



**Australian Government**

**Biosecurity Australia**

# Final Import Risk Analysis Report for the Importation of Cavendish Bananas from the Philippines



**Part B**

**November 2008**

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Cite this report as:

Biosecurity Australia (2008) Final Import Risk Analysis Report for the Importation of Cavendish Bananas from the Philippines, Part B. Biosecurity Australia, Canberra.

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Cover image: Emerging banana bunch showing bracts, flowers and fingers (Photo: D Peasley)

**This import risk analysis has been released by the Chief Executive of Biosecurity Australia.**

Stakeholders have 30 days from the publication of this document to lodge an appeal in writing with the Import Risk Analysis Appeals Panel – a body independent of Biosecurity Australia – on one or both of the following grounds:

There was a significant deviation from the process set out in the Import Risk Analysis Handbook (BA 2003) that adversely affected the interests of a stakeholder.

A significant body of scientific information relevant to the outcome of the IRA was not considered.

In lodging appeals, stakeholders must give reasons for their appeal.

Appeals should be submitted to:

IRAAP Secretariat  
Corporate Policy Division  
Department of Agriculture, Fisheries and Forestry  
GPO Box 858  
CANBERRA ACT 2601

Facsimile: +61 2 6272 5926

E-mail: [IRAAP@daff.gov.au](mailto:IRAAP@daff.gov.au)

Further details of the appeal process are provided in the Handbook (BA 2003).



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# 1. Biosecurity framework

## 1.1 Introduction

This chapter outlines:

- the legislative basis for Australia's biosecurity regime
- Australia's international rights and obligations
- Australia's appropriate level of protection (ALOP) and risk management
- import risk analysis
- policy determination.

## 1.2 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.

### 1.2.1 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

- (a) *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*
- (b) *having as their object the prevention or control of the introduction, establishment and spread of diseases or pests<sup>1</sup> 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, the Cocos Islands or Christmas Island; and*
  - (ii) *the disease or pest causing harm to human beings, animals, plants, other aspects of the environment, or economic activities; and*
- (b) *the probable extent of the harm.*

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

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<sup>1</sup> 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.*

## 1.2.2 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 (also known as the Director of Animal and Plant 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.*

## 1.3 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. Changes to the import risk analysis process announced by the Australian Government in late 2006 were implemented on 5 September 2007, when regulations made under the *Quarantine Act 1908* formally took effect. Under transitional arrangements, announced in Biosecurity Australia Policy Memorandum 2007/20, a number of IRAs, including this IRA, which were well underway or nearly completed, will be finished under the pre-regulated process as described in the *Import risk analysis handbook* (BA 2003)<sup>2</sup>.

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 and consistency.

## 1.4 Australia's international rights and obligations

It is important that IRAs conform with Australia's rights and obligations as a World Trade Organization (WTO) Member. These rights and obligations derive principally from the WTO's

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<sup>2</sup> Available at <http://www.daff.gov.au>

*Agreement on the Application of Sanitary and Phytosanitary Measures* (SPS Agreement)<sup>3</sup>, 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 protect human, animal or plant life or health within their territory from pests and diseases, as well as to prevent other damage from pests within a member's territory. Sanitary (human and animal health) and phytosanitary (plant health) measures (SPS measures) typically apply to trade in or movement of animal-based and plant-based goods within or between countries. The SPS Agreement applies to all SPS measures that may directly or indirectly affect international trade.

The SPS Agreement includes the following:

- the right of WTO Members 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, Member's 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
- SPS measures must be adapted to the SPS characteristics of the area from which the product originated and to which the product is destined. WTO Member's are also required to recognise the concepts of pest/disease-free areas and areas of low pest/disease prevalence.

## 1.5 Australia's appropriate level of protection (ALOP)

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

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<sup>3</sup> [http://www.wto.org/english/docs\\_e/legal\\_e/15-sps.pdf](http://www.wto.org/english/docs_e/legal_e/15-sps.pdf)

Like many other countries, Australia expresses its ALOP in qualitative terms. Australia's ALOP, which is 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 1.1). The cells of this matrix describe the product of likelihood 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*. 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 report.

The band of cells marked 'Very low risk' illustrates Australia's ALOP.

**Table 1.1 Risk estimation matrix**

*Likelihood of entry, establishment and spread	High	Negligible risk	<b>Very low risk</b>	Low risk	Moderate risk	High risk	Extreme risk
	Moderate	Negligible risk	<b>Very low risk</b>	Low risk	Moderate risk	High risk	Extreme risk
	Low	Negligible risk	Negligible risk	<b>Very low risk</b>	Low risk	Moderate risk	High risk
	Very low	Negligible risk	Negligible risk	Negligible risk	<b>Very low risk</b>	Low risk	Moderate risk
	Extremely low	Negligible risk	Negligible risk	Negligible risk	Negligible risk	<b>Very low risk</b>	Low risk
	Negligible	Negligible risk	Negligible risk	Negligible risk	Negligible risk	Negligible risk	<b>Very low risk</b>
		Negligible	Very low	Low	Moderate	High	Extreme
<b>Consequences of entry, establishment and spread</b>							

\*When this likelihood is assessed quantitatively, the qualitative descriptors on the vertical axis are replaced by numerical likelihood ranges as follows: *High* by 0.7–1; *Moderate* by 0.3–0.7; *Low* by 0.05–0.3; *Very low* by 0.001–0.05; *Extremely low* by 1.0E–06 to 0.001; and *Negligible* by 0 to 1.0E–06.

Australia's expression of ALOP as a very low level of risk, illustrated by a matrix and associated methodology, provides a transparent means for determining if sanitary and phytosanitary measures meet Australia's quarantine policy objectives.

The expression of Australia's ALOP has been discussed at different levels of government since publication of the Draft Guidelines (BA 2001). For example the Primary Industries Ministerial Council (PIMC) discussed this issue in 2002 and agreed that:

*the work done to date on the policy framework surrounding ALOP including practical guidelines for risk analysis which illustrate the concept of a risk estimation matrix adequately meets Australia's present needs and further work on this definition is not a PIMC priority<sup>4</sup>.*

Biosecurity issues have been a standing agenda item at PIMC meetings held biannually. Since this agreement, there have been no proposals from the Australian or state and territory governments to change the approach used by Biosecurity Australia to express ALOP.

<sup>4</sup> [http://www.mincos.gov.au/pdf/pimc\\_res\\_01.pdf](http://www.mincos.gov.au/pdf/pimc_res_01.pdf)

## 1.6 Risk management and sanitary and phytosanitary 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 ALOP, 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 assessment.

Australia's approach to addressing requests for imports of animals, plants and their products which may pose 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 and determine the SPS measures needed to achieve Australia's ALOP.

## 1.7 Import risk analysis (IRA)

### 1.7.1 Description

In animal and plant biosecurity, an import risk analysis (IRA) identifies the pests and diseases relevant to an import proposal, assesses the risks they pose and, if those risks are unacceptable, specifies the measures that could be taken to reduce those risks to an acceptable level. Each analysis is conducted within an administrative process described in the *Import risk analysis handbook* (BA 2003). Changes to the import risk analysis process announced by the Australian Government in late 2006 were implemented on 5 September 2007, when regulations were made under the *Quarantine Act 1908* formally took effect. Under transitional arrangements, announced in Biosecurity Australia Policy Memorandum 2007/20, a number of IRAs, including this IRA, which were well underway or nearly completed, will be finished under the pre-regulated process.

### 1.7.2 Undertaking IRAs

Biosecurity Australia may undertake an IRA if:

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

### 1.7.3 Environment and human health

The *Quarantine Act 1908* requires the Director of Animal and Plant Quarantine to ensure that environmental factors are considered in the IRA decision-making process. A memorandum of understanding (MOU) is in place between Biosecurity Australia and the Australian Government Department of the Environment and Heritage to facilitate input of advice on environmental matters in IRAs.

Biosecurity Australia also consults with other 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.

#### 1.7.4 The IRA process in summary

The process consists of the following major stages:

**Initiation:** The requirement for an IRA is identified.

**Scheduling and scoping:** Biosecurity Australia considers all factors that affect scheduling and consults with stakeholders, including state, territory and other Australian Government agencies. There is opportunity for appeal by stakeholders at this stage of the process.

**Risk analysis:** Here, the major scientific and technical work relating to risk assessment and risk management is performed. An external team with appropriate expertise may be engaged to provide advice. There is detailed consultation with stakeholders.

**Reporting:** The final results of the IRA are communicated formally to stakeholders. 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 (Secretary of the Department of Agriculture, Fisheries and Forestry) for decision. The Eminent Scientists Group provides independent advice to the Director of Animal and Plant Quarantine ensuring that stakeholder comments have been properly considered.

**Policy determination:** The Director of Animal and Plant Quarantine makes the final policy determination. Biosecurity Australia then notifies the proponent/applicant and registered stakeholders and the WTO of the final policy determination.

**Implementation:** The final IRA report, the policy determination and the outcomes of any appeals are provided to the proponent/applicant and registered stakeholders. They are also placed on the Biosecurity Australia website and on the public file. Biosecurity Australia notifies the Australian Quarantine and Inspection Service (AQIS) of the new policy and liaises with AQIS on implementation.

## 2. Background

This chapter provides the background to this IRA and outlines Australia's biosecurity policy for fresh bananas. The Philippines Bureau of Plant Industry (BPI) proposes to export mature hard green banana fruit of four Cavendish varieties (referred to as mature hard green bananas in this report) (Extra Dwarf, Giant Cavendish, Grand Nain and Williams) from specified areas of Davao (Davao del Sur, Davao del Norte and Davao Oriental), Cotabato (South Cotabato, North Cotabato and Sarangani) and Bukidnon, on the island of Mindanao in the Philippines. This chapter summarises Australia's response to the proposal. It concludes with a summary of the international trade in bananas and the banana industry in the Philippines and in Australia.

### 2.1 Australia's response to the proposal

Following a formal submission from BPI in May 2000, Australia initiated an IRA on mature hard green banana fruit from the Philippines in June 2000. Biosecurity Australia informed stakeholders on 17 October 2000 that a Risk Analysis Panel (RAP) would complete the IRA. The appointment of panel members was confirmed on 4 January 2001. The name of the panel was later changed to the Import Risk Analysis (IRA) team, consistent with the terminology used in Biosecurity Australia's *Import risk analysis handbook 2003* (BA 2003).

An issues paper was released in May 2001 to describe the scope of the IRA, outline the preliminary pest categorisation process, and advise of the establishment of three technical working groups to assist with insect pests, plant pathogens and horticultural/environmental aspects respectively.

#### 2.1.1 Previous drafts

Biosecurity Australia released a technical information paper in May 2002, which contained the preliminary pest categorisation and reports on the technical working groups (BA 2002b). This was followed in June 2002 by a draft IRA report, for stakeholder comment. Twenty submissions were received on the draft report, including substantial comments from Australian and Philippines stakeholders.

In February 2004 a revised draft IRA report was released which took account of stakeholder submissions and reports, as well as new technical information. Following the release of the revised draft IRA report, Biosecurity Australia found a transcription error in the Excel spreadsheet model used to assist with the estimation of risk. The IRA team reviewed the implications of correcting the error and advised Biosecurity Australia of suggested changes to the report and to the recommended quarantine conditions. These findings were released in June 2004 and presented in an Addendum to the revised draft IRA report.

Biosecurity Australia advised stakeholders in August 2004 that a further revised draft IRA report would be issued to address statistical issues raised by the Australian Banana Growers Council (ABGC) that would significantly alter the pest risk assessments. When the Australian Government created Biosecurity Australia as a Prescribed Agency in late 2004, the Australian Government undertook that Biosecurity Australia would review and reissue the draft IRA report. In 2005, there were further consultations with stakeholders to clarify their comments and request further information. Supplementary reports relevant to that IRA were received from the two main stakeholders, the ABGC (ABGC 2006c) and the Philippines Government. Given the substantial submissions, reports and differing technical viewpoints, the IRA team considered it appropriate to undertake an extensive review of the technical information for each quarantine pest identified in the IRA. Additionally, the IRA team considered all the other technical issues documented in the submissions and reports.

All stakeholder comments provided on the previously issued revised draft IRA report (BA 2004) and its Addendum were considered in the revised report released for stakeholder comment 1 March 2007. Subsequently, the IRA team met with an Australian stakeholder separately to clarify information provided in their written submissions. The IRA team also considered new scientific and technical information and reports of the Senate Committee on Rural and Regional Affairs and Transport (Commonwealth of Australia 2004, 2005).

The revised draft IRA report for the importation of Cavendish bananas from the Philippines (Biosecurity Australia 2007) included a minority view in Part A of that report. The minority view was provided by one member of the IRA team regarding the risk management measures for Moko as they were expressed in the revised draft IRA report. The IRA team, in considering all stakeholder comments provided on the 2007 revised draft report, further developed the risk management section for Moko noting the comments of stakeholders and the issues raised by the member of the IRA team in their minority view. All members of the IRA team provided full endorsement to the contents of the draft final report with no qualifications.

All stakeholder comments provided on the 2007 revised draft IRA report were considered by Biosecurity Australia and the IRA team in developing this report.

### **2.1.2 Scope of this report**

In its submission of June 2000, BPI proposed to export Gros Michel and four varieties of Cavendish (Extra Dwarf, Giant Cavendish, Grand Nain and Williams) banana fruit from regions (Davao, Cotabato and Bukidnon) on the island of Mindanao in the Philippines.

In October 2001, following stakeholder comments on the Issues Paper and discussions with the Chairs of the technical working groups during their visit to the Philippines in August 2001 (BA 2002a), BPI clarified that the proposed export areas for Davao were Davao del Sur, Davao del Norte and Davao Oriental, and for Cotabato were South Cotabato, North Cotabato and Sarangani. At the same time, BPI advised Biosecurity Australia that Gros Michel cultivar is no longer produced in Philippines banana plantations.

This report therefore presents an assessment of biosecurity risks associated with the importation into Australia of fresh mature hard green banana fruit of four Cavendish varieties (Extra Dwarf, Giant Cavendish, Grand Nain and Williams) from specified areas of Davao (Davao del Sur, Davao del Norte and Davao Oriental), Cotabato (South Cotabato, North Cotabato and Sarangani) and Bukidnon, on the island of Mindanao. The report also considers and evaluates, as appropriate, risk management measures.

Following the QDPI (2000) definition, this report uses the term ‘mature hard green bananas’ to refer to bananas that are fresh, mature, hard green, have unbroken skin and are of Cavendish type.

Hard green bananas have the following characteristics:

- the flesh is hard and not flexible, the skin is green and shows no yellow colouration except for the areas towards the flower end of a fruit which the sun has bleached the skin to a yellow to white colour but the flesh beneath is still hard; and
- no single banana or banana on the outside whorl of a hand or cluster (except a wing banana or distorted banana) has a diameter that exceeds 42 mm, when measured at right angles to the curvature of the fruit at a point one third from its flower end.



### 2.1.3 IRA team

The members of the IRA team involved in analysis and preparation of this final report are:

Dr Brian Stynes	Chair, Senior Plant Scientist – Plant Biosecurity, Biosecurity Australia
Dr Rob Allen	Consultant (Plant Pathologist) (resigned during the final preparation of the report due to ill health April 2008)
Mr Bob Paton	Consultant (Entomologist)
Mr David Peasley	Consultant (Horticulturalist)
Mr Mike Robbins	Manager – Plant Quarantine, Australian Quarantine and Inspection Service

Biosecurity Australia provided a technical secretariat for the IRA team.

## 2.2 Australia's biosecurity policy for fresh bananas

### 2.2.1 National Quarantine Policy

Currently, fresh banana fruit for human consumption is not imported by Australia. A risk analysis on the importation of fresh banana fruit from Ecuador was started in 1991. However, import conditions were not developed because the access request was withdrawn. A position paper (AQIS 1991) was published on this subject in May 1991.

Fresh banana fruit may be imported for *in vitro* laboratory work under secure quarantine conditions and at quarantine approved premises (QAPs). However, Australia is free of many pests and diseases of bananas, and strict quarantine conditions are observed for these imports. The importation of certain 'banana products' from several countries is permitted. These include processed banana fruit (cooked, boiled, fried, baked or dried) for human consumption.

### 2.2.2 State government arrangements

Although the Australian Government is responsible for regulating the movement of plants and their products into and out of Australia, the state and territory governments have primary responsibility for plant health controls within Australia. Legislation for plant health may be used by state and territory government agencies to control intrastate and interstate movement of plants and plant products.

Information specific to the legislative requirements for the movement of bananas within and between Queensland, New South Wales, Western Australia and the Northern Territory can be found in the Appendix 1 of Part C.

Interstate arrangements are subject to informal harmonisation arrangements through the Domestic Quarantine Market Access Working Group (DQMAWG), which is established under PIMC. Other informal arrangements, such as the Quality Banana Approved Nursery (QBAN) scheme exist within industry organisations.

Primary concerns of legislative and informal arrangements surround the movement of pests in plants and propagation material, particularly in regard to the spread of *banana bunchy top virus* and *Fusarium oxysporum* f. sp. *cubense*. There are standing controls on the movement of fruit flies in banana fruit and a number of other arthropod pests. Mature hard green fruit is permitted access to all Australian markets under supervised state inspection or quality assurance arrangements. Interstate certification arrangements, such as ICA06, are developed under DQMAWG (QDPI 2000).

State legislation can be quickly amended to deal with emerging pest issues. For example, legislation was introduced in 2001 to control the movement of fruit from north Queensland when black Sigatoka was discovered near Tully. This legislation remained in force until the disease was eradicated.

Information specific to the legislative requirements for the movement of bananas within and between Queensland, New South Wales, Western Australia and the Northern Territory can be found in the Appendix 1 of Part C.

### **2.2.3 National response to incursions**

Plant Health Australia (PHA) provides a forum for the development of national plant health policy issues. Arrangements exist for the Australian and state and territory governments to cooperate with peak industry bodies at times of pest incursion through the international border. Through PHA, the ABGC entered into an Emergency Plant Pest Response Deed with the Australian and state and territory governments. This deed specifies the obligations of each party in maintaining plant health infrastructure, surveillance programs and emergency response programs. In the event of an incursion, a National Management Group is formed from the parties to the Emergency Plant Pest Response Deed to oversee appropriate response activities. Additionally, the Australian banana industry has developed an industry biosecurity plan through PHA.

## **2.3 Production and trade**

This chapter provides a summary of information about the banana industry. Specific information on the Philippines banana industry that is used in this assessment is presented in Chapter 7.

### **2.3.1 Banana taxonomy**

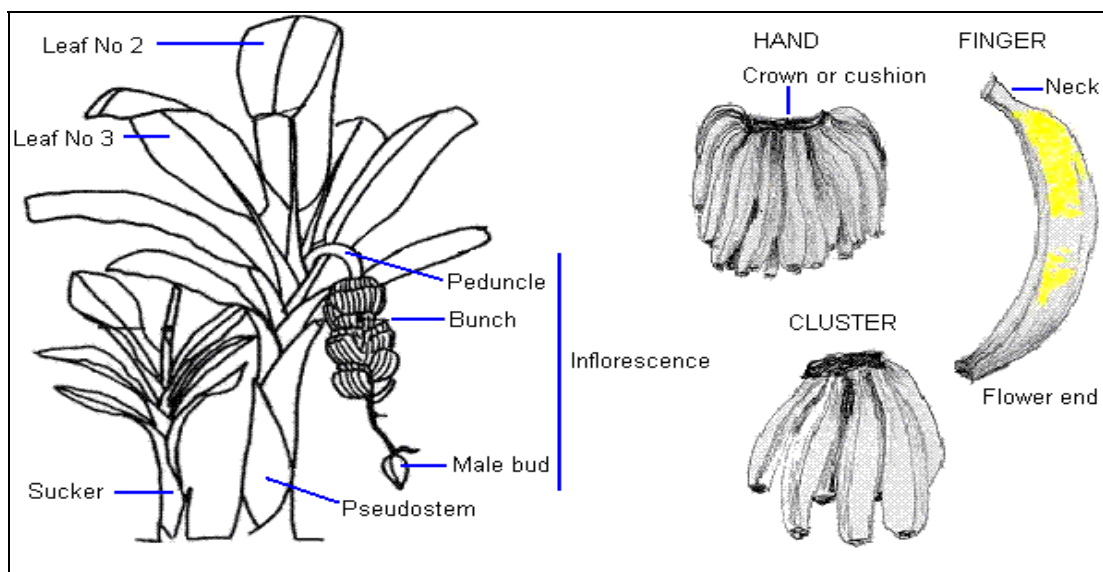
The word ‘banana’ is a common term for the 30–40 plant species belonging to the genus *Musa*. They are categorised as ‘dessert’ or ‘cooking’ bananas. Dessert bananas (such as cultivars of the Cavendish subgroup) have low starch and high sugar content. They are the most commonly produced banana type in Australia and the major type exported by the Philippines.

Cooking bananas have a high proportion of starch and are the most commonly eaten type in south-eastern Asia. Plantains are a type of cooking banana.

Cultivated bananas are a hybrid of the species *M. acuminata* and *M. balbisiana*. The relative contribution of *M. acuminata* and *M. balbisiana* to each banana cultivar is described using a shorthand lettering system of A and B, respectively. Cultivars of the Cavendish subgroup (for example, Giant Cavendish) are denoted as AAA. Cooking bananas include genes from both *M. acuminata* and *M. balbisiana*. The major South American cooking cultivar Bluggoe, which is a triploid hybrid of both species, is ABB. Virtually all dessert banana cultivars are AAA, and plantains are mostly AAB, ABB or BBB (Ploetz et al 1994).

### **2.3.2 The banana plant**

The banana plant is a tree-like, perennial herb. It grows to 2–9 metres from large underground rhizomes and, once mature, produces fruit in the form of bunches (Figure 2.1).



**Figure 2.1 Diagram of a banana plant and elements of banana fruit**

Source: Adapted from International Plant Genetic Resources Institute (IPGRI 1996) and Transport Information Service (2005)

The trunk of the plant is known as the pseudostem and consists of the furred bases of the leafstalks. As the plant grows, leaves unfurl upwards and outwards in a spiral arrangement. The true stem (peduncle) rises from the rhizome and emerges from the top of the pseudostem. Flowers develop on the stem in hands which spiral around the main axis. The female flowers develop into fruit. Throughout the plant's development, suckers rise from the rhizome. Once the pseudostem has flowered and produced mature fruit, it dies and the oldest sucker replaces the main plant. This process of succession can continue indefinitely.

The banana plant, together with suckers arising from its rhizome, is called a mat. Throughout this report the terms mat and plant are used interchangeably. It has been reported (Blomme et al 2000) that the banana root system generally spreads 2–3 metres (and up to 5 m) from the plant, but most of the root system occurs within a 60 cm radius from the stem (Avilan et al 1982; Gousseland 1983). Roots are mainly limited to the upper 40 cm of the soil profile, but their distribution is strongly influenced by soil type (Irizarry et al 1981).

The first banana crop after planting is defined as the plant crop, while subsequent crops are called ratoons (QDPI 1998). Bananas are also grown as annual crops and with the advent of tissue culturing technology this trend is increasing. The time from planting to harvesting depends on the cultivar, cultural practices and climate. It takes about 14 months for the first bunches to be harvested from a plant crop, but subsequent bunches are harvested at intervals of about 10 months.

Various terms are used to describe the harvested units of a banana. All fruit in a single inflorescence are known as a bunch, a bunch consists of a series of hands, sections of a hand are known as clusters (equivalent to 5–7 fruits per cluster) and individual fruits are termed fingers (Figure 2.1).

Information discussed in this IRA is expressed in several different units. The following units are used: seven fingers per cluster (about 1 kg), 13 clusters per carton and 1000 clusters per tonne.

### 2.3.3 Crop management and fruit processing

Commercial production of bananas requires intensive management to control weeds, insect pests and diseases. It also requires ongoing plant maintenance such as the removal of excess suckers and

diseased or old leaves. Banana plants have high water and nutrient requirements, particularly for nitrogen and potassium.

Soon after flowering, banana bunches are de-belled (removal of male flowers) and bagged (covered with plastic sleeves) to improve fruit quality and yield. Bunches are harvested by cutting the peduncle with a knife when fruit is in a mature hard green condition. They are then taken to a packing station and separated into hands. Hands are cut or broken into clusters and then immersed in water flotation tanks to remove dirt, leaf trash and latex exuding from the cut surfaces. Fruit is graded by size, packed into plastic-lined cartons and transported at temperatures of 13–14 °C. The final processing occurs in ripening rooms, where bananas are artificially ripened at a higher temperature with ethylene gas before being distributed to retailers.

### 2.3.4 Global production of bananas

Bananas are one of the world's major fruit crops. In 2004, 130 countries grew bananas. Approximately 98% of all bananas are produced in developing countries (mostly India, Brazil, China, Ecuador, Indonesia and the Philippines) with Cavendish types dominating export production (Arias et al 2003; UNCTAD 2005). Almost all bananas traded worldwide are Cavendish.

In the period from 2001–2003 on average about 12 million tonnes of bananas were annually traded worldwide (Table 2.1). In 2003, Ecuador supplied one-third of the global trade, while Costa Rica, the Philippines and Colombia each supplied between 12–15% of exports. India, the world's largest producer of bananas, is a negligible exporter, since its production is almost entirely for domestic use.

**Table 2.1 Major exporters of bananas worldwide (2001 – 2003)**

Exporting country	Annual exports ('000 tonnes)			
	2001	2002	2003	Percent of 2003 total (%)
Ecuador	3,526	4,199	4,209	33.4
Costa Rica	1,739	1,612	1,887	15.0
Philippines	1,601	1,685	1,829	14.5
Colombia	1,516	1,570	1,543	12.3
Guatemala	874	980	936	7.4
Honduras	432	441	444	3.5
Panama	321	406	387	3.1
Others	1,148	1,363	1,354	10.8
<b>Total</b>	<b>11,157</b>	<b>12,256</b>	<b>12,589</b>	<b>100.0</b>

Source: FAO 2005b

### 2.3.5 The banana industry in the Philippines

Bananas are the main fruit grown in the Philippines. In 2003, 5.4 million tonnes of bananas were produced from 410,000 hectares (BPI 2005). Bananas are grown primarily in Mindanao, in the provinces of Davao del Norte, Davao del Sur and Davao City in southern Mindanao, as well as Lanao del Norte in central Mindanao and Misamis Oriental in northern Mindanao. Outside Mindanao, the biggest banana-producing provinces are Iloilo in Western Visayas and Isabela of Cagayan Valley.

The most common varieties grown are Cavendish dessert types and the local cooking varieties Saba, Lakatan and Latundan. There is very little local demand for Cavendish bananas, with 90% of the fruit that is produced being exported (Philippines Scientific Delegation 2002).

The Philippines exports fresh bananas throughout the world. In 2003, approximately 50% of total exports went to Japan. Other major markets were China, the United Arab Emirates, Taiwan and the

Republic of Korea (BPI 2005). The Philippines is also the largest exporter of banana chips worldwide, with the United States and the European Union being the major markets (Arias et al 2003).

Information on the conditions for growing bananas on the Philippine Island of Mindanao (where export bananas would be sourced) can be found in the Appendix 2 of Part C.

### 2.3.6 The banana industry in Australia

The gross value of the Australian banana industry in 2003–04 was \$286 million (DAFF 2005). It comprises approximately 1850 banana growers, with about 5000 workers directly employed and possibly another 5000 in support industries. The industry is concentrated on the tropical Queensland coast between Babinda and Cardwell (designated ‘north Queensland’), with the largest production area in the Tully region. Other banana production areas are south-east Queensland (from Bundaberg to the New South Wales border), northern New South Wales (from the Queensland border to Kempsey), Carnarvon and Kununurra in Western Australia, and Darwin in the Northern Territory. Approximately 95% of Australia’s banana production is Cavendish cultivars. Ladyfinger accounts for the majority of the remaining 5%, while the residual proportion is made up of dessert and cooking varieties, including Ducasse and Goldfinger (Smith 2002; ABGC 2006a).

Australia’s banana production in the period from 2002–2005 was approximately 265,000 tonnes annually, and was dominated by the Queensland industry (Table 2.2). Of the 14,000 hectares under commercial banana production in Australia, 90% is located in northern Queensland. In contrast to the banana industry in the Philippines, almost all bananas produced in Australia are consumed domestically. Additionally, some Australian banana fruit may be exported to New Zealand following the recent government determination that hard green bananas from Australia would be, subject to quarantine requirements, permitted entry into that country.

Information pertaining to the conditions for growing bananas in each production region of Australia can be found in the Appendix 2 of Part C.

**Table 2.2 Australian banana production by state of origin**

State	Banana production (tonnes)			Percent of 2004–05 total (%)
	2002–03	2003–04	2004–05	
Queensland	231,896	226,090	237,516	89.4
New South Wales	25,289	21,656	18,009	6.8
Western Australia	6,184	7,915	8,112	3.1
Northern Territory	1,403	1,576	1,933	0.7
<b>Total</b>	<b>264,772</b>	<b>257,237</b>	<b>265,570</b>	<b>100.0</b>

Source: ABS 2004, 2005a, 2006



## 3. Method for import risk analysis

### 3.1 Introduction

The Secretariat of IPPC has issued a series of international standards for phytosanitary measures (ISPM). The International Standard, ISPM 11 *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO 2004) was used extensively in developing the method used for this import risk analysis (IRA).

