species.

Increased insecticide use may cause undesired effects on the environment.

The introduction of new biocontrol agents may affect existing biological control programs.

Communities – B

The indirect consequences on communities would not be discernable at the regional level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**D**', the overall consequences are considered to be 'low'. Therefore, the overall consequences of mealybugs are '**low**'.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for mealybugs is shown in Table 77.

Table 77 Unrestricted risk estimation for mealybugs

Overall probability of entry, establishment and spread	Moderate
Consequences	Low
Unrestricted annual risk	Low

As indicated in Table 77, the unrestricted annual risk for mealybugs is **'low'**, which is above Australia's ALOP. Therefore, risk management would be required for this pest for importation of New Zealand apples into Western Australia.

Risk management for mealybugs

Visual inspection and remedial action

Visual inspection by AQIS officers may be conducted at pre-clearance in New Zealand (if pre-clearance is adopted for apples) or upon arrival at first port of call in Australia.

AQIS will inspect the consignment using standard 600-unit AQIS sampling procedures (to provide 95% confidence of detecting a 0.5% defect level or greater). Remedial action when pests are present is proposed as an appropriate risk management option for these pests, given trained inspectors can readily detect these pests.

Consignments inspected and found to be free of *P. calceolariae* and *P. mali* will not require further risk management measures to be applied.

When a consignment is found to be infested with these mealybugs at pre-clearance inspection in New Zealand or at on-arrival inspection in Australia, the following phytosanitary measures may be applied to maintain Australia's ALOP:

- withdrawing the consignment from export to Western Australia (pre-clearance);
- re-export of the consignment from Western Australia;
- destruction of the consignment; or
- treatment of the consignment to ensure that the pest is no longer viable.

The objective of this measure is to ensure that consignments of apple fruit from New Zealand infested with these mealybugs can be readily identified and subjected to appropriate remedial action. This measure is considered to reduce the risk associated with mealybugs (*P. calceolariae* and *P. mali*) to meet Australia's ALOP.

Oriental fruit moth

Introduction

This assessment relates to Oriental fruit moth, *Grapholita molesta* Busck.

This species is not present in Western Australia and is a pest of regional quarantine concern for that state.

Biology

The Oriental fruit moth, *Grapholita molesta* Busck, is a moth with four life stages: adults, eggs, larvae (or caterpillars) and pupae. It is native to northwest China, and spread from Japan to Australia, central Europe, the east coast of the USA and Brazil at the beginning of the twentieth century. Since then, the pest has been introduced into many other countries (Gonzalez, 1978). The Oriental fruit moth is not a primary pest of apples but is a serious pest of stone fruit in Europe, Australia and North America (Murrell and Lo, 1998). It mainly occurs as a pest of apple fruit where these fruits are grown adjacent to peaches (Rothschild and Vickers, 1991).

Adult moths have a wingspan of about 10–16 mm and are dark-grey to brown with a series of darker lines on the forewings. Egg deposition usually begins 2 to 5 days after the females emerge and continues for 7 to 10 days. Some 50 to 200 eggs are laid on the underside of leaves near the growing tips.

The full-grown larva is approximately 12 mm in length and is pink to almost red. The head, top of prothorax and anal plate are brown; a black anal-fork is present above the anal opening. The pupa is reddish brown and is protected by a cocoon made of silken threads and particles of the substrate on which it is resting (CABI, 2002). Cocoons can be found on the host within fissures, under bark, on the ground beneath the leaf litter, under mummified fruit and within the soil. The overwintering generation of larvae of Oriental fruit moth prefer to pupate in litter on the ground.

Other information relevant to the biology of Oriental fruit moth is available in the data sheet in Appendix 3 in Part C.

Risk scenario

The risk scenario of concern for Oriental fruit moth in this draft IRA is the presence of larvae that have bored into apple fruit (Murrell and Lo, 1998).

The potential for viable Oriental fruit moth eggs or larvae to be associated with trash after harvesting, packing house processing and transport would be minimal. Oriental fruit moth larvae infest the young shoots of fruit trees in spring and fruits in summer. The pupae are found on the host plant within fissures, under bark, on the ground beneath leaf litter, under mummified fruit and within the soil. Oriental fruit moth eggs may be deposited on the underside of foliage.

Probability of entry, establishment and spread

The following analysis examines the likelihoods of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk, with respect to Australia's ALOP.

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed.

Importation

The likelihood that Oriental fruit moth will arrive in Western Australia with the importation of apple fruit from New Zealand: **Very low**.

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, while the end-point is the release of imported apples from the port of entry.

Supporting evidence for a 'very low' probability of importation is provided in the text below.

Source orchards

The main plant hosts are species of the genera *Prunus* and *Pyrus*, damage to other crops such as apples and quinces is usually of minor importance in economic terms and occurs where these fruits are grown adjacent to peaches (Rothschild and Vickers, 1991).

Oriental fruit moth is considered a major pest of stone fruit, such as peach and nectarine, and it is not a major pest of apple fruit (HortResearch, 1999b).

Oriental fruit moth has a restricted distribution in New Zealand (Baker, 1982). It was first discovered in Auckland in 1976 (Cox and Dale, 1977) and had reached Hawke's Bay by 1982 (Baker, 1982), but is still confined to the North Island (Murrell and Lo, 1998). Oriental fruit moth has been slow to spread in Hawke's Bay (Murrell and Lo, 1998) where it is currently at its southern limit (McLaren et al., 1999).

Oriental fruit moth has been found on 5 of 19 Hawke's Bay orchards monitored in 1997/98 (Murrell and Lo, 1998).

Oriental fruit moth lays its eggs on the under surface of leaves on apples and quince (Peterson and Haeussler, 1930). Freshly hatched larvae look for an appropriate entry site on host plants such as near the tip of a shoot, often through a petiole, or directly where two fruits touch each other or are in contact with a twig or leaf.

Freshly hatched larvae are usually unable to directly penetrate hard young fruits. Later instars are able to enter the fruit after feeding in the pedicel (Rothschild and Vickers, 1991).

Oriental fruit moth caterpillars feed by boring into the centre of shoots and young stems of fruit trees, particularly stone fruit. This causes the shoot to change colour and die back; sap may exude from the damage holes. This damage is rare in apple trees, where the caterpillars feed more commonly on ripe fruit (HortResearch, 1999b).

Harvesting fruit for export

Infestations of hosts such as apple, pear and quince are primarily confined to the fruits (Rothschild and Vickers, 1991).

Up to 50% of the spring and early summer generations form their cocoons on trees, however, later generations locate cocooning sites on the ground (Russell, 1986).

Cocoons of earlier generations may be constructed in depressions on the fruit surface, in leaf axils or under bark (Helson, 1939). The overwintering generations are found under bark near the base of the tree.

Fruit are picked into picking bags and then transferred into bins kept on the ground in the orchard before transportation to the packing house.

Processing of fruit in the packing house

Where the fruit are attacked directly, an individual larva will usually complete its feeding period within the same fruit (Rothschild and Vickers, 1991). Thus the total number of infested/infected apples will not increase. Final instar larvae leave the shoots, stems or fruits to find an appropriate cocooning site.

Later instar larvae that have not yet exited the apple fruit when harvested will not be affected by washing, brushing or waxing processes.

Sorting and grading would remove some fruit that show damage. However, given the volume of fruit passing through the grading areas some would avoid detection.

Oriental fruit moth larvae occasionally enter fruit through the inside of the stem-end of and therefore leave no wound area except for a small mark at the stem-end of the picked fruit (Polk et al., 2003).

Gum and frass protrude from the wound area as the larvae bore into the fruit. As the gum ages a sooty mould may form on it turning the wound area black (Polk et al., 2003).

Infested fruit exhibiting gummy exudates or superficial feeding areas would be rejected during sorting and grading. However, early instar larvae may escape detection during grading operations because of lack of gum or surface feeding scars on fruit and their small size.

Packaging would have little effect on the survival of Oriental fruit moth. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture, these conditions would favour survival of Oriental fruit moth.

Pre-export and transport to Australia

The diapausing overwintering generation remains as a pre-pupa for 130–300 days (Rothschild and Vickers, 1991) suggesting that temporary cold storage would not be effective to kill the larvae of Oriental fruit moth.

Oriental fruit moth larvae remaining inside the fruit would not move about to reinfest other apple fruit.

Oriental fruit moth larvae surviving inside apple fruit would survive the palletisation, quality inspection, containerisation and refrigerated transport to Australia.

On-arrival procedures

The minimum on-arrival border procedures as described in the method section would not be effective in detecting larvae inside the fruit.

Distribution

The likelihood that Oriental fruit moth will be distributed to the PRA area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Moderate**.

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The sequence of events that has to be completed for a successful transfer of Oriental fruit moth to a susceptible host is summarised below.

The insect stage associated with apples is the larvae inside the fruit. Most fruit displaying obvious signs of Oriental fruit moth infestation such as entry holes into the fruit and frass (waste) attached to the outside of the fruit would usually be discarded during the harvest, processing and quality control procedures.

If the larva were to survive fruit harvesting, processing, cold and/or controlled atmosphere storage and transport to Western Australia it would then have to move out from the fruit to find a site to pupate. Once a suitable site has been found, the pupae (surrounded by a silk cocoon) take approximately 15 days to emerge as adults, depending on temperature.

If the pupae were to survive, they could emerge at unpacking and repacking facilities, retailers, on discarded fruit in waste, at landfills where the waste is disposed, during transportation of purchased apples from retailers to households, or at the consumers' residence.

After successful pupation, adults would disperse and look for a mate. Dispersal of adults is by flight. Most adults do not disperse over distances greater than 200 metres although distances exceeding 1 km have been recorded. Sexual reproduction is essential in Oriental fruit moth and the female produces a pheromone to attract males. The adult lifespan ranges from 11 to 40 days. Egg deposition usually begins 2–5 days after the females emerge and continues for 7–10 days, if a suitable host plant is available.

In summary, a successful transfer of Oriental fruit moth from infested fruit to a suitable host requires several crucial steps. Larvae need to survive processing and transport, mature larvae need to emerge from fruit to pupate, pupae need to develop into adults in sufficient numbers and proximities to ensure adult females could locate a male to mate with and then find a susceptible host on which to lay their eggs. Finally, environmental conditions need to be suitable to allow continued population development.

Supporting evidence for a 'moderate' probability of distribution is provided in the text below.

Viable larvae could be present in the fruit and remain with the commodity during distribution via wholesale or retail trade.

Distribution of the fruit in Western Australia would be for retail sale, as the intended use of the commodity is human consumption.

Waste material would be generated during distribution and consumption. Waste produced by apple retailers and processors may be disposed into landfills. Commercial host fruit crops would usually not be near these sites; however, wild and amenity host plants may be in the proximity of landfill areas and may be susceptible to Oriental fruit moth infestation if they were able to survive landfill processing procedures and reach maturity.