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.

#### 3.1.1 Initiation of a pest risk analysis (PRA) – Stage 1

A PRA may be initiated for a number of reasons, one of which is a request to import a plant product into Australia. The initial stage of the PRA identifies pests and pathways that may be of quarantine concern.

For some pests and commodities, a new risk analysis may not be needed since an existing analysis or policy can be used. ISPM 11, Section 1.3.1 (FAO 2004) specifically mentions:

*A check should also be made as to whether pathways, pests or policies have already been subjected to the PRA process, either nationally or internationally. If a PRA exists, its validity should be checked as circumstances and information may have changed. The possibility of using a PRA from a similar pathway or pest, that may partly or entirely replace the need for a new PRA, should also be investigated.*

As described in Chapter 2, this PRA was initiated by a proposal from the Philippines and relates specifically to the importation of mature hard green banana fruit into Australia from designated export areas in the Philippines. The PRA area considered in this report is Australia.

There are no international standards to address the specific quarantine concerns associated with imports of bananas. Australia does not import mature hard green bananas from other countries, nor does it have existing import conditions upon which to base a response to the Philippines proposal. Since a PRA had not been completed on importing bananas into Australia, the next stage of the process – pest risk assessment – needed to be considered. Three previous draft IRAs relating to this proposal were released in June 2002, February 2004, and March 2007 and are available at <http://www.daff.gov.au>.

#### 3.1.2 Pest risk assessment – Stage 2

PRA is the process of identifying pests of biosecurity concern and estimating the risk (the probability of entry, establishment and spread, and the magnitude of the potential consequences) associated with each.

The PRAs done in Stage 2 determine the unrestricted risk – the risk from importation if there are no risk management procedures other than routine industry practices and minimum border measures. The assessment can be divided into four components:

- pest categorisation
- assessment of the probability of entry, establishment and spread in the absence of any specific risk

management

- assessment of consequences from the introduction of pests
- combination of these two assessments of probability and consequence to give an assessment of the unrestricted risk.

Details of these components are given in Chapters 4–6. Chapter 7 gives information about banana retailing in Australia used in each PRA. The results of the pest categorisation are given in Chapter 8, and indicate whether a PRA was required, whether existing policy was sufficient or whether no PRA was required. The assessments of the risk posed by specific pests are given in the individual PRA chapters, starting from Chapter 9.

The PRA uses a model of the importation, distribution and transmission pathways to assess the probability of entry, establishment and spread (PEES) of the pest – see Section 3.3. The consequences resulting from the introduction of a pest are assessed for eight criteria at four geographical levels and the risk is determined by combining the consequences with the probability of entry, establishment and spread (Chapter 6).

The conclusions from the unrestricted PRA are used to decide whether risk management is required, and if so, what level of risk management.

### 3.1.3 Pest risk management – Stage 3

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

To manage risk 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 (as is done at Stage 2). In contrast, restricted risk estimates are those derived when risk management is applied. The same method is used to assist in the estimation of risk as for Stage 2, except that the pathways in the model are re-assessed in light of the measures which may be applied.

Pests that have an estimate of unrestricted risk that exceeds Australia's ALOP require risk management measures. A discussion on potential risk management measures (if needed) is included in the PRA chapter for each pest.

## 3.2 Approach to pest risk analysis

Like most quarantine agencies, Biosecurity Australia generally undertakes PRAs using a qualitative approach in which the likelihoods of various events are considered and evaluated using descriptive terms linked to probability intervals. However, in the previous revised *Draft import risk analysis on the importation of fresh bananas from the Philippines* report (BA 2004) Biosecurity Australia adopted a semi-quantitative risk.

For some pests this report uses a quantitative framework to assess the probability of entry, establishment and spread (PEES) supplemented with a qualitative analysis of consequences. For the consequence analysis, the report also uses descriptive terms for qualitative values, which is consistent with the approach followed in the 2007 revised draft IRA report.



In some cases there may be no need to undertake a new risk assessment as an existing assessment or policy can be used where this is relevant or appropriate. ISPM 2: *Guidelines for pest risk analysis* (FAO 2005c) specifically allows for this situation, 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, nationally or internationally. If the 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.

In this report, several different approaches have been used to assess the risk of pests entering Australia and to decide whether risk management measures are needed. They can be divided into three broad groupings:

- 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
- pests for which no recent PRA has been completed by Biosecurity Australia.

The allocation of pests to the three broad groups is based on the categorisation process (described in Chapter 4) and information in previous IRAs. The results are given in Chapter 8.

### **3.3 Modelling the importation, distribution and transmission pathways**

To facilitate the estimation of the probability of entry, establishment and spread (PEES) of a pest from imported fruit, a model was constructed for the major pathways associated with:

- the importation of bananas from harvest in the Philippines to release from quarantine into Australia
- the distribution of bananas within Australia until unsound fruit and peels are discarded as waste
- the transmission of the pest from waste – the exposure of a suitable host to the pest, the establishment of the pest on the host and its spread to other hosts.

The details of the steps that make up the pathways of the model are described in Chapter 5.

#### **3.3.1 Modelling uncertainty**

Where a path in the model divides into two pathways, values must be given for the proportion of bananas that follow each pathway. Determining the values used must take into account both natural variation and uncertainty arising from lack of knowledge. In some cases, a value can be estimated reasonably accurately. In other cases, where the available information does not give a precise value, the assessment gives the estimate as a range of values and assigns a relative likelihood to each value, expressed in terms of a statistical distribution. The distributions and values used in the model represent the IRA team's best judgment, based on all available data.

One component of variability arises because pests and diseases will often cluster, either spatially or temporally depending on the time of year or the particular location from which bananas were sourced. However, much of this variation can be taken into account in the model by basing the analysis on a year's production, and using information averaged over a number of years. The use of a range of values accounts for the uncertainty associated with these averages.

At a different scale of disease clustering, an infected bunch will be cut into a number of infected clusters of bananas. These banana clusters may remain together during processing, transportation and distribution. However, their purchase by individual customers would separate the fruit sufficiently (both by separation of banana clusters and individual fruit), to reduce the effect of disease clustering.

For some pests an increase in the number of pests present simultaneously has a correspondingly greater effect on the likelihood of establishment. The effect of this was considered as necessary in the assessment. Other than this, the model does not explicitly consider clustering.

Occasionally, the value applicable to one part of the model will depend on a value determined at an earlier part of the model. For example, the likelihood of contamination may be related to the level of disease present in the population. Such relationships were considered when assigning the dependent values, although an explicit relationship was not incorporated into the model.

The model uses average values rather than worst case values. The consistent use of worst case values leads to a result that would significantly overestimate the risk. Nonetheless, the values used in the model reflect Australia's conservative approach on quarantine.

A value for each of the distributions used in the model is simulated, and the PEES calculated using the simulated values. The simulation is repeated many times to provide the range and relative likelihood of the PEES. The IRA uses the median value of these simulated values as a measure of the PEES when the qualitative estimate of consequences is combined with the PEES to determine risk (as described in Chapter 6.2). However, the spread of PEES values (based on the 5<sup>th</sup> and 95<sup>th</sup> percentile values) is considered by the IRA team in reaching its recommendations.

### **3.3.2 Representing quantitative information**

Quantitative data on a probability or estimates of other numeric quantities are modelled either as a point estimate or as a probability distribution. Two types of distributions have been used: Triangular and Uniform.

A Triangular distribution is defined by its minimum, most likely and maximum values. For a Triangular distribution, the likelihood of a particular value increases at a constant rate from the minimum value to the most likely value, and then decreases at a constant rate until the maximum value. The distribution does not have to be symmetric – it will be skewed to the left if the most likely value is nearer the minimum than the maximum. For example, this distribution was used when information (for example, literature and expert opinion) on the most likely value was available.

A Uniform distribution has a minimum and maximum value, with each value between these limits occurring with the same likelihood. Uniform distributions were used in cases where insufficient information was available to determine the most likely value, or when it was thought that all values in the range were equally likely.

For the PRAs in this report, likelihoods were assessed using a quantitative approach based on information represented by numerical ranges. In all cases the assessors considered carefully whether they were confident that the range they had chosen would contain the actual value and that the chosen distribution reflected their beliefs. However, a qualitative risk analysis is used for several pests covered by this report where the evaluation of the risk is based on existing policy and previous PRAs.

The methods used in these analyses follow those set out in the draft Guidelines (BA 2001).

### **3.3.3 Numerical notation for small probabilities**

The extremely small numbers associated with likelihoods means that it is convenient to use some form of scientific notation to show probabilities. In this report, the form used is consistent with that commonly found in spreadsheets, for example, by showing one millionth as 1.00E-06 rather than

0.000001. The ‘E’ stands for exponent and is equivalent to the ‘ten raised to the power of’ in the other common representation (for example,  $1.0 \times 10^{-6}$ ) for very small numbers.

Proportions will be expressed as percentages or decimal fractions where it is more appropriate to do so. In some parts of the text, a decimal approximation of a fraction will be given although the exact value will be used in intermediate calculations.

### **3.3.4 The model in context**

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

The structure and form of the model was developed by the IRA team taking into account relevant information, stakeholder comments and expert advice provided by the Bureau of Rural Sciences (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.

When the unrestricted risk estimate for an individual pest is unacceptable (that is, exceeds ‘very low’), it is necessary to determine if there are risk management measures or pest limits that, if met, would reduce the risk estimate to a level that would achieve Australia’s ALOP. Such pest limits are referred to in the report as pest thresholds. The ‘restricted’ risk is determined by repeating the risk analysis taking into account the effects of the proposed measures or the pest threshold. This is repeated for each proposed measure and/or combination of measures and the value is checked against the matrix to determine whether the proposed measure reduces the risk sufficiently to achieve Australia’s ALOP.

In considering the outputs of the model, the IRA team was aware that the model is based on various assumptions and therefore has limitations. To reach 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.

The methodology (including the matrices used to combined values and determine if the risk associated with a pest achieves the ALOP) reflects Australia's conservative approach on quarantine risk. In determining input values, the IRA team has carefully considered all available information including the ‘worst case’ scenarios.

### **3.3.5 Qualitative assessment within existing policy**

The assessment of a pest considered under existing policy uses a qualitative method for assessing the PEES, rather than the quantitative method described in Chapter 5. While the considerations of the assessment are similar, the main difference is that a qualitative method is used to assess each of the four probabilities associated with importation, distribution, establishment and spread. The rules for combining qualitative likelihoods given in Table 3.1 are used to determine the overall PEES.

**Table 3.1 A matrix of rules for combining descriptive likelihoods**

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

For combining more than two likelihoods, the rules are applied successively. The result obtained from combining the first two likelihoods is combined with the third likelihood, and the result of that is combined with the fourth, and so on.

The PEES is then combined with the qualitative estimate of consequences to give an estimate of the risk using Table 3.2 (which is the same as Table 1.1 and similar to Table 6.2 that is used for quantitative assessments). The method followed is described in the draft Guidelines (BA 2001).

**Table 3.2 Determining risk by combining the PEES with consequences**

		Risk					
<b>PEES</b>	<i>High likelihood</i>	Negligible	Very low	Low	Moderate	High	Extreme
	<i>Moderate likelihood</i>	Negligible	Very low	Low	Moderate	High	Extreme
	<i>Low likelihood</i>	Negligible	Negligible	Very low	Low	Moderate	High
	<i>Very low likelihood</i>	Negligible	Negligible	Negligible	Very low	Low	Moderate
	<i>Extremely low likelihood</i>	Negligible	Negligible	Negligible	Negligible	Very low	Low
	<i>Negligible likelihood</i>	Negligible	Negligible	Negligible	Negligible	Negligible	Very low
		<i>Negligible impact</i>	<i>Very low impact</i>	<i>Low impact</i>	<i>Moderate impact</i>	<i>High impact</i>	<i>Extreme impact</i>
		Consequences					

## 4. Pest categorisation

Pest categorisation is the process that assesses the quarantine status of each pest using a specific set of criteria. The aim is to screen each potential quarantine pest against the criteria before undertaking the main risk assessment.

The IPPC (FAO 2004) 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 losses.*

The results from the pest categorisation are shown in Chapter 8.

### 4.1 Elements in the categorisation of a pest

ISPM 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 and environmental consequences in the PRA area.

Further details on these elements are provided in ISPM 11.

### 4.2 Categorisation process

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

- |        |   |
|--------|---|
| Step 1 | Compilation of pest lists   |
| Step 2 | Documenting each pest's presence or absence within Australia                    |
| Step 3 | Potential of each pest for being associated with fruit                          |
| Step 4 | Potential of each pest to establish and spread                                  |
| Step 5 | Potential of each pest for being associated with economic or other consequences |
| Step 6 | Final categorisation.   |

#### Compilation of pest lists (step 1)

Pest species identified as being associated with banana fruit or banana plantations in the Philippines were obtained from a number of sources such as information provided by the Philippines Government, literature research by Biosecurity Australia and technical information provided in comments by stakeholders on both revised *Draft import risk analysis on the importation of bananas from the Philippines* (BA 2004) and the *Draft import risk analysis report for the importation of Cavendish bananas from the Philippines* (BA 2007) (Chapter 8).

### Determine presence within Australia (step 2)

For each pest recorded in Step 1, a systematic process was followed to determine the pest status within Australia. This process involved reviewing published records, checklists and catalogues, various pest and disease databases and consulting relevant specialists. Subsequently, pests were classified as:

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

### Potential for being on the pathway (step 3)

Pests present in Australia, categorised as ‘Yes’ in Step 2, were not considered further in this analysis. Pests categorised as ‘No’, ‘Uncertain’ or ‘Yes\*’ were assessed for their potential to be on the pathway. This potential was then categorised as ‘likely’ or ‘not likely’. Table 4.1 provides the criteria used to assess the potential of a species to be on the pathway.

On the basis of established policy, pests not known to be directly associated with mature hard green Cavendish bananas from the Philippines (for example, weed seeds and other contaminants) were removed from the pest categorisation process and were dealt with using existing policy for contaminants. Pests associated with banana plant material, such as leaf trash, were considered to be associated with mature hard green fruit and were therefore considered in the pest categorisation process.

**Table 4.1 Potential of a species to be on the pathway (Step 3)**

Potential for being on pathway	Description of criteria
Likely	The species would be likely to be on the pathway if at least one life stage can persist in or on mature hard green Cavendish bananas, or in trash and packaging.
Not likely	The species would be unlikely to be on the pathway as it cannot persist in or on mature hard green Cavendish bananas (but may be found on other parts of the banana plant).

### Potential for establishment and spread (step 4)

The potential for establishment and spread was assessed as ‘Feasible’ for all those species rated as ‘Likely’ in Step 3 because:

- bananas are grown in northern parts of Australia and climatic and ecological conditions in these areas are similar to those of the Philippines
- potential alternative hosts are present in Australia.

### Potential for consequences (step 5)

The potential for consequences was only assessed for species with the rating of ‘Likely’ for their potential for being on pathway and ‘Feasible’ for their potential for establishment and spread. Their potential for consequences was categorised as ‘Significant’ or ‘Not significant’ using the criteria set out in Table 4.2.

**Table 4.2 Criteria for categorisation of the potential for consequences (Step 5)**

Potential for consequences	Description of criteria
Significant	The species would have potential for causing 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 (iii) it is known to be a vector of a disease.
Not significant	The species would not exhibit potential for causing 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.

### Final categorisation (step 6)

The final outcome of pest categorisation is to decide if the species needs to be considered further. The answer to the question ‘Consider the species further?’ can be ‘Yes’, ‘Yes\*’ or ‘No’.

The answer ‘Yes\*’ indicates that while the pest is present in Australia, it is not widely distributed and is being officially controlled, or areas of regional freedom exist in Australia.

The answer ‘No’ applies if the pest is assessed as being present in Australia (subject to the proviso just given), or it is absent from Australia but is rated as ‘Not likely’ for its potential for being on the pathway or ‘Not significant’ for its potential for consequences.

Pests absent from Australia may still be potential quarantine pests for Australia in other contexts as they could be imported on commodities other than bananas from the Philippines.





## 5. Probability of entry, establishment and spread (PEES)

This chapter describes the process for assessing the probability that the importation of bananas from the Philippines over an average year would result in the entry, establishment and spread of the particular pest being considered.

Following the harvest of banana fruit in the Philippines, a sequence of events must occur if the importation of that fruit is ultimately to lead to the entry of a pest, its establishment and its further spread in Australia. It is convenient to group these when determining their likelihood:

- Importation – considers the change in the proportion of infected or infested banana clusters from when bananas are harvested in the Philippines until they are released from quarantine in Australia.
- Distribution – considers the use of bananas and changes to the proportion of banana clusters that are infected or infested from when the bananas are released from quarantine in Australia until the disposal of their waste.
- Exposure – considers the likelihood that infected or infested waste would be in proximity to a susceptible host and that this would result in the transfer of the pest to the host.
- Establishment and spread – considers the likelihood that the exposure of a susceptible host results in the establishment of the pest and its subsequent spread to other susceptible hosts.

The term ‘entry’ covers the first three of these – importation, distribution and exposure.

Importation and distribution are based on pathway scenarios. Importation models the steps in sourcing the commodity for export, its production, processing, transport and border clearance. Distribution models the steps in the supply chain of imported clusters, their storage, ripening and utilisation in Australia, and the generation and disposal of waste. Scenarios for importation and distribution are described in general in this chapter, while pest-specific issues are covered in the PRA chapters.

The likelihoods of exposure, establishment and spread are obtained from an examination of the pest’s biology, its possible interaction with suitable hosts and the environment, and the availability of necessary dispersal mechanisms. These factors are summarised in ISPM 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO 2004) and are also described later in this chapter.

All of the individual PRAs in this report follow the general approach described in this chapter. However, details of the approach used and its application to estimate the individual components may vary for some pests due to differing commodity characteristics. Any variation is described in the individual PRA chapters.

### 5.1 Background

#### 5.1.1 Unit of analysis – the cluster

The basic unit for all risk assessments in this report is one cluster of bananas (about seven bananas, weighing about one kilogram in total). This recognises that a cluster is the basic unit derived from bunches in packing stations and essentially maintains its integrity throughout the marketing chain until it reaches the consumer. It was also considered likely that individual clusters could provide a pathway for the entry and establishment of pests without considering large quantities of fruit.

While a cluster of bananas is considered to be the appropriate unit for all risk assessments in this report, it is also recognised that a cluster of bananas may be consumed over several days. As a result,

the waste produced from individual fingers may go to different locations. Accordingly, the assessment of the likelihood of transfer of the pest from waste to host is based on an individual banana.

The assessment of risks associated with leaf trash or packaging is pest-specific and is addressed in the PRA chapters as appropriate.

### 5.1.2 Parameters

The model described in the following sections approximates the importation, distribution, exposure, establishment and spread pathways. Many of the parameters used in the model are not known with certainty. Consequently, their values are estimated using one or more sources of information, such as scientific literature, expert opinion, survey data and census data.

Occasionally, different sources (for example, scientific papers) may indicate different values for a given parameter. Various techniques are used to combine different sources of information and so derive distributions for the value of each parameter that accords with the judgment of the IRA team (see Section 3.3.1). The parameters in the model represent the IRA team's best judgment based on all available data.

### 5.1.3 Unrestricted and restricted risk

For each pest, the IRA evaluated the risk associated with the importation of bananas without any prescribed phytosanitary measures. This is referred to as the 'unrestricted' risk. The unrestricted risk assumes that there are no restrictions on fruit that can be imported and that no regulatory measures or special treatments are taken to reduce pest contamination levels over and above current horticultural and marketing practices, and minimum border procedures on arrival in Australia.

If an unrestricted risk was unacceptably high (that is, above Australia's ALOP) the report then considered what risk management options might be available to achieve an acceptable level of risk – called the 'restricted' risk.

The approach described in this chapter was used to assess both the unrestricted and restricted risk.

## 5.2 Importation

The sequence of steps starting from just before bananas are harvested until their release from quarantine in Australia is termed the 'importation scenario'. The analysis determines how the proportion of infected or infested clusters changes as the fruit passes through each step of the scenario. The proportions are combined to give an overall estimate of the total proportion of imported clusters that might be infected or infested.

These importation steps are designed to approximate the trade in bananas with sufficient accuracy to estimate the proportion of imported clusters that will be infected or infested at the point of being released from quarantine.

Figure 5.1 shows the importation scenario that is used for all quarantine pests (except for those considered under existing policy) to determine both the unrestricted and restricted risks. Each step on the pathway represents an action or process that could change the proportion of infected or infested clusters.

The Imp value given in the figure is the proportion of clusters that follow the pathway for fruit that is infected or infested (solid lines) after passing through the importation step. The proportion of fruit going down the other pathway leading from the step (dotted lines) is '1 – Imp'. The clusters that move along the dotted lines in the scenario are not infected or infested. The Imp number is also used as a shorthand name for the step.

The following sections describe the guidelines for allocating likelihoods to each of the eight steps in the importation scenario. Details considered in deciding these likelihoods are given in each individual PRA.

The Imp value assigned to a step is considered to be the same for all bananas reaching the step regardless of the pathway the bananas followed. For example, the typical proportion of infected or infested fruit must be taken into account when considering steps relating to contamination or increase in pest numbers or, for the assessment of restricted risk, the efficacy of inspection.

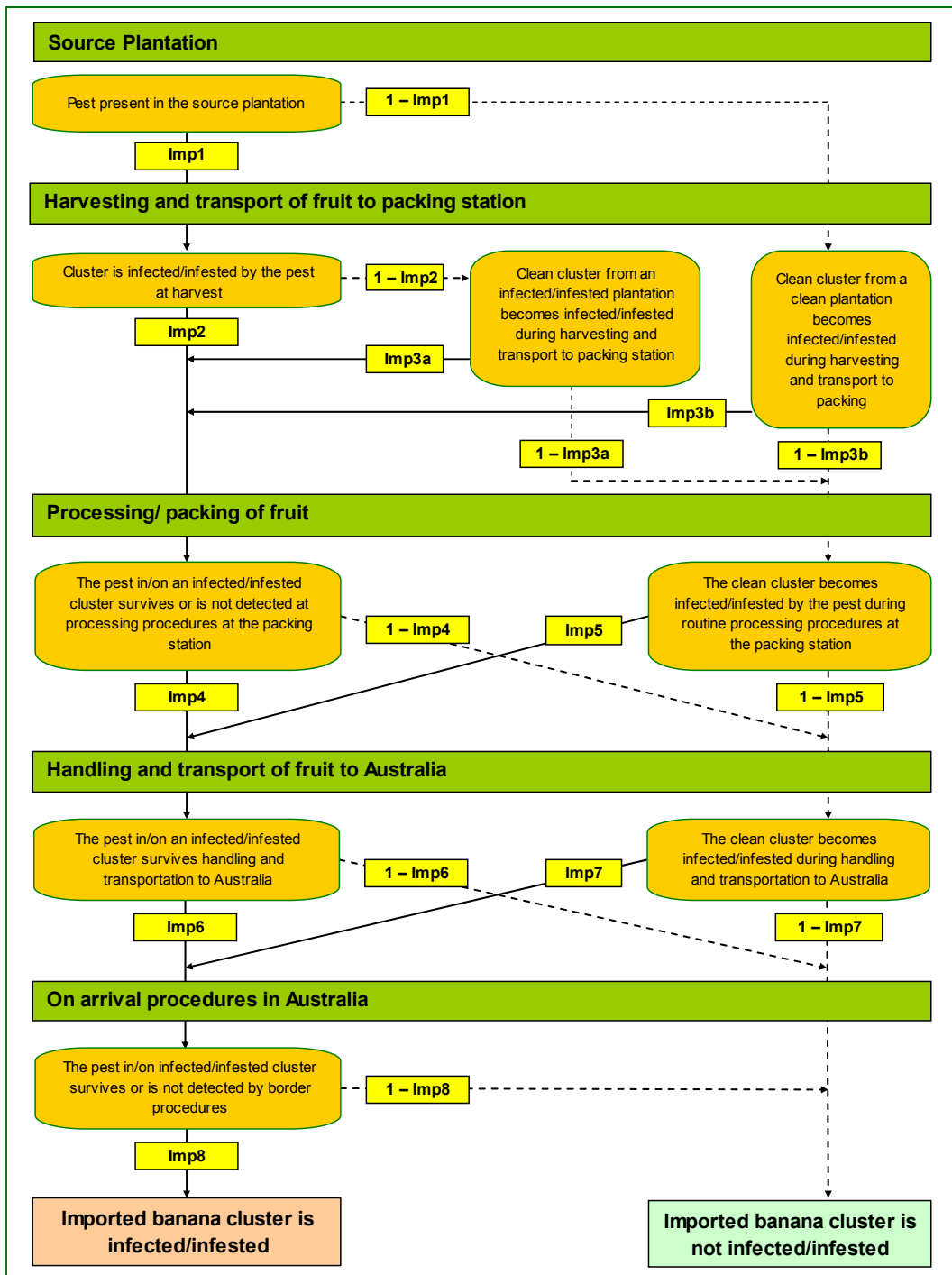
### **5.2.1 The proportion of plantations where the pest is present (Imp1)**

Imp1 is the proportion of plantations in the Philippines in which the pest is present. A plantation is an area of bananas managed in a generally consistent manner by one owner or management unit. It may include several blocks planted at different times and have pests at different stages in their lifecycles.

The proportion of infected or infested plantations is influenced by many factors, including:

- climate and environment
- plantation management
- varietal susceptibility
- pest epidemiology.

Evidence for estimating Imp1 comes primarily from reports and survey data on the distribution of pests or diseases in the Philippines, and secondly from a knowledge of the dispersal process of the pest or disease, the varietal susceptibility, variations between locations in the source area and aspects of plantation management.



**Figure 5.1 Importation scenario for banana fruit from the Philippines**

*Imp2* relates to the status of the plantation while the values *Imp2, ..., Imp8* give the proportion of clusters leaving the step that are infected or infested.

### 5.2.2 Pest level within a plantation (Imp2)

Imp2 is the proportion of clusters from infected or infested plantations that would be infected or infested at harvest. Such infection or infestation may have occurred at any time during the development of the bunch of bananas.

Using available information, each PRA systematically considers the following questions:

- What proportion of blocks within an infected or infested plantation will be infected or infested?
- What proportion of plants in an infected or infested plantation will be infected or infested?
- How likely is it that the bunch of bananas from an infected or infested plant will be infected or infested at harvest?
- What proportion of clusters from an infected or infested bunch will be infected or infested at harvest?

### **5.2.3 Contamination by the pest before packing (Imp3a/b)**

Imp3 is the proportion of clean clusters of bananas that become infected or infested during harvesting and transport from the plantation to the packing station.

The importation scenario has two separate pathways for this type of contamination because the proportion of contaminated fruit depends on the pest level in the source plantation. Imp3a refers to clean clusters from infected or infested plantations and Imp3b refers to clusters from clean plantations. The values are estimated in the individual PRAs.

Contamination could occur as a result of the clean clusters coming into contact with infected or infested plants or with contaminated equipment during harvest or transport to the packing station.

In infected or infested plantations, infective materials, such as bacterial cells and fungal spores, may be produced and transferred onto surfaces of other bananas, containers or equipment. The infective material may persist in a stable form and infect or infest bananas in the same or subsequent batches. The ability of some arthropods to move freely between bananas or within the environment influences the likelihood that they will persist during this step.

While more complicated pathways could be considered, such as allowing Imp3a to vary according to the level of infection or infestation of the plantation, they were not considered here because the IRA team concluded that representing the additional detail and the added complexity would not lead to significant differences in the outcome of the assessments.

### **5.2.4 Pest level surviving packing procedures (Imp4)**

Imp4 is the proportion of infected or infested clusters that remain infected or infested after routine processing procedures in the packing station.

For many pests, this likelihood is dictated largely by whether the surface of fruit was infested or whether the pest lived inside the fruit. External pests are likely to be more vulnerable to physical treatments (for example, washing, sponging and brushing) and chemical treatments (for example, dips).

Because this likelihood is complex, it is approached in each PRA systematically by considering the available information about the processes used in packing stations:

- How likely is it that the pest will survive and remain on fruit after post-harvest quality assurance procedures?
- How likely is it that the pest will survive and remain on the fruit after high-volume/high-pressure washing?
- How likely is it that the pest will survive and remain on the fruit after passing through the dip tank?
- How likely is it that the pest will survive and remain on the fruit after sponging or brushing?
- How likely is the pest's survival, or the persistence of infected or infested fruit, after sorting and grading?
- What is the efficacy of any risk management procedures proposed?

### **5.2.5 Contamination during packing (Imp5)**

Imp5 is the proportion of clean clusters that would become infected or infested during processing at the packing station.

The characteristics of the pest are considered, in particular its tolerance to the physical and chemical processes used in packing stations and its ability to move from cluster to cluster. Other factors considered include the quality management practices within packing stations, the most important being adherence to rigorous hygiene practices at steps such as water baths (dip tanks and flotation tanks) where contamination may be most likely to occur.

### **5.2.6 Pest level surviving post-packing processes (Imp6)**

Imp6 is the proportion of clusters in or on which the pest survives during palletisation, quality inspection, containerisation and transport to Australia.

Consideration is given to the characteristics of the pest, its resilience to a range of temperatures and humidity, aspects of its lifecycle and the nature of its infection or infestation of bananas.

### **5.2.7 Contamination by the pest during post-packing processes (Imp7)**

Imp7 is the proportion of clean clusters that would become infected or infested during palletisation, quality inspection and transport to Australia.

Consideration is given to the tolerance of the pest to the physical and thermal processes and its ability to move among bananas within and between cartons.

### **5.2.8 Pest level remaining after border procedures (Imp8)**

Imp8 is the proportion of clusters in or on which pests survive and remain with the fruit after on arrival border procedures.

For the unrestricted risk assessment, the factors considered relate only to the minimum border procedures used by government agencies, such as verifying that the commodity matches the shipping documents and checking for any external and internal contamination of containers and their packaging. Any AQIS on arrival inspection specifically for quarantine pests associated with bananas is not part of the assessment of the unrestricted risk.

### **5.2.9 Number of infected/infested clusters**

The overall number of imported clusters that are infected/infested can be obtained by calculating the proportion of infected/infested clusters at each major point in the importation pathway (see Figure 5.1). These proportions are combined with the projected volume of trade in Philippine bananas, to provide an estimate of the number of infected/infested clusters that may be imported (Table 5.1).

The proportion of infected/infested clusters at a point is equal to the proportion of infected/infested clusters arriving at the point that are not detected or effectively treated, plus the proportion of non-infected/non-infested clusters that have become contaminated.

For example, the proportion of infected/infested clusters arriving at the packing station can be calculated as:

$$P_{\text{arrive packing}} = \text{Imp1} \times \text{Imp2} + \text{Imp1} \times (1 - \text{Imp2}) \times \text{Imp3a} + (1 - \text{Imp1}) \times \text{Imp3b}$$

The first two parts of the calculation refer to infected/infested plantations. The first part,  $\text{Imp1} \times \text{Imp2}$ , relates to the infected/infested clusters. The second part,  $\text{Imp1} \times (1 - \text{Imp2}) \times \text{Imp3a}$ , relates to those non-infected/infested clusters that subsequently become infected/infested. The third part,  $(1 - \text{Imp1}) \times \text{Imp3b}$ , refers to the clusters that leave non-infected/non-infested plantations but become infected/infested during transport to the packing station.

**Table 5.1 The number of infected or infested clusters of bananas that might be imported during 12 months**

Variable	Description and calculation
No. imported infected	The number of infected or infested clusters likely to be imported during 12 months = Annual volume $\times$ $P_{\text{imported}}$
Annual volume	The number of clusters likely to be imported into Australia during 12 months
$P_{\text{imported}}$	The proportion of individual imported clusters that will be infected or infested. It is determined by successively calculating the proportion of infected or infested clusters at points along the importation pathway:
$P_{\text{arrive packing}}$	= $\text{Imp1} \times \text{Imp2} + \text{Imp1} \times (1 - \text{Imp2}) \times \text{Imp3a} + (1 - \text{Imp1}) \times \text{Imp3b}$
$P_{\text{leave packing}}$	= $P_{\text{arrive packing}} \times \text{Imp4} + (1 - P_{\text{arrive packing}}) \times \text{Imp5}$
$P_{\text{arriving Australia}}$	= $P_{\text{leave packing}} \times \text{Imp6} + (1 - P_{\text{leave packing}}) \times \text{Imp7}$
$P_{\text{imported}}$	= $P_{\text{arriving Australia}} \times \text{Imp8}$
$\text{Imp1}, \dots, \text{Imp8}$	= pest specific

### 5.3 Distribution

The distribution pathway describes the steps in the movement of bananas within Australia, from the time of their release at the border (see Section 5.2.8) until the disposal of their waste. The skin (peel) and crown (cushion) of almost every banana, and occasionally part of the pulp, will become waste. The aim of this part of the risk analysis is to identify and quantify, as far as is practicable:

- the likely pattern of distribution and use of imported banana fruit
- the generation and disposal of banana waste
- the change in the proportion of infected/infested clusters as bananas pass from importation to waste.

It is assumed that the imported bananas would follow the same distribution pattern as Australian bananas that pass through wholesalers, and so it is this distribution pattern that is modelled in this section.

Figure 5.2 shows the main pathways of bananas from importation through handlers and consumers, to waste, and is based on four concepts:

- Areas – commercial banana growing areas and other areas
- Utility points – wholesalers, retailers, food processors, food services and consumers
- Waste points – controlled waste, uncontrolled consumer waste and other uncontrolled waste
- ‘Dist’ steps – changes in the proportion of infected/infested clusters from when bananas are released at the border to disposal of their waste.

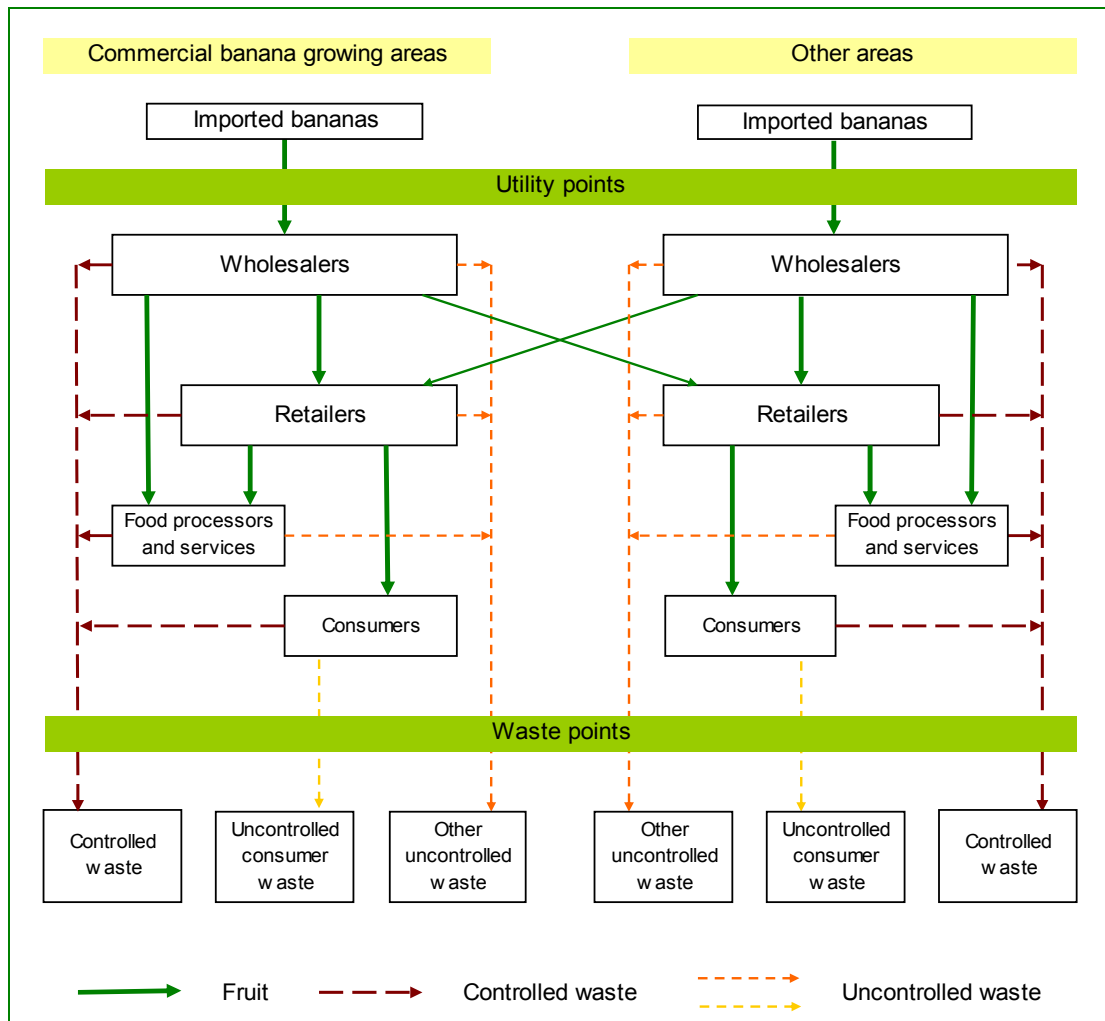
The end of the distribution pathway is to determine the likely number of infected/infested banana clusters that go to each waste point. The Dist steps are modelled by:

- calculating the number of infected/infested clusters at all waste points; then
- calculating the number of imported clusters at each waste point; and then
- simulating the allocation of infected/infested clusters between waste points.

### **5.3.1 Grower areas and other areas**

The distribution pathway divides Australia into two areas based on the extent of commercial banana production, to account for the large differences in the relative prevalence of banana plants (commercial or otherwise) and in other biological factors between the two areas. Shires in which commercial banana plantations occur were classified as *commercial banana growing areas* (abbreviated as *grower areas*). The grower areas cover much of coastal Queensland, the north coast of New South Wales, parts of Western Australia and the Northern Territory. The remaining shires were classified as *other areas*. Further information about the grower areas and the other areas is given in Section 7.1.





**Figure 5.2 Major pathways of bananas from importation through handlers and consumers to waste points**

### 5.3.2 Utility points

There are five main locations (termed ‘utility points’) at which bananas are handled or used and at which banana waste will be generated:

- wholesalers/ripeners
- retailers
- food processors – such as manufacturers
- food services – such as restaurants, cafes and hospitals
- consumers.

There are two types of commercial users: food processors and food services. Food processors would obtain fruit from wholesalers, and food services would obtain fruit from both wholesalers and retailers. It is assumed in most cases that the commercial users are in the same area as the wholesaler or retailer supplying them. However, some wholesalers in grower areas supply bananas to retailers in other areas and those in other areas send bananas to retailers in grower areas.

Other than for wholesaler sales to retailers, it was considered that the volume of bananas traded between areas would be small. It is assumed that waste would be disposed of in the same area as the utility point that produced it.

Some retailers and food processors purchase bananas directly from growers. This proportion of consumption is excluded from the analysis since imported bananas would only be distributed through the wholesale network.

### 5.3.3 Waste points

The model assumes that a portion of each banana becomes waste, and that each infected/infested banana cluster would pose the same (disease specific) risk regardless of the size or type of the waste.

Each utility point creates waste. The waste is classified according to its method of disposal, since this has a significant influence on the likelihood of exposure to susceptible hosts.

Three key methods (called waste points) of waste disposal are considered:

- controlled waste
- uncontrolled consumer waste – from consumers
- other uncontrolled waste – from wholesalers, retailers, food processors and food services.

Controlled waste will usually be disposed of, using municipal garbage collection, to a municipal tip but can also include package recycling and commercial waste recycling. It is considered that the pest risk posed by controlled waste is the same regardless of the utility points through which the bananas pass.

Because consumers would dispose of a much greater proportion of uncontrolled waste in home gardens than other utility points, uncontrolled waste was divided into two categories. *Uncontrolled consumer waste* only originates from consumers and would be, for example, material put in compost bins or compost heaps, and littering away from home.

The uncontrolled waste from the other four utility points is classified as *other uncontrolled waste*. The pest risk posed by uncontrolled other waste is considered to be the same regardless of the utility point that generated it.

### 5.3.4 Pest level surviving during distribution within Australia (Dist1)

This is the first of two steps in the distribution pathway that allow for a reduction in the proportion of infected/infested clusters between the time bananas are released from quarantine and the disposal of their waste. Dist1 is the proportion of the infected/infested clusters released at the border, in or on which pests survive ripening, transport and sale within Australia until being discarded as waste.

Consideration is given to the physical characteristics of the pest, its resilience to a range of physical and chemical processes, aspects of its lifecycle and the nature of its infection or infestation of banana fruit.

### 5.3.5 Contamination by the pest during distribution within Australia (Dist2)

The second step in the distribution pathway considers the ability of the pest to move among bananas within and between cartons, and possibly to reproduce. It allows for an increase in the proportion of infected/infested clusters from the time bananas are released at the border until their waste is discarded. Dist2 is the number of clean clusters that would become infected or infested during ripening, transportation and sale within Australia from a single infected or infested cluster.

For much of the distribution pathway, the clusters are in cartons. Because of the limited scope for infection or contamination, Dist2 is modelled in terms of the number of clusters infected/infested by a single infected/infested cluster (rather than in terms of the proportion of clean clusters becoming infected/infested). The number of clusters in a carton and the typical number of infected/infested clusters in the carton is considered when estimating the values for Dist2.

### 5.3.6 The number of infected/infested clusters at all waste points

The number of infected/infested clusters arriving at all waste points is calculated from the number of infected/infested imported clusters and the two 'Dist' values as shown in Table 5.2. The number of infected/infested clusters at each waste point/area combination is calculated as in Section 5.3.8, after first calculating the amount of waste going to each waste point.

**Table 5.2** The number of infected/infested clusters at all waste points

Variable	Description and calculation
$N_{\text{infected waste}}$	The number of infected or infested clusters arriving at all waste points that are likely to be imported during 12 months $= N_{\text{imported}} \times P_{\text{infected waste}}$
$N_{\text{imported}}$	The number of clusters that are likely to be imported into Australia during 12 months
$P_{\text{infected waste}}$	The probability that an individual imported cluster will be infected or infested when it becomes waste $= P_{\text{imported}} \times \text{Dist1} \times (1 + \text{Dist2})$
$P_{\text{imported}}$	The probability that an individual imported cluster will be infected or infested when it is released from quarantine (Table 5.1)
Dist1, Dist2	= pest specific values

### 5.3.7 The number of clusters at each waste point

The number of clusters arriving at each waste point is calculated by considering the proportion of bananas following each step of the distribution pathway, as shown in Figure 5.2, Section 7.3, describes in more detail the information collected for each area to determine:

- the tonnes of bananas handled by wholesalers
- the tonnes of bananas sent by wholesalers to food processors and food services
- the proportion of wholesaler throughput to retailers that goes to retailers in the same area
- the proportion of bananas sold by retailers going to consumers
- the proportion of wholesaler and retailer throughput that becomes waste
- the proportion of waste from each utility point that becomes controlled waste.

Estimates (as distributions) for these parameters are used to determine the relative proportions of bananas handled by wholesalers in grower areas and in other areas. The unrestricted risk analysis assumes that wholesalers import bananas in grower areas and in other areas in the same proportions as they currently handle. For a restricted risk analysis, it is possible to vary this proportion.

The proportion of bananas that becomes waste is estimated for wholesalers and retailers. Every banana used by food processors, food services and consumers also generates waste. Table 5.3 summarises the calculations to estimate the throughput of each utility point and the amount of generated waste. Similar calculations are done for utility points in other areas.

**Table 5.3** The number of imported clusters passing through a utility point

Variable	Definition and calculation
$N_{\text{utility point}}$	Number of imported clusters passing through a utility point.
<b>Utility point</b>	
Wholesaler	= the number of clusters imported multiplied by the proportion of the domestic market that passes through grower areas wholesalers
Retailer	= a proportion of the throughput of wholesalers in the grower areas plus a proportion of the throughput of wholesalers from other areas
Food processors	= a proportion of the throughput of grower areas wholesalers
Food services	= a proportion of the throughput of wholesalers in grower areas plus a proportion of the throughput of retailers in grower areas
Consumers	= a proportion of the throughput of retailers in grower areas

The proportion of waste that is sent to control waste facilities is estimated for each utility point and used to calculate the total number of clusters that become waste in each of the waste point/area combinations (Table 5.4). Similar calculations are done for utility points in other areas.

**Table 5.4** The number of imported clusters at waste points

Variable	Definition and calculation
	The calculations are done separately for grower areas and other areas.
$W_{\text{utility point}}$	Number of imported clusters that become waste from a utility point = $N_{\text{utility point}} \times PW_{\text{utility point}}$
$N_{\text{utility point}}$	Number of imported clusters passing through a utility point = Table 5.3
$PW_{\text{utility point}}$	Proportion of throughput that becomes waste = estimated for wholesalers and retailers; and = 100% for other utility points
$CW_{\text{utility point}}$	Number of imported clusters that become controlled waste from a utility point = $W_{\text{utility point}} \times PC_{\text{utility point}}$
$PC_{\text{utility point}}$	Proportion of waste that is controlled waste = estimated for each utility point
$UW_{\text{utility point}}$	Number of imported clusters that become uncontrolled waste from a utility point = $W_{\text{utility point}} \times (1 - PC_{\text{utility point}})$
$N_{\text{waste point}}$	Number of imported clusters arriving at a waste point = calculated below
<b>Waste point</b>	
Controlled waste	= $CW_{\text{wholesalers}} + CW_{\text{retailers}} + CW_{\text{food processors}} + CW_{\text{food services}} + CW_{\text{consumers}}$
Uncontrolled consumer waste	= $UW_{\text{consumers}}$
Other uncontrolled waste	= $UW_{\text{wholesalers}} + UW_{\text{retailers}} + UW_{\text{food processors}} + UW_{\text{food services}}$

### 5.3.8 The number of infected/infested clusters at each waste point

The average number of infected/infested clusters at each waste point equals the total number of infected/infested clusters at all waste points multiplied by the proportion of clusters going to that waste point (Table 5.5). However, the analysis looks at the variation in the probability of exposure, establishment and spread (PEES) resulting from importing bananas over one year, and a small

component of this variation results from the randomness associated with the possible destination waste point of an infected/infested cluster. Consequently, in each simulation run of the model, the number of infected/infested bananas arriving at each waste point is determined by randomly allocating the total number of infected/infested clusters in proportion to the number of clusters that go to each waste point.

For the first waste point considered when doing this allocation, a hypergeometric distribution is used to simulate the number of infected or infested clusters going to it taking into account:

- the total number of clusters becoming waste (Table 5.2)
- the number of clusters going to the waste point (Table 5.4)
- the number of clusters that are infected or infested when becoming waste (Table 5.5).

The simulated value for subsequent waste points is done similarly, after reducing the number of available clusters and infected/infested clusters by the number already allocated to other waste points.

**Table 5.5 The number of infected or infested clusters at each waste point**

Variable	Description and calculation
Average infected waste point	Average number of infected or infested clusters arriving at the waste point. = $N_{\text{infected waste}} \times N_{\text{waste point}} / N_{\text{imported}}$
$N_{\text{infected waste}}$	The number of infected or infested clusters arriving at all waste points during 12 months. = Table 5.2
$N_{\text{waste point}}$	The number of clusters that arrive at the particular waste point. = Table 5.4
$N_{\text{imported}}$	The number of clusters that are imported during 12 months. = Table 5.1
$N_{\text{infected at waste point}}$	The number of infected or infested clusters at a waste point = (first waste point) a simulated value using the hypergeometric distribution to select $N_{\text{waste point}}$ clusters from $N_{\text{imported}}$ clusters of which $N_{\text{infected waste}}$ are infected or infested. The simulated value for subsequent waste points is done similarly, after taking into account the number of clusters and infected or infested clusters already allocated to waste points.

## 5.4 Exposure

Exposure is the third of the three components that make up the concept of ‘entry’ (importation, distribution and exposure). It encompasses the biological factors which determine the likelihood that a pest will successfully transfer to a host. This section deals with factors relating to exposure, while the next section deals with events subsequent to exposure that may result in establishment (the propagation on or in that host) and spread (the dispersal to other susceptible host plants).

The analysis first considers what proportion of waste points would be in ‘proximity’ to susceptible hosts, which are broadly classified into three types of ‘exposure groups’. It then determines the likelihood that the pest would be actually transferred to a host from an infected/infested cluster near to a host. This is done by considering biological factors associated with the survival of the pest and the availability of necessary mechanisms for dispersal.

### 5.4.1 Exposure groups

The analysis of the probability of exposure considers the relationship between waste points and ‘exposure groups’ – categories of suitable host plants in Australia. They delineate collections of

suitable host plants for which the likelihoods of exposure, establishment and spread are likely to be significantly different. This enables a more precise and transparent assessment of overall risk to be made.

Three exposure groups are identified in this analysis:

**commercial crops:** banana plantations and other susceptible commercial crops.

**home gardens:** that have susceptible plants, including weed species.

**other plant communities:** such as susceptible wild (native and introduced) and amenity plants including susceptible plants growing on parklands, bushland and farmland (includes weeds, feral banana plants, and abandoned and derelict plantations).

A possible fourth exposure group – ‘no available hosts’ – is not required since there is no risk. The concept of an exposure group implies that there will be suitable host plants present, although the plant species that are at risk will depend on the pest.

#### 5.4.2 The probability of exposure

The term ‘exposure’ means that the pest from an infected or infested banana’s waste has come in contact with a susceptible host plant in a sufficient dose to have the potential to infect or infest it.

The probability of exposure considers factors such as:

- closeness to a host
- viability of the pest
- survival mechanisms of the pest
- transfer mechanisms
- host receptivity
- environment.

It is convenient to divide the calculation of the probability of exposure into two components:

- Exposure – proximity (based on demographic information on the distribution of hosts).
- Exposure – transfer (based on the biology of the pest).

Because the bananas in a cluster will usually be consumed over a number of days, and the waste from individual fingers in a cluster may be disposed of in different locations, the analysis of exposure is based on an individual banana. The number of fingers is calculated by multiplying the number of clusters by seven (if each banana in an infected/infested cluster is considered to be infected/infested). The multiplier can be a lower number if it is not considered that all fingers would be infected/infested, dependent on pest biology. The multiplier can be one for an analysis being done on clusters (for example, if the risk is associated only with the cluster).

#### 5.4.3 Exposure – proximity

‘In proximity’ means that infected/infested waste has been discarded sufficiently near to a host plant as to allow for the possibility of exposure occurring. The proportion of waste in proximity to an exposure group is assessed for each of the 18 combinations of the three waste points, three exposure groups and two areas.

Since different pests have different spread mechanisms, the distance associated with proximity will vary according to the specific pest. In addition, different pests have different host ranges, which in turn will determine the likelihood of a host occurring within the dispersal range of the particular pest. Relevant proximity factors are discussed in each PRA.

Section 7.3.4 has information about the distribution of exposure groups in Australia used to calculate the proportion of waste in proximity to exposure groups for each of the pests considered.

#### 5.4.4 Exposure – transfer

The probability of transfer is also considered for each of the 18 waste point, exposure group and area combinations. The analysis determines the probability that an infected/infested finger in proximity to an exposure group would cause exposure (that is, the transfer of a population of the pest sufficient to initiate infection/infestation at a suitable site).

The probability of transfer is determined in the context of the waste point and exposure group being considered, and takes into account how proximity was defined.

Many factors could affect the transfer of the pest from the waste material including:

- the population level of the pest associated with the discarded waste
- the time that the pest remains viable in or on the discarded waste material
- the degree to which the pest multiplies on the discarded waste
- whether or not the pest is buried or otherwise contained in the waste
- the density of host plants in the exposure group over which the pest may disperse (thereby providing a target for settling on a suitable host)
- vectors and possible intermediate hosts
- any behaviour of the pest in actively seeking host plants.

### 5.5 Establishment and spread

Determining the likelihood of establishment and spread encompasses biological factors that determine the likelihood that a pest will successfully propagate on or in an exposed host (establishment) and disperse from there to other susceptible host plants (spread). These probabilities are obtained from the pest biology associated with the interaction of the host and environment, and the availability of necessary mechanisms for dispersal. International guidelines on factors to consider when evaluating the likelihood of establishment and spread have been prepared by the IPPC (FAO 2004). Many of the criteria below are relevant to defining the risk scenario, and may be covered in the introductory sections of a PRA.

#### 5.5.1 IPPC criteria for establishment and spread

The assessment of establishment and spread in this IRA followed the guidelines of the IPPC (FAO 2004) and considered the points summarised below.

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

This covers:

- whether hosts and alternate hosts are present and how abundant or widely distributed they are
- 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 required for the dispersal of the pest, is already present in the PRA area or is likely to be introduced
- whether another vector species occurs in the PRA area.

##### *Suitability of environment*

Factors in the environment (for example, suitability of climate, soils, topography, predators and parasitoids, pest and host competition) critical to the development of the pest, its host and (if applicable) its vector, and to its ability to survive periods of climatic stress and complete its lifecycle,

should be identified. The probability of establishment in a protected environment, such as a glasshouse, should also be considered.

### *Cultural practices and control measures*

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

Pest control programs and natural enemies that are present in the PRA area and that might reduce the probability of establishment must be considered. Pests for which control is not feasible should be considered to present a greater risk than those for which treatment is easy. The availability or lack of suitable methods for eradication should also be considered.

### *Other pest characteristics*

Characteristics that enable the pest to reproduce effectively in the new environment, such as parthenogenesis/self-crossing, length of the lifecycle, number of generations per year, resting stage and diapause 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 similar to those in the PRA area – must be considered. For instance, there may be host-specific races or races adapted to a wider range of habitats or to different hosts. Genotypic (and phenotypic) variability enhances 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.

The minimum population needed for establishment should be estimated if possible.

### *Probability of establishment*

Calculating the probability of establishment involves examining the factors relevant to the successful colonisation of a susceptible host to the point at which a sustainable population has developed and from which spread could occur to other susceptible hosts in the endangered area. The probability of establishment if exposure has occurred is determined for each of the three exposure groups in the two areas.

### *Probability of spread*

The probability of spread for each exposure group is derived from a comparative assessment of those factors in the source country and the 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
- potential for movement with commodities or conveyances
- rate of increase
- intended use of the commodity
- potential vectors of the pest in the PRA area
- current management practices in the PRA area
- availability of control measures
- likelihood of early detection
- potential natural enemies of the pest in the PRA area.

The time it takes for spread to occur is not considered in the analysis. The probability of spread if establishment has occurred is determined for each of the three exposure groups in the two areas.



## 5.6 Annual PEES

The PEES is determined for each exposure group from each waste type in each area as shown in Table 5.6. If waste from a particular infected/infested finger is to cause the spread of the pest, four events must happen:

- the banana waste at a waste point must be in proximity to a host plant
- as a result of that proximity, the pest must transfer to the host (exposure)
- as a result of that exposure, establishment must occur on that host
- as a result of that establishment, the pest must spread to other hosts.

The probability of all four of these events occurring is calculated by multiplying together the probabilities of each event occurring. This probability is subtracted from 1 to calculate the probability that spread does not occur from a single infected/infested finger.

The probability that at least one occurrence of entry, establishment and spread might occur from infected/infested fruit at the waste point via a particular exposure group is 1 minus the probability that none of the infected/infested fruit at the waste point cause an outbreak via the exposure group.

**Table 5.6 Calculation of the PEES in susceptible host plants in an exposure group from the infected or infested waste at a waste point**

Variable	Description and calculation
PEES <sub>WP to EG</sub>	The calculation is done for each exposure group and area (EG) and waste point (WP). Probability that at least one pest will gain exposure to susceptible hosts in the exposure group and result in establishment and spread, as a result of infected/infested waste at the waste point. $= 1 - (1 - \text{Prox}_{\text{WP to EG}} \times \text{Exp}_{\text{WP to EG}} \times \text{Est}_{\text{EG}} \times \text{Spr}_{\text{EG}})^{N_{\text{Infected at WP}} \times N_{\text{fingers}}}$
N <sub>infected at WP</sub>	Number of infected or infested clusters at the waste point. = pest-specific (see Table 5.5)
N <sub>fingers</sub>	Number of infected or infested fingers in a cluster. = pest-specific value
PROX <sub>WP to EG</sub>	Probability that an exposure group is in the proximity of the waste point. = pest-specific value
Exp <sub>WP to EG</sub>	Probability that transfer occurs in susceptible hosts within the exposure group as a result of a cluster of infected/infested bananas being in proximity of susceptible hosts. = pest-specific value
Est <sub>EG</sub>	Probability that establishment occurs given that exposure has occurred within the exposure group. = pest-specific value
Spr <sub>EG</sub>	Probability that spread occurs given that establishment has occurred within the relevant exposure group. = pest-specific value

Finally, as Table 5.7 shows, the 18 individual results are combined to give the overall annual likelihood of entry, establishment and spread resulting from a year's trade. The probability of at least one occurrence of entry, establishment and spread is one minus the probability that none of the waste point and exposure group combinations cause an outbreak.

The median of the simulated values for the overall annual probability of entry, exposure and spread of the pest is combined with an assessment of the consequences to give an overall estimate of risk (as described in Section 6.2).

**Table 5.7 Calculation of PEES**

Probability	Description and calculation
PEES	$= 1 - (1 - \text{PEES}_{\text{Controlled waste to Commercial plantings in Grower areas}})$ $\times (1 - \text{PEES}_{\text{Controlled waste to Household plantings in Grower areas}})$ $\times \dots [18 \text{ terms in all}] \dots$ $\times (1 - \text{PEES}_{\text{Other uncontrolled waste to Household plantings in Other areas}})$ $\times (1 - \text{PEES}_{\text{Other uncontrolled waste to Other plantings in Other areas}})$
PEES <sub>WP to EG</sub>	<p>Estimated probability that the infected or infested waste at a waste point (WP) causes at least one establishment and spread event in the exposure group (EG).</p> <p>= Table 5.6</p>

## 6. Consequences and risk

This chapter gives details on how the consequences of an outbreak of a pest or disease from imported bananas are determined, and how the overall consequence rating is combined with the likelihood of such an outbreak (see Chapter 5) to give a measurement of the risk.

For each pest, the consequences are evaluated according to eight criteria that cover the economic, environmental and social impacts that may have economic effects (for example, effect on amenity value) of the pest's establishment and spread, both over the short and longer term, as appropriate. The impact of each of these criteria is determined at four levels – local, district, regional and national – and combined to give an impact score for each of the eight criteria. The impact scores for all eight criteria are combined to give a consequence rating.