Some households dispose of their organic waste as compost, host plants within the garden may be exposed to Oriental fruit moth from infested apples if larvae are able to survive and transfer from the composting site.

Early instar larvae escaping detection are likely to survive cold storage and distribution to the endangered area where they could develop to pre-pupation within the fruit before fruit desiccation or decay. Provided a sheltered site is available, larvae that escape detection could pupate and emerge as adults.

Consumption or discarding of the apple fruit and the search by the larvae for a suitable pupation site may increase mortality.

Although host plants are available within the PRA area, newly emerged females would need to find a male, mate and lay eggs within the first 7 to 10 days of the female's life.

Most adults do not disperse over distances greater than 200m.

Probability of entry (importation x distribution)

The likelihood that Oriental fruit moth will enter the PRA area as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Very low**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that Oriental fruit moth will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a 'high' probability of establishment is provided in the text below.

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

The principal economic hosts are fruit trees of the genera *Prunus* (stone fruit), *Malus* (apple), *Pyrus* (pear) and *Cydonia* (quince).

Other ornamental hosts include *Cotoneaster*, *Crataegus*, *Photinia* and *Rosa* (Russell, 1986). Late ripening peach cultivars are particularly vulnerable to this pest.

Many of these host plants are widespread in Western Australia.

Suitability of the environment

Oriental fruit moth is present in New South Wales, Queensland, South Australia, Tasmania and Victoria and similar environmental conditions exist in Western Australia.

Oriental fruit moth had previously established and was subsequently eradicated in Western Australia.

The reproductive strategy of the pest

Oriental fruit moth has an effective reproductive strategy that would assist its establishment in Western Australia.

Adults become sexually active 24–28 hours after emergence, and mating can occur on the same day as emergence (Smith and Summers, 1948; Dustan, 1964).

Sexual activities are mediated by female pheromones and the calling period (release of pheromones to attract males) extends from about 3 hours before to 1 hour after sunset.

Males are sexually responsive over a longer period than females (Rothschild and Vickers, 1991).

Males usually only mate once in a 24-hour period, but may mate with different females on successive nights (Rothschild and Vickers, 1991).

A single mating is sufficient for a female to lay her full complement of viable eggs (Smith and Summers, 1948).

Egg deposition usually begins 2 to 5 days after the females emerge and continues for 7 to 10 days or longer, if she is successfully mated (USDA, 1958).

Eggs are laid singly and each female lays 50 to 200 eggs on the underside of leaves near growing tips in peach orchards or on the upper surface of leaves in quince and apple orchards (USDA, 1958).

Oriental fruit moth is not reliant on fruit to establish, as larvae emerging in spring will attack new vegetative shoots (Robinson et al., 1997).

Oriental fruit moth passes the winter as a full-grown larva in a cocoon. Cocoons are found in cracks, under flakes of bark, under old bark wounds and in holes in twigs exposed by pruning. They are also found under infested trees, where they occur in the dried remains of fruit, in the stems of stubble and even in cracks in the soil. Early in the spring, at temperatures above 10°C, pupation takes place. The duration of the pupal stage averages 16 days, compared with a mean pupation period of seven days in summer (CABI, 2005).

Minimum population needed for establishment

At least one male and one female need to mate for fertilised eggs to develop. The mated female lays its eggs singly on twigs or on the undersides of leaves near growing terminals (CABI, 2002). A population can be started from these eggs.

Cultural practices and control measures

Practices employed during the cultivation and production of host crops is similar in New Zealand and Australia:

- Integrated pest management (IPM) programs used in the production of apples in both Western Australia and New Zealand.
- On commercial New Zealand orchards Oriental fruit moth is controlled by sprays applied against leafrollers, principally light brown apple moth (Murrell and Lo, 1998). Some leafroller species occur in Western Australia, and control of these species could also have some impact on Oriental fruit moth.

Probability of spread

The likelihood that the Oriental fruit moth will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **High**.

Spread is defined as the ‘expansion of the geographical distribution of a pest within an area’ (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

Supporting evidence for a ‘high’ probability of spread is provided in the text below.

Suitability of natural and/or managed environment

There is limited information on the ability of Oriental fruit moth to spread in natural or managed environments. Considering that the species has spread throughout the eastern Australian states and New Zealand since its accidental introduction, it may also spread in similar environments in Western Australia.

Presence of natural barriers

The Western Australian commercial host orchard areas are mainly located in the far south west of the state. This region is separated from other areas of the state and the eastern states by large tracts of arid land. It would be difficult for Oriental fruit moth to spread between regions of Western Australia unaided.

Potential for movement with commodities or conveyances

Oriental fruit moth can spread both independently and in association with host material. Spread independent of host material is by adult flight and in association with farm equipment and packaging. Oriental fruit moth can also spread with host material by the commercial distribution of the host fruit and nursery stock. Spread could be facilitated on nursery stock within Western Australia as there are limited intrastate quarantine controls in place in Western Australia on the movement of nursery stock.

Intended use of the commodity

Apples would be used mostly for consumption by humans and would be widely distributed around Western Australia. If larvae or pupae have contaminated the fruit, they will be distributed with the commodity around Western Australia.

Potential vectors of the pest

There is no reported vector for Oriental fruit moth.

Potential natural enemies

Natural enemies in the PRA area, especially generalist predators, may slow the spread but there is no evidence that they would be effective.

Conclusion – probability of entry, establishment and spread

The overall likelihood that Oriental fruit moth will enter the PRA area as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Western Australia: **Very low**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of ‘rules’ for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Oriental fruit moth is a quarantine pest of regional concern for Western Australia. The following assessment of consequences applies only to the regional level (Western Australia) not the national level. Impact scores for the direct and indirect criteria are shown in Table 78. Available supporting evidence is provided in the text below.

Table 78 Impact scores for Oriental fruit moth

Direct impact	Impact scores
Plant life or health	E
Human life or Health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	E
Domestic trade or industry	B
International trade	D
Environment	B
Communities	B

Direct impact

Plant life or health – E

Consequences affecting plant life or health are significant at the regional level and highly significant at the district level. Thus a rating of ‘**E**’ was assigned for this criterion.

Although Oriental fruit moth is not a serious pest for apples, it is a serious pest of economic importance in commercial peach, nectarine and apricot orchards, and can also attack and cause economic damage to other commercial fruits.

In severe attacks, young trees can suffer distortion of growing shoots and stems. Consequent fruit damage considerably reduces quality and market value (Hogmire and Beavers, 1998).

Human life or health – A

There are no known direct impacts of Oriental fruit moths on human life or health and the rating assigned to this criterion was therefore ‘**A**’.

Environmental effects – A

There are no known impacts of Oriental fruit moth on any other aspects of the environment and the rating assigned to this criterion was therefore ‘**A**’.

Indirect impact

Control or eradication – E

The indirect consequences of eradication, control, surveillance/ monitoring and compensation strategies are likely to be significant at the regional level and highly significant at the district level. A rating of '**E**' was assigned to this criterion.

There may be increases in the use of insecticides for control of Oriental fruit moth because of difficulties in estimating the optimum time for insecticide application.

There may be a subsequent increase in the cost of production to producers in Western Australia and thus orchard profitability.

There may be increased costs for crop monitoring and consultant's advice to the Western Australian producer.

Additional programs to minimise the impact of this pest on host plants may be necessary in Western Australia. Monitoring/surveillance will result in extra costs to stone fruit growers and eradication is an expensive option.

This pest has costed the Western Australian Government and fruit industry several million dollars to eradicate three outbreaks of Oriental fruit moth. Eradication and control would be significant at the regional level.

Oriental fruit moth may potentially increase production costs by triggering specific controls as these are of quarantine concern to important trading partners.

Domestic trade or industry– B

The indirect consequences on domestic trade are unlikely to be discernible at the regional and district level and minor at the local level. A rating of '**B**' was assigned to this criterion.

The presence of Oriental fruit moth on commercial Western Australian fruit crops would result in quarantine measures to prevent movement of commodities from infected districts to others area or markets within Western Australia. However, interstate trade would not be affected.

International trade – D

The indirect consequences on international trade are likely to be minor at the regional level and significant at district level. A rating of '**D**' was assigned to this criterion.

The presence of Oriental fruit moth in commercial production areas of Western Australia may have a significant effect at the district level because of any limitations or measures required to access overseas markets where this pest is absent.

Environment – B

The indirect consequences on environment are unlikely to be discernible at the regional and district levels and of minor significance at the local level. A rating of '**B**' was assigned to this criterion.

Additional pesticide applications or other control activities may be required to control Oriental fruit moth on susceptible fruit crops adding to the chemical load already present in the environment but any impact on the environment is likely to be minor at the local level.

The hosts of Oriental fruit moth are several species of commercial fruit crops of the family Rosacea which means the moth may not cause reduction or displacement of plant species that are components of Western Australian ecosystems.

The introduction of Oriental fruit moth into a new environment (Western Australia) may lead to competition for resources with native species.

Communities – B

The indirect consequences on communities would not be discernable at the regional level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are '**E**', the overall consequences are considered to be 'moderate'. Therefore the overall consequences of Oriental fruit moth are '**moderate'**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for Oriental fruit moth is shown in Table 79.

Table 79 Unrestricted risk estimation for Oriental fruit moth

Overall probability of entry, establishment and spread	Very low
Consequences	Moderate
Unrestricted annual risk	Very low

As indicated in Table 79, the unrestricted annual risk for Oriental fruit moth is 'very low', which meets Australia's ALOP. Therefore, risk management would not be required for this pest.

Introduction

This assessment relates to Oystershell scale, *Diaspidiotus ostreaeformis* (Curtis).

This species is not present in Western Australia and is a pest of regional quarantine concern for that state.

Biology

Oystershell scale, *Diaspidiotus ostreaeformis* (Curtis), is a diaspidid hard scale. The female life stages include adult, egg and nymph while the male has adult, egg, nymph, pre-pupa and pupa stages. There is no pupal stage in the female lifecycle. Oystershell scale originates from Europe and now occurs in USA, Canada, New Zealand and Australia (Victoria, Tasmania and South Australia) (Brookes and Hudson, 1969).

The nymphs and adult female settle and feed on branches and fruit of the host plant. The mature male, is typical of diaspid scales, being seldom seen and approximately 1mm in length (Giliomee, 1990). The mature adult female is grey, conically shaped and approximately 1.3 mm in diameter; the male is winged and lives from 1 to 3 days. Oystershell scale reproduces sexually with one annual generation and overwintering occurs as diapausing second instar nymphs. The male is attracted to the female by pheromones and dies after mating.

Crawlers hatch from eggs and are active between December and early June, with the peak between mid-December and mid-April; once the crawlers settle down on the plant to feed, they become immobile and develop a protective covering (McLaren et al., 1999).

Like other scale insects, oystershell scale debilitates plant hosts by sucking sap during feeding. Although heavy infestations of oystershell scale are on the bark and stems of apple trees (HortResearch, 1999b), they can also be found on fruit near the calyx or stem-end.