### 6.1 Consequences

The following method is used to assess the consequences associated with each pest analysed in this IRA.

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 with 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
  - the relative cost-effectiveness of alternative approaches to limiting risks.
- The IPPC elaborates on the 'relevant economic factors' to differentiate between the 'direct' and 'indirect' effects of a pest, and provides examples of factors that will typically be relevant to a PRA.

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 on consumers in the importing country.

The direct and indirect consequences considered in this report are discussed below, based on the framework provided in the draft *Guidelines for import risk analysis* (BA 2003).

It should be noted that consequences are also mutually exclusive – that is, an effect is not assessed more than once. For example, the direct effects of a pest on a native or wild species are assessed under the criterion 'plant life or health, including plant production losses', whereas the indirect or 'flow-on' effects on the environment are assessed under the last indirect criterion, 'environment'.

ISPM 11: Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms (FAO 2004) provides examples of both direct and indirect consequences. Importantly, in 2004, supplementary text on the analysis of environmental risk was added to the earlier version of ISPM 11 giving prominence to environmental considerations.

In this analysis, a single estimate of consequences was determined for each pest. The assessment of consequences was carried out in two steps.

- Initially, the magnitude of impact of a pest on each of the direct and indirect criteria was evaluated using the descriptive (qualitative) system outlined above (see Table 6.1).
- Subsequently the assessments of impact obtained for the direct and indirect criteria were combined to give an overall (qualitative) estimate of the consequences of establishment and spread as outlined below.

### **6.1.1 Direct criteria**

#### *Plant life or health*

Examples cited in ISPM 11 (FAO 2004) that could be considered for the direct consequences on plant life or health:

- known or potential host plants
- types, amount and frequency of damage
- crop losses, in yield and quality
- biotic factors (for example, adaptability and virulence of the pest) affecting damage and losses
- abiotic factors (for example, 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 11 (FAO 2004) as a factor that is not directly relevant to the scope of the IPPC, although it 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*

Examples from ISPM 11 (FAO 2004) that could be considered for the direct consequences on any other aspects of the environment (for example, the physical environment or other life forms – micro-organisms etc.):

- 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.

### **6.1.2 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 11 (FAO 2004) that could be considered for the indirect consequences on eradication, control, etc:

- changes to producer costs or input demands, including costs of control
- 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*

Examples from ISPM 11 (FAO 2004) that could be considered for the indirect consequences on domestic trade:

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

*International trade*

Examples from ISPM 11 (FAO 2004) that could be considered for the indirect consequences on international trade:

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

*Environment*

Examples from ISPM 11 (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 (for example, amenity value, tourism)
- significant effects on plant and animal communities
- significant effects on designated environmentally sensitive or protected areas
- significant change in ecological processes and on the structure, stability, resilience and function of an ecosystem (including further effects on plant species, erosion, water table changes and nutrient cycling, or increased fire hazards)
- costs of environmental restoration.

*Communities*

An example from ISPM 11 (FAO 2004) that could be considered for the indirect consequences on communities is the effect on human uses (for example, ecosystem services, water quality, tourism, recreational uses, animal grazing, hunting and fishing). Examples (not listed in ISPM 11) include:

- reduced rural and regional economic viability
- any side effects of control measures.

**6.1.3 Rating the impact of a pest**

The objective of the assessment of consequences is to determine the likely impact of a pest on the Australian community as a whole. Effects on industry and on sections of the Australian community are relevant to the assessment, but the assessment applies across all of Australia. For a pest of regional quarantine concern, the impact is assessed at the regional rather than the national level.

### *Geographical levels*

The impact of a pest or disease on each direct and indirect consequence criterion is estimated at four levels:

1. **Local:** An aggregate of households or enterprises – for example, a rural community, or a town.
2. **District:** A geographically or geopolitically associated collection of aggregates – generally a recognised section of a state, such as the Coffs Harbour district or Tully Valley.
3. **Regional:** A geographically or geopolitically associated collection of districts – such as the ‘northern coast of New South Wales’ or ‘Far North Queensland’ – or a state.
4. **National:** The whole endangered area where suitable hosts are present or could be grown in Australia.

### *Impact descriptions*

At each geographical level, the impact is assessed and 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 plant mortality or a minor decrease in production. For non-commercial factors, this impact is not expected to threaten the intrinsic value of the criterion – though the value of the criterion would be considered as ‘disturbed’. Effects would generally be reversible.

A ‘significant’ impact would threaten economic viability through a moderate increase in plant mortality 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 plant mortality 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 the pest on the geographical level being assessed as a whole rather than on individual parties directly affected.

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.

When evaluating the impact at the different levels, the following two rules apply:

- If the impact at the local, district or regional level is *significant* or *highly significant*, then the impact at the next broader level cannot be *unlikely to be discernible*. In other words, if the impact is *significant* or *highly significant* at one level, the impact at the next level must be at least *minor*, but may be *significant* or even *highly significant*.
- The impact at a lower level will never be less than the impact at a higher level, although it can be an equal rating.

### *Overall impact of a criterion*

The impact at each of the four geographic levels is considered when giving an impact score for the criterion using the scale A–G as shown in Table 6.1. The impact scores for each of the eight criteria are combined to give an overall rating of consequence as described in Section 6.1.4.

**Table 6.1 Combining the assessment of the local, district, regional and national consequences to give an impact score for a single criterion**

Impact score	Consequences			
	National level	Regional level	District level	Local level
G	highly significant			
F	significant	highly significant		
E	minor	significant	highly significant	
D		minor	significant	highly significant
C			minor	significant
B				minor
A	unlikely to be discernible	unlikely to be discernible	unlikely to be discernible	unlikely to be discernible

Table 6.1 shows the impact score (A–G) corresponding to each possible consequence and geographic level combination.

The overall impact score (A–G) for a criterion is the highest of the impact scores corresponding to the assessed consequences at each of the four geographical levels.

#### 6.1.4 Determining the consequence

In this analysis, a single assessment of consequences was determined for each pest. The assessment of consequences for banana fruit from the Philippines was carried out in two steps:

- Initially, the magnitude of impact of a pest (on a scale from A to G) on each of the direct and indirect criteria was evaluated using the descriptive (qualitative) system outlined above (see Table 6.1).
- Subsequently the magnitude of the impact obtained for each of the direct and indirect criteria was combined to give an overall (qualitative) estimate of the consequences of establishment and spread as outlined below.

The magnitude of the consequences is obtained from the impact scores for each of the eight direct and indirect criteria. The following rules are followed in sequence until the overall consequence is determined.

The overall consequence is considered to be *extreme* if:

- any criterion has an impact of ‘G’; or
- more than one criterion has an impact of ‘F’; or
- a single criterion has an impact of ‘F’ and each remaining criterion an ‘E’.

Otherwise, the overall consequence is considered to be *high* if:

- a single criterion has an impact of ‘F’; or
- all criteria have an impact of ‘E’.

Otherwise, the overall consequence is considered to be *moderate* if:

- one or more criteria have an impact of ‘E’; or
- all criteria have an impact of ‘D’.

Otherwise, the overall consequence is considered to be *low* if:

- one or more criteria have an impact of ‘D’; or
- all criteria have an impact of ‘C’.

Otherwise, the overall consequence is considered to be *very low* if:

- one or more criteria have an impact of ‘C’; or
- all criteria have an impact of ‘B’.

Otherwise, the overall consequence is considered to be *negligible*.

## 6.2 Risk

Risk is a function of the likelihood of an event occurring and the consequences or impact resulting from that event. The risk estimation matrix in Table 6.2 shows how the PEES is combined with the result of the consequence assessment to provide an estimate of the risk associated with the pest being considered. The median PEES resulting from a year’s trade was determined as described in Section 5.6, and Section 6.1.4 described how the consequence rating was determined.

**Table 6.2 Rules for determining risk from probability and consequence categories**  
(Derived from Table 1.1)

Probability range		Risk					
0.3	1						
0.05	< 0.3						
0.001	< 0.05						
10 <sup>-6</sup>	< 0.001						
0	< 10 <sup>-6</sup>						
		Negligible	Very low	Low	Moderate	High	Extreme
		<b>Consequences</b>					

## 6.3 Need for risk management

This is the third of the three stages of an IRA as described in Section 3.1. For each pest, the unrestricted risk associated with the importation of bananas from the Philippines over 12 months is evaluated.

If the unrestricted risk achieves Australia’s ALOP, the pest is considered to not require management. The unrestricted risk assumes there are no prescribed phytosanitary measures in place, that is:

- there are no prescribed restrictions on fruit that can be supplied
- there are no prescribed measures to inhibit infestation
- there are no prescribed special treatments or inspection procedures at packing houses or at the Australian border.

If the unrestricted risk exceeds Australia’s ALOP, the risk assessment then considers what risk management measures might be available to reduce the risk to achieve Australia’s ALOP, as described in Section 3.1.3.

The determination of the measures which might be applied to achieve Australia’s ALOP, and which are not more trade restrictive than required, is based on a process of testing potential risk management measures both alone and in combination.



## 7. Banana industry

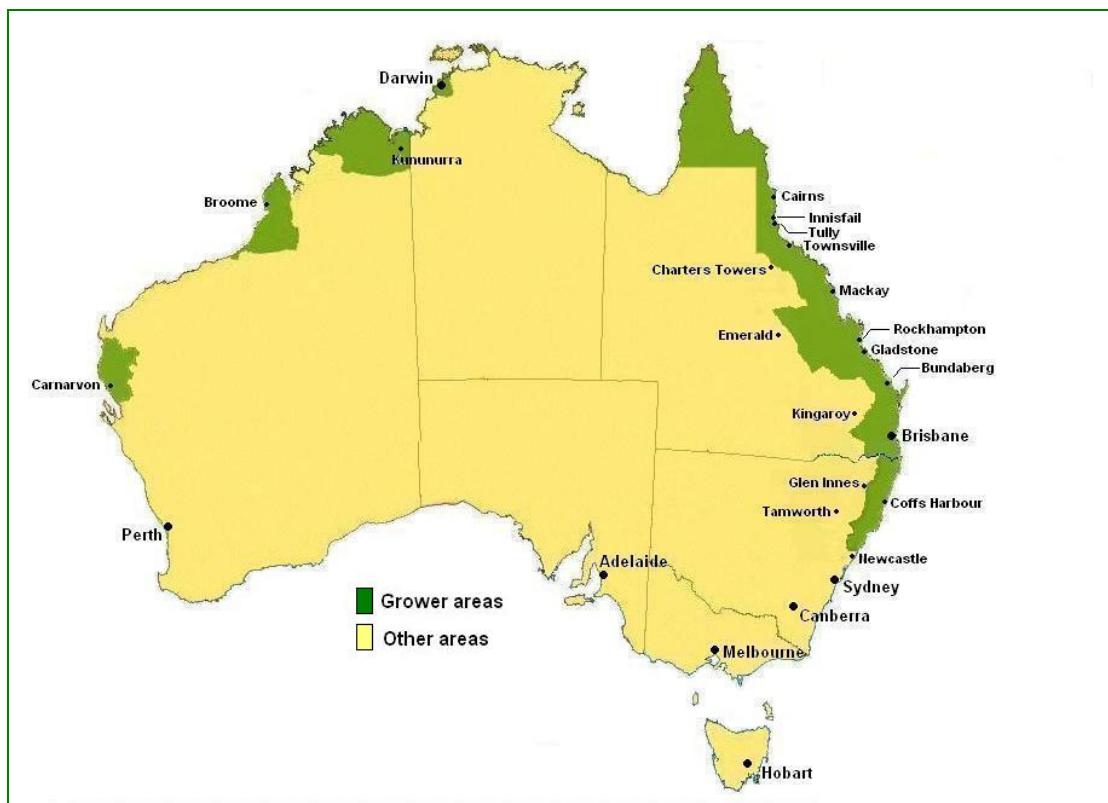
This chapter outlines information to estimate parameters used in modelling the proposed importation of Philippine bananas. It describes the following:

- production of Philippine bananas for the unrestricted importation risk scenario
- proposed distribution of Philippine bananas through the Australian supply chain
- accumulation and handling of banana waste in Australia
- density of banana and heliconia plants grown in commercial plantations, home gardens and other plant communities.

General information relating to the banana industries in the Philippines and Australia can be found in Section 2.3, while detailed information on the conditions for growing bananas in each country is discussed in the Appendix 2 of Part C.

### 7.1 Grower areas in Australia

The commercial banana industry in Australia consists of approximately 1850 growers with 14,000 hectares under production. It is concentrated in north Queensland, but includes areas in south-east Queensland, the north coast of New South Wales, Carnarvon and Kununurra in Western Australia, and Darwin in the Northern Territory (Figure 7.1).



**Figure 7.1 Grower areas defined by local government area boundaries and state government legislation**

Based on state government definitions of Local Government Areas (LGAs) (in Queensland and New South Wales) and the location of commercial banana plantations (in Western Australia and the Northern Territory), 84 of the 678 LGAs in Australia are considered to be grower areas. The grower

areas comprise 66 LGAs in Queensland, 14 in New South Wales, three in Western Australia and one in the Northern Territory. The remaining 594 LGAs comprise the other areas. About 20% of Australia's population reside in grower areas and 80% in other areas. The grower area covers 692,370 square kilometres, which is about 9% of Australia's land mass.

## **7.2 Production of Philippine bananas and distribution in Australia**

This section describes the standard industry practices associated with the steps in the importation and distribution scenarios described in Chapter 5. The steps include the production and handling of bananas in the Philippines, their transport to Australia and their associated ripening and distribution in Australia.

### **7.2.1 Grower areas in the Philippines**

The proposed export area is restricted to Mindanao Island. It includes both lowland areas (for example, Davao and Cotabato) and the more recently developed highland areas (such as Bukidnon). Pest and disease pressure is significantly less in the highland areas where rainfall, temperature and humidity are lower than in the coastal lowlands. This results in a slower growing and bunch-filling time in the highlands of 18–20 weeks, compared with 10–13 weeks in the coastal lowlands (Philippines Scientific Delegation 2002).

### **7.2.2 Plantation management in the Philippines**

Cavendish plantations in the Philippines are predominately corporately owned and managed. Commercial plantation sizes range from about 70 ha–6250 ha, and production and handling is large-scale and labour-intensive. There is little field mechanisation in ratoon plantations, except for the use of cableways to transport bunches to permanent packing stations, and of machinery to remove annual crops and prepare fields for new annual crops.

Bananas cannot be grown commercially in wet tropical areas unless diseases are controlled in a consistent manner throughout the year. For fungal diseases such as black Sigatoka (*Mycosphaerella fijiensis*) and freckle (*Guignardia musae*), control is achieved by a combination of pruning to remove diseased leaf tissue and regular application of fungicides. More than 45 fungicide sprays may be applied per year, depending on weather conditions and the results of disease monitoring (Philippines Scientific Delegation 2002).

For bacterial and viral diseases, such as Moko (*Ralstonia solanacearum* race 2), banana bunchy top disease (BBTV) and banana bract mosaic disease (BBrMV), control is achieved by the use of clean planting material, weekly inspections for disease symptoms and the immediate removal of diseased plants and of any plants within 5 m.

Insecticides are also frequently used to manage insect pests. At the shooting (bud emergence) growth stage, inflorescences are injected with insecticide. Two weeks later, developing bunches are sprayed, de-belled and bagged with polythene bunch covers, which in some areas are chlorpyrifos-impregnated.

### **7.2.3 Harvesting in the Philippines**

Banana bunches are harvested in a fresh mature hard green stage – 30.2–38.9 mm in diameter (BPI 2001), and transported to a packing station within about two hours of harvesting.

Lowland growers use a cableway system to move banana bunches from the field to packing stations. The average cableway is 400 m in length, but can be up to two kilometres.

Some highland producers use mobile packing stations to de-hand and process bananas to the packed carton stage in the field. This constitutes about 10% of plantations (Philippines Scientific Delegation 2002).

#### **7.2.4 Handling at packing stations in the Philippines**

On arrival at the packing station, polythene bunch covers are removed and the fruit hosed with water to remove dirt, leaf trash and latex exuding from the cut surfaces. Bunches are then de-handed and fruit immersed in water flotation tanks for up to 25 minutes. Most of the trash is removed as a result of the washing process but some is known to remain with the fruit (Peterson et al 2006).

At the packing stations, the bananas are inspected for quality assurance and any misshapen, damaged, pest-affected or yellowed fruit is rejected. Finally, clusters are packed in new cartons lined with a polythene bag, some of which may be partially vacuum-packed. The fruit is wet when packed.

#### **7.2.5 Packing and transport to Australia**

The cartons, which are packed to a weight of 13 kg, are placed on fumigated or new wooden pallets. The pallets are delivered from packing stations to a wharf either in refrigerated containers or covered trucks. The refrigerated containers and pallets from covered trucks are loaded into the holds of refrigerated ships and subsequently shipped to export destinations. All export fruit is shipped within 24 hours of harvest and generally within 15–18 hours. During shipping, fruit is maintained at 13–14 °C. It is estimated that the shipping time to Sydney from the Philippines would be between 10 and 14 days (Philippines Scientific Delegation 2002). As the skin of the fruit is wet when packed, it is highly likely to remain so during transportation to Australia.

#### **7.2.6 Quarantine procedures on arrival to Australia**

AQIS inspection is commonly tailored to meet the requirements of particular phytosanitary protocols. However, a number of AQIS procedures are common for all consignments arriving in Australia, including:

- AQIS will check documentation and inspect the outside of all containers for freedom from objects of quarantine concern, for example, Giant African snails, insects, hitchhikers, weed seeds, plant debris and soil.
- AQIS will ensure compliance with other entry requirements relating to wood dunnage or other packaging of quarantine concern.

For the purposes of evaluating unrestricted risk, it is assumed there will be no inspections specifically aimed at detecting pest infestations of bananas.

#### **7.2.7 Ripening in Australia**

After AQIS inspection and clearance of the consignment, bananas will normally be transported to a wholesale distribution centre where ripening is initiated. Bananas are stored at 13–14 °C for two to seven days, with the length of time depending on the distance of the wholesaler from the port of entry and on market demand. To ripen the bananas artificially, the polythene bag is opened and ethylene gas applied to the fruit. Controlled ripening is undertaken at 14.5–21 °C. Humidity is generally maintained at 85–95% in the early stages of ripening and, once a trace of colour appears, it is reduced to 70–80%. Ripening rooms are usually gassed with ethylene on each of two successive days (AUF 1999).

### **7.2.8 Retail sale in Australia**

Bananas are transported from wholesalers to retail shops in cities, regional centres and towns throughout Australia. In supermarkets and retail shops, air conditioning generally maintains the temperature around 20–22 °C. Smaller independent fruit shops generally operate at ambient temperatures which may be seasonally higher or lower.

During transport from a wholesale distribution centre to retailers, some leaf trash and small mobile arthropods, especially mites and first instars of mealybugs and hard scales will become dislodged from clusters because of the vibration and gradual shrinkage of fruit as moisture is lost. (Cartons are generally packed slightly above the nominal weight to allow for weight loss of about 1% between packing station and retailer). It is assumed a small amount of trash may become part of the waste packaging material that is normally discarded by retailers.

### **7.2.9 Conversion factors**

Information discussed in this IRA is expressed in several different units. The following units are used:

- 7 fingers per cluster (approximately 1 kg)
- 13 clusters per carton
- 1000 clusters per tonne.

## **7.3 Supply of banana fruit and accumulation of banana waste in Australia**

It is assumed that the distribution of imported bananas will follow the current Australian supply chain. This section estimates the proportion of bananas supplied to the different utility points in both grower and other areas. Banana waste (peel or damaged or bruised whole fruit) is generated at each step of the distribution pathway. Waste disposal is also considered, along with associated packaging material.

The distribution scenario for the movement of bananas after release from quarantine, via utility points, to becoming waste at waste points is described in Section 5.3.

### **7.3.1 Wholesaler turnover and waste**

Currently about 265,000 tonnes of domestically produced bananas are distributed by the grocery supply chain each year in Australia. About half of this volume is sold through two major supermarket chains, both of which have an integrated distribution/retailer supply chain. Most of the remaining bananas are sold by independent wholesalers. About 45,000 tonnes are distributed through wholesalers in grower areas and 220,000 tonnes through wholesalers in the other areas.

Information was obtained on the distribution of Australian bananas and disposal of banana waste by surveying members of the Association of Australian Banana Wholesalers (AABW). The survey was carried out from December 2005 to January 2006 (BA 2006a). Three-quarters of AABW members responded to the survey. The volume distributed by members of the AABW accounts for about 55% of bananas distributed annually through the Australian wholesale system.

#### *Sales to food processors*

The survey of members of the AABW found that about 100 tonnes of bananas were distributed to food processors in grower areas and about 550 tonnes to processors in other areas (BA 2006a). Food processors in grower areas also obtain about 12,000 tonnes of bananas directly from growers (Peasley 2005), but this was not included in the distribution model since processed fruit is generally discarded fruit and of a low grade. Occasionally higher grade fruit may be used by processors during periods of

over-supply or low prices. In such a case, a small proportion of imported fruit would most likely be diverted from consumers to food processors, resulting in a marginal reduction in the PEES.

The variability in the quantity of bananas purchased by food processors was entered into the model as a Triangular distribution. For grower areas, a mode of 100 tonnes, a minimum of 50 tonnes and a maximum of 150 tonnes were used. For other areas, a mode of 550 tonnes and a range from 450–650 tonnes were used.

#### *Sales to food services*

Some food services purchase bananas from wholesalers, while others purchase them directly from retailers. The survey of members of the AABW suggests that food services purchase about 650 tonnes from wholesalers in grower areas and 7600 tonnes from wholesalers in other areas (BA 2006a). Using a Triangular distribution for the quantity of bananas purchased by food services from wholesalers, a mode of 650 tonnes, a minimum of 550 tonnes and a maximum of 750 tonnes was used for grower areas. For other areas, a mode of 7600 tonnes and a range from 7300–7900 tonnes was used.

#### *Sales to retailers*

The vast majority of domestically produced bananas distributed by wholesalers are sold to retailers. Normally, wholesalers sell fruit to retailers located in the same area (that is, grower area or other area). Based on information from the survey and population information, about 6.8% of bananas sold by wholesalers in grower areas are purchased by retailers in other areas. In contrast, about 4.2% of bananas sold by wholesalers located in other areas are purchased by retailers in grower areas (BA 2006b). A Triangular distribution was used to model the variation for these proportions, using these values as the mode and a range of  $\pm 0.2\%$  around the mode.

#### *Waste from wholesalers*

Banana waste generated at the ripening, distribution and wholesale levels is largely derived from damaged or unsold whole cartons of fruit. This waste is mainly discarded through controlled systems such as municipal garbage collection and burial, or through commercial composting. A small quantity of banana waste is sent for stock feed and is considered as other uncontrolled waste.

The survey of members of the AABW (BA 2006b) and information from the two major supermarket chains indicated that 0.3–0.4% of bananas were disposed of as waste. Of this, between 90–95% was deposited as controlled waste. Uniform distributions with these end points are used in the simulation.

Of the waste from packaging materials generated by AABW members, virtually all empty banana cartons, including the plastic lining, are disposed of through controlled systems.

### **7.3.2 Retailer turnover and waste**

There are approximately 8600 supermarkets, grocery and convenience stores in Australia (ABS 2005b). A telephone survey was conducted in February 2006 of supermarkets and grocery stores throughout Australia (BA 2006b) to determine how banana waste is disposed of by retailers. While the majority of bananas sold by retailers are purchased by consumers, food services also purchase bananas from retailers.

#### *Sales to food services*

The BA survey determined that 2.5% of the bananas sold by retailers in grower areas were sold to food services (BA 2006b). The corresponding value for other areas was 1.6%. For the simulation, the variation of these proportions was modelled as a Triangular distribution with a range of  $\pm 0.2\%$  about the mode.

### *Waste from retailers*

Waste generated at the retail level includes unsold fruit, damaged fruit and packaging (used cartons and plastic lining). This waste is discarded mainly through controlled systems such as municipal garbage collection and burial. The BA survey of supermarkets and grocery stores suggests 3.5–4.0% of bananas handled at the retail level were disposed of as waste. Of this waste, about 90–95% was discarded through controlled municipal systems (BA 2006b). Uniform distributions with these end points were used in the simulation.

The remaining 5–10% of banana waste was discarded as animal feed, except for less than 0.5% of waste which was disposed of in compost bins or as untreated mulch.

### **7.3.3 Food processors, food services and consumer waste**

Bananas used by food processors, food services and consumers all generate waste in the form of a peel and cushion (stem) material. Additionally, waste may be in the form of pulp from rejected fruit, whether whole or a part.

#### *Waste from food processors*

A high proportion of waste from food processors is used for animal feed, while about 10% of banana waste is discarded through controlled systems. It was assumed that packaging material would be discarded through controlled systems, such as recycling or the municipal tip.

#### *Waste from food services*

It was estimated that about 95–100% of the banana waste from food services was discarded through controlled systems. A Uniform distribution with these end points was used in the simulation.

#### *Waste from consumers*

In February 2006, BA conducted a survey of 101 LGA councils to determine the proportion of consumers who compost household food waste at home. Responses by councils to the proportion of food waste composted by consumers in their LGA ranged from 1–50%. Based on that information, it seems that, on average, 16% of households compost food waste at home.

However, other sources suggest the proportion of households composting food waste is 40–50%:

- In March 2003 the Australian Bureau of Statistics reported that 47% of Australian households recycled or re-used kitchen/food waste (ABS 2003).
- A survey in Victoria in September 2004 found that about 50% of respondents used a compost bin or worm farm for kitchen waste (Nathan and Katos 2005).
- A survey by the ACT Government in 2004–05 found that 37% of households surveyed recycled virtually all food waste, and 14.6% recycled some.

Given that there is a nationwide trend to recycling, a range of 40–50% was used for the proportion of households composting food waste at home. For the simulation, it was assumed that the proportion of consumer waste discarded through controlled systems was 50–60%. A Triangular distribution with a mode of 55%, a minimum of 50% and a maximum of 60% was used to model the uncertainty for this proportion.

### **7.3.4 Summary of values used in the model**

Table 7.1 and Table 7.2 summarise the information that has been derived in this section concerning banana turnover and waste generation, based on the current domestic supply of bananas. This

information is used in each quantitative PRA for the proposed importation of bananas from the Philippines.

Quantities and destinations of bananas handled by wholesalers and retailers.

**Table 7.1 Quantities and destinations of bananas handled by wholesalers and retailers**

<b>Grower areas</b>	
Tonnes handled by wholesalers	45,000
Tonnes used by food processors	Triangular; Min = 50; Mode = 100; Max = 150
Tonnes used by food services obtained from wholesalers	Triangular; Min = 550; Mode = 650; Max = 750
Proportion of bananas handled by wholesalers in growers areas sold to retailers in other areas	Triangular; Min = 6.6%; Mode = 6.8%; Max = 7.0%
Proportion of bananas handled by retailers sold to food services	Triangular; Min = 2.3%; Mode = 2.5%; Max = 2.7%
<b>Other areas</b>	
Tonnes handled by wholesalers	220,000
Tonnes used by food processors	Triangular; Min = 450; Mode = 550; Max = 650
Tonnes used by food services obtained from wholesalers	Triangular; Min = 7300; Mode = 7600; Max = 7900
Proportion of bananas handled by wholesalers in other areas sold to retailers in grower areas	Triangular; Min = 4.0%; Mode = 4.2%; Max = 4.4%
Proportion of bananas handled by retailers sold to food services	Triangular; Min = 1.4%; Mode = 1.6%; Max = 1.8%

**Table 7.2 Percentages of banana waste from imported bananas and the proportion that goes to controlled facilities**

<b>Proportion of bananas becoming waste</b>	
Bananas arriving at wholesalers	Uniform; Min = 0.3%; Max = 0.4%
Bananas arriving at retailers	Uniform; Min = 3.5%; Max = 4.0%
Bananas used by food processors	100%
Bananas used by food services	100%
Bananas used by consumers	100%
<b>Proportion of waste that goes to controlled facilities</b>	
Waste from wholesalers	Uniform; Min = 90%; Max = 95%
Waste from retailers	Uniform; Min = 90%; Max = 95%
Waste from food processors	10%
Waste from food services	Uniform; Min = 95%; Max = 100%
Waste from consumers	Triangular; Min = 50%; Mode = 55%; Max = 60%

### 7.3.5 Projected volume of trade in Philippine bananas

The quantitative and qualitative analyses in this report use the volume of imports for a single year when estimating the PEES.

The volume of imports will be dictated by several inter-related factors. These include supply and demand of bananas within Australia and internationally, the cost of shipment, the price differential

between bananas produced in Australia and those imported from the Philippines, and consumer preferences for local or imported product.

As there are no current imports of mature hard green bananas into Australia, it is difficult to estimate the likely volume. For this report, a volume of 105,000 tonnes of imported bananas in a year was used in the simulation model. This is based on findings from recently published economic modelling papers of the Australian banana market (Abdalla and Sheales 2005; Javelosa and Schmitz 2006), the impact of natural disasters on the Australian banana industry (Cyclones Winifred in 1986 and Larry in 2006 significantly reduced north Queensland banana production), and the retail price of bananas in New Zealand. Values of 50,000 tonnes and 160,000 tonnes were also used for a sensitivity analysis. This range corresponds to about 20–60% of the bananas currently distributed through the wholesale system each year. The tonnage was converted to clusters (one tonne equals 1000 clusters), since the assessment is based on clusters of bananas. There may be situations where major disruptions occur to domestic supplies (for example, cyclones) and import volumes increase significantly. In these situations import requirements and/or operation procedures will be reviewed (Section 20.7) and resultant changes implemented.

Table 7.3 shows the quantity of imported bananas handled by different utility points in Australia. This is based on 105,000 tonnes of bananas being imported from the Philippines. Table 7.4 illustrates the proportion of the total banana waste generated from imported bananas at each utility point in the Australian supply chain and Table 7.5 the proportion of waste disposed of at different waste points. The values in Table 7.3–Table 7.5 were calculated by the method described in Section 5.3.7 using the mean values in Table 7.1 and Table 7.2. However, when estimating PEES, the calculations are done using the simulated values.



**Table 7.3 Turnover and consumption of imported bananas**

Utility point	Tonnes of imported bananas		
	Grower areas	Other areas	Total
Handled by wholesalers	17,830	87,170	105,000
Handled by retailers	19,795	81,311	101,106
Used by food processors	40	218	258
Used by food services	752	4,312	5,064
Used by consumers	18,558	76,961	95,519

**Table 7.4 Source of banana waste from imported bananas**

Utility point	Grower areas	Other areas
Wholesalers	0.06%	0.29%
Retailers	0.71%	2.90%
Food processors	0.04%	0.21%
Food services	0.72%	4.11%
Consumers	17.67%	73.30%
<b>Total</b>	<b>19.20%</b>	<b>80.81%</b>

**Table 7.5 Disposal of banana waste from imported bananas**

Waste point	Grower areas	Other areas
Controlled waste	11.10%	47.30%
Uncontrolled consumer waste	8.00%	33.00%
Other uncontrolled waste	0.10%	0.50%
<b>Total</b>	<b>19.20%</b>	<b>80.80%</b>

## 7.4 Methods for handling waste

The methods of handling controlled and uncontrolled waste influence the likelihood that waste will be in the proximity of a susceptible host, and hence the likelihood that a pest could transfer from waste to a host. Information in this section was taken into consideration when assessing the likelihood of exposure in the PRAs. In some cases, pests on the waste may be in proximity to more than one of the exposure groups because of the distance over which the pest can disperse and the location where the waste is discarded.

### 7.4.1 Controlled waste

#### *Management practices*

Our survey of 101 LGA councils throughout Australia in February 2006 provided information on the management practices of municipal tips (BA 2006c). Based on the annual quantity of waste received, the survey indicated that 87.8% of waste at municipal tips was covered at least once per day, 4.6% was covered several times a week, 7.2% was covered weekly, and 0.4% was covered less than weekly. These figures are based on an 87% response rate by LGA councils (BA 2006c).

Banana waste arriving at a municipal tip would normally not be in a fresh condition, as the collection of kerbside garbage in residential areas usually occurs once a week. Therefore, banana waste would be, on average, three and half days old before being disposed at a municipal tip. In addition, household

food waste picked up at kerbside collections is frequently contained within plastic bags, further limiting the chance of immediate exposure at the tip. These factors, along with the frequent coverage of municipal tips, largely limit the opportunities for banana waste to be exposed to susceptible hosts at any municipal tip.

#### *Proximity of waste to banana plants*

The survey of LGA councils examined the occurrence of live banana plants close to municipal tips. Of 47 municipal tips surveyed in grower areas, 87% had no banana plants within one kilometre. Four percent of tips had banana plants growing at the tip itself (BA 2006c).

The likelihood of pests on banana waste being near suitable host plants at a tip is considered separately for each PRA, since it depends on the distance that pests can disperse.

Although LGA councils in other areas generally reported that they had no knowledge about the distance of banana plants from municipal tips, it is improbable that banana plants would occur within one kilometre of a tip located in these areas.

### **7.4.2 Uncontrolled consumer waste**

#### *Disposal practices*

The majority of uncontrolled consumer waste is disposed of as compost. The method of composting varies between households. Data suggests that 60–80% of households which compost food waste at home used closed systems such as worm farms, compost bins or tumblers. The remaining 20–40% of composted food waste most likely remains exposed – for example, in compost heaps. This information was considered in specific PRAs when determining the survival of pests and diseases and the likelihood of exposure of susceptible host plants to such pests and diseases.

Another disposal practice considered in individual PRAs is littering. It is estimated that between 1–5% of consumer waste is discarded as litter into non-household environments. These other environments incorporating plant communities include public parks, schools, sporting grounds and along roadsides, paths and agricultural land (including commercial banana plantations).

In this document, the term ‘consumer’ is used to include both residents and tourists. It is expected that tourists will have a different pattern of waste disposal than residents, as a greater proportion of their banana waste is most likely controlled waste and they will dispose of a greater proportion of uncontrolled waste in other plant communities rather than near household plants. Although many international and domestic tourists travel throughout Australia each year, their number must be expressed in terms of one year’s stay in order to compare them. For example, the 2.1 million international tourists who visit Queensland each year correspond to about 80,000 additional residents over a year. This is relatively small compared to about four million residents in grower areas. Hence, differences in waste disposal patterns by tourists were not considered further as they have only a minor impact on waste flows.

Uncontrolled consumer waste may be disposed of near banana plantations in various ways. These may include farm workers and tourists littering within a plantation and the general public discarding waste in the vicinity of plantations (for example, throwing it out of a car).

#### *Proximity of waste to banana and heliconia plants*

The number of farm workers in the banana industry is about 5000 full-time equivalents, which represent a proportion of  $2.50\text{E}-04$  of Australia’s population. Approximately 1000 tourists visit banana plantations each day. Assuming that one percent of farm workers and tourists dispose of banana waste outside controlled systems within a susceptible host plantation, the proportion of all uncontrolled consumer waste that might be discarded in banana plantations is  $3.00\text{E}-06$ . It was

considered that the proportion of the uncontrolled consumer waste discarded along a roadside that is located near a commercial banana plantation is  $2.50E-06$ .

For some PRAs, the proximity of banana waste to heliconia plants is also relevant. The heliconia nursery industry employs about 200 full-time equivalent staff. This increases the proportion of all uncontrolled consumer waste that might remain in banana and heliconia plantations to  $3.10E-06$ .

The proximity of uncontrolled consumer waste to banana and heliconia plants to home gardens and other plant communities is based on the information above and plant density data provided in Section 7.5.

### 7.4.3 Other uncontrolled waste

#### *Disposal practices*

Other uncontrolled waste is generated by wholesalers, retailers, food processors and food services. The waste will often be generated in bulk and in the process be substantially decomposed. It may be fed to livestock, used directly as organic mulch or disposed of in areas not subject to controlled waste management. The vast majority of uncontrolled waste generated by retailers is used for animal feed (BA 2006b).

The greater proportion of other uncontrolled banana fruit waste is disposed of in what is classified as 'other plant communities' (which can have wild or volunteer plants in farmland or bushland).

It is highly unlikely that such waste will be discarded close to commercial banana plantations, although it may be discarded near other commercial crops. A figure of  $1.00E-06$  was used for the proportion (in grower areas) of other uncontrolled waste that might be discarded near commercial banana plantations.

It was considered that 5% of other uncontrolled waste is discarded or used near households.

#### *Proximity of waste to banana plants*

The proximity of other uncontrolled waste to banana plants and other hosts is based on the plant density information provided in Section 7.5.

## 7.5 Density of banana and heliconia plants

In the quantitative PRAs, the density of banana plants in commercial and non-commercial situations must be considered in order to determine the likelihood that waste may be discarded in their proximity. Similarly, the planting density of heliconias is relevant to the reports on Moko and black Sigatoka and is discussed below. The densities of other susceptible hosts are relevant only to specific pests and are considered within individual PRAs. For example, several weed species are asymptomatic carrier hosts which support the survival of Moko and are discussed in Chapter 9.

When calculating the density of bananas and heliconia plants it was assumed that one mat of bananas is equivalent to one clump of heliconias.

### 7.5.1 Commercial banana plantations

Plant densities of bananas grown commercially in Australia range from 1100 mats per hectare for the cultivar Ladyfinger, to 2400 mats per hectare for Dwarf Cavendish. As the main commercial cultivar of Cavendish bananas, Williams, is grown at an average density of 2000 mats per hectare, a density of 200,000 mats per  $\text{km}^2$  was used in the model.

### 7.5.2 Bananas in home gardens

Banana plants in home gardens in grower areas are normally cultivated from single plants, with one or more suckers forming a mat (given that regular de-suckering is carried out); however, in unmanaged situations form clumps. In Queensland, state regulatory authorities permit up to 30 mats to be cultivated in household gardens, although it is rare for bananas to be cultivated to this extent without being regarded as commercial. Plants grown in other areas are generally less vigorous due to their sensitivity to cold and frost.

#### *Grower areas*

The percentage of home gardens containing banana plants differs between regions and between suburbs. A phone survey conducted in May 2005 (OGS 2005a) found that 6.7% of households in the Brisbane Statistical Division and 16.3% of households in the Far North Statistical Division had banana plants growing in the garden. Other assessments (BA 2002b) estimate that up to 25% of home gardens in old residential suburbs have a banana plant in the garden. However, in newer residential areas, banana plants are unlikely to occur in more than 1% of home gardens, probably because newer house blocks are smaller.

Based on the above information, it was estimated that between 7–11% of home gardens in grower areas contain banana plants. Allowing for variations in house block size and assuming that most home gardens have only one banana mat, this is equivalent to an average density of about 90–130 plants per km<sup>2</sup>.

#### *Other areas*

In the major cities of other areas, such as Melbourne and Perth, less than 1% of home gardens contain banana plants. The proportion of gardens in Sydney with banana plants varies between suburbs, but is estimated at 1–5% (BA 2002b). It is generally considered that few banana plants would be grown in other areas, as about 70–80% of gardens are prone to frost.

Using the end points of these two ranges, it was estimated that 0.2–1.5% of home gardens in other areas contain banana plants. This is equivalent to a range of 3–18 banana mats per km<sup>2</sup> in other areas.

### 7.5.3 Bananas in other plant communities

Bananas (such as feral, amenity or native plants) occur commonly in other plant communities (Section 5.4.1) in grower areas, but rarely in other areas.

#### *Feral plants*

Feral bananas mostly occur in association with abandoned plantation areas. However, some feral bananas may grow from rhizomes discarded by householders and occasionally through the dispersal of seed from illegally cultivated ornamental bananas, such as *M. velutina*, *M. ornata* and *Ensete ventricosum*. Regulatory authorities and industry organisations endeavour to remove feral bananas since they pose a risk of harbouring pests and diseases. However, many of these plants exist in regrowth forest areas that are not easily accessible. Other plants may be found adjacent to creeks and rivers as a result of plants being dumped or being carried by flood waters.

#### *Amenity plants*

The use of bananas as amenity plants is prohibited in grower areas except under permit for educational purposes in botanic gardens. Amenity banana plants are generally uncommon in other areas, as they are largely restricted to a small number of botanic gardens.

### *Native species*

Three native *Musa* species, *M. acuminata* subsp. *banksii* (Eumusa), *M. jackeyi* (Australimusa) and *M. fitzalanii* (Australimusa) occur in Australia. All of these are associated with isolated rainforest environments in tropical northern Australia (Ross 1987; Daniells 1991). *M. acuminata* subsp. *banksii* represents the most common of the native species, occurring in small and scattered populations between Ingham and Cape York, while the other two species have been described as extremely rare and extinct, respectively (Daniells 1991). Native *Musa* species occur in the banana grower areas but are not easily accessed as they are found in isolated rainforest environments.

### *Average plant density of bananas in other plant communities*

It was considered that the average density of banana plants growing in other plant communities in grower areas would be between one plant per km<sup>2</sup> and one plant per 10 km<sup>2</sup>. As mentioned in Section 7.5.1, a small number of municipal tips have bananas growing within their precincts.

Although there is little information on the distribution of feral bananas growing in other areas, they are considered to be almost non-existent. Any significant feral banana populations would be restricted to the coastal region between Sydney and the grower areas in New South Wales, and small areas in the north of the Northern Territory. Based on population density and area, it was estimated that such areas would make up about 5% of the readily accessible parts of other areas. The value for the density of feral bananas in grower areas (one plant per 10 km<sup>2</sup>) was used as the density in this restricted area, giving an overall average density of 0.005 plants per km<sup>2</sup> for other areas.

## **7.5.4 Commercial heliconia plantations**

Commercial heliconia nurseries (mainly for cut flowers) are present in grower areas, but not in other areas. In Australia, they are established in northern Queensland and around Darwin in the Northern Territory. The cut flower industry consists of about 35 growers in the Northern Territory, generating an annual value of about \$3 million (B Hoffmann, Leader of the Northern Territory Cut Flower Group, pers comm 15 March 2006) and about 40 growers in Northern Queensland, generating an annual value of \$1.5 million (C Adriaansen, General Manager, Plant Biosecurity, QDPIF, pers comm 14 March 2006). Heliconia plants are widely available to the public through nurseries in Australia's tropics and subtropics.

It was considered that the average density of heliconia clumps in commercial plantations is approximately 600,000 clumps per km<sup>2</sup>. In comparison, a density of 200,000 mats per km<sup>2</sup> was used in the model for banana plants in commercial plantations. However, given the much greater area under commercial banana production, the density of both hosts is still about 200,000 plants per km<sup>2</sup> in grower areas.

## **7.5.5 Heliconias in home gardens**

Heliconia species are popular garden specimens and are often planted in residential gardens in the same areas where bananas are grown commercially (grower areas). Few heliconias are grown in other areas.

Heliconias cultivated in Queensland home gardens have been estimated at 30% in the Cairns district and 20% in the city of Bundaberg (A Webb, President, Tropical Foliage Society, pers comm 26 April 2006). In south-east Queensland, estimates are 10% in the Sunshine Coast region and 0.4–5% in Brisbane (B Dunstan, Secretary, Heliconia Society International, pers comm 28 March 2006; R McKinnon, Curator in Charge, Brisbane Botanic Gardens, pers comm 26 April 2006).

It has also been estimated that heliconias are planted in 0.1% of home gardens in Sydney (B Dunstan, Secretary, Heliconia Society International, pers comm 28 March 2006). In Darwin, heliconias are

planted in about 5% of gardens (B Hoffmann, Leader of the Northern Territory Cut Flower Group, pers comm 15 March 2006). Up to 50% of home gardens in frost-free grower areas contain heliconias (Peasley 2006b) particularly the elevated areas close to the coast which might have high tourist and residential population density.

### *Grower areas*

Based on the above information, it was assumed that a similar proportion of home gardens in grower areas contained heliconia clumps as banana mats (7–11% of gardens) and that the average garden with heliconias in grower areas had three heliconia clumps. Therefore, approximately 360–520 banana mats and heliconia clumps are grown per square kilometre in home gardens in grower areas.

### *Other areas*

In other areas, it was assumed that there were approximately only 20% as many home gardens with heliconias as there were with banana plants and that the average garden with heliconias had two heliconia clumps. Therefore, when considering both types of plants, plant density is increased by about 40%. Given that the density of banana mats in home gardens is 3–18 per km<sup>2</sup>, the density of both banana mats and heliconia clumps is approximately 4.2–25.2 per km<sup>2</sup> in other areas.

## **7.5.6 Heliconias in other plant communities**

Heliconias rarely occur in environments such as public parks and landscape areas because of their maintenance requirements (D Warmington, Curator, Flecker Botanical Gardens, Cairns, pers comm 2 March 2006). They also are not common outside populated areas, most likely because they generally do not set seeds (Bailey Hortorium 1976; Sewake and Uchida 2005). In other plant communities in grower areas, it was estimated that approximately three times more clumps of heliconias grow than banana mats. As the average density of bananas in other plant communities is 0.1–1.0 per km<sup>2</sup>, approximately 0.4–4.0 heliconia clumps and banana mats are grown per square kilometre in grower areas. There are a negligible number of heliconias in other plant communities in other areas, and hence the average density of both banana mats and heliconia clumps is 0.005 per km<sup>2</sup>.

## **7.5.7 Summary of plant density of bananas and heliconias**

The density of banana plants grown in commercial plantations, home gardens and other plant communities is summarised in Table 7.6. This information is used in the quantitative PRAs when determining the probability of exposure to assess the likelihood that banana waste will be near to a host plant.

**Table 7.6 Average number of banana plants by exposure group in Australia**

Exposure group	Host group	Plant density (per sq km)	
		Grower areas	Other areas
Commercial plantations	Bananas only	200,000	Nil
	Bananas and heliconias	200,000	Nil
Home gardens	Bananas only	90–130	3–18
	Bananas and heliconias	360–520	4.2–25.2
Other plant communities	Bananas only	0.1–1	0.005
	Bananas and heliconias	0.4–4.0	0.005

## 8. Quarantine pests

This chapter describes the results of the pest categorisation and lists the species associated with banana plants and fruit in the Philippines. PRAs for all pests determined as needing further consideration using either quantitative or qualitative risk assessment methods are provided in Chapters 9–19.

### 8.1 Summary of pests categorised

In Part C of this report, 122 pests that could potentially be associated with bananas in the Philippines are categorised according to their presence or absence in Australia. The descriptions include information on their regulatory status (where applicable), their potential for being present on the pathway (associated with banana fruit), their potential for establishment and spread in Australia, and the potential consequences of their establishment and spread.

Table 8.1 gives the total number of pests that were categorised. The columns correspond to the six steps described in Chapter 4 that are needed to decide whether or not the pests:

- are known to be associated with bananas in the Philippines
- are absent, their presence in Australia is uncertain, or they are of regional concern
- have the potential for being on the pathway
- have the potential for establishment and spread
- have the potential for consequences
- are considered further in the risk assessment.

**Table 8.1 Summary of the results of the pest categorisation**

Groups	Associated with bananas in the Philippines	Not in Australia, uncertain or of regional concern	Potential for being on pathway (Likely)	Potential for establishment and spread (Feasible)	Potential for consequences (Significant)	No. of species to be considered further
<b>Arthropods</b>						
Insects	77	39	23	23	20	20
Mites	8	5	5	5	5	5
<b>Pathogens</b>						
Bacteria	2	1	1	1	1	1
Fungi	23	3	2	2	2	2
Viruses	6	3	3	3	3	3
<b>Nematodes</b>	6	0	0	0	0	0
<b>Total</b>	<b>122</b>	<b>51</b>	<b>34</b>	<b>34</b>	<b>31</b>	<b>31</b>

Results of the pest categorisation identified thirty-one pests, which includes six pathogens and twenty-five arthropod pests that should be considered further.

Six pathogens and seventeen of the twenty-five arthropods were identified as quarantine pests for all of Australia. The remaining eight arthropod pests are present in Australia but absent from Western Australia (Table 8.3).

One mealybug species, one mite species and four species of scales were considered further for Western Australia as part of the qualitative pest risk assessments for groups of pests. Two species of thrips were considered solely for Western Australia. Consignments of mature hard green bananas proposed for movement into Western Australia would be subjected to quarantine action if required, including treatment, destruction or re-export.

Molluscs and spiders are not pests of banana fruit, but are considered further in Section 8.3.

## 8.2 Pests to be considered further

Table 8.2 lists six pathogens and seventeen arthropod species that were identified for further consideration in separate pest risk analyses. Table 8.3 lists eight arthropod pests that are present in Australia, but absent from Western Australia. PRAs for these pests are presented in Chapters 9–19.

**Table 8.2 Pests of mature hard green Cavendish fruit considered further for the whole of Australia**

Common name	Scientific name
<b>Bacteria</b>	
Moko	<i>Ralstonia solanacearum</i> race 2 [Burkholderiales: Ralstoniaceae]
<b>Fungi</b>	
Freckle	<i>Guignardia musae</i> (Cavendish strain) [Dothideales: Mycosphaerellaceae]
Black Sigatoka	<i>Mycosphaerella fijiensis</i> [Dothideales: Mycosphaerellaceae]
<b>Viruses</b>	
Bract mosaic	<i>Banana bract mosaic virus</i> (Potyviridae)
Bunchy top	<i>Banana bunchy top virus</i> (Nanoviridae) Abacá bunchy top virus [Unassigned: Nanoviridae]
<b>Arthropods</b>	
Fruit flies	<i>Bactrocera occipitalis</i> [Diptera: Tephritidae] <i>Bactrocera philippinensis</i> [Diptera: Tephritidae]
Armoured scales	<i>Aspidiotus coryphae</i> [Hemiptera: Diaspididae] <i>Aspidiotus excisus</i> [Hemiptera: Diaspididae] <i>Pinnaspis musae</i> [Hemiptera: Diaspididae]
Mealybugs	<i>Dysmicoccus neobrevipes</i> [Hemiptera: Pseudococcidae] <i>Nipaecoccus nipae</i> [Hemiptera: Pseudococcidae] <i>Pseudococcus jackbeardsleyi</i> [Hemiptera: Pseudococcidae]
Spider mites	<i>Oligonychus orthius</i> [Prostigmata: Tetranychidae] <i>Oligonychus velascoi</i> [Prostigmata: Tetranychidae] <i>Raoiella indica</i> [Acari: Tenuipalpidae] <i>Tetranychus piercei</i> [Prostigmata: Tetranychidae]
Weevils	<i>Philicoptus demissus</i> [Coleoptera: Curculionidae] <i>Philicoptus iliganus</i> [Coleoptera: Curculionidae] <i>Philicoptus strigifrons</i> [Coleoptera: Curculionidae] <i>Philicoptus</i> sp. 1 [Coleoptera: Curculionidae] <i>Philicoptus</i> sp. 2 [Coleoptera: Curculionidae]



**Table 8.3 Pests of mature hard green Cavendish fruit considered further for Western Australia**

Common name	Scientific name
<b>Arthropods</b>	
Armoured scales	<i>Abgrallaspis cyanophylli</i> [Hemiptera: Diaspididae] <i>Hemiberlesia palmae</i> [Hemiptera: Diaspididae] <i>Pseudaulacaspis cockerelli</i> [Hemiptera: Diaspididae] <i>Selenaspis articulatus</i> [Hemiptera: Diaspididae]
Mealybugs	<i>Planococcus minor</i> [Hemiptera: Pseudococcidae]
Spider mites	<i>Tetranychus marianae</i> [Prostigmata: Tetranychidae]
Thrips	<i>Chaetanaphothrips signipennis</i> [Thysanoptera: Thripidae] <i>Elixothrips brevisetis</i> [Thysanoptera: Thripidae]

### Pathogens

Biosecurity Australia has not previously completed PRAs for the six pathogens which cause Moko, black Sigatoka, freckle, bract mosaic and two bunchy top diseases of bananas (refer to Table 8.2). On the basis of the present pest categorisation, the IRA team considered that it was appropriate to use a quantitative risk assessment method for these six pathogens.

The IRA team also considered the quarantine status of fusarium wilt or Panama disease (*Fusarium oxysporum* f. sp. *cubense*). It determined that the risk of entry, establishment and spread was minimal, taking into account the results of previous risk assessments (BA 2002d) and existing conditions for trade in bananas from areas where the disease is present. The minimal likelihood of occurrence of infected trash in banana shipments and the fact that Panama disease does not infect banana fruit are the key reasons for not conducting further assessment of this disease.

Soil is another pathway for the entry, establishment and spread of Panama disease, but the risk of contaminated soil occurring in banana shipments of commercially produced bananas is minimal and can be managed. Under the existing quarantine policy for contaminants of quarantine concern, if soil were to be detected in shipments during AQIS on arrival inspection (Section 7.2.6) it would be subject to action, including acceptable treatment, destruction or re-export of the affected shipment.

### Arthropods

Biosecurity Australia has previously assessed the unrestricted quarantine risk for the following groups of pests on other commodities:

- fruit flies
- scales
- mealybugs
- weevils
- thrips
- mites.

In order to facilitate access to information by stakeholders, and completeness of the document, qualitative risk analyses are presented in this report for fruit flies, scales, mealybugs, spider mites, weevils and thrips.

The analyses are accepted as ‘existing policy’ for these pests. There will be some differences in the probabilities of entry, establishment and spread for some pests in this document from those assessed in previous IRAs because they refer to different commodities. Also there may be differences in host preferences and differences in plant structure which will influence infestation sites on the fruit. These

differences translate into different likelihoods for importation and subsequently for entry, establishment and spread.

### **8.3 Contaminant pests**

Contaminants include organisms that are not pests of bananas, but may enter Australia in shipments of bananas.

The revised draft IRA report (BA 2004) identified a range of potential contaminants of Philippine bananas, including:

- amphibians (for example, frogs and toads)
- arthropods (for example, spiders and ants)
- mammals (for example, rats, mice and bats)
- molluscs (for example, snails)
- reptiles (for example, snakes and lizards)
- weeds.

These pests have not been subjected to further detailed assessment in this report as they are not pests of mature hard green Cavendish bananas. If they were to be detected in shipments of bananas, they would be subject to action under existing quarantine policy for contaminants of quarantine concern. This includes treatment, destruction or re-export of the affected shipment.

Commodities currently imported from the Philippines for which similar contaminant pests could be an issue include pineapples and mangoes. For more detailed information on these commodities the reader is directed to the AQIS Import Conditions database<sup>5</sup>. Risk mitigation measures for contaminant pests are covered in this report in the sections on risk management and draft operational framework.

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<sup>5</sup> [www.aqis.gov.au/icon](http://www.aqis.gov.au/icon)

## 9. Moko

### 9.1 Introduction

Moko is a vascular wilt disease of bananas caused by the bacterium *Ralstonia solanacearum* race 2. Moko disease affecting bananas and bacterial wilt disease affecting heliconias are caused by the same bacterium, *Ralstonia solanacearum* race 2. For ease of understanding in this pest risk analysis, ‘Moko’ is used to refer to both diseases.

Moko occurs in tropical regions of 20 countries in Central and South America, the Caribbean, India and the Philippines (Lehmann-Danzinger 1987; Black and Delbeke 1991; ProMed 2004; Fegan 2005). Moko is also known as Bugtok disease of cooking bananas in the Philippines (Hayward 2007).

*Ralstonia solanacearum* race 2 has several close relatives that are present in Australia:

*R. solanacearum* race 1, which occurs on a wide variety of hosts, including *Musa* species (bananas and plantains) (Akiew 1992) and *Heliconia* species (Diatloff et al 1992) and *R. solanacearum* race 3, which is specific to potato and some weed species (Hayward 2000). This pest risk analysis focuses explicitly on *R. solanacearum* race 2.

*Ralstonia solanacearum* race 2 was eradicated from the Cairns region after an outbreak caused by the importation of infected *Heliconia* rhizomes from Hawaii in 1989 (Hyde et al 1992). Following the eradication program Moko is considered not to be present in Australia.

Ferreira et al (1991) reported the occurrence of Moko disease on *Heliconia* in Hawaii. A total of 17 isolates were compared in pathogenicity on *Heliconia*, tomato and banana. Five of the isolates were pathogenic to banana, indicating that there is pathogenic variability in isolates from this host and potential to cause infection on banana. Although Moko disease has been present in *Heliconia* in Hawaii for about 20 years there are no reports of Moko disease in banana in commercial plantations on the big island of Hawaii on which both the cut flower and dessert banana production are concentrated. One possible mechanism of transmission of the Moko bacterium to commercial banana production would be by insects. There is no evidence that this has occurred (refer to Part C, Moko datasheet).

### 9.2 Biology

#### 9.2.1 Species description and host plant association

All diploid, triploid and tetraploid *Musa* species are considered Moko hosts (Buddenhagen 1961; Stover 1993; Soguilon et al 1995; Thwaites et al 2000) as are all species of *Heliconia* (Buddenhagen 1960, 1961; Sequeira and Averre 1961; Kastelein and Gangadin 1984; Ferreira et al 1991; Assis et al 2005). Three diploid *Musa* species, *M. fitzalanii*, *M. jackeyi*, and *M. acuminata* subsp. *banksii*, are endemic to Australia and grow in isolated rainforest environments in tropical northern Australia (Ross 1987; Daniells 1991). *Musa fitzalanii* and *M. jackeyi* are listed on the World Conservation Monitoring Centre website<sup>6</sup> as extinct and rare, respectively. *Musa acuminata* subsp. *banksii* is the most common of the native species, and small and scattered populations are found between Ingham and Cape York (Daniells 1991).

Moko has also been reported in association with a range of other plant species, considered predominantly as weeds, where visible symptoms are either absent or suppressed (Belalcazar et al 1968; Berg 1971; Granada 2002).

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<sup>6</sup> <http://www.unep-wcmc.org.index.html>

Asymptomatic hosts of Moko belong to a range of plant families including the Solanaceae, Asteraceae and Brassicaceae (Belalcazar et al 1968; Berg 1971; Granada 2002; BPI 2002b). Many weed species that could host Moko are widespread in Australia (Hnatiuk 1990) including *Solanum nigrum* (blackberry nightshade), *Solanum torvum* (devil's fig), *Datura stramonium* (thorn apple), *Brassica campestris* (field mustard) (Belalcazar et al 1968; Berg 1971; Granada 2002) and *Bidens pilosa* (cobbler's-pegs) (Granada 2002). These species grow opportunistically in disturbed soil, including commercial banana plantations, home gardens and along roadsides (Hussey et al 1997; Lazarides et al 1997; Parsons and Cuthbertson 2001; Peasley 2006a).