Risk scenario

The risk scenario of concern for oystershell scale in this draft IRA is the presence of nymphs and adults on apple fruit. Oystershell scale is found near the calyx or stem end of apple fruit (HortResearch, 1999b).

The potential for viable oystershell scale nymphs or adults to be associated with trash after harvesting, packing house processing and transport would be minimal. Oystershell scale nymphs and adult females prefer to settle and feed on the branches and fruit of their host plant where they can be assured of a supply of plant sap.

Probability of entry, establishment and spread

The following analysis examines the likelihoods of entry, establishment and spread in detail and combines this likelihood with the estimated consequences for this pest to give an overall estimate of the unrestricted annual risk, with respect to Australia’s ALOP.

The probability of entry is obtained by considering the ‘importation’ and ‘distribution’ pathways for the commodity and the likelihood that a given pest will remain viable and undetected as each of the component steps is completed.

Importation

The likelihood that oystershell scale will arrive in Western Australia with the importation of apple fruit from New Zealand: **Low**.

The initiating step for the importation scenario for apple fruit is the sourcing of apples from orchards in New Zealand, while the end-point is the release of imported apples from the port of entry. Supporting evidence for a 'low' probability of importation is provided in the text below.

Source orchards

Oystershell scale distribution within New Zealand is largely limited to southern pipfruit production areas of Canterbury and Otago (HortResearch, 1999b).

The majority of New Zealand export apple orchards are located in areas north of Canterbury and Oystershell scale is either absent or very rare on apples and pears in these areas (HortResearch, 1999b).

Fruit cultivars with rough bark are often the first infested as the bark crevices provide refuge for the scale insect from predators and pesticides (Ker and Walker, 1990).

Oystershell scale infests mostly the bark on stems and branches of the trees; sometimes it can be found on the fruit, where it causes red spot (CABI, 2002).

On apple, the infection is usually concentrated around the calyx or stem-end, but may occur anywhere on the fruit surface (HortResearch, 1998).

Harvesting fruit for export

Fruit are picked into picking bags and then transferred into bins kept on the ground in the orchard before transportation to the packing house.

Oystershell scale produces one generation a year and during harvesting time, all stages of the oystershell scale are present. However, the majority of mobile crawlers are present only from mid-December to mid-March (McLaren et al., 1999).

Crawlers are the only mobile stage that could contaminate clean fruit.

Crawlers move about for 48 to 72 hours then affix permanently in position (Ker and Walker, 1990). Fruit picked between late March and May will be less exposed to mobile stages of oystershell scale, as crawlers numbers diminish from March onwards.

All stages except for crawlers and adult males are firmly attached to the fruit and unable to move, therefore those dislodged from the fruit, will be unable to get back onto the fruit.

Winged adult male oystershell scale only present in October and early November, a period that does not overlap with that of the apple harvest.

Processing of fruit in the packing house

The washing process would reduce the number of oystershell scale on the fruit. In particular, the crawlers will be easily dislodged by washing. All stages present on fruit are only found on the apple surface either near the calyx or at the stem-end, not inside the calyx.

Immobile stages of oystershell scale and eggs protected by the female scale's covering would be able to survive low temperature waxing as they are protected by a grey waxy covering (scale).

Sorting and grading would remove some fruit that is contaminated with scale. It is expected that some infested fruit would remain undetected.

Packaging would have little effect on the survival of oystershell scale. In most cases the packaging of apples is designed to maximise heat discharge from the fruit while minimising loss of moisture, these conditions would favour the survival of oystershell scale.

Oystershell scale overwinters as second instar nymphs. This suggests that temporary cold storage would not be effective in killing second instar nymphs.

Pre-export and transport to Australia

Crawlers are the only mobile stage that could contaminate clean fruit by moving from infested fruit. However, they are very fragile and will not be active or would be killed during cool storage and transportation.

All other oystershell scale stages present during harvest are immobile and unable to move from infested to clean fruit.

Oystershell scale overwinters as second instar nymphs suggesting that temporary cold storage would not be effective in killing the scale.

On-arrival procedures

The minimum border procedures as described in the method section would not be effective in detecting oystershell scale.

Distribution

The likelihood that oystershell scale will be distributed to the endangered area as a result of the processing, sale or disposal of apple fruit from New Zealand: **Low.**

The initiating step for the distribution scenario is the release of imported apples from the port of entry, while the last step is the pest being distributed (as a result of the processing, sale or disposal of these apple fruit) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The sequence of events that has to be completed for a successful transfer of the pest to a susceptible host is summarised below.

The insect stage associated with the apple fruit is the nymphs or adults. Oystershell scale females and nymphs live under firmly attached scales and cannot disperse by themselves. Male oystershell scales are winged but they are fragile and only live from 1 to 3 days.

If nymphs or adults survive harvest, processing, cold or controlled atmosphere storage and transport they need to mature, mate, and lay eggs on fruit, which would develop and hatch. Egg laying and hatching could occur at unpacking and repacking facilities or retailers (utility points), on discarded fruit in waste, at landfills where the waste is disposed, and during transportation of purchased apples from retailers to households. The only means for oystershell scale to leave fruit or packaging and enter the environment of exposure groups is through crawling or wind assisted dispersal of first instar nymphs or flight of adult males.

A successful transfer of oystershell scale from infested fruit or waste to a susceptible host means that the hatched first instar nymphs would need to move onto a susceptible host plant by crawling or with assistance from wind. All life stages would need to survive by avoiding predation or environmental stress.

Supporting evidence for a ‘low’ probability of distribution is provided in the text below.

Host plants have been reported from 41 genera in 18 families including apples, pears, and stone fruits, particularly plum (European and Japanese) but also cherry, peach, prune, almond and nectarine, quince, currants, blueberry, and walnut. Willows, birches, elms, alders, poplars, maples, lindens, hornbeam, rowans and other common ornamental trees serve as reservoir hosts for this pest outside apple orchards. Most of these hosts are present within the PRA area.

Wholesaler, retailer and food service industry apple waste is disposed into bins and taken to landfills. Some hosts may be located adjoining these sites. However, the lack of mobility of mature female scales, low mobility of crawlers and short lifespan of males may reduce their ability to transfer to these hosts.

The majority of consumers are located in metropolitan and suburban areas. Some consumer waste in suburban and rural areas may be utilised for composting and some is disposed of into bins and deposited into landfill sites. Some hosts may be located adjoining composting or landfill sites. However, the lack of mobility of mature female scales, low mobility of crawlers and short lifespan of males may reduce their ability to transfer to these hosts.

Several fresh food markets may also have nursery plants near apple fruit. However, the lack of mobility of mature female scales, low mobility of crawlers and short lifespan of males may reduce their ability to transfer to these hosts.

Susceptible feral host plants may be present near waste disposal sites, however, the lack of mobility of mature female scales, low mobility of crawlers and short lifespan of males may reduce their ability to transfer to these hosts.

Probability of entry (importation x distribution)

The likelihood that oystershell scale will enter the PRA area as a result of trade in apple fruit from New Zealand and be distributed in a viable state to the endangered area: **Very low**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Probability of establishment

The likelihood that oystershell scale will establish based on a comparative assessment of factors in the source and destination areas considered pertinent to the ability of the pest to survive and propagate: **High**.

Establishment is defined as the 'perpetuation for the foreseeable future, of a pest within an area after entry' (FAO, 2004). In this assessment the initiating point for establishment of the pest starts with a sufficient number of viable eggs being laid on a susceptible host and the end-point is the persistence of the pest in the PRA area from the first colonising generation.

Supporting evidence for a 'high' probability of establishment is provided in the text below.

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

Oystershell scale has a wide range of host plants, mainly deciduous trees. Host plants have been reported from 41 genera in 18 families.

The hosts include apples, pears, and stone fruits, particularly plum (European and Japanese) but also cherry, peach, prune, almond, nectarine, quince, currants, blueberry, and walnuts. Willows, birches, elms, alders, poplars, rowans, and other common ornamental trees.

Shelter trees are often the most important sources of oystershell scale dispersing in the orchard environment in New Zealand (HortResearch, 1999b).

Suitability of the environment

Oystershell scale is widely distributed in the Palearctic and Nearctic Regions and has been introduced to Argentina, New Zealand as well as Australia (South Australia, Victoria and Tasmania) (CABI, 2005).

Poole et al. (2001) provided climate matching scenarios using Climex® modelling data from oystershell scales' current Australian distribution and the results indicate that there are regions within Western Australia which are suitable for the establishment of oystershell scale.

The potential for adaptation of the pest

There are no reports of these scale insects in New Zealand developing resistance to insecticides.

The reproductive strategy of the pest

Sexual reproduction is essential in oystershell scale and successful mating between a male and a female must occur for viable eggs to be produced.

The sex ratio is about 1:1, although a higher ratio of females to males has been reported in spring in Europe. The female releases a sex pheromone during the day when males are active, which attracts the winged males for mating. Males fly for up to a few days and may locate females after flight or by walking over the bark of the host tree. Oystershell scale males and females are able to mate almost immediately after emergence and multiple matings may occur.

Females have a high fecundity, on reaching adulthood (30–50 days old) produce eggs over a period of 2–3 months. This may result in a large population increase.

Oystershell scale has only one generation per year and the winter is spent mainly as immature second instars (nymphs). Mated females of oystershell scale can lay from 100 to 203 eggs each (HortResearch, 1999b). A population can be started from these eggs.

Minimum population needed for establishment

The mated female of the oystershell scale can lay from 100 to 203 eggs (HortResearch, 1999b). A population can be started from these eggs.

Cultural practices and control measures

IPM programs are utilised in the production of apples in Australia including Western Australia. Many aspects of the IPM are similar to the IFP program used by New Zealand orchardists. This may reduce the likelihood of establishment of scales.

A significant part of fruit infestations in summer originate from wind-blown scale crawlers moving from shelter and other host plants. Spraying of shelter in spring and/or summer is a useful part of a shelter management program that assists scale control (HortResearch, 1999b).

Oystershell scale is attacked by a group of biocontrol agents. In New Zealand the more important of these are tiny wasps of the family Aphelinidae: *Encarsia citrina*, *Aphytis mytilaspidis* and a predacious mite (*Neophyllobius* spp.) (HortResearch, 1999b). These species are not known in Western Australia.

Probability of spread

The likelihood that oystershell scale will spread based on a comparative assessment of those factors in the source and destination areas considered pertinent to the expansion of the geographical distribution of the pest: **Moderate**.

Spread is defined as the 'expansion of the geographical distribution of a pest within an area' (FAO, 2004). In this assessment, spread considers factors relevant to the movement of the pest from a point of establishment on an exposed plant, or group of plants, to susceptible plants in other parts of Australia.

Supporting evidence for a 'moderate' probability of spread is provided in the text below.

Suitability of natural and/or managed environment

Oystershell scale is reported in South Australia, Tasmania and Victoria and is absent from Western Australia. There are similar environments in Western Australia that would be suitable for its spread.