The potential host range of Moko in Australia is unknown. *Ralstonia solanacearum* attacks a diverse group of plant species including many important economic and ornamental plants as well as several weed species (Kelman 1953; Hayward 1991). The number of hosts infected by all strains of this pathogen exceed 300 plant species worldwide (Bradbury 1986). Alvarez et al (2008) have used histological studies to determine three categories of host plants based on xylem colonisation; (1) susceptible hosts (2) tolerant hosts and (3) non-hosts. The first two categories include plants infected by high densities of the pathogen in xylem vessels at the root level. Invasion of xylem at the middle part of the stem is heavy in susceptible plants and strongly limited in tolerant plants. Bittersweet nightshade (*Solanum dulcamara*) is a symptomless carrier of some potato strains of *R. solanacearum* and therefore a tolerant host, although wilting has been occasionally reported. The third category refers to non-host plants and includes species in which no xylem invasion was observed, though some external contamination of the rhizoplane and rare cortical infection pockets may occur (refer to Part C, Moko datasheet, *Hosts*).

## 9.2.2 Disease symptoms

Under field conditions, *Musa* species and *Heliconia* species infected with Moko exhibit externally visible symptoms in the form of moderate to severe wilt, depending on host genotype, pathogen strain and environmental conditions (Buddenhagen 1960, 1961; Sequeira and Averre 1961; Sequeira 1962; Stover 1972; Woods 1984; Lehmann-Danzinger 1987; Diatloff et al 1992; Molina 1996; Fegan 2002; Fegan and Prior 2005).

Typical of bacteria belonging to the *R. solanacearum* complex, Moko causes systemic infection of the xylem vessels of its hosts. This leads to wilting and necrosis of the younger leaves followed by plant death. Within hosts, large numbers of bacteria are concentrated in the primary and secondary xylem vessels, with some colonisation of the intercellular spaces, and some leakage into the adjacent parenchyma cells. Within the xylem vessels, the pathogen alters water movement as a result of blockage of the vascular system which, amongst other symptoms, may result in dry rot of fruit. Symptom expression in *Musa* and *Heliconia* species is generally rapid under ideal conditions but can also be delayed for some months (Stover 1972; Thwaites et al 2000).

Asymptomatic hosts infected with Moko can appear healthy, although they often have discoloured vascular tissue within roots and stems (Berg 1971). While Moko bacteria are known to colonise the rhizosphere of asymptomatic hosts, vascular discolouration is also indicative of colonisation of the vascular system. Nevertheless, it is considered that colonisation by the pathogen of such asymptomatic hosts is generally not at a sufficient level to induce visible wilt symptoms. Visible symptoms are, at most, subtle under natural conditions (Belalcazar et al 1968; Berg 1971; Granada 2002). However, external symptoms have been observed after artificial inoculation and incubation under favourable environmental conditions (Belalcazar et al 1968; Berg 1971).

### 9.2.3 Dispersal mechanisms

The Moko pathogen can be dispersed by various methods, including:

- movement of plant material
- equipment (machetes, cutting/slashing machinery and similar)
- insects
- soil and water.

The primary method of dispersing Moko is through the movement of infected plant material. Examples of local and international dispersal of Moko have been associated with the movement of plant material such as banana corms from Central America to the Caribbean and to the Philippines, and on heliconia rhizomes within Central America and the Caribbean, and from Hawaii to Australia and India (Hayward 2000).

In areas where the Moko pathogen occurs, the most common means of spread is through the use of contaminated tools by plantation labourers (Sequeira 1958; Stover 1972; Buddenhagen 1986; Black and Delbeke 1991; Fucikovsky and Santos 1992). A study from Taiwan shows that the incidence of bacterial wilt (race 1) in perilla plants (Lamiaceae) grown in monoculture increased during a growing season due to the harvesting of the new growth by mechanical means (Hsu et al 1993). This suggests that Moko disease could also be spread by mowing or cutting infected asymptomatic carrier hosts, which include weed species such as *S. nigrum*, *S. torvum*, *D. stramonium* and *B. pilosa*.

Fifty species of insect have been collected from the inflorescences of Moko diseased banana plants (Buddenhagen and Elsasser 1962). Of the species known to visit inflorescences, only bees, wasps and thrips have been confirmed to disperse Moko by coming into contact with Moko bacteria oozing from open plant wounds such as fresh bract and flower scars while foraging (Buddenhagen and Elsasser 1962; Kenyon 1997). Many insect species including many genera of flies, (including *Drosophila* spp.) are also considered to be involved in the transmission of Moko (Buddenhagen & Kelman 1964; Buddenhagen 2006). Insect transmission is more likely in banana cultivars that have *Musa balbisiana* (B) as a parent due to the attraction of insects to the high sugar content in the nectars of male flowers in these cultivars (Setyobudi and Hermanto 2000). Cultivars that have *M. balbisiana* as a parent include Bluggoe (ABB) in Central and South America and Saba (ABB) and Cardaba (BBB) in the Philippines (Soguilon et al 1995; Jones 2000). In Cavendish plantations, the removal of the male flower bud after emergence of the last female hand is considered to decrease insect visits and limit the spread of the bacterium (Buddenhagen and Elsasser 1962; Stover 1972; Molina 1996; Setyobudi and Hermanto 2000). While studies on inter/intra host transmission are not comprehensive, a number of reports suggest that insect transmission within heliconias or between heliconias and bananas does not occur (Buddenhagen and Elsasser 1962; Stover and Richardson 1968; Buddenhagen 1994).

Moko disease is caused by a variety of *R. solanacearum* race 2 strains (see Table 1.2 in Denny 2006). The SFR and A strains of *R. solanacearum* race 2 are closely associated with insect vectors and the rapid spread of Moko disease in Honduras (Buddenhagen & Elsasser 1962; Buddenhagen & Kelman 1964) and other countries in Central and South America (Denny 2006). The strain of *R. solanacearum* race 2 in the Philippines belongs to the B strain that is mainly soil transmitted and infrequently transmitted by insects because infected plants exude relatively little bacterial ooze (Denny 2006). B strains are not associated with the rapid dispersal of Moko in Central America (Buddenhagen & Kelman 1964). It would be expected that banana waste would contain relatively low levels of bacteria by comparison with infected live plants. Considering the low numbers of Moko bacteria in banana waste and the particular strain of Moko present in the Philippines, the probability of insect dispersal from banana waste is expected to be limited.

The movement of Moko bacteria into soil from discarded fruit waste is dependent on the presence of free water in the soil (Satou et al 2006) and the release of bacteria from vascular tissue exposed through damage, trampling or decomposition.

Soil from Moko infested banana plantations has been shown to be infectious when smeared directly on fresh wounds (Sequeira 1958). However, the factors affecting the dispersal of Moko bacteria in soil are complex. A variety of inter-related factors are involved in the survival and movement of bacteria in soil, including soil structure, soil composition and the presence of free water (van Veen et al 1997; Garbeva et al 2004; Satou et al 2006). Wardlaw (1972) reported that under field conditions, the spread of the Moko pathogen in soil from diseased mats to surrounding healthy mats is slow as the pathogen spreads to one or at most two neighbouring plants during the course of one year. However, it is likely that in situations where there is a higher level of mechanisation the rate of spread could be accelerated.

#### 9.2.4 Survival

Moko disease occurs in tropical regions characterised by a relatively even temperature and consistent rainfall or irrigation throughout the year (Hayward 2000). However, in subtropical regions it is expected that the bacterium would survive when climatic conditions are suitable. No definitive studies could be found that show how temperature affects the survival of Moko bacteria in the field. There are no data on temperature relations of Moko strains of *R. solanacearum*. However, the optimum population growth temperature for *R. solanacearum* race 3, based on laboratory experiments, is about 32–35 °C and the maximum about 37 °C (Kelman 1953; Jeger et al 1995). The minimum population growth temperature for Moko bacteria is not known but the related, cool adapted strain of *R. solanacearum* biovar 2/race 3 (potato brown rot) has a minimum population growth temperature of between 8–10 °C (Moraes 1947 as cited in Kelman 1953).

The ability of the Moko bacterium to survive in discarded imported banana fruit waste or peel and to enter the soil maintains a pathway for Moko disease to enter, establish and spread in Australia. The related strain, *R. solanacearum* biovar 2/race 3 has been recorded as being introduced into Europe by infected potato waste (Olsson 1976).

The survival characteristics of Moko bacteria in fruit and waste peel above ground and in the soil are discussed below.

##### *Survival in banana fruit and waste*

In banana fruit Moko bacteria occur within the vascular bundles beneath the skin. These bundles are concentrated at the cushion and flower end of fruit. Soguilon (2003a) reported that the highest concentration of Moko bacteria in asymptomatic Moko-infected Cavendish fruit is in the cushion tissue where the vascular strands converge (refer to Part C, Moko datasheet, *Location of bacteria*).

Bacterial wilt infected plants that show visible symptoms have been reported to contain about  $10^8$ – $10^{10}$  bacterial cells per gram of tissue or more (Grimault et al 1994; Hayward 2000; Pradhanang et al 2000). For example, when tomato or other susceptible host plants express wilt symptoms, this is accompanied by browning of the vascular tissue. Cutting visibly infected plants, or submerging portions of brown vascular tissue in clear water always shows bacterial ooze (Kelman 1953; Wardlaw 1972). If bacterial ooze is visible from stem sections from wilted plants, then the concentration of bacteria in the stem tissue is likely to be within the range of concentrations given above (that is,  $10^8$ – $10^{10}$  bacterial cells per gram of tissue or more). If no ooze is visible, then bacterial concentrations are likely to be lower. For example, Pradhanang et al (2000) provided several examples of weed species in which bacteria could be cultivated in the extracts from macerated stem tissue that contained less than  $10^7$  bacterial cells per gram of tissue. None of the stem tissue showed visible bacterial ooze when suspended in clear water.

The IRA team considered that the concentration of bacteria present in asymptomatic fruit is likely to be from very low numbers of cells to  $10^8$  bacterial cells/grams of tissue, and on average would not exceed  $10^6$  bacterial cells/grams of tissue. Independent advice from C Hayward (Bacteriologist, consultant, pers comm., 20 September 2006) supported these values.

While fruit is intact, bacteria would most likely remain viable, as they are protected from prevailing physical and biological factors including the effects of temperature, radiation, and competing and predatory micro-organisms. However, post harvest banana fruit will be subject to water loss and as fruit decomposes the activity of antagonistic microbiota increases (Kelman 1953), and the viability of bacterial cells is likely to decline. The implications of these factors on the population growth and survival of Moko bacteria are discussed below.

Several factors affect the potential for survival and population growth of *R. solanacearum* in fruit after harvest. The most important of these are temperature and water availability.

The temperatures relevant to the importation of banana fruit and the survival and population growth of *R. solanacearum* include those that are present in the Philippines and Australian environments (Part C, Appendix 2, Figure 2.1 and Figure 2.2 respectively), during transport and ripening.

Fruit transported from the Philippines and stored in Australia would be held at temperatures between 13–14 °C only. Minimal bacterial population growth would be expected as the temperature range only marginally exceeds the minimum temperature required by the Moko bacteria to grow. Bacterial numbers are likely to increase in intact fruit held at ambient temperatures exceeding this range if other factors are not limiting. For example, the relative growth rate at 25 °C, estimated from *in vitro* research, is about 50% of that observed at the optimum temperatures of 32–35 °C (refer to Part C, Moko datasheet, *Effect of temperature on the growth of R. solanacearum race 2*).

Water available for bacteria is another critical factor for reproductive growth of the Moko pathogen as it is extremely sensitive to drying out (desiccation) (Kelman 1953). After the banana bunches are severed from the transpiration stream, water content in fruit peel and cushion will decline due to evaporation losses from the skin (Imsabai et al 2006; Saengpook et al 2007). Water availability is typically measured as water potential on a negative scale starting at zero using the unit of mega Pascal (MPa). The water potential that Moko bacteria are normally exposed to in banana plants is close to zero, and even under extreme moisture deficit banana plants maintain a water potential of –0.35 MPa in their leaves (Kallarackal et al 1990). In contrast, the osmotic potential of the peel in detached whole ripe banana fruit is in the order of –0.62 to –1.49 MPa (Stratton and von Loesecke 1931; Fukushima et al. 1980). Based on these data, the water potential of the peel is estimated to be –0.7 MPa (David Turner, Associate Professor, Plant physiologist consultant, pers comm., 25 June 2008).

The population growth of Moko bacteria in fresh green bananas after harvest is very unlikely because of low temperatures and decreasing water potentials will adversely affect survival during the period after harvest and before disposal as waste (refer to Part C, Moko datasheet, *Growth and survival of R. solanacearum race 2 in banana fruit*).

Once banana fruit is disposed of as waste the available nutrients will gradually diminish as tissue decomposes. Similarly, the ability of Moko bacteria to survive in the waste will decrease. The rate of decomposition will depend on a range of physical and biological factors in the environment. For example, under dry conditions, the banana waste disposed of in the environment will be subjected to further rapid water loss causing sharply decreased water potentials. This would adversely affect the survival of Moko bacteria that has a low resistance to drying out (Kelman 1953).

Under wet conditions, that could prolong the survival of Moko bacteria, re-hydration of the banana waste will occur and bacteria will diffuse and wash to the surface and into the soil. In the longer term, it is doubtful whether the physiological state of the pathogen would enable it to compete with a diverse range of fast growing saprophytic micro-organisms that are adapted to the colonisation of waste material. Kelman (1953) has documented many examples of where *R. solanacearum* under ideal culture conditions fail to compete and survive against a range of soil and saprophytic micro-organisms. In inoculation experiments, *R. solanacearum* was out competed by the secondary micro-organisms if they were present in the cultures (Kelman 1953).

In contrast to the likely competitive ability of the Moko pathogen in banana waste, Greene and Goos (1963) have reported the development of rot and mould causing organisms in freshly cut crown surfaces of banana hands, a condition referred to as crown rot and a wide variety of fungi have been frequently isolated. All the fungi associated with crown rot of bananas as reported by Greene and Goos (1963) are recorded present in Australia (Rippon 1972; APPD 2008). It is possible that these fungi can contaminate the cut surface from inoculum present on the fruit in the field or on arrival in Australia. Similarly, a high incidence of crown rot, caused by several fungal genera, has been detected on bananas grown without the use of chemicals in the Philippines (de Lapeyre de Bellaire and Mourichon 1997; Alvindia et al 2002). These authors have demonstrated from artificial inoculation experiments that several fungi or a mixture of fungi were capable of causing rots in banana crowns/cushions. In general, activity of all the pathogens causing rots was retarded at lower temperatures (14.4 °C) and enhanced at higher temperatures (23.9 °C), with moderate to severe rotting of tissue within 6 days after inoculation. Therefore, it can be assumed that many of the fungi shown above and other micro-organisms present in the soil would assist in the decay of banana cushions discarded as waste within a short period.

In summary, the Moko pathogen in banana waste would not be competitive because of its attenuated state after importation, relatively slow population growth rate, lack of nutritional versatility and inability to cope with the stresses of exposure to solar radiation, desiccation and moderately high temperatures where it is likely to be restricted to the vascular tissue of the waste in dry conditions. In compost, the heat generated by micro-organism metabolism will kill low numbers of Moko bacteria in hours. Under wet conditions that favour saprophytes, the competition from a diverse microbial community growing in banana waste is likely to include members that produce lytic enzymes and antibiotic substances harmful to the Moko pathogen. Taking these factors into consideration, the survival of the Moko pathogen in banana waste will be limited to a very short period of time.

On balance, the IRA team considered that conditions related to the wide range of limiting factors, including physical (water potential, radiation, heat stress) and biological (competition from saprophytes, exposure to lytic enzymes and antibiotic substances), would be such that bacteria within waste would rapidly decline. The IRA team judged that any bacteria within waste would not survive for any more than five days.

### *Survival in soil*

Generally, Moko bacteria enter the soil by exuding from infected roots of host plants. These may be in close proximity to or intermingled with roots of other hosts (Kelman and Sequeira 1965; Schell 2000; Swanson et al 2005). Moko bacteria could enter the soil from infected fruit waste (with an average concentration of  $10^6$  cells/grams of tissue at harvest) that has been discarded. For this to occur free water would need to be available for the re-hydration of banana waste and bacteria would need to diffuse and wash to the surface of the waste and into the soil. Survival of the bacteria in soil will depend on the physical and biological status of the soil environment. Van Veen et al (1997) highlight the difficulty of introducing new species of bacteria into soil due to the scarcity of available nutrients, and competition and predation by other microbes. However, it is known that the Moko bacterium, although referred to as a poor competitor in soil (Sequeira 1998), will survive in the nutrient-rich rhizosphere of the host as well as non-host plant species and invade their roots (Granada and Sequeira 1983; and refer to Part C, Moko datasheet, *Survival in Soil*).

In association with suitable hosts, Moko bacteria, once established, can occur in a wide variety of soil types (Kelman 1953; Stover and Simmonds 1985). The bacterium can survive in soil in the rhizosphere of hosts and non-hosts for up to two years (Granada and Sequeira 1983). Survival for more than two years depends on the ability of the bacterium to infect the roots of suitable hosts, as all Moko bacteria populations decline over time in the absence of hosts (Granada and Sequeira 1983).



### 9.2.5 Risk scenarios

Risk scenarios that are considered relevant to the entry, establishment and spread of Moko disease as a result of importing bananas from the Philippines relate to the successful transfer of Moko bacteria from infected banana fruit waste to suitable host plants.

The following four scenarios were considered the most likely means by which the transfer of Moko bacteria from infected waste to a host could occur:

- A Insects – transfer of Moko bacteria by insects from banana waste to host plants.
- B Leaching – transfer of Moko bacteria in free water (including irrigation and floodwater) from banana waste through soil to host plants.
- C Movement of machinery, vehicles and implements – transfer of Moko bacteria by vehicles and implements from banana waste to host plants.
- D Cutting, mowing and slashing – transfer of Moko bacteria by mowing, cutting and slashing that carries bacteria from banana waste to asymptomatic host plants.

Each of these scenarios is considered in detail in later sections that deal initially with the probabilities of exposure of host plants to infection by Moko and subsequently the establishment and spread of Moko in the endangered area.

#### *Scenario A – Transfer by insects*

This scenario considers the sequence of events that needs to occur for any insect species to transfer Moko bacteria from discarded waste to susceptible host plants that subsequently become infected. Initially insects would need to take up an infective dose of bacteria from the waste, then move to a host plant and subsequently transfer the bacteria to the plant in such a way as to initiate an infection. Insects with diverse feeding habits, including browsing, chewing and sucking, could potentially be involved with this scenario.

Invertebrate groups associated with waste plant material, particularly the complex polysaccharides that can take many weeks to decompose, will have the life-history and opportunity to visit banana waste. Detritivores (animals that feed on waste material) constitute the majority of the invertebrates in most environments and provide a key role in organic matter turnover (Paoletti et al 2007). Detritivores are diverse in taxa and include isopods, amphipods, millipedes, oribatid mites, dipteran larvae, earthworms and collembolans. Detritivores influence decomposition rates directly by shredding organic matter as they feed on it and indirectly by producing faecal pellets that enhance the activity of bacterial and fungal colonisers that metabolise organic matter (Paoletti et al 2007). Other functional groups likely to visit banana waste are foragers and include the numerically abundant cockroaches and ants (CSIRO 1991).

Given the primarily flightless habit and restricted territorial range of detritivores and foragers that are likely to visit banana waste, any inoculum that adheres to these insect groups will be lost quickly due to their frequent contact with the substrate they move across. Their role in the transmission of bacteria is a negative one as they will remove bacteria from banana waste that would have been available for insect vectors.

Browsing insects are the vectors most likely to come into contact with Moko bacteria due to their abundance and attraction to banana waste. For bacteria from discarded waste to come into contact with browsing insects, bacteria would need to be on the surface of the fruit. In dry conditions, this could occur when the skin of the banana is peeled from the fruit and in that process vascular strands are damaged, and vascular fluid containing bacteria are forced to the surface of the waste. In wet conditions, that allow banana waste to re-hydrate, bacteria will diffuse from the peel. Since vascular fluid with bacteria could only be exposed for short periods of time, the availability of bacteria for insect vectors will be limited. The newly exposed bacteria will then survive for a short time due to their weakened state and intolerance to a range of environmental conditions (refer to Part C, Moko

datasheet, *Survival in the environment*). If vascular fluid is available, when insects browse on the waste surface, bacteria would need to adhere to the external surface of the insects. Subsequently, an insect would need to move to a host plant and transfer the bacteria to a suitable site on the plant to initiate an infection. Fresh wounds resulting from damage to the plant, or exposed tissue resulting from dehiscing bracts or flowers, would provide suitable points of entry for Moko bacteria though insect transmission has only been proved via dehiscing flower bracts.

Chewing insects could damage vascular tissue more generally over the surface of the fruit waste exposing vascular fluid containing bacteria, which in turn could adhere to the external surface of insects. Subsequently, the insect would need to move to a host plant and transfer the bacteria to a suitable site on the plant to initiate an infection. Unlike browsing insects, chewing insects would not be reliant on natural wounds to find a suitable entry point.

A third category, sucking insects, could also take up Moko bacteria from infected fruit waste and transfer it to host plants (for more detail on transfer by insects refer to Part C, Moko datasheet, *Insect transmission*).

### ***Scenario B – Transfer by leaching***

This scenario considers the sequence of events that needs to occur for Moko bacteria to be released from discarded waste into the soil, to then be leached through the soil by free water and finally be brought into contact with roots of host plants resulting in infection.

The essential first step in this scenario is the release of Moko bacteria from infected waste. As in the previous scenario, this could occur when the skin of a banana fruit is damaged by, for example, peeling of the fruit and in that process vascular strands are damaged. Bacteria on the surface of the waste could then be transported in rain water or irrigation water. In the presence of free water, re-hydration of the banana waste will occur and bacteria will diffuse from the peel and eventually the bacteria would soak into soil and could encounter the root system of a suitable host. Root development by branching and extension provides entry points for the bacteria to infect host plants. Waste could also be discarded in bodies of water or waterways and release bacteria that could similarly come into contact with host plants.

### ***Scenario C – Transfer by movement of machinery, vehicles and implements***

This scenario considers the sequence of events whereby discarded banana waste would be physically compressed against a host plant, forcing bacteria to be exuded from the waste and at the same time damaging the host plant by providing entry points for infection.

This scenario is particularly relevant to the highly mechanised banana plantations in Australia where machinery and vehicle traffic is continuous and intensive and where various implements (such as tractors, 4 wheel drive quad bikes, harvesting trailers, bagging machines and spray equipment) are used in day-to-day management of the plantations. Predominantly, this scenario involves the transfer of bacteria to roots damaged by tyres. However, to a lesser extent it could involve other diverse situations such as foot traffic, foraging animals and movement of ladders and props.

### ***Scenario D – Transfer by cutting, mowing and slashing***

This scenario considers the sequence of events whereby Moko bacteria could be transferred from discarded banana waste to host plants by mowers or slashing machines.

This scenario is particularly relevant to the transfer of Moko bacteria to asymptomatic weed hosts growing in areas subject to cutting, mowing or slashing. Banana waste discarded in such areas could be cut by the blades of various machines providing an opportunity for bacteria to be forced from the waste and contaminate surfaces of the cutting or slashing blades. In turn, with successive revolutions of the blades, bacteria could be deposited on freshly cut surfaces of host plants. Such a situation would

be analogous to the most common means of transmission between plants in plantations linked to field workers using contaminated tools (Stover 1972; Buddenhagen 1986; Black and Delbeke 1991; Fucikovsky and Santos 1992).

The most vulnerable areas for transfer by such means include managed recreation areas, parklands and roadside verges where potential asymptomatic weed species are a dominant component of the plant communities and are subject to routine mowing by local government councils. However, other situations could also be important, including lawns in home gardens and traffic ways in banana plantations.

The choice of equipment that would be used depends on the work to be done. For covering extensive areas, large slashers are used by councils to reduce the fire hazards along roadsides and large cylinder mowers are used in parks and gardens. Cylinder mowers, rotary mowers, slashers, whipper snippers and brush cutters would be used within plantations and home gardens.

### 9.3 Importation

The importation stage begins with the sourcing of mature hard green banana fruit from plantations in the Philippines and ends when the imported fruit is released at the Australian border. It is analysed in eight steps, as described in Section 5.2. This section provides evidence supporting the likelihood assessments for each step.

#### 9.3.1 The proportion of plantations where the pest is present

*Imp1: The proportion of banana plantations where Moko is present is 1.*

This step estimates the proportion of banana plantations that are infested with Moko. Survey results from weekly inspections of banana plantations in the Philippines demonstrate that Moko is present year round in commercial Cavendish plantations throughout the island of Mindanao from where export bananas are to be sourced (BPI 2002a, 2002b). The pathogen has also been reported from highland plantations of Cavendish bananas in Bukidnon province (Raymundo and Ilagan 1999; Philippines Scientific Delegation 2002). There is no scientific literature that indicates that any banana growing areas of Mindanao are free of Moko.

Imp1 was therefore assessed as 1.

#### 9.3.2 Incidence of Moko within an infected plantation

*Imp2: The proportion of clusters of bananas sourced from infected plantations that are actually infected with Moko at harvest has a Uniform distribution with a range of 1.00E-05 to 1.00E-03.*

This step estimates the proportion of clusters infected at the time of harvest. Since plants (including bunches of fruit) that express symptoms would be destroyed soon after visible symptoms of wilt disease were detected (PBGEA 2004), infected clusters would only be harvested from infected plants on which symptoms have not been detected. Additionally, the proportion of infected plants that bear infected bunches at the time of harvest is also considered.

The proportion of infected clusters at the time of harvest depends on five factors:

- the proportion of plants detected with Moko symptoms each week
- the number of infected plants removed when symptoms are detected
- plant density (plants/hectare)
- the number of weeks elapsed from the time of infection until symptoms are detected
- the proportion of clusters that are infected in a bunch from an infected plant.

These five values were considered when determining the proportion of harvested clusters that may be infected.

The report has utilised the data on the prevalence of Moko in plantations provided by the Philippines Department of Agriculture for the period 1998 to 2001. Biosecurity Australia recognises that the data set on disease prevalence is only for a short period and that it does not differentiate between plantations in the proposed export area and other geographic areas. Biosecurity Australia has continued to seek more technical information on this issue. However, several previous requests to Philippine authorities to provide more data have been unsuccessful.

In accordance with the guidelines provided in the ISPM 2, *Framework for Pest Risk Analysis* (2007), this report documents the uncertainties, for purposes of transparency, and the rating assigned for Imp2 has taken into account the uncertainties when conducting the risk assessment.

The proportion of plants detected with Moko symptoms each week provides an indication of the rate at which new infections are occurring. Statistics provided by BPI (2002b) indicate that an average of 0.708 Moko cases were detected per hectare in export Cavendish plantations in the four years from 1998–2001. This equates to an average of 1.36E–02 cases per hectare per week. Some stakeholders have commented that Moko disease may be more prevalent in the Philippines than indicated by the average value reported by BPI (2002b). Data presented in Part C, Moko datasheet, *Incidence of Moko disease in the Philippines* indicate that there was a six-fold difference in the minimum and maximum four-week infection rates from 1998–2001. More disease incidences were evident in 2000–2001 than in 1998–1999 and there was evidence of an annual trend in the prevalence of Moko.

The issue of the upward trend in disease incidence from 1998–2001 has two possible explanations. There may be unrecognised asymptomatic carrier hosts in the Philippines which are acting as reservoirs of inoculum. A second possibility is that the eradication program for Moko in the field is inefficient and that pockets of infection may remain in the soil.

The data presented by BPI (2001) do not differentiate between plantations in the proposed export area or Cavendish banana plantations in other areas in the Philippines, nor do they identify the proportion or numbers of plantations involved in the survey. No data have been provided on the number of infected plants amongst the apparently healthy, neighbouring plants removed when disease symptoms are detected.

Each case reported by BPI (2002b) represents the removal of one diseased plant and at least six neighbouring plants. This sanitation measure indicates that one to two of these additional plants are also likely to be infected with the Moko bacterium. The prevalence reported by BPI (2002a) has therefore been increased by a factor of two to three to estimate the total number of infected plants per hectare.

Plant density allows the above estimates of disease prevalence to be converted to a proportion of infected plants amongst all plants in the plantation. Under Philippine conditions, plant densities may vary from 1700–2400 per hectare but are most commonly about 2000 per hectare (BPI 2002b).

The proportion of infected plants that remain undetected at any weekly harvest is also affected by the time between infection and appearance of disease symptoms (the incubation period) and the time between visible symptom expression and detection of the disease by inspectors (the detection period).

The incubation period of Moko disease depends on the infection site on the plant and the method of inoculation. For example, 40% of mats showed symptoms after 70 days and 60% of mats within

90 days when plants were pruned with contaminated machetes in Honduras (Stover 1972). In contrast, the spread of infection throughout the plant is more rapid in young, actively growing plants, which generally express symptoms within 2–4 weeks (Buddenhagen 1961, 1994), compared to mature plants where the bacterium moves slowly (Sequeira 1958). Woods (1984) reported that symptom development may be delayed until 8–24 weeks or more after inoculation. This was based on bacterial suspension being poured over the cut stub of the fourth newest leaf of young, actively growing one-metre-high plants. The incubation period may therefore vary from 2–24 weeks or more. This range reflects a diversity of conditions reported in the literature and there appears to be no reason that the range of values would be any different in the Philippines.