Poole et al. (2001) provided climate matching scenarios using Climex® modelling data from oystershell scales' current Australian distribution and the results indicate that there are only limited regions within Western Australia which are suitable for the spread of oystershell scale.

Oystershell scale is present in areas of Asia, Europe, Africa, North America and has been introduced to Argentina, New Zealand and Australia (CABI, 2002). These areas share similar environmental conditions suitable for the spread of oystershell scale.

Presence of natural barriers

Several commercial host fruit crops of oystershell scale are grown in the south-western part of Western Australia and there are considerable natural geographic barriers between some of the production districts. It would be difficult for the scales to disperse from one district to another if unaided as oystershell scale has limited dispersal capabilities, with only the winged adult males and young crawlers being mobile.

Potential for movement with commodities or conveyances

Historically long-distance dispersal of oystershell scale has occurred because of the distribution of infested nursery stock (Beardsley and Gonzalez, 1975).

Intended use of the commodity

Imported apples would be used mostly for human consumption and would be widely distributed to consumers. If young crawlers have contaminated the fruit and have survived the harvesting, processing, storage and transport procedures, they will be distributed with apple fruit.

Potential vectors of the pest

There are no known animal vectors for oystershell scale.

Potential natural enemies

Several natural enemies attack oystershell scale in New Zealand including: the parasitic wasps *Aphytis mytilaspidis*, *Encarsia citrina*, *Epitetracnemus zetterstedtii*, and *Zaomma lambinus*, several predatory mites including *Hemisarcoptes malus*, a ladybird of the genus *Rhyzobius* (CABI, 2002). Several species of *Rhyzobius* occur in Western Australia, however, their role as a biocontrol agent for oystershell scale is unclear.

Other natural enemies of oystershell scale such as thrips, spiders, predatory mites and generalist predators occur within the PRA area and would attack oystershell scale.

Conclusion – probability of entry, establishment and spread

The overall likelihood that oystershell scale will enter Western Australia as a result of trade in apple fruit from New Zealand, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Western Australia: **Very low**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, of establishment and of spread using the matrix of 'rules' for combining descriptive likelihoods available in Table 13.

Assessment of consequences

Oystershell scale is a quarantine pest of regional concern to Western Australia. The following assessment of consequences applies only to the regional level (Western Australia) and not the national level.

Impact scores allocated for the direct and indirect criteria are shown in Table 80. Available supporting evidence is provided in the text below.

Table 80 Impact scores for oystershell scale

Direct impact	Impact scores
Plant life or health	D
Human life or health	A
Any other aspects of environment	A
Indirect impact	
Control or eradication	C
Domestic trade or industry	B
International trade	C
Environment	B
Communities	B

Direct impact

Plant life or health – D

Consequences affecting plant life or health are likely to be minor at the regional level and significant at the district level. A rating of '**D**' was assigned to this criterion.

Oystershell scale is highly polyphagous and has been recorded from hosts in 18 plant families, mainly deciduous trees.

The commercial fruit crops of oystershell scale include apples, pears, stone fruits, particularly plum (European and Japanese), cherry, peach, almond, nectarine, quince, currants, blueberry, and walnuts.

One of the impacts of oystershell scale infestation is that fruit quality can be reduced by the presence of discolouration near the calyx or stem-end (HortResearch, 1999b).

Some apple varieties often exhibit red marks on the skin where the scales have been feeding (McLaren, 1998).

Oystershell scale can reduce plant vigour and crop yield.

In the absence of natural predators and parasites, population increase is rapid. Heavy infestations debilitate branches, because feeding interferes with the growth of the cambium leading to desiccation (HortResearch, 1999b).

Human life or health – A

There are no known direct impacts of oystershell scale on human life or health and the rating assigned to this criterion was therefore '**A**'.

Any other aspects of environmental effects – A

There is no known direct impact of oystershell scale on any other aspects of the environment and a rating of '**A**' was assigned to this criterion.

Indirect impact

Control or eradication – C

The indirect impact on new or modified eradication, control, surveillance/monitoring and compensation strategies is unlikely to be discernable at the regional level, minor at the district level and significant at the local level. A rating of '**C**' was assigned to this criterion.

Existing control programs can be effective for some hosts (for example, broad spectrum pesticide applications) but not all hosts (for example, where specific integrated pest management programs are used).

Existing IPM programs may be disrupted because of the need to re-introduce or increase the use of organophosphate insecticides. This may result in a subsequent increase in cost of production. Additionally, costs for crop monitoring and consultant's advice to manage the pest may be incurred by the producer.

Existing control strategies are already in-place for economically important hard scale species including San José scale. These existing control strategies would temper the impact of oystershell scale within Western Australian.

Domestic trade or industry – B

The indirect consequences on domestic trade are unlikely to be discernable at the regional level and would be minor at the local level. A rating of '**B**' was assigned to this criterion.

Trade restrictions in the sale or movement of fruit between districts in Western Australia may be imposed by State quarantine agencies. However, there would not be any interstate trade restrictions imposed.

International trade – C

The indirect consequences on international trade are unlikely to be discernable at the regional level and significant at the local level. A rating of '**C**' was assigned to this criterion.

Western Australia's oystershell scale pest free status for international markets would be compromised. However, San Jose scale is already present in Western Australia and it is considered that any additional impacts would not be greater than those experienced in association with San Jose scale.

Environment – B

The indirect consequences on the environment would not be discernible at the regional level and would be of minor significance at the local level and a rating of '**B**' was assigned to this criterion.

Increased insecticide use could cause undesired effects on the environment.

The introduction of new biocontrol agents could affect existing biological control programs.

Many of the hosts of the oystershell scale are introduced deciduous trees that are commonly grown as ornamentals or as shelter belt trees. Infestation of native vegetation has not been significant in Australian states where the pest currently exists.

Communities – B

The indirect consequences on communities would not be discernable at the regional level and would be of minor significance at the local level, thus a rating of '**B**' was assigned to this criterion.

San Jose scale is already present in Western Australia and it is considered that any additional impacts would not be greater than those experienced in association with San Jose scale.

Conclusion – consequences

Based on the decision rule described in the method section, that is, where the consequences of a pest with respect to one or more criteria are **'D'**, the overall consequences are considered to be 'low'. Therefore the overall consequences of oystershell scale are **'low '**.

Unrestricted risk

Unrestricted annual risk is the result of combining annual probability of entry, establishment and spread with the outcome of overall consequences. Probabilities and consequences are combined using the risk estimation matrix in the method section. The unrestricted annual risk estimation for oystershell scale is shown in Table 81.

Table 81 Unrestricted risk estimation for oystershell scale

Overall probability of entry, establishment and spread	Very low
Consequences	Low
Unrestricted annual risk	Negligible

As indicated in Table 81, the unrestricted annual risk for oystershell scale is 'negligible', which is below Australia's ALOP. Therefore, risk management measures are not required for this pest.

Results of risk assessments for quarantine pests

The pest categorisation identified 16 pest species as potential quarantine pests requiring further consideration, 10 of concern to whole of Australia (Table 15) and six of concern to Western Australia (Table 16). Detailed risk assessments conducted on these pests are reported in this section. The outcome of the detailed risk assessment on the potential quarantine pests is summarised in Table 82.

Table 82 shows that the unrestricted biosecurity risk because of the pests fire blight, European canker, apple scab, apple leafcurling midge, leafrollers (five species), codling moth and mealybugs are above Australia's ALOP and require risk management measures.

Table 82 Summary of the assessment of unrestricted risk of quarantine pests

Common name of pest	Annual probability of entry, establishment and spread (PEES) [46]	Consequences	Unrestricted annual risk	Management measures needed
Pests of concern to the whole of Australia				
Fire blight	Low	High	Moderate	Yes
European canker	Low	Moderate	Low	Yes
Apple leafcurling midge	High[47]	Low	Low	Yes
Garden featherfoot	Very low	Low	Negligible	No
Grey-brown cutworm	Low	Low	Very low	No
Leafrollers	Low	Moderate	Low	Yes
Pests of concern to Western Australia				
Apple scab	High	Moderate	Moderate	Yes
Codling moth	Low	Moderate	Low	Yes
Mealybugs	Moderate	Low	Low	Yes
Oriental fruit moth	Very low	Moderate	Very low	No
Oystershell scale	Very low	Low	Negligible	No

[46] Median value shown for fire blight, European canker and apple scab
[47] This value was derived from the published data for Apple leafcurling midge

Risk management and draft operational framework

The risk management measures required are discussed in earlier sections on each pest. The following pests were found to require specific risk management as the unrestricted risk exceeds Australia's ALOP:

- fire blight
- European canker
- apple leafcurling midge
- leafrollers
- apple scab
- codling moth
- mealybugs.

This section provides further details on the quarantine conditions (risk management measures together with phytosanitary procedures) and operational procedures required to manage the quarantine risks.

Biosecurity Australia considers that the proposed quarantine conditions are the least trade restrictive means of ensuring that Australia's ALOP would be met and are commensurate with the identified risks.

Biosecurity Australia invites technical comments on the economic and practical feasibility of the measures. Equivalent measures for managing risk can also be evaluated. Those seeking to propose alternative risk management measures should provide a submission for consideration; such proposals are welcome and should include supporting scientific data that explain the extent to which alternative measures would meet Australia's ALOP.

Recognition of the competent authority

New Zealand's Ministry of Agriculture, Fisheries and Forestry (MAFNZ) is the designated National Plant Protection Organization (NPPO) under the International Plant Protection Convention (IPPC). MAFNZ is the official plant protection organisation. Its responsibilities include inspection of plants and plant products moving in international trade, and the issuing of certificates relating to phytosanitary condition and origin of consignments of plants and plant products.

MAFNZ must ensure that service and certification standards, and Work Plan procedures are met by all New Zealand organisations participating in this program.

As part of its responsibilities MAFNZ must ensure that administrative processes are established that provide assurance that the requirements of the program are being met.

Operating manual and work plan

It is a requirement that MAFNZ or the registered agency prepare a documented standard operating procedure (SOP) or manual that describes the phytosanitary procedures for each of the pests of quarantine concern for Australia and the various responsibilities of all parties involved in meeting this requirement. The operating procedure must be approved by AQIS before exports commence and will be subject to audit by AQIS.

A draft work plan will be developed between DAFF and MAFNZ following the finalisation of this revised draft IRA.

Requirement for pre-clearance

It is proposed that at least for the initial trade the quarantine measures will be undertaken through a standard pre-clearance arrangement with AQIS officers being directly involved. The need for pre-clearance would be reassessed after experience had been gained following significant trade.

Under these arrangements AQIS officers would be involved in orchard inspections for European canker and fire blight, in direct verification of packing house procedures and in fruit inspection. The involvement of AQIS officers in pre-clearance would also facilitate a rigorous audit of other arrangements including registration procedures, standard commercial practice, traceability and handling export fruit in a secure manner.

Under the pre-clearance arrangement on-arrival procedures would provide verification that the consignment received was the pre-cleared consignment and that the integrity of the consignment had been maintained.

Audit

The New Zealand apple production and certification system is subject to audit by AQIS.

Audits may be conducted at the discretion of AQIS during the entire production cycle and also as a component of any pre-clearance arrangement.

AQIS field audits will measure compliance with orchard registration, block identification, disease management/monitoring, records management and the administration of the area freedom and accreditation requirements.

Audits will be conducted to measure compliance with packing house responsibilities, traceability, labelling, segregation and product security, and MAF/Agency certification processes.

Participants in pre-clearance arrangements will be audited by AQIS during the season to verify that requirements such as the following are continuing to be met:

- There is an effective approved documented system in operation, including product identification and labelling at each facility to ensure that pre-cleared and non pre-cleared products are kept separate.
- At any time pre-cleared product is moved, the transport systems used maintain the integrity of the pre-cleared product.
- Appropriate records are maintained for all pre-cleared product in storage.

Registration of export orchards or blocks

All export orchards or orchard blocks supplying apples for export to Australia must be registered with MAFNZ for the purpose of providing ‘traceback’ and monitoring in field controls.

Export orchards or orchard blocks must be registered before the start of each apple season in time to allow the inspection for fire blight symptoms and European canker to take place.

Growers must notify MAFNZ of their intention to register an orchard or orchard block, providing sufficient detail that clearly identifies the orchard or orchard block boundaries. For identification purposes orchards or blocks may be identified by maps or physical landmarks that can be used to define boundaries. Growers must retain copies of orchard descriptions/maps for audit purposes.

Copies of orchard registration records must be made available to Australia if requested.

Each export orchard or orchard block must be allocated a unique identification number by MAFNZ. This unique identification number will be used to enable traceback.

Growers/packing houses must have approved documented systems (including appropriate records) in place ensuring that apples destined for Australia are harvested only from orchards or orchard blocks that are registered for Australia.

Apples destined for Australia must be clearly identified at all times post-harvest, including reference to the orchard or orchard block registration number. Growers must ensure that apples from registered orchards/blocks and destined for Australia are kept segregated from apples from non-registered orchards/blocks (see segregation requirements below).

Growers must provide access to registered orchards or blocks for the purpose of monitoring/surveillance for compliance with the requirements for freedom from specified disease symptoms and arthropods.

Standard commercial practice

Information provided by New Zealand on orchard and packing house practices and procedures and levels of pest infestation/infection in orchards and on apples is largely based on data derived from commercial apple production systems used in New Zealand. Therefore this risk analysis and the proposed risk management measures are based on apples produced under normal commercial production practices. Where relevant, commercial production practices are discussed under specific pests.

MAFNZ will ensure that all orchards registered for export to Australia are operating under standard commercial practices. Growers are responsible for maintaining adequate records relating to pest control, orchard monitoring, and spray diaries that confirm that standard commercial practices are being used. These records may be audited by AQIS.

Inspection

Fire blight symptoms

The inspection regime will be undertaken at an inspection intensity that would, at a 95% confidence level, detect visual symptoms if shown by 1% of the trees. This inspection should take place between 4 to 7 weeks after flowering when conditions for fire blight disease development are likely to be optimal. MAFNZ must provide details of the proposed inspection methodology including an analysis showing that the methodology will achieve the required efficacy in advance of commencement of exports. This analysis must address practical issues such as visibility of symptoms in the tops of trees, the inspection time needed to meet the efficacy level and training and certification of inspectors. The proposed system will need to be approved before the commencement of trade.

The detection of any visual symptoms of fire blight would result in the suspension of the orchard/block for the season.

European canker

Risk management for European canker is based on establishing that export orchards or blocks are pest-free places of production. The requirements are:

- Orchards/blocks should be inspected after leaf fall and before winter pruning for symptoms of European canker.
- Orchards/blocks in areas less conducive for disease (for example, Hawke's Bay and Otago) should be inspected by walking down every row and visually examining all trees on both sides of each row for symptoms.
- Areas more conducive for disease (the Waikato, Nelson and Auckland areas and any other export areas with similar climate) should be inspected using the procedure above combined with inspection of the upper limbs of each tree with ladders (if needed).
- Detection of European canker would result in suspension of exports in that orchard/block for the coming season. Reinstatement would require eradication of the disease, confirmed by inspection.

General requirements

All suspected symptoms of quarantinable diseases are to be reported to AQIS immediately. Suspected symptoms are to be verified by a MAFNZ accredited plant pathologist for confirmation. All exports from the suspect orchard or orchard block will be suspended until the symptoms are formally identified.

Records must be kept of all confirmed fire blight and European canker detections.

The detection of any confirmed symptoms of quarantinable diseases will disqualify the orchard or orchard block from supplying apples to Australia for the remainder of the season.

Detailed inspection records are to be maintained for audit by MAFNZ and AQIS.

Packing houses

Registration

MAFNZ will register all exporters and export packing houses before the start of harvest each season to maintain quarantine integrity of the commodity, and provide for traceability of consignments should non-compliance with import conditions occur.

Each export packing house must be allocated a unique registration number by MAFNZ.

All apples for export to Australia must be processed by registered packing houses. Biosecurity Australia requires that packing houses registered for export of apples source fruit only from registered orchards.

Each packing house must have an approved documented system for traceability, including record keeping of: receival receipts, orchard and/or orchard block identification numbers, storage, packing and load-out records.

The manager of the packing house will ensure that equipment and storage areas used for handling export apples are clean and are free from quarantine pests or other regulated articles before being used to process export fruit.

Packing houses must provide details of the layout of the premises including storage areas and procedures for product segregation. Packing houses must also provide details of the equipment that will be used to comply with the chlorine or approved alternative dip requirements.

The packing house must maintain hygiene standards and weed control to reduce the potential contamination of picked fruit.

MAFNZ will inspect packing houses during the packing and storage of export apples to monitor and verify that the necessary requirements, including measures to prevent contamination of fruit and packing materials with quarantine pests and other regulated articles, are met.

MAFNZ will conduct audit checks on approved packing houses to monitor the measures taken to prevent mixing or substituting non-export apples with apples destined for export to Australia.

MAFNZ must immediately suspend exports from packing houses found to be non-compliant and notify AQIS of the suspension.

Suspended packing houses may only be reinstated for processing of apples for export to Australia when MAFNZ and AQIS are satisfied that non-compliance issues have been adequately addressed.

MAFNZ must make available to AQIS, on request, information on its supervisory activities in relation to packing houses.

Apples for other markets may be packed in conjunction with apples for Australia provided that all apples have been sourced from orchards or orchard blocks registered for Australia. Apples for Australia must not be mixed with apples from non-registered orchards at any time.

Disinfection treatment in the packing house

Disinfection treatment of apples in the packing house is a mandatory requirement. The operational procedures below are based on the use of chlorine. However, other agents may be as effective as chlorine. New Zealand would need to submit supporting documentation for other agents for approval by AQIS.

All apples for export to Australia must have been subjected to complete immersion in a water solution containing a minimum 100 ppm available chlorine for a minimum of one minute.

Packing houses must have a documented system approved by MAFNZ for measuring the available chlorine and pH levels in the water and ensuring that the available chlorine levels do not fall below 100 ppm. This system is subject to audit by AQIS.

The pH must be kept between 5 and 6.

The level of available chlorine in the water must be maintained at or above the required level. Monitoring of the available chlorine and pH must occur at the start of packing each day and least every 2 hours throughout the packing process and be adjusted as required.

Records must be maintained and be available for audit of all chlorine monitoring and top-up and pH levels, including when water is replaced.

Packing houses must have an approved system in place to limit the buildup in the chlorine treatment tank of extraneous organic matter, including leaves, stems, twigs, bark, grass, weeds, soil, clay or any other material that would interfere with the chlorine treatment.

Prevention of contamination after disinfection treatment

Procedures should be in place to prevent contamination of the apples after the disinfection treatment.

Packing houses must ensure that all grading and packing equipment that comes in direct contact with apples is cleaned and disinfected using an approved disinfectant (for example, sodium hypochlorite (NaOCl) solution) immediately before each Australian packing run. Maintenance of good hygiene on the packing line is normal practice in New Zealand (see discussion under Imp5 for fire blight) but this must be documented and is subject to audit by MAFNZ and AQIS.

Adequate labelling of lots

Identification of origin of fruit will be displayed on each carton – including orchard identification number (as per register) or block identification number, packing house number and date of packing.

Palletised product is to be identified by attaching a uniquely numbered pallet card to each pallet or part pallet to enable traceback to registered orchards and packing houses.

All pre-cleared product must be identified by pallet card number.

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.

Prevention of contamination in storage, transport and handling

After inspection, packed fruit will be immediately loaded into a shipping container or onto a vehicle and transported to the wharf.

All packed apples that are not immediately transported to the wharf must be stored in MAFNZ approved premises free from quarantine pests.

Packed product and packaging is to be protected from pest contamination during and after packing, and during movement between locations (e.g. by use of bulkheads, tarpaulins and shrink-wrap).

Apple fruit inspected and certified by MAFNZ for export to Australia must be securely stored and segregated from fruit for other destinations, to prevent mixing.

Security of the consignment is to be maintained until release from quarantine in Australia.

Fruit must transported in an enclosed unit or packages covered to prevent contamination with quarantine pests.

If fruit is not containerised, palletised fruit at the wharf will be stored separately from domestic or other export fruit in areas free from quarantine pests.

A consignment will not be split or have its packaging changed while in transit between or while in another country en route to Australia.

Management of apple leafcurling midge

Following are two options that the IRA team consider will address the risk associated with apple leafcurling midge. Included under these two options are procedures relevant to the management of other quarantine pests. These options are based on information provided by New Zealand on apple leafcurling midge. The IRA team acknowledges that it may be possible to develop other risk management measures (for example, perhaps based on low pest prevalence in orchards or pest free places of production) but this would require more detailed information on apple leafcurling midge than is currently available.

Option 1: Inspection with treatment

All apples for export to Australia will be subjected to inspection by MAFNZ or their accredited Agency for apple leafcurling midge and all visually detectable quarantine pests, diseases, and trash.

Each lot will be inspected on the basis of a 3000 unit sample selected at random across the whole lot. A unit is one piece of fruit. Where the lot comprises apples from more than one supplying orchard or block then the inspection sample should be selected proportionally across all orchards/blocks.

During inspection of packed fruit all apples are removed from the box and the empty box and packaging material is examined for dislodged insects and trash. Each individual apple in the inspection sample is examined.

The full 3000 unit inspection sample is completed, regardless of the lot passing or failing.

The inspected sample must be free from apple leafcurling midge and all symptoms of quarantinable diseases, arthropods, trash and weed seeds.

Any apples suspected of harbouring pests are cut and examined.

Where any live quarantinable arthropod is found the lot must be subjected to an appropriate treatment (for example, fumigation) or rejected for export.

The detection of apple showing symptoms of a quarantinable disease within the inspection sample will result in the rejection of the entire lot for the Australian market.