The detection period after expression of visible symptoms is likely to be no more than 2 weeks because it is reported that all commercial Cavendish plantations of Mindanao are thoroughly examined by trained staff at least once a week and the efficiency with which disease symptoms can be detected is considered by BPI to be high (BPI 2002b).

The combination of incubation and detection periods, in the opinion of the IRA team, indicates that the proportion of infected plants at any weekly harvest date may be 4–26 times greater than the average infection rates indicated above.

The proportion of fruit clusters that are infected on infected plants translates the field incidence of disease in plants generally to that in the harvested product. Opportunities for infection of fruit occur at any time from the initiation of the floral bud to the time of harvest, some 25–30 weeks later. Opportunities for direct infection of the bunch are greater once the bunch has emerged from the pseudostem. Little information has been found on the proportion of fruit that become infected on infected Cavendish banana plants. Some stakeholders consider that fruit infection is rare in export quality Cavendish bananas because bunches are not harvested from diseased plants and fruit with premature ripening symptoms (an indication of Moko infection) are removed in the packing station (BPI 2002a).

However, Soguilon (2003a) found that Moko could be recovered from up to 13% of hands of mature hard green Cavendish fruit after inoculating wounded pedicel tissue at the time of de-belling between 9–11 weeks earlier. The experiments conducted by Soguilon (2003a) were carried out under conditions more favourable for infection to occur than would be the case under natural conditions. Soguilon (2003a) sprayed a suspension of the bacteria on to the entire cross section of the fruit stalk (peduncle) at the time of debelling. Suspensions of the pest were derived from actively growing cultures. After inoculation the sprayed surfaces were immediately covered with plastic film, in order to prevent evaporation and increase the likelihood of infection, and removed after 48 hours. Soguilon (2003a) sampled two fingers per hand of fruit, but did not report on the proportion of fingers from which *R. solanacearum* race 2 was subsequently cultured. However, it is unlikely that the bacterium was isolated from all fingers on apparently infected hands. Neither the fruit nor plants in these experiments displayed external symptoms of Moko disease over the 9–11 week incubation period but all inoculated plants displayed various degrees of vascular discolorations in the peduncle (as observed at bunch harvest) or in the crown tissue (when bunches were de-handed).

In contrast, a photograph of Moko-infected fruit of the Cavendish Grand Nain variety in Thwaites et al (2000) showed that all fingers that were cut exhibited visible symptoms of internal tissue infection. Considering that consecutive fingers within the same hand showed signs of infection, it is reasonable to assume that all fruit of an infected plant could be infected, either with or without visible symptoms. The IRA team considered that, based on the above evidence, asymptomatic infection of clusters within a bunch and determined that it is within 15–100%.

After considering all the uncertainties associated with:

- field infection of plants
- the numbers of infected plants removed in routine sanitation measures
- the variations in incubation and detection periods due to the nature of inoculum and condition of tissue at the time of inoculation
- the proportion of fruit clusters that may be infected on bunches harvested from infected plants.

It was considered that the proportion of harvested clusters that are infected is in the range of  $1.00E-05$  to  $1.00E-03$ . Insufficient data were available to suggest any central tendencies, so a Uniform distribution was applied.

### 9.3.3 Contamination by Moko during harvest and transport to packing station

In this section the terms infection, infestation and contamination are used. Infection is 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. The term infestation and contamination are used interchangeably and refer to the ‘epiphytic’ colonisation of the surface of a plant, or plant organ, and is characterised by the absence of disease symptoms. The infestation or contamination of an open wound can lead to infection if conditions are favourable for bacterial growth.

*Imp3a: The proportion of clean clusters of bananas from infected plantations that become infected with Moko during harvest and transport to the packing station is 0.*

Clusters are transported as entire bunches on cableways to permanent packing stations. This process is completed in 1–2 hours (Section 7.2.2). There is little opportunity for infection to occur in this situation.

In the case of bunches processed in mobile packing stations, which currently process about 10% of all export fruit (Philippines Scientific Delegation 2002), bunches are de-handled in the field and hands are carried on stretcher carrier tables to the mobile packing station. Contamination and subsequent infection of clean clusters may result from the use of contaminated knives or similar, but infection is not likely to be any greater than at an equivalent point (Imp5) in permanent packing stations.

On this basis, Imp3a was assigned a value of 0 and any infection that might occur in mobile packing stations was carried forward to Imp5.

*Imp3b: The proportion of clean banana clusters from clean plantations that become infected with Moko during harvest and transport to the packing station is 0.*

It is unlikely that there would be contamination and infection of bananas during harvesting in clean plantations.

Therefore the value for Imp3b is 0.

### 9.3.4 Proportion of pests surviving packing procedures

*Imp4: The proportion of infected clusters that remain infected with Moko during routine processing procedures at the packing station is 1.*

The first visible symptoms of Moko on fruit are expressed as premature ripening or splitting of the fruit (Stover 1972). Most bananas with these symptoms would be detected at harvesting (Imp2). Remaining fruit showing visible symptoms should be detected at this point of the processing chain as part of quality control, while visual inspection would not detect internal fruit infection.

The routine processes undertaken in Philippine banana packing stations have no influence on the viability of Moko bacteria infecting banana fruit internally.

Therefore the value for Imp4 is 1.

### 9.3.5 Contamination during packing

*Imp5: The proportion of clean clusters of bananas that would become infected with Moko during routine processing at the packing station has a Uniform distribution with a range of  $2.50E-09$  to  $2.50E-07$ .*

This step relates to the transfer of bacteria to freshly cut cushions of clean clusters and subsequent infection of the exposed clusters.

Infection of clean clusters following processing of infected fruit could occur during packing station operations that include de-handing, cutting and trimming of clusters with a contaminated knife and dipping and flotation of clusters in contaminated water tanks. The potential exists for live bacteria to be absorbed into the freshly cut cushion of clean clusters (Greene and Goos 1963; Muirhead and Jones 2000; Bartz et al 2001; Alvindia et al 2004). Although contamination of the surface of fruit with Moko bacteria is also likely to occur during packing station operations, it is unlikely to lead to infection of clean clusters as Moko infections only occur through wounded tissue (Soguilon 2003b). Surface contamination may occur during packing and transport at mobile packing stations.

Infection of clean clusters would depend on various factors including:

- the number of processed infected bunches
- the level of inoculum picked up by a knife from previous cuts through infected cushions
- time elapsed between contamination of a clean cluster and its transfer to a water tank
- dilution of inoculum depending on the size and type of a water tank
- time elapsed between inoculation of clean clusters with a sufficient load of Moko bacteria and cooling the fruit down to about 13 °C.

As compared with fixed packing stations the risk of infection of clean clusters is expected to be higher in mobile packing stations that have smaller water tanks and the time elapsed between de-handing and dipping of fruit in water is longer.

When the clusters are de-handled, a combination of latex and plant material will exude from the cut into the wash tank. It was considered that about 5 ml of such material would be exuded per cluster (about 200 ml for a bunch). About 90% of the exudate would be latex with no bacteria, and the remainder would have about one million bacteria per gram. It was considered that during the period in the tank, the 5 ml of exudate would be replaced by liquid from the tank. While there would be temporary, localised, high concentrations of bacteria in the tank as the result of cutting an infected cluster, this would have a minimal effect during the slow uptake of liquid.

The value of Imp5 will be proportional to Imp2 since the concentration of bacteria in the tank will be proportional to the number of infected clusters. One infected cluster would contribute about  $4.44E-02$  bacteria per ml in a tank 15 m long by 1.5 m wide by 0.5 m deep. Based on that concentration, about 1 in 5 clusters could be contaminated by a single bacterium when the 5 ml of exudate are replaced by tank water. The bacterium is unlikely to double more than three times until low temperatures of cold storage will retard the population growth of the bacteria. The total number of bacteria absorbed when 50,000 clusters are processed during a day would be  $8.89E+04$ , which is about 0.025% of the number of bacteria in the peel of an infected cluster. Accordingly, the IRA team considered that the value for Imp5 would be about 0.025% of the values for Imp2. The IRA team considered the proportion of clean cluster that may become infected following contamination in the packing stations will be between  $2.50E-09$  to  $2.50E-07$ .

### 9.3.6 Pest level surviving post-packing procedures

*Imp6: The proportion of infected clusters that would remain infected with Moko after routine packing station procedures, and survive handling and transport to Australia is 1.*

Moko bacteria carried internally would remain viable during post-packing procedures. The proportion of infected clusters remaining infected through the post-packing procedures is 1.

### 9.3.7 Contamination by the pest during post-packing procedures

*Imp7: The proportion of clean clusters of bananas becoming infected with Moko during post-packing procedures is 0.*

The palletising of boxed plastic-wrapped fruit and the storage conditions during transport are very unlikely to result in new infection of fruit. Any external contamination during transport would not lead to new infections of previously uninfected banana clusters.

Therefore the value assigned to Imp7 is 0.

### 9.3.8 Pest level remaining after border procedures

*Imp8: The proportion of infected clusters that remain infected with Moko after on arrival minimum border procedures is 1.*

Minimal border procedures would not detect symptomless internal fruit infection. A value of 1 was therefore assigned to this step.

## 9.4 Distribution

Distribution within Australia starts from the release of imported fruit at the port of entry and ends with the disposal of waste material under controlled or uncontrolled conditions. The two distribution steps associated with distribution are outlined in Section 5.3. As mentioned in Section 7.2, distribution occurs through established wholesale and retail outlets and includes processes to store fruit at 13–14 °C for between 2–7 days and ripening at 14.5–21 °C. The effect on Moko bacteria during the distribution process is assessed below.

Any surface contamination of the fruit that might have occurred during importation is unlikely to survive exposure to light or to low relative humidity conditions during the distribution steps (refer to Imp3a).

### 9.4.1 Pest survival during distribution

*Dist1: The proportion of infected fruit that will remain infected during transport and handling in Australia is 1.*

The proportion of Moko infection in banana fruit is not affected by the fruit ripening processes. The number of bacteria is likely to decrease due to a number of adverse conditions (for example, decreasing water potential). However, the proportion of infected clusters that remain infected during distribution is 1.

### 9.4.2 Contamination by Moko during distribution

*Dist2: The number of clean clusters that will become infected with Moko from an infected cluster during transport and handling in Australia is 0.*



There is no mechanism for clean fruit to become contaminated from internally infected fruit during distribution and so Dist2 was assigned the value of zero.

### 9.4.3 The number of infected clusters at each waste point

The distribution pathway ends when banana waste is discarded. As mentioned in Section 5.3, the waste will be in one of three waste categories (controlled waste, uncontrolled consumer waste, and other uncontrolled waste) in one of two areas (grower areas and other areas) according to the proportions given in Section 7.3. About 0.05% of imported clusters (about 1 in 2000) would be infected and the result of the importation and distribution steps are summarised in Table 9.1, which shows how many infected clusters would be in 105,000 tonnes of imported bananas.

**Table 9.1 Estimated numbers of infected clusters distributed to each waste point from 105,000 tonnes of imported bananas**

Areas	Waste category					
	Controlled		Uncontrolled consumer		Other uncontrolled	
Grower areas	5,904	11.1%	4,218	8.0%	58	0.1%
Other areas	25,083	47.3%	17,494	33.0%	281	0.5%

## 9.5 Exposure – proximity considerations

As outlined in Section 5.1.1, the unit for assessing the likelihood of transfer of the pest from waste to a host is an individual banana finger.

The probability of exposure is determined in two parts. The first part (considered in this section) determines how likely it is that waste from infected fruit would be close enough to a host to be able to infect it, if conditions are favourable. The second part (considered in the next section) determines how likely it is that the pest would be transferred to a host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a value greater than zero for the likelihood of transfer of bacteria to a host plant. The likelihood of banana waste being disposed of sufficiently close to a suitable host depends on the method of waste disposal and the exposure group (commercial crops, home gardens and other plant communities).

Proximity of discarded waste is considered for all hosts (bananas, heliconias and asymptomatic hosts). In addition, the proximity values consider the different distances associated with the four pathway scenarios.

For the insect-transmitted pathway (Scenario A) in this assessment, the initial movement of vectors will be largely within the immediate area of the waste. It is assumed that an insect would lose any contaminating bacteria quickly due to physical contact with the substrate they move over or land on. For this assessment, the IRA team considered the flight range of an insect between picking up the inoculum and the loss of viable bacteria will be relatively small and within 30 m from the waste. This gives a proximity radius of 30 m for Scenario A, acknowledging that outliers can occur.

For the leaching pathway (Scenario B) it is assumed that banana waste is discarded over the root zone (mat) of a *Musa* plant or *Heliconia* clump, or over the root area of asymptomatic hosts. The root zone of a banana mat or a *Heliconia* clump was considered to cover an area up to 5 m in radius (refer to Section 2.3.2).

Scenarios C and D are specific case scenarios. Scenario C uses those proximity values for Scenario B relating to commercial plantations. Scenario D considers three specific situations where asymptomatic

carrier hosts might be mechanically cut. While the proportion of waste discarded near each exposure group (as outlined in this section) is relevant to the scenario, a proximity estimate is not because of the ubiquitous nature of asymptomatic carrier hosts.

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 9.2–Table 9.5 for four combinations of hosts and distances. For each value, the likelihood was determined by multiplying the following two probabilities together:

- the proportion of waste discarded at a waste point that is near the exposure group
- the likelihood that a host plant in an exposure group would be within the appropriate distance of the waste (30 metre radius for Scenario A and 5 m radius for Scenarios B, C and D).

The data for these calculations are provided for bananas and heliconias in Section 7.5, and for asymptomatic hosts in Section 9.5.4 below.

### 9.5.1 Proportion of waste near each exposure group

The proportion of each type of waste that is near each exposure group (commercial crops, home gardens and other plant communities) is based on the information on general distribution of waste given in Section 7.4.

#### Controlled waste

Commercial host crops or home gardens do not occur within 30 m of any controlled waste facility. Although there are no banana plants growing at controlled facilities in other areas, some grow at controlled waste facilities in grower areas. Averaged over all the controlled waste facilities in grower areas, the IRA team considered that no more than a proportion of  $8.74\text{E}-05$  of the waste would be within 30 m of the plants at the facility and no more than  $1.00\text{E}-09$  could be within 5 m.

#### Uncontrolled consumer waste

Uncontrolled consumer waste is generated by consumers and most will be discarded in home gardens, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other plant communities such as roadsides, public parks, farmland and bushland. It is very unlikely that uncontrolled consumer waste will be discarded within 30 m of a commercial banana plantation. A value of  $5.60\text{E}-06$  was considered appropriate for 30 m and  $3.10\text{E}-06$  for 5 m.

#### Other uncontrolled waste

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. Most of this waste is discarded in other plant communities by being fed to livestock or used directly as organic mulch. It was considered that about 5% of other uncontrolled waste is discarded or used near home gardens. It is very unlikely that other uncontrolled waste will be discarded within 30 m of a commercial banana plantation. A value of  $1.00\text{E}-06$  was considered appropriate.

#### Scenario D

Scenario D considers the mechanical cutting of weeds in commercial plantations and home gardens, and along roadsides in other environments. It is considered that littering would be the main way that banana waste would enter these environments. It was considered that no more than 1% of uncontrolled consumer waste would be littered around the garden. Some uncontrolled consumer waste is discarded into other plant communities. Of this waste, it is estimated that no more than 20% would be discarded along roadsides and in other maintained areas that undergo cutting. For other uncontrolled waste it was considered that no more than 0.1% would be littered by the roadside or around the garden. The incidence of littering in commercial plantations is the same as described under uncontrolled consumer waste.

### 9.5.2 Probability of banana and heliconia plants being within a 30 metre circle (Scenario A)

The average number of plants within a random circle of 30 m radius is equal to the area of the circle multiplied by the planting density (Table 7.6). The average number is then used to determine the probability that there would be at least one host plant within the circle.

#### *Commercial crops*

There would be an average of 566 host plants within a circle of 30 m radius, in a commercial host crop (banana or heliconia) plantation in grower areas. By definition, there are no commercial host crops located in other areas.

#### *Home gardens*

Although on average, there would be between 1.02 banana mats and 1.47 heliconia clumps within a circle of 30 m radius for home gardens in grower areas, there may occasionally be no host plant. The probability that there would be at least one plant within the circle is between  $6.39E-01$  and  $7.70E-01$ . The corresponding probabilities for home gardens in other areas are  $1.18E-02$  and  $6.88E-02$ .

#### *Other plant communities*

The probability of wild, volunteer and amenity banana and heliconia plants occurring within a circle of 30 m radius in other environments is between  $1.13E-03$  and  $1.12E-02$  for grower areas and about  $1.41E-05$  for other areas.

### 9.5.3 Probability of banana and heliconia plants being within a 5 metre circle (Scenarios B and C)

The likelihood of a plant being within a random circle of 5 m radius is equal to the area of the circle multiplied by the planting density (Table 7.6).

#### *Commercial crops*

There would be about fifteen banana plants in a circle of 5 m radius in a banana plantation in grower areas. There are no commercial banana and heliconia plantations in other areas.

#### *Home gardens*

There is a likelihood of between  $2.79E-02$  and  $4.00E-02$  that there would be banana and heliconia plants in a random circle of 5 m radius in a home garden, for grower areas. The corresponding figures for other areas are  $3.30E-04$  and  $1.98E-03$ .

#### *Other plant communities*

The likelihood of there being wild, volunteer or amenity banana or heliconia plants in a random circle of 5 m radius in other environments is between  $3.14E-05$  and  $3.14E-04$  for grower areas and about  $3.93E-07$  for other areas.

### 9.5.4 Probability of asymptomatic carrier hosts being within a 30 metre and 5 metre circle (Scenarios A, B and D)

Over twenty plant species are known to be asymptomatic hosts for Moko. Even though many of the individual species would be geographically restricted, it is considered that, as a whole, they would be broadly distributed over Australia. Consequently, it was considered certain that there would be some

asymptomatic carrier hosts within an area in grower regions, and that, on average, these asymptomatic carrier hosts could make up between 5–10% of plants present.

However, when considering other areas, the fact that Moko is sensitive to low temperatures must also be taken into account when considering waste discarded in other areas. Taking temperature and the population density and area into account, the IRA team estimated that about 10% of the readily accessible parts of other areas would be suitable for the survival of Moko in asymptomatic carrier hosts. Although there will be asymptomatic carrier hosts in the remaining parts of other areas, these plants will not contribute to the spread of the disease, and hence are not considered further.

Consequently, the likelihood that an asymptomatic carrier host plant would be within a random circle of discarded waste is 1 for grower areas and 0.1 for other areas.

### **9.5.5 Summary of proximity values**

The proportion of waste near an exposure group is multiplied by the probability of host plants being within either a 30 m or a 5 m radius (according to the scenario) to determine the proximity value. Table 9.2–Table 9.5 summarise these values for each combination of waste point and exposure group for Scenarios A, B, C and D. Where values were expressed as a range, the minimum values were multiplied together as were the maximum values. In each case the data were insufficient to suggest any central tendencies and so Uniform distributions were used.

**Table 9.2 Scenario A: Proximity values for Moko for *Musa* spp. and *Heliconia* spp. (30 m proximity zone)**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	5.60E-06	1.00E-06
home gardens	0	U(6.39E-01, 7.70E-01)	U(3.19E-02, 3.85E-02)
other plant communities	8.74E-05	U(1.13E-05, 5.62E-04)	U(1.13E-03, 1.12E-02)
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	U(1.18E-02, 6.88E-02)	U(5.90E-04, 3.44E-03)
other plant communities	0	U(1.41E-07, 7.07E-07)	1.41E-05

**Table 9.3 Scenarios B and C: Proximity values for Moko for *Musa* spp. and *Heliconia* spp. (5 m radius proximity zone)**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	3.10E-06	1.00E-06
home gardens	0	U(2.79E-02, 4.00E-02)	U(1.39E-03, 2.00E-03)
other plant communities	1.00E-09	U(3.14E-07, 1.57E-05)	U(3.14E-05, 3.14E-04)
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	U(3.30E-04, 1.98E-03)	U(1.65E-05, 9.89E-05)
other plant communities	0	U(3.93E-09, 1.96E-08)	3.93E-07

**Table 9.4 Scenarios A and B: Proximity values for Moko for asymptomatic weeds**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	(A) 5.60E-06 (B) 3.10E-06	1.00E-06
home gardens	0	1	5.00E-02
other plant communities	(A) 8.74E-05 (B) 1.00E-09	U(1.00E-02, 5.00E-02)	1
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	1.00E-01	5.00E-03
other plant communities	0	U(1.00E-03, 5.00E-03)	1.00E-01

**Table 9.5 Scenario D: Proximity values for Moko for asymptomatic weeds**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	3.10E-06	1.00E-06
home gardens	0	1.00E-02	5.00E-05
other plant communities	1.00E-09	U(2.00E-03, 1.00E-02)	1.00E-03
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	1.00E-03	5.00E-06
other plant communities	0	U(2.00E-04, 1.00E-03)	1.00E-04

## 9.6 Exposure – transfer considerations

Section 5.4 describes the considerations for determining the second value that is needed to determine the probability of exposure – the likelihood of transfer.

Transfer considerations include the transmission pathways from infected banana waste peel to a suitable host and the likelihood that bacteria will cause infection of that host. The assumption for this step is that infected waste is discarded close enough to a suitable host for infection to occur.

As discussed in Section 9.2.5, four primary pathways were identified by which Moko could transfer from discarded infected banana waste to a suitable host plant, causing an infection. The scenarios are:

- A transfer by insects
- B transfer by leaching
- C transfer by movement of machinery, vehicles and implements
- D transfer by cutting, mowing and slashing.

The likelihood of transferring Moko bacteria from infected banana waste to a suitable host was assessed for each of these pathways and for each group of hosts – *Musa* species, *Heliconia* species and asymptomatic carrier hosts.

## 9.7 Exposure – transfer by insects (Scenario A)

The transfer considerations describe the likelihood that the Moko pathogen will be carried by insects from discarded peel or other banana waste to an infection site on a host plant, given that infected waste is discarded within 30 m of a susceptible host plant (see Section 9.5).

The following sequence must occur for Moko bacteria to be successfully transferred via insect transmission:

1. The waste must be accessible to insect vectors.
2. The waste must contain viable bacteria for acquisition by insects.
3. An insect must find the waste and pick up infectious material.
4. An insect must find a host and deposit infectious material on a fresh wound.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of factors 1, 2, 3 and 4 was calculated to determine the minimum values for the transfer value. A similar calculation was carried out to determine the maximum value. In some cases for some factors there were only point values. These values are presented in Table 9.6 to Table 9.8. In each case, the data were insufficient to suggest any central tendencies and so a Uniform distribution was used.

The likelihood values associated with these factors are assessed below. Factors 1, 2 and 3 are the same for each type of host species. Factor 4 must be considered separately for banana, heliconia and asymptomatic carrier hosts.

### **Factor 1 – Waste accessibility**

Factor 1 evaluates the likelihood that banana waste is available in a way that is accessible to insect vectors.

Most of the waste in controlled waste facilities is contained in garbage bags or buried under other waste. It is greatly diluted with other household waste and heavily compacted in the waste collection process. The degree to which burial reduces the ability of insects to access banana waste has not been quantified, but it is considered very unlikely. Factor 1 was therefore assigned a value of  $1.00E-06$  for controlled waste.

A significant proportion of uncontrolled consumer waste may be buried or contained in compost heaps, but some of this waste will be discarded on the soil surface as litter. The degree to which burial reduces the ability of insect vectors to access banana waste has not been quantified, but it is considered that not more than 40% of the waste would be accessible. Factor 1 was therefore assigned a value of  $4.00E-01$  for uncontrolled consumer waste.

Uncontrolled other waste may be taken to agricultural land and discarded in heaps or be subject to some containment. The degree to which the disposal method reduces the ability of insect vectors to access banana waste has not been quantified, but it is considered that no more than 40% of the waste would be accessible. Factor 1 was therefore assigned a value of  $4.00E-01$  for other uncontrolled waste.

### **Factor 2 – Availability of Moko bacterial cells**

Factor 2 considers the availability of Moko bacterial cells in the waste. The IRA team considered that the bacterium would be present in all fingers of an infected cluster and remain viable for up to five days after waste is discarded but in a progressively weakened state because of increasing water loss and/or competition from a range of saprophytic micro-organisms. In the absence of free water, movement of Moko bacteria from the xylem vessels of banana waste, especially from the cushion, can occur by a number of ways to overcome the negative water potential that trap bacteria inside the banana waste. For example, the peeling of a banana or the random trampling of banana waste by large animals or machinery could force vascular fluid out of the xylem and make it available for insect vectors. In the presence of free water, re-hydration of the banana waste will occur and bacteria will diffuse and wash from the waste. On this basis, it was considered that Factor 2 has a value of 1 for uncontrolled consumer waste and other uncontrolled waste. However, for controlled waste, Factor 2 was assigned a value of 0.1 given the more rapid onset of decomposition of older waste held in garbage bins over a seven day collection period.

### **Factor 3 – Contamination of insects with bacteria**

Factor 3 considers the likelihood of an insect finding the waste and being contaminated by Moko bacteria. Given the large number of insects available, it is considered certain that some insects would find the banana fruit waste within a few days after its disposal.

In the absence of free water, movement of Moko bacteria from the xylem vessels of banana waste, especially from the cushion, can occur by a number of ways to overcome the negative water potential that trap bacteria inside the banana waste. For example, the peeling of a banana or the random trampling of banana waste by large animals or machinery could force vascular fluid out of the xylem when insect vectors are on the fruit. In the presence of free water, re-hydration of the banana waste will occur and bacteria will diffuse and wash from the waste. It is considered possible that a small amount of fluid (containing bacteria) could exit damaged xylem tissue for a short period of time for which the bacteria would remain viable. The IRA team considered this would occur in about 70% of

instances for uncontrolled consumer waste and other uncontrolled waste, and between 1–10% for instances involving controlled waste.

The chance of an insect walking on banana waste and coming into contact with bacteria, plus contamination of chewing insects, is estimated to be between 1–10%. If contact was made, the likelihood that the insect would be contaminated with Moko bacteria was considered to be between 50–70%.

Multiplying these values together gives a range for Factor 3 between  $5.00\text{E}-05$  and  $7.00\text{E}-03$  for controlled waste and between  $3.50\text{E}-03$  and  $4.90\text{E}-02$  for both uncontrolled consumer waste and other uncontrolled waste. The IRA team considered that the dose adhering to an insect would be about 100 bacterial cells.

#### **Factor 4 – Transfer of bacteria to cause infection of a Host**

Factor 4 considers the likelihood that an insect contaminated with Moko bacteria will move from banana waste to a fresh wound on a host plant and subsequently cause successful transmission.

This scenario assumes that an insect would be carrying an infective load of about 100 bacterial cells and would deposit it within a 30 m radius of the infected waste. It is considered that insects would find such a location by chance, since they are not generally attracted to the xylem sap associated with cuts.

The likelihood that a suitable infection site on a host plant would be found and the likelihood of subsequent transfer of bacteria to the host is dependent on the type of host, and is considered separately for bananas, heliconias and asymptomatic carrier hosts, below.

##### ***Bananas***

The likelihood that an insect would come into contact with a receptive wound surface depends on the planting density, the proportion of wounded surface relative to the overall plant surface area, the frequency of wounding a banana plant and insect behaviour.

It is assumed there would be one banana plant in the target zone for all exposure groups with the exception of commercial crops. The above-ground parts of a single banana plant cover an area of about 1.5 m in radius, which is about 0.25% of the 30 m radius proximity zone. Since most waste discarded in proximity to a commercial plantation will be discarded near a plantation rather than in it, the target area (the proportion of the proximity zone with hosts) is estimated to be between 0.25–50%.

As mentioned above, the likelihood that an insect would come into contact with a wound depends on the area of the wound relative to the overall plant surface area, and how often wounding may occur on the plant. A large pruning wound would be about  $0.03\text{ m}^2$  compared to the surface area of a banana plant, which is about  $17.5\text{ m}^2$ . This gives a relative proportion of about 0.002.

The likelihood of freshly incurred wounds, either from cutting or from the dehiscence of bracts, depends on the frequency of cutting and the rate of flowering. The general leaf pruning frequency of banana plants in commercial plantations in Australia is about once per month. For plants grown in home gardens, de-leafing or other plant maintenance that could cause wounding would be carried out about every second month. For plants in other plant communities, exposed surfaces might occur about twice per year. Since the newly exposed cushion remain receptive to infection for about two days (Buddenhagen and Elsasser 1962), the proportion of time that plants might have receptive wound surfaces was considered to be one fifteenth for commercial crops, one thirtieth for home gardens and one ninetieth for other plant communities.

The likelihood of transfer of Moko to a wound on a host plant is also considered in the context of the physiological state of the pest. An inoculum dose of 100 bacteria from actively growing Moko cultures caused infection on fresh wound surfaces on banana plants that were then covered in plastic film to prevent moisture loss (Soguilon 2003a). However, the low temperature and reduced water potential during the 3–4 week period from harvest to consumption of fruit would significantly weaken the



physiological state of bacterial cells to one that is less likely to be infectious, in comparison to those used in the experiment. There are many examples of where *R. solanacearum* under ideal culture conditions fail to compete and survive against a range of soil and saprophytic micro-organisms (Kelman 1953). In inoculation experiments, *R. solanacearum* was out competed by the secondary micro-organisms if they were present in the cultures (Kelman 1953). For a more complete review of the relevant information refer to part C, Moko datasheet, *Survival in banana waste*.