If the lot is rejected because of the presence of symptoms of the quarantinable diseases fire blight or European canker, all remaining apples from the supplying orchard/block must be removed from the Australian program, and AQIS notified as agreed. The non-compliant orchard/block will be suspended from the Australian program for the remainder of the current season.

Where ‘in-line’ inspection is being proposed the system must ensure that fruit is packed into clean boxes/bins. The procedures for inspection for freedom from insects and trash in bins/boxes must be approved by AQIS.

Inspection records must be maintained that identify the product in the lot, the inspection result, any action taken for failed inspections, and a record of quarantine pests detected.

Each inspection lot is appropriately identified (for example, by pallet card numbers) on the accompanying Phytosanitary certificate or Declaration of Intent (DOI).

The lot contains only apples from orchards or orchard blocks that are registered for Australia and comply with the orchard monitoring requirements for freedom of symptoms of fire blight and European canker.

The apples comply with the chlorine dip requirements and relevant records are checked

Only lots that pass the MAFNZ/Agency phytosanitary inspection may be presented for AQIS pre-clearance inspection.

Lots that pass the MAFNZ/Agency phytosanitary inspection must be kept segregated from non-inspected product and product destined for other markets.

Where apples from multiple orchards/blocks are present in one lot and only one orchard/block is found to be non-compliant then the lot can be reconfigured to remove fruit from the non-compliant orchard/block. However, the entire newly configured lot must be re-inspected according to the requirements set out above.

If an organism that has not been categorised is detected, it will require assessment to determine its quarantine status and if phytosanitary action is required. The detection of any significant pests of quarantine concern not already identified in the analysis may, depending on the circumstances, result in the suspension of trade while a review is conducted to ensure that measures are implemented that continue to provide the appropriate level of phytosanitary protection for Australia.

Lots which are rejected must be withdrawn from the Australian program. Failed lots must be identified with an appropriate label or sticker and be kept separate from other passed product or product awaiting inspection.

The inspection location must maintain records regarding the storage and movement/disposal of apples rejected for the Australian market.

Under pre-clearance arrangements AQIS would be involved in the supervision of these procedures.

Option 2: Mandatory treatment

MAFNZ must confirm that:

- The lot contains only apples from orchards or orchard blocks that are registered for Australia and comply with the orchard monitoring requirements for freedom of symptoms of fire blight and European canker.
- The apples comply with the chlorine dip requirements and relevant records have been checked.

Each lot will be inspected on the basis of a 600-unit sample selected at random across the whole lot. A unit is one piece of fruit. Where the lot comprises apples from more than one supplying orchard or block then the inspection sample should be selected proportionally across all orchards/blocks. All apples are removed from the box and the empty box and packaging material is examined for trash.

Where any apples are detected showing symptoms of a quarantinable disease or trash the entire lot must be rejected.

Where apples from multiple orchards/blocks are present in one lot and only one orchard/block is found to be non-compliant then the lot can be reconfigured to remove fruit from the non-compliant orchard/block. However, the entire newly configured lot must be re-inspected according to the requirements set out above.

If an organism that has not been categorised is detected, it will require assessment to determine its quarantine status and if phytosanitary action is required. The detection of any significant pests of quarantine concern not already identified in this IRA may, depending on the circumstances, result in the suspension of trade while a review is conducted to ensure that measures are implemented that continue to provide the appropriate level of phytosanitary protection for Australia.
Lots are subjected to an appropriate treatment (for example, methyl bromide fumigation). Under pre-clearance arrangements AQIS would be involved in supervision of this treatment.

Records are maintained that identify the treated product in the lot and details of the treatment.

Each treatment lot is appropriately identified (for example, by pallet card numbers) on the accompanying Phytosanitary certificate or Declaration of Intent (DOI).

The inspection location must maintain records regarding the storage and movement/disposal of apples rejected for the Australian market.

Management of leafrollers and quarantine pests including contaminant pests

Each lot will be inspected on the basis of a 600-unit sample selected at random across the whole lot. A unit is one piece of fruit. Where the lot comprises apples from more than one supplying orchard or block then the inspection sample should be selected proportionally across all orchards/blocks. All apples are removed from the box and the empty box and packaging material is examined for trash.

Where any apples are detected showing symptoms of a quarantinable disease or trash the entire lot must be rejected.

Where fruit from multiple orchards/blocks are present in one lot and only one orchard/block is found to be non-compliant then the lot can be reconfigured to remove fruit from the non-compliant orchard/block. However, the entire newly configured lot must be re-inspected according to the requirements set out above.

If an organism that has not been categorised is detected, it will require assessment to determine its quarantine status and if phytosanitary action is required. The detection of any significant pests of quarantine concern not already identified in this IRA may, depending on the circumstances, result in the suspension of trade while a review is conducted to ensure that measures are implemented that continue to provide the appropriate level of phytosanitary protection for Australia.

Requirements for packaging materials

Packing materials (boxes, liners, trays) should be new and have been stored in a manner that has prevented contamination with pests. Bulk bins must be clean and free of soil, trash or other foreign matter. Timber packaging and pallets must conform with Australian quarantine requirements.

Phytosanitary certification

MAFNZ is to issue a phytosanitary certificate for each consignment after completion of the pre-export inspection. Each phytosanitary certificate is to contain the following information:

- reference to the shipping container number and container seal number, or flight number
- full description of the consignment, including registered packing house number, and registered orchard/block number/s.

Additional declarations: '*The apples in this consignment have been produced in New Zealand in accordance with the conditions governing the entry of fresh apple fruit from New Zealand to Australia.*'

Notification of non-compliance

MAFNZ will notify AQIS immediately of any notifiable non-compliance, including detection of fire blight symptoms in a registered orchard and details of deregistered orchards and packing houses.

Import permit

A valid 'Permit to import quarantine material' is required to be obtained from the AQIS.

Quarantine entry

A Quarantine entry application must be lodged with AQIS for import of consignments of fresh apple fruit. An importer or their agent or broker may lodge the Quarantine entry application.

Use of accredited personnel

Operational components and the development of risk management procedures may be delegated by MAFNZ to an accredited agent under an agency arrangement as appropriate (for example, through an accredited independent verification agency – IVA). This delegation must be approved by AQIS and will be subject to the requirements of the pre-clearance system. MAFNZ is responsible for auditing all delegated risk management procedures.

Orchard inspections must be undertaken by MAFNZ or persons accredited by MAFNZ. Accredited persons must be assessed and audited as being competent in the recognition of disease symptoms of concern in the field. Accredited persons may include MAFNZ officers, agency staff, plant pathologists, commercial crop monitors/scouts, or other accredited persons. The accrediting authority must provide MAFNZ with the documented criteria upon which accreditation is based and this must be available for audit by MAFNZ and AQIS. AQIS will audit these systems before commencement of trade.

Movement of fruit into Western Australia

State legislation in Western Australia currently prohibits the importation of apples from other States and Territories in Australia because of the presence of apple scab within the apple production areas of eastern Australia and the lack of suitable risk management measures to prevent the introduction of apple scab into Western Australia. MAFNZ and appropriate experts have been consulted and the scientific literature reviewed but the IRA team has not been able to determine adequate risk management measures for apple scab. To maintain Western Australia's regional freedom from apple scab, the IRA team is proposing that New Zealand apples should not be exported into Western Australia. However, if suitable risk management measures were to be developed for apple scab importation of New Zealand apples to Western Australia would require the application of risk management measures for codling moth and mealybugs as outlined in earlier sections of this report.

Verification of documents and inspection on arrival where pre-clearance is not used

It is proposed that at least for initial trade pre-clearance be used (see above). However, it is possible that this requirement may change in the future. This section sets out the provisions that would apply to shipments that do **not** undergo pre-clearance.

AQIS will undertake a documentation compliance examination for consignment verification purposes followed by inspection before release from quarantine. The following conditions will apply:

- The importer must have a valid import permit.
- The shipment must have a phytosanitary certificate that identifies registered orchards/blocks and registered packing houses and bears the additional declaration.
- No land bridging of consignments will be permitted unless the goods have cleared quarantine.
- Any shipment with incomplete documentation, or certification that does not conform to conditions may be refused entry, with the option of re-export or destruction. AQIS would notify MAFNZ immediately of such action, if taken.
- Subject to the specific risk management measures used consignments will be subject to appropriate inspection by AQIS.

The confirmed detection of any visible symptoms of diseases for which orchard freedom is required (fire blight and European canker) will result in the rejection of the consignment or lot and the suspension of the orchard from supplying apples for export to Australia for the remainder of the export season. The consignment must be re-exported or destroyed. AQIS will notify MAFNZ/Agency of the rejection to facilitate suspension of the orchard.

Any trash detected will result in the consignment or lot being rejected. Trash includes twigs, sticks, whole or parts of leaves (whether loose or attached to fruit), organic matter, grass, weeds, seeds.

The detection in Australia of live quarantinable arthropods including contaminant pests will require the consignment to be treated or to be re-exported or to be destroyed.

If any pests are detected that have not previously been assessed or categorised in respect to their quarantine status for Australia, the lot will be held. AQIS in consultation with Biosecurity Australia will determine the quarantine status of the pest and appropriate action taken.

Review of import conditions

AQIS may review operational procedures at any time and may, in consultation with MAFNZ, suspend the importation of apples, if deemed necessary because of phytosanitary considerations. A suspension would be reviewed following a joint AQIS, BA and MAFNZ investigation.

It is proposed that Biosecurity Australia, in consultation with MAFNZ, will review the import requirements after the first year of trade. Further reviews will occur if circumstances or information warrant such action.

Further steps in the import risk analysis process

The administrative process adopted requires that the following steps be undertaken:

- release of the revised draft IRA report (this report) for stakeholder comment
- comments to be received within a specified period usually 60 days
- consideration of stakeholder comments on the revised draft IRA report and preparation of a final draft report
- consideration of the final draft report by an independent Eminent Scientists Group to ensure all stakeholder comments have been taken properly into account
- preparation of the final IRA report
- release of the final IRA report (30 day appeal period)
- consideration of appeals, if any
- if there are no appeals or the appeals are rejected, the Director of Animal and Plant Quarantine makes the policy determination
- Notification of the proponent/applicant, registered stakeholders, and the WTO of the policy determination.

Stakeholders will be advised of any significant variation to the process.

Biosecurity Australia is committed to a thorough risk analysis of the proposed importation of apples from New Zealand. This analysis requires that technical information be gathered from a wide range of sources. If you have information relevant to this IRA process for the proposed importation of apples from New Zealand, it should be provided as quickly as possible if you wish to have it taken into account as part of the quarantine decision making process.

Acknowledgements

Biosecurity Australia wishes to acknowledge the extensive work of the IRA team on this *Revised Draft IRA Report*. Others who deserve special acknowledgement are the many scientists, government personnel and apple industry people from Australia and overseas who have contributed in various ways, including collecting and providing technical information.

Appendix 1

Overview of Bureau of Rural Sciences involvement in New Zealand Apple Import Risk Assessment process

Scope of involvement

The construction of an import risk assessment is a large and complex task and, appropriately, Bureau Rural Sciences has only provided input into certain technical aspects. BRS was initially tasked with working with the IRA team to address stakeholder comments relating to the Biosecurity Australia apple model. In so doing, BRS was asked to recognise the considerable work that had already gone into developing the model, and to focus on any issues relating to logic and refining the structure of the existing model. Given the policy issues involved, final judgement about whether the model was adequate to assist the IRA team in recommending policy for New Zealand apples was not within scope of BRS tasks.

BRS input has concentrated on reviewing the model's structure, its logical basis and its possible interpretations with respect to biosecurity risk. In doing this a distinction was made between the logical construction of the model, and the construction of the inputs into the model. With apples, the inputs are an amalgam of research by Biosecurity Australia staff, the views and experiences of the panel and additional research and comments by stakeholders. In the vast majority of cases inferences cannot be made directly on the basis of the available data, as it may be temporally and spatially limited and it is often not directly related to the needs of the model. Generally BRS was not involved in advising on data inputs, as BRS does not have relevant entomology or pathology skills. The responsibility for the production of inputs remains with Biosecurity Australia. The foundation of the Biosecurity Australia approach is the transparent expert assessment of risk, based on available information from experts and therefore it was important that BRS did not take the role of risk assessor.

BRS did not consider the consequences side of the assessment.

The major issues identified by BRS are outlined below. They include model structure, elicitation of expert opinion, temporal representation, model changes, arthropod pests and percentiles reported.

Model structure

The BRS interpretation of the model was explained to Biosecurity Australia staff and panel members by BRS on a number of occasions, in particular during IRA team meetings. In summary the draft Biosecurity Australia apple model has no explicit temporal, spatial or clustering structure. It simply represents the trade in apples as a virtual bucket of apples. This bucket contains all the apples that will arrive from New Zealand in a year, and the Biosecurity Australia model utilises experts to estimate the proportion of apples in the bucket that came from infected farms, were infected on those farms and so on. These considerations are of course strongly related to concepts of the probability of events used in the 2004 model.

To see the distinction, observe that the variable imp2 is ‘the likelihood that picked fruit is infected or infested’, given that the orchard is infected. This is surely variable across orchards, but the model treats this as a fixed value in each simulation, implying it is fixed across all orchards. The way of interpreting this is as the proportion of apples coming from infected orchards that were infected at the time of picking. This is a property of all apples coming from infected orchards.

This bucket model analogy was used as a device to guide the import risk team in the interpretation of the probability values as simple proportions, and to stress to them that their estimates should be consistent with this interpretation. For example with imp2 they should rightly consider the expected rates of infection of fruit on individual farms but they were assessing the proportion across all infected farms.

Elicitation of expert opinion

There were multiple discussions with the panel and Biosecurity Australia staff about the eliciting of expert opinion. Three considerations were stressed by BRS. They were:

That Biosecurity Australia should be completely satisfied that the bounds of distribution chosen to represent their views would contain the true value.

That the chosen distribution shape should represent expert views. The interpretation of prior distributions in terms of gambling odds was discussed, and the uniform, triangular and Pert distributions presented as starting points.

It was made clear that qualitative likelihood ranges should not constrain their options and that BRS was available to assist in expressing the experts’ views if necessary.

The issue of expressing divergent opinions was also discussed and different approaches to handling divergence of opinion were canvassed.

Temporal representation

Given the structure of the bucket model, it is necessary to consider what particular year the model is representing. For example is it the worst year in 5, 10 or 100 years or is it the average proportion of apples over some horizon? This is not made explicit in the draft model and IRA Guidelines in general. After discussion and observation of the process, it appears that the model is in some sense an amalgam of these things. This occurs due to the paucity of data and the variation in quality and scope of the available information.

The model attempts to characterise a generic, average year, but often lack of data could lead to conservative (i.e. closer to worst case) assessments or available data may be unwittingly skewed towards the worst case, as the scientific literature may be biased towards reporting extremes. These are matters for the IRA team’s consideration.

The issue of conservatism is difficult. One aspect is that the model is complicated and paradoxes arise (such as the effect of sampling) where conservatism in one step may reduce conservatism at another. A second issue is that it is difficult to demonstrate that an expert opinion is conservative, as this requires actual data that is not available. If it were, it would have been used in preference to expert opinion. For example, the actual apple leafcurling midge data from New Zealand, which arrived near the conclusion of the modelling work, shows infection rates maybe substantially lower than the originally modelled values.

Model changes

There are a number of things that have been changed in response to stakeholders’ comments. The conditioning in the importation steps has been improved, and the effect of sampling has been considered rigorously. These steps are written up in the model descriptions in the report. With conditioning, the effect of contamination is conditioned on the whether the fruit comes from infected orchard. While additional steps could have been conditioned it was considered that mixing would lead to the marginal estimates being sufficient for the later steps, given the other approximations in the model.

The effect of sampling is complicated, as the efficiency depends on the clustering of risk, and conservatism in import assessments can have counter-intuitive effects on the assessment. The issue and changes made are discussed in the model description in the report.

The IRA team apple model calculates the probability of at least one event and then calculates probability of establishment and spread conditional on one event. This is a reasonable approximation if the likely number of exposure events is very small, but will become increasingly inaccurate as the number of events increases. This will be a significant issue for pests that have a reasonable chance of exposure but low chance of establishment or spread. This issue relates to all Biosecurity Australia assessments, both quantitative and qualitative and was addressed by changing the structure of the establishment or spread calculations

Arthropod pests

The largest change in the model was for arthropod pests where the entomologists advised that the risk is dependent in a non linear way on the number of infected apples in proximity to susceptible hosts. Thus the concept of the risk of a single apple does not make sense, as its context (i.e. number of infected apples around it) is the main determinant of risk. As discussed above, the bucket model cannot make inferences about this, as it does not consider the clustering of infected fruit in the pathways and it simply calculates the proportion of fruit going to abstract distribution points. After extensive discussion with Biosecurity Australia entomologists and team members it was decided that it would allow clearer consideration of the risks from arthropods to calculate estimates of the number of infested apples in each exposure point per week. In addition, crude estimates of lot to lot variation were derived in infected apples based on assumptions about clustering implied in the importation steps. This allowed the risk assessors a more concrete and tangible scenario to assess for likelihood.

Another change in the model at this point was to make the expert assessment of the risk over all apples for each exposure by distribution points, rather than trying a complicated numerical approach. This was done for a number of reasons.

The risk for each cluster or distribution point could not be adequately modelled marginally by the IRA team as a fixed value. Uncertainties (such as the climate match, in the inoculum size vs. invasion success and the clustering of risk in the import pathways) will impact across the population. The model’s structure could not adequately address these points and the available quantitative data is poor.

Allowing the expert assessor the freedom to carry out the assessment based on all available information on natural and intuitive elements rather than on abstract model constructs, will potentially lead to more accurate assessments. This approach is consistent with Biosecurity Australia’s qualitative risk assessments, and uses the quantitative approach to frame the question from steps where data is available (i.e. importation and distribution) while using expert assessment for the critical step where quantitative data is limited.

These arguments could be applied to all pathogens of apples. However, experts were more comfortable expressing risk on a per apple basis for the diseases as they were associated with apples to the final end point. BRS recommended that Biosecurity Australia ensure that their expert judgements were consistent with both the per-apple risk and the overall risk estimate, and this was accepted.

Percentile reported

Stakeholders have raised concerns about the percentile used to summarise the model.

Technically, there are simple theoretical arguments that can be made to support the use of the mean of the distribution. For example, if we have a posterior probability which is the belief about the probability of an establishment or spread event conditional on our data and beliefs, our prediction about the expected probability of an establishment or spread event in the next year is simply the expected value of this distribution. As this posterior probability is independent of the consequences (i.e. the impact of an outbreak is independent of the probability of an outbreak) this argument can be sustained. If this is the case then we can technically argue for the use of the mean as outlined above, and while not identical, this is not radically different from Biosecurity Australia's approach of looking at the median and the category where the bulk of the risk lies.

In general, use of the 95^{th} percentile represents a conservative estimate of quarantine risk (i.e. in the belief of the team, it is 95% likely to be larger than the actual risk) rather than expression of what the team believes is the expected risk. That one or the other is consistent with policy is a matter for Biosecurity Australia.

Further complicating this issue is the impact of conservatism (from lack of data) in the model. This will tend to overestimate risk, and mean that higher percentiles may be overly conservative, but as discussed previously this may be hard to categorically demonstrate.

Bureau of Rural Sciences
Canberra
17 October 2005

Abbreviations and acronyms

AAPGA	Australian Apple & Pear Growers Association (now Apple & Pear Australia Limited)
ABS	Australian Bureau of Statistics
AFFA	Agriculture, Fisheries and Forestry – Australia, now the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF)
AHL	n-acyl homoserine lactone
AIGN	Associated International Group of Nurseries
ALOP	appropriate level of protection
ANAO	Australian National Audit Office
APAL	Apple & Pear Australia Limited
APPD	Australian Plant Pest Database
AQIS	Australian Quarantine and Inspection Service
BA	Biosecurity Australia, an operating group within the Australian Government Department of Agriculture, Fisheries and Forestry
BFP	biological fruit production
BRS	Bureau of Rural Sciences
c.	*Circa*, about
CABI	CAB International, Wallingford, UK
CBD	central business district
cfu	colony-forming unit; an individual cell or group of cells that is able to divide to produce an entire colony of cells
CSIRO	Commonwealth Scientific and Industrial Research Organisation
cv.	cultivar
DAFF	Department of Agriculture, Fisheries and Forestry (was Agriculture, Fisheries and Forestry - Australia)
DAFF-PDI	Department of Agriculture, Fisheries and Forestry – Pest and Disease Information Database
DAWA	Department of Agriculture, Western Australia
DBSA	dodecylbenzenesulphonic acid
DEA	designated export area
DMI	dimethylation inhibitors
DNA	deoxyribo nucleic acid; the molecule responsible for the transference of genetic characteristics