Moko bacteria that could be transferred onto a cut or wound under field conditions may be exposed to unfavourable environmental conditions, including desiccation, UV light and a diverse and large number of competing or antagonistic micro-organisms that would be part of the inoculum load. Consequently, the likelihood of infection resulting from insect transmission of bacteria from waste to a wound on the host plant was considered to be within the range of  $1.00\text{E}-06$  to  $1.00\text{E}-04$ .

The various components were multiplied together to provide estimates for Factor 4 for each waste point and exposure group combination.

#### *Heliconias*

The likelihood that an insect would land by chance on a receptive surface depends on the planting density, the proportion of cut surface and the frequency of cutting. While some species of heliconia may have dehiscent floral parts, the extent of natural wounding was considered insignificant in relation to the extensive wounding as a result of harvesting flowers.

It was considered that a clump of heliconia plants was equivalent to a banana mat, and so covers about 0.25% of the 30 m radius proximity zone. The target area (the area occupied by a host) is proportional to the number of hosts in the proximity zone. Home gardens contain about three heliconia clumps in grower areas and two clumps in other areas. It is estimated that there would be no more than one heliconia clump in the proximity zone for other plant communities. The target area in a commercial heliconia plantation constitutes between a quarter and three-quarters of the proximity zone.

The likelihood that an insect would land on wound tissue depends on the area of the wound relative to the overall plant surface area and how often a wound might occur on the plant. A pruning wound might be of the order of  $0.0016\text{ m}^2$  compared to the surface area of a heliconia plant of about  $8.75\text{ m}^2$ . This gives a relative proportion between about  $1.80\text{E}-04$  and  $7.00\text{E}-04$ .

The likelihood of fresh wounds depends on the frequency of cutting. The 'general' harvesting frequency of heliconia plants in commercial plantations in Australia is about five stems per week. For home gardens, plant maintenance (including the cutting of flowers) that could potentially inflict wounding would be carried out less frequently, possibly monthly. For plants in other environments, exposed surfaces might occur about twice per year. It was considered that wounds on heliconia plants would remain receptive to infection for the same period as bananas (about two days). Hence, the proportion of time that plants might have receptive cut surfaces was considered to be 100% for commercial crops, one fifteenth for home gardens and one ninetieth for other plant communities.

The likelihood of transfer of Moko from a wound to a host plant has to be considered in the context of the physiological state of the pest, which is the same as described above for banana plants. The transmission of Moko bacteria by insects to bananas has been proven while there is no information on insect transmission to heliconia plants. It was considered that the likelihood of transfer would not be greater than for bananas, hence, the same values of between  $1.00\text{E}-06$  to  $1.00\text{E}-04$  were used.

The various components were multiplied together to provide estimates for Factor 4 for each waste point and exposure group combination.

#### *Asymptomatic carrier hosts*

The likelihood that an insect lands by chance on a receptive wound surface depends on the planting density, the proportion of wound surface, and the frequency of cutting.

Although not every species that can be an asymptomatic host for Moko is known, it is considered that between 5–10% of plants would be asymptomatic carrier hosts. In home gardens and other plant communities, it was considered that 5–10% of the plants within the 30 m radius proximity zone would be asymptomatic carrier hosts.

Wounded surfaces could consist of small abrasions, for example from grazing or trampling, or larger cuts caused by mowing or pruning. The probability that an insect would land on a wound depends on the area of the wound relative to the overall plant surface area and the location of the cut on a plant. Cuts close to the ground would most likely consist of the plant stem. A wound on a carrier host such as *S. nigrum* or *B. pilosa* might be of the order of 0.78 cm<sup>2</sup> as the diameter of the stem would not exceed 1 cm. It was considered that cuts might make up about 0.1% of the plant surface.

The likelihood of fresh wounds depends on the frequency of cutting. It was considered that general slashing of weeds in commercial plantations would occur about 4–6 times per year. For home gardens, cutting and maintenance that potentially could inflict wounds would be conducted opportunistically, possibly monthly. For plants in other plant communities, cuts might occur between six to twelve times annually. It was considered that wounds on asymptomatic carrier hosts would remain receptive to infection for the same period as on banana plants (about two days). Hence, the proportion of time that plants might have receptive cut surfaces was considered to be between one forty-fifth and one thirtieth for commercial crops, one fifteenth for home gardens and between one thirtieth and one fifteenth for other plant communities.

The likelihood of transfer of Moko from a cut surface to the host plant has to be considered in the context of the physiological state of the pest. It was considered that the likelihood of transfer would not be greater than for bananas, and the same values of between 1.00E–06 to 1.00E–04 were used.

The various components were multiplied together to provide estimates for Factor 4 for each waste point and exposure group combination.

### **Summary – Scenario A**

To estimate the likelihood that at least one transfer event will occur, values of the four factors are combined as indicated above.

Table 9.6 to Table 9.8 summarise the transfer values for each combination of waste point and exposure group for the three types of hosts. For Scenario A, bananas and heliconias were considered together when determining the probability of entry, establishment and spread (PEES). The transfer values are similar for bananas and heliconias, and the larger value of the two was used in the calculation of the PEES.

**Table 9.6** Transfer values for insect transmission of Moko to *Musa* spp.

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(1.67E-24, 4.67E-18)	U(4.67E-16, 1.31E-10)	U(4.67E-16, 1.31E-10)
home gardens	U(8.33E-25, 1.17E-20)	U(2.33E-16, 3.27E-13)	U(2.33E-16, 3.27E-13)
other plant communities	U(2.78E-25, 3.89E-21)	U(7.78E-17, 1.09E-13)	U(7.78E-17, 1.09E-13)
<b>Other areas</b>			
commercial crops	U(1.67E-24, 4.67E-18)	U(4.67E-16, 1.31E-10)	U(4.67E-16, 1.31E-10)
home gardens	U(8.33E-25, 1.17E-20)	U(2.33E-16, 3.27E-13)	U(2.33E-16, 3.27E-13)
other plant communities	U(2.78E-25, 3.89E-21)	U(7.78E-17, 1.09E-13)	U(7.78E-17, 1.09E-13)

**Table 9.7** Transfer values for insect transmission of Moko to *Heliconia* spp.

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(2.24E-22, 3.68E-17)	U(6.28E-14, 1.03E-09)	U(6.28E-14, 1.03E-09)
home gardens	U(4.49E-25, 2.45E-20)	U(1.26E-16, 6.86E-13)	U(1.26E-16, 6.86E-13)
other plant communities	U(2.49E-26, 1.36E-21)	U(6.98E-18, 3.81E-14)	U(6.98E-18, 3.81E-14)
<b>Other areas</b>			
commercial crops	U(2.24E-22, 3.68E-17)	U(6.28E-14, 1.03E-09)	U(6.28E-14, 1.03E-09)
home gardens	U(2.99E-25, 1.63E-20)	U(8.38E-17, 4.57E-13)	U(8.38E-17, 4.57E-13)
other plant communities	U(2.49E-26, 1.36E-21)	U(6.98E-18, 3.81E-14)	U(6.98E-18, 3.81E-14)

**Table 9.8** Transfer values for insect transmission of Moko to asymptomatic carrier hosts

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(5.56E-24, 2.33E-19)	U(1.56E-15, 6.53E-12)	U(1.56E-15, 6.53E-12)
home gardens	U(1.67E-23, 4.67E-19)	U(4.67E-15, 1.31E-11)	U(4.67E-15, 1.31E-11)
other plant communities	U(8.33E-24, 4.67E-19)	U(2.33E-15, 1.31E-11)	U(2.33E-15, 1.31E-11)
<b>Other areas</b>			
commercial crops	U(5.56E-24, 2.33E-19)	U(1.56E-15, 6.53E-12)	U(1.56E-15, 6.53E-12)
home gardens	U(1.67E-23, 4.67E-19)	U(4.67E-15, 1.31E-11)	U(4.67E-15, 1.31E-11)
other plant communities	U(8.33E-24, 4.67E-19)	U(2.33E-15, 1.31E-11)	U(2.33E-15, 1.31E-11)

## 9.8 Exposure – transfer by leaching (Scenario B)

Given that waste banana peel infected with Moko has been discarded over the root zone of a host plant, the transfer considerations describe the likelihood that the Moko pathogen will be leached from discarded banana waste, through the soil to an infection site in/on roots or other below ground parts of host plants. For a detailed discussion of the various factors affecting survival and infection in the soil refer to Part C, Moko datasheet, *Soil transmission* and *Survival in soil*.

The following sequence of factors must occur for Moko bacteria leaching through soil to infect bananas, heliconias or asymptomatic carrier hosts:

1. the waste must be accessible
2. the waste must contain viable bacteria
3. bacteria must be able to enter the soil
4. transferred inoculum load must cause infection.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of factors 1, 2, 3 and 4 was calculated to determine the minimum values for the transfer value. A similar calculation was carried out to determine the maximum value. These values are presented in Table 9.9 and Table 9.10. In each case, the data were insufficient to suggest any central tendencies and so a Uniform distribution was used. The likelihood values associated with these factors are assessed below. Factors 1, 2 and 3 are the same for each type of host species. Factor 4 is host-dependent.

### **Factor 1 – Waste accessibility**

Factor 1 concerns the likelihood that waste will be discarded in such a way that water can wash bacteria from the waste into the soil. This will be affected by the manner in which waste is discarded, but will be similar for both grower areas and other areas.

Waste in a controlled waste facility is generally buried or contained in plastic disposal bags. The waste is diluted with general household waste and has been heavily compacted in the waste disposal process. The time that it is exposed is limited by the frequency of other waste being brought to the facility and by the frequency with which waste is covered with overburden. Data are not available to quantify Factor 1 but it is considered that the proportion of controlled waste exposed for a significant time is  $1.00E-06$ .

Most uncontrolled consumer waste is disposed of in compost bins or discarded on compost heaps or into vegetation. Generally, the waste is covered by other waste material within a few days. Exposure to rain would be limited. Data are not available to quantify Factor 1 but it is considered that only 10–20% of waste would be exposed for a significant period of time. For uncontrolled consumer waste, Factor 1 would have a value of  $1.00E-01$  to  $2.00E-01$ .

Other uncontrolled waste is discarded on the soil surface in heaps. Data are not available to quantify Factor 1 but it is considered that only 10–20% of waste would be exposed for a significant period of time. For other uncontrolled waste, Factor 1 would have a value of  $1.00E-01$  to  $2.00E-01$ .

### **Factor 2 – Availability of Moko bacterial cells**

Factor 2 concerns the availability of Moko bacterial cells in the waste. It is assumed that the bacterium would be present in all fingers of an infected cluster and would remain viable for up to five days in a progressively weakened state after waste is discarded. On this basis, Factor 2 was assigned a value of 1 for uncontrolled consumer waste and other uncontrolled waste. However, for controlled waste, Factor 2 was assigned a value of 0.1, given the more rapid onset of decomposition of older waste held in garbage bins over a 7 day collection period.

### **Factor 3 – Bacteria must wash from the waste**

Factor 3 concerns the likelihood that viable bacteria are washed from infected banana waste and enter the soil.

The diffusion and washing of bacteria over time from damaged xylem vessels of banana waste, is a process that requires the presence of free water. It was considered likely that there would be a small amount of fluid (containing bacteria) released from damaged xylem tissue on the inner surface of the waste peel for most of the time that bacteria remain viable. The Moko cells would need to leech out of the tissue that contains most bacteria, that is, the freshly exposed inner surface of the cushion after

peeling a banana fruit. This would most likely occur about 70% of the time for uncontrolled consumer waste and other uncontrolled waste and between 1–10% for controlled waste.

Sufficient free water (either as rain or irrigation) would need to come into contact with the waste to wash bacteria from the surface of the peel and then into the soil. The number of days per year with 5 mm or more of rain would be between 50–75 in grower regions and 30–50 in other regions (refer to Part C, Appendix 2). These various components were multiplied together to provide estimates for Factor 3 for each waste point and exposure group combination.

The number of viable bacteria will decrease with increased desiccation and drying of the waste or through competition from saprophytic micro organisms. Diffusion of bacteria into water out of banana waste will become progressively slower over the five day period that bacteria are expected to remain viable as desiccation and competition limit the movement and viability of Moko. Considering all of the above, the number of bacteria washed into soil is estimated to be between 1000–10,000 viable Moko bacteria per wetting incident, and, allowing for release of bacteria, possibly up to 100,000 bacteria from a piece of waste over a five day period.

#### **Factor 4 – Transfer of bacteria to cause infection of a host**

Factor 4 considers the likelihood that Moko bacteria that have entered the soil will continue to leach through the soil profile and will infect roots of a host plant.

Moko bacteria are known to survive in soil for up to six months in the absence of plant roots. Consequently, it was considered that Moko bacteria would survive until they reached the root zone of suitable hosts.

However, Moko bacteria washed from waste will generally be dispersed, rather than be present as aggregates. Unlike other bacteria, such as *Xanthomonas* species, which are able to form gum-like capsules well adapted to surviving and retaining a critical mass to initiate infection, bacteria belonging to the *R. solanacearum* complex do not form coherent aggregates.

The likelihood that the bacteria will contact a host root and transfer to it will be host-specific and is considered below for each host type.

##### ***Bananas***

The likelihood of bacteria encountering a banana root depends on the root density and distribution of roots within the soil profile. A suitable infection site on a *Musa* root consists of secondary root axils, the exudation sites at the root tips, or freshly wounded root tissue (Sequeira 1958; Lehmann-Danzinger 1987). For commercial banana plantations, the root density of banana plants is such that a bacterium leached into the soil would always come in contact with a root. However, for individual plants in home gardens and other environments, the root density of a banana plant would be such that a bacterium would always contact a root if discarded within 1.5 metres of the plant. Thereafter, the density of roots would decrease as distance from the plant increased and reach a density of zero by the edge of the 5 metre proximity zone. If the reduction in plant density is linear with respect to distance from the plant, the proportion of the proximity zone for which a bacterium leaching through the soil would contact a root is 139/300, or about 46%. The IRA team considered that this was an adequate description of root density, and used a value of 50%.

After taking into account the low number of bacterial cells that would come in contact with a suitable site on a root, the physiological state (lag phase) of Moko bacteria and competitive and predatory interactions with other soil biota, the probability of transfer of bacteria and infection of a *Musa* host was given a range of 5.00E–05 to 5.00E–03 in commercial plantations and half those values for home gardens and other environments.

### *Heliconias*

The same considerations apply for determining the likelihood of bacteria finding a suitable infection site on a heliconia root. A clump of heliconias was considered to be the equivalent of a banana mat and the same values as for bananas were used for the estimated root density (100% in commercial plantations and 50% in home gardens and other environments) and proportion of root surface (5%) that would be suitable for infection.

It was considered that the susceptibility of a heliconia root to Moko bacteria is not greater than that of a banana host and so the same probability range as for bananas applies for Factor 4.

### *Asymptomatic carrier hosts*

A suitable infection site on an asymptomatic carrier root consists of secondary root axils, the exudation sites at the root tips, or freshly wounded root tissue. It was considered that a similar proportion of root surface (5%) to that for bananas would be suitable for infection.

The high root density of asymptomatic hosts, coupled with the ability of the root to attract water and the bacteria's ability to detect roots in close proximity means that a bacterium that leached over the root zone of an asymptomatic host would inevitably come in contact with a root (David Turner, Associate Professor, Plant physiologist consultant, pers comm., 25 June 2008).

It is considered that the potential of Moko bacteria to cause infection of an asymptomatic host is no greater than the potential for causing infection of bananas. Taking this into account, the probability of infection on the root system of an asymptomatic host was considered small. Therefore, Factor 4 was given a probability in the range of 2.50E-06 to 5.00E-04.

### **Summary – Scenario B**

The values of the four factors are multiplied together to give the transfer value. Table 9.9 and Table 9.10 summarise the values for each combination of waste point and exposure group in the presence of *Musa* and *Heliconia* species, and of asymptomatic carrier hosts.

**Table 9.9 Transfer values for leaching through soil to *Musa* spp. and *Heliconia* spp.**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(6.85E-15, 1.03E-11)	U(4.79E-07, 1.44E-04)	U(4.79E-07, 1.44E-04)
home gardens	U(3.42E-15, 5.14E-12)	U(2.40E-07, 7.19E-05)	U(2.40E-07, 7.19E-05)
other plant communities	U(3.42E-15, 5.14E-12)	U(2.40E-07, 7.19E-05)	U(2.40E-07, 7.19E-05)
<b>Other areas</b>			
commercial crops	U(4.11E-15, 6.85E-12)	U(2.88E-07, 9.59E-05)	U(2.88E-07, 9.59E-05)
home gardens	U(2.05E-15, 3.42E-12)	U(1.44E-07, 4.79E-05)	U(1.44E-07, 4.79E-05)
other plant communities	U(2.05E-15, 3.42E-12)	U(1.44E-07, 4.79E-05)	U(1.44E-07, 4.79E-05)

**Table 9.10 Transfer values for leaching through the soil to asymptomatic carrier plants**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(3.42E-16, 1.03E-12)	U(2.40E-08, 1.44E-05)	U(2.40E-08, 1.44E-05)
home gardens	U(3.42E-16, 1.03E-12)	U(2.40E-08, 1.44E-05)	U(2.40E-08, 1.44E-05)
other plant communities	U(3.42E-16, 1.03E-12)	U(2.40E-08, 1.44E-05)	U(2.40E-08, 1.44E-05)
<b>Other areas</b>			
commercial crops	U(2.05E-16, 6.85E-13)	U(1.44E-08, 9.59E-06)	U(1.44E-08, 9.59E-06)
home gardens	U(2.05E-16, 6.85E-13)	U(1.44E-08, 9.59E-06)	U(1.44E-08, 9.59E-06)
other plant communities	U(2.05E-16, 6.85E-13)	U(1.44E-08, 9.59E-06)	U(1.44E-08, 9.59E-06)

## 9.9 Exposure – transfer by movement of machinery, vehicles and implements (Scenario C)

Scenario C considers the likelihood whereby the movement of machinery, vehicles or implements will result in the transfer of Moko bacteria from banana waste to a host plant, where infection could occur. This scenario considers the sequence of events whereby discarded banana waste would be physically compressed, forcing bacteria to be exuded from the waste and come into contact with roots.

The series of events that need to take place are specific to commercial banana plantations and would be most unlikely to occur elsewhere. Consequently, this scenario is restricted to commercial banana plantations.

Given that banana waste peel infected with Moko is within 5 m (that is, the root zone) of a banana plant, these transfer considerations describe the likelihood that the Moko pathogen will be forced from discarded banana waste. It will infect the roots of a banana plant as a result of being traversed and compressed by some form of machinery or by equivalent means including foot traffic or the placement of ladders and props.

The following sequence of factors must occur for Moko bacteria to be successfully transferred:

1. the waste must be accessible
2. the waste must contain viable bacteria
3. waste must be subject to compression, forcing bacteria to be exuded from the waste by machinery or by some equivalent means

4. transferred inoculum load must cause infection.

The product of the minimum values for the likelihood of factors 1, 2, 3 and 4 occurring were calculated to determine the minimum values for the transfer value. A similar calculation was carried out to determine the maximum value. These values are presented in Table 9.11. In each case, the data were insufficient to suggest any central tendencies and so a Uniform distribution was used. The likelihood values associated with these factors are assessed as follows:

#### **Factor 1 – Waste accessibility**

Vehicles are regularly driven between rows of banana plants and occasionally driven over the remaining areas in the plantation. Hence, Factor 1 has a value of 1.

#### **Factor 2 – Viability of bacteria**

Since waste discarded in plantations would be the result of littering, the waste would be fresh and so Factor 2 has a value of 1.

#### **Factor 3 – Likelihood that banana waste will be subject to compression by machinery or by some equivalent means**

Compression of the waste must occur while it is still fresh. This is considered a certainty (100%) for waste in the vehicle tracks between rows, since it is assumed that machinery would be driven along each row about three times per week (Peasley 2006a). The main traffic along rows would occur on about half of the surface area of a plantation. It is less likely that banana waste discarded elsewhere would be run over. The chance that machinery would pass over this waste while it is still fresh was considered to be not greater than 20%. Overall, this gives Factor 3 a value of 0.6.

#### **Factor 4 – Transfer of bacteria to cause infection of a host**

This factor will depend on what proportion of the top layer of roots is near the soil surface and the likelihood that bacteria will cause infection.

The roots of banana plants in commercial plantations will extend under the vehicles tracks between the rows, although tyres would not make contact with much of the root mat because of its depth. Bananas are herbaceous plants and feeder roots are close to the soil surface. Therefore, the roots at the base of a plant and some roots in the vehicle tracks between the rows will be on the surface, and contact would occur regularly. Other roots would be close to the surface, with contact only occurring under muddy or wet soil conditions. While these proportions have not been quantified, the IRA team considered that not more than 10% of waste around a plant will be compressed onto a root by machinery or an implement.

Although Moko bacteria may be diluted in a large body of soil among antagonistic and predatory micro-organisms, there would still be a number of viable bacteria in the waste in a progressively weakened state. The IRA team estimated that the probability of infection from banana waste being pushed onto a banana root is between 20–50%.

Multiplying these two probabilities together gives a value for Factor 4 of between 2.00E–02 and 5.00E–02.

#### **Summary – Scenario C**

The values of the four factors are multiplied together to give the transfer value. Table 9.11 gives the values for the waste point and the exposure group (commercial crops) relevant to this scenario.



**Table 9.11** Transfer values for transmission of Moko to *Musa* spp. by machinery, vehicles and implements

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(1.20E-02, 3.00E-02)	U(1.20E-02, 3.00E-02)	U(1.20E-02, 3.00E-02)
<b>Other areas</b>			
commercial crops	U(1.20E-02, 3.00E-02)	U(1.20E-02, 3.00E-02)	U(1.20E-02, 3.00E-02)

## 9.10 Exposure – transfer by cutting, mowing and slashing (Scenario D)

This scenario considers mechanised weed control. In commercial plantations, home gardens and those parts of other plant communities that are regularly mown or slashed, uncontrolled household waste could become trapped in a mixed growth of grass and weeds, including asymptomatic carrier hosts, before cutting.

Banana fruit waste may also be distributed onto the soil surface in a home garden, such as around the edges of an uncovered compost heap, or used as a form of organic fertiliser around plants while still fresh. Mowers, brush cutters and whipper snippers are the most likely garden implements that could cut into discarded banana waste.

The transfer considerations describe the likelihood that the Moko pathogen will be transferred from the discarded banana waste to an infection site, that is, the cut or severed stems of asymptomatic carrier plants.

The following sequence of factors must occur for Moko bacteria to be successfully transferred by mechanised means:

1. the waste must be accessible
2. the waste must contain viable bacteria
3. waste must come into contact with cut or wounded asymptomatic carrier weeds
4. transferred inoculum load must cause infection.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of Factors 1, 2, 3 and 4 occurring was calculated to determine the minimum values for the transfer value. A similar calculation was carried out to determine the maximum value. These values are presented in Table 9.12. In each case, the data were insufficient to suggest any central tendencies and so a Uniform distribution was used.

For infected Moko bacteria to make contact with and cause infection in an asymptomatic carrier host by high speed blade/cord action, the following must occur:

### Factor 1 – Waste accessibility

The scenario assumes that the infected banana waste would be accessible to the cutting device. Factor 1 was assigned a probability of 1 for all three exposure groups.

### Factor 2 – Availability of Moko bacterial cells

The scenario assumes that the infected banana waste is uncontrolled waste discarded as fresh litter and containing viable Moko bacteria. Factor 2 was assigned a probability of 1.

### **Factor 3 – Transfer of bacteria from infected banana waste to a cutting blade/cord**

It is considered almost certain that banana waste will be picked up by fast rotating blades or whipper snipper cords. However, the transfer of bacteria can only occur if the waste is fresh (no more than five days old). Hence, the likelihood that bacteria would be transferred to the cutting blade/cord depends on the frequency of mowing.

It is considered that major roadsides and other public places would not be mown more than once a month in grower areas. Mowing of public places in other areas is considered to occur at about half that rate due to the variation in climate. A blade would become contaminated if waste had been discarded within five days of mowing. Therefore, the probability of bacteria from waste contaminating a cutting blade is one sixth for other plant communities in grower areas and one twelfth in other areas.

It is estimated that the frequency of using a whipper snipper or brush cutter in a home garden would be monthly in both grower and other areas. This gives a value of one sixth for the probability of waste being cut while fresh.

Slashing of weeds in commercial banana plantations has been estimated at about 4–6 times per year. This equates to 20–30 out of 365 days that fresh waste would be cut, giving a probability of about 0.055 to 0.082 for Factor 3.

### **Factor 4 – Transfer of bacteria to cause infection of asymptomatic carrier hosts**

It is considered that Moko bacteria would be transferred onto a blade or cord when fruit waste is cut and then transferred from the contaminated blade or whipper snipper cord to a stem as the stem is cut. A piece of waste may be cut several times, contaminating several parts of the implement. It was considered that no more than 100 stems would be cut by contaminated portions of blades or cords.

The probability that the stem being cut is an asymptomatic carrier host is equal to the relative proportion of carrier plants to all other (weed) plants in the area being cut. Because not all species of asymptomatic carrier plants have been identified, this proportion cannot be quantified. Nonetheless, it is considered that the average proportion of asymptomatic carrier hosts within the general plant community is between 5–10% in each exposure group.

Most Moko bacteria on the cut surface will be present as larger pieces of plant material or macerated xylem vessels, rather than pure cells or groups of cells. Taking into account the debris, dust and other extraneous material associated with mowing that may contaminate suitable infection sites, and therefore limit the ability of Moko bacteria to cause infection, it was considered that the probability of causing successful infection in a living plant is in the range of 1.00E–06 to 1.00E–04.

These three values were multiplied together to give a range of 5.00E–06 to 1.00E–03 for Factor 4.

### **Summary – Scenario D**

The values of the four factors are multiplied together to give the transfer value. Table 9.12 summarises the values for each exposure group.

**Table 9.12** Transfer values for transmission of Moko to asymptomatic carrier hosts by cutting, mowing and slashing

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(2.74E-07, 8.22E-05)	U(2.74E-07, 8.22E-05)	U(2.74E-07, 8.22E-05)
home gardens	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)
other plant communities	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)
<b>Other areas</b>			
commercial crops	U(2.74E-07, 8.22E-05)	U(2.74E-07, 8.22E-05)	U(2.74E-07, 8.22E-05)
home gardens	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)	U(8.33E-07, 1.67E-04)
other plant communities	U(4.17E-07, 8.33E-05)	U(4.17E-07, 8.33E-05)	U(4.17E-07, 8.33E-05)

## 9.11 Establishment

Establishment relates to the perpetuation of a pest within an area after entry (FAO 2004). The initiation point is the exposure of a susceptible host to viable and sufficient numbers of Moko bacteria at a suitable (endangered) site. The end point is the occurrence of systemic infection within its host. The probability of establishment refers to the likelihood of such an event occurring.

The relevant information for the assessment for the probability of establishment is presented against the factors listed in ISPM 11 (see Section 5.5).

### Estimation of establishment values in grower areas

It is expected that Moko is likely to establish in a host if bacteria have transferred to the vascular tissues of a suitable host under optimal climatic conditions such as those occurring in banana growing areas. The establishment value for each of the exposure groups (commercial crops, home gardens and other plant communities) was considered to be of Uniform distribution between 0.7 and 1 (see Table 9.13).

### Estimation of establishment values in other areas

The establishment of Moko in the other areas is less likely to be successful than in grower areas. The climate during cooler periods of the year could lower the likelihood of establishment of the pathogen in these areas. On this basis, the establishment value for each of the exposure groups was considered to be of Uniform distribution with a minimum of 0.5 and a maximum of 0.8.

**Table 9.13** The probability of establishment for Moko after exposure

Exposure group	Grower areas	Other areas
commercial crops	U(0.7, 1)	U(0.5, 0.8)
home gardens	U(0.7, 1)	U(0.5, 0.8)
other plant communities	U(0.7, 1)	U(0.5, 0.8)

## 9.12 Spread

Spread is the expansion of the geographical distribution of a pest within an area (FAO 2004). It considers factors relevant to the movement of the pest from a point of establishment on a host, or group of hosts, to susceptible hosts in other parts of Australia.

The relevant information for the assessment for the probability of spread is presented against the factors listed in ISPM 11: *Pest risk analysis for quarantine pests, including analysis of environmental risks and living modified organisms* (FAO 2004).

For Moko, the likelihood of spread must consider spread between susceptible species as well as the spread between banana plants. The role of asymptomatic carrier hosts must also be considered.

Once established in a host, Moko could spread to other hosts by various means, including:

- root-to-root contact
- contaminated cutting implements
- contaminated soil adhering to machinery or moved by water
- movement of infected plant material
- insects
- flood water.

The density of bananas and heliconias grown commercially would mean that spread from an infected plant or asymptomatic carrier host within the crop would be almost certain. Hence, the value for spread in commercial plantations is 1.

For home gardens and other plant communities, the rate of spread will be determined by the density of suitable host plants. Isolated host plants that become infected may die before other plants become infected. In areas with higher host plant densities, it would be expected that the bacterium would be more likely to spread to neighbouring plants. Spread to more distant plants requires