DOI	declaration of intent
DPIFQ	Department of Primary Industries and Fisheries, Queensland
DPINSW	Department of Primary Industry, New South Wales
DPIV	Department of Primary Industry, Victoria
DRIRA	draft import risk analysis
DSB	dispute settlement body
ENZA	The brand 'ENZA' was introduced for export pipfruit by the New Zealand Apple & Pear Marketing Board in 1991
EPS	exopolysaccharides
Exp.	exposure
FAO	Food and Agriculture Organization of the United Nations
FSANZ	Food Standards Australia New Zealand
GATT	General Agreement on Tariffs and Trade
HAL	Horticulture Australia Limited
HortResearch	Horticulture and Food Research Institute of New Zealand Ltd
ICON	AQIS Import Conditions database
ID_{50}	infestation density
IFP	integrated fruit production; a program undertaken by horticultural industries that requires good management practices in orchards and packing houses
Imp.	importation step
IPM	integrated pest management; integration of chemical means of pest control with other methods, notably biological control and habitat manipulation
IPDM	integrated pest and disease management
IPPC	International Plant Protection Convention, as deposited in 1951 with FAO in Rome and as subsequently amended
IRA	import risk analysis
ISPM	International standards for phytosanitary measures
IVA	independent verification agency
kPa	kilopascal. One kilopascal equals 1000 Pa (pascal). A pascal is a unit of pressure equal to one newton per square metre
kt	kilotonne equals 1,000 metric tons
L	likelihood
lux	a unit of illumination equal to 1 lumen per square metre; 0.0929 foot candle
MAFNZ	Ministry of Agriculture and Forestry, New Zealand; New Zealand's National Plant Protection Organization
MIP	multiple infection period

MOU	memorandum of understanding
MRL	maximum residue levels
mt	metric ton equals 1000 kilograms which is equivalent to 1 tonne
µm	micrometre/micron
NIWA	National Institute of Water and Atmospheric Research
OIE	Office International des Epizooties
OP	organic production
OPENZ	The Organic Products Exporters of New Zealand Inc.
NPPO	National Plant Protection Organisation
NSWFA	New South Wales Farmers' Association
NVFA	Northern Victorian Fruitgrowers' Association Ltd
P	probability
PAD	potential ascospore dose
PBPM	Plant biosecurity policy memorandum
PCR	polymerase chain reaction
PDI	pest and disease information database
PFGE	pulsed-field gel electrophoresis
PGNZI	Pipfruit Growers New Zealand Inc.
PEES	probability of entry, establishment and spread
PID	potential infection days
PM	pest management
PPD	partial probabilities of distribution
PPEES	partial probability of entry, establishment and spread for exposure group
PPES	partial probability of establishment and spread for exposure group
PRA	pest risk analysis; the process of evaluating biological or other scientific evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it
Prox.	proximity
QFVG	Queensland Fruit and Vegetable Growers
RAP	risk analysis panel; replaced by the Import Risk Analysis team (IRA team) in the *Import Risk Analysis Handbook*, 2003
RBG	Royal Botanic Gardens
RDIRA	revised draft import risk analysis
REB	registered export block; a defined section of a contiguous apple planting registered for export of apples to Australia

SBI	sterol biosynthesis inhibitors
SNZ	Standards New Zealand
SPS	sanitary and phytosanitary
SPS Agreement	International Agreement on the Application of Sanitary and Phytosanitary Measures
t	tonne (see metric ton)
T	triangular distribution; used in the notation T(0.7, 0.85, 1) which denotes a triangular distribution with a lower limit of 0.7, an upper limit of 1 and a most likely value of 0.85.
TAPGA	Tasmanian Apple and Pear Growers Association
U	uniform distribution; used in the notation U(0, 10^{-6}) which denotes a uniformly spread distribution with a lower limit of 0 and an upper limit of 0.000001.
USDA-APHIS	United States Department of Agriculture's Animal and Plant Health Inspection Service
VBNC	viable but not culturable
WebSPIRS5	Silverplatter's Information Retrieval System for the World Wide Web – Contains databases such as CABI abstracts and AGRICOLA
WTO	World Trade Organization

List of terms

The terms provided in this list are representative of their usage in this draft report only. Some terms, particularly those of a biological nature, may have alternative uses outside of the context of this document.

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
Acaricide	An agent, usually chemical, used to kill mites
Aestivate	Also ‘estivate’ – to pass the summer in a dormant or torpid state
Agrochemical	A generic term for the various chemical products used in agriculture
Alluvial	Relating to soil deposited by a river or other body of running water
Amenity plant	Any plant located in a public place, or intended for public usage
Apoplast	The contents of a plant cell, excluding the cell cytoplasm (i.e. the cell walls and spaces between cells)
Area	An officially defined country, part of a country or all or parts of several countries (ISPM 5)
Arthropod	The largest phylum of animals, including the insects, arachnids and crustaceans
Ascoma	An ascus-producing structure; a fruit-body containing asci
Ascospore	A sexual spore produced in an ascus
Ascus	The sac-like cell of the sexual state of a member of the Ascomycota in which the ascospores are produced
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
Biotic	Relating to living organisms, substances and processes
Block	An identifiable sub-area of an orchard
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
Conidiophore	A simple or branched, fertile hypha bearing conidiogenous cells from which conidia are produced

Conidium	A non-motile, usually deciduous, asexual spore
Consignment	The apples covered by one phytosanitary certificate shipped via one port in New Zealand to a designated port in Australia
Contaminant	An organism responsible for transferring a chemical or other substance from one site to another
Control (of a pest)	Suppression, containment or eradication of a pest population (ISPM 5)
Crawler	Intermediate mobile nymph stage of certain Arthropods
Crotch	Area where tree trunk splits into two or more limbs
Cruciferous plant	A plant with four-petalled flowers belonging to the family Cruciferae/Brassicaceae (mustard family)
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
Deciduous plant	Plants, principally trees and shrubs, that lose their foliage for part of the year
Diapause	Period of suspended development/growth occurring in some insects, in which metabolism is decreased
Diaspidid	Belonging to the family Diaspididae (armoured scale insects)
Dicotyledon	A flowering plant whose embryo has two (rarely more) cotyledons (seed leaves)
Dunnage	Loose packing material used to protect a ship's cargo from damage during transport
Eclosion	The emergence of an adult insect from its pupal case, or the hatching of an insect larva from an egg
Endangered area	An area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important loss (ISPM 5)
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 (ISPM 5)
Entry potential	Likelihood of the entry of a pest
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 (of a pest)	The perpetuation, for the foreseeable future, of a pest within an area after entry (ISPM 5)
Establishment potential	Likelihood of the establishment of a pest
Ethylene	An important plant hormone associated with stimulation of fruit ripening, opening of flowers and the abscission of leaves
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
Exposure group	A category of susceptible host plants for which the likelihood of exposure, or the impact of a pest, are likely to be meaningfully different. Exposure groups in this analysis include: commercial fruit crops; nursery plants; household and garden plants, including weed species; and, wild (native and introduced) and amenity plants including susceptible plants growing on farmland
Exudation	Active secretion of fluid from cells as a result of disease or injury
Fecundity	The fertility of an organism
Feral plant	Any plant that has escaped from domestication and returned, partly or wholly, to its wild state
Frass	Insect droppings or excrement
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
Gall	Abnormal swelling of plant tissue caused by insects, micro-organisms or injury
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.
Herbaceous	Not woody
Herbivore	An organism that feeds primarily upon plants.
Host	An organism that harbours a parasite, mutual partner, or commensal partner, typically providing nourishment and shelter.
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.
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
Inoculum	Pathogen or its parts, capable of causing infection when transferred to a favourable location
Introduction (of a pest)	The entry of a pest, resulting in its establishment (ISPM 5)
Introduction potential (of a pest)	Likelihood of the introduction of a pest
Instar	A stage of insect larval development which is between two moults
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	All apple fruit packed for export to Australia each day by a registered packing house
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

Meristem	A type of embryonic tissue in plants consisting of unspecialised developing cells called 'meristematic cells' and found in areas of the plant where growth is or will take place (eg. roots/shoots)
Midge	A small two-winged insect belonging to the Order Diptera
Mite	An arthropod belonging to the Order Acarina (mites and ticks)
Monocotyledon	A flowering plant distinguished by having a single cotyledon or embryonic leaf in its seeds.
Monoculture	An agricultural term used to describe plantings of a single species over a substantial area (examples include lawn and field crops)
Morbidity	The prevalence and/or incidence of a particular disease
Mortality	The total number of organisms killed by a particular disease
Mycelium	The vegetative body of a fungus, consisting of hyphae
Nectary	The gland that secretes nectar, usually located at the base of the flower
Neonate	A new-born or newly-hatched organism
Non-quarantine pest	Pest that is not a quarantine pest for an area (ISPM 5)
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	Established, authorised or performed by a National Plant Protection Organization (ISPM 5)
Official control (of a regulated pest)	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 (ISPM 5)
Omnivore	An organism that consumes both plant and animal material
Orchard	A contiguous area of apple trees operated as a single entity
Organophosphate	A soluble fertiliser material consisting of organic phosphate esters (glucose, glycol, etc.)
Ovule	A structure found in seed plants that develops into a seed after fertilisation
Noctuid	A large family of dull-coloured, medium-sized moths
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)
Parthenogenesis	The growth and development of an embryo or seed without fertilization by a male
Pathogen	A biological agent that can cause disease to its host
Pathogenesis	Production and development of disease
Pathway	Any means that allows the entry or spread of a pest (ISPM 5)

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	The collective term used for insect pests, plant diseases, viruses, bacteria and fungi that could harm plants. The formal definition used is the one provided in the International Plant Protection Convention (IPPC): any species, strain, or biotype of plant, animal or pathogenic agent injurious to plants of plant products
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 (ISPM 5)
Pest Free Area	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 (ISPM 5)
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 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 (ISPM 5)
Polymerase	An enzyme whose central function is associated with polymers of nucleic acids such as RNA and DNA
Polymorphic	Having more than two distinct morphological variants
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
Potable water	Water of sufficient quality that it is suitable for drinking
PRA area	Area in relation to which a pest risk analysis is conducted (ISPM 5)
Practically free	Of a consignment, field, or place of production, without pests (or a specific pest) in numbers or quantities in excess of those that can be expected to result from, and be consistent with good cultural and handling practices employed in the production and marketing of the commodity (ISPM 5)

Propagule	A reproductive structure, e.g. a seed, a spore, part of the vegetative body capable of independent growth if detached from the parent
Pseudothecium	Perithecium-like fruiting body containing asci and ascospores dispersed rather than in an organised hymenium
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 (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 non-quarantine pest	A non-quarantine pest whose presence in plants for planting affects the intended use of those plants with an economically unacceptable impact and which is therefore regulated with the territory of the importing contracting party (ISPM 5)
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
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
Shelterbelt	One or more rows of trees planted in such a manner as to provide shelter from the wind and to prevent soil erosion, commonly around the edges of fields on farms
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
Stakeholders	Government agencies, individuals, community or industry groups or organisations, whether in Australia or overseas, including the proponent/applicant for a specific proposal, having an interest in the subject matter of an IRA
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, leaf spot, wilt
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.
Understorey	Any plants growing under the canopy formed by other plants, particularly herbaceous and shrub vegetation under a tree canopy
Utility points	The five key points at which apples are distributed or utilised and at which apple waste will be generated: orchard wholesalers; urban wholesalers; retailers; food services; and, consumers
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
Volunteer plant	A plant that grows on its own, rather than being deliberately planted by a farmer or gardener. Unlike weeds, which are unwanted plants, a volunteer plant may be encouraged to grow once it appears.
Xylem	In vascular plants, the tissue that carries water up the root and stem

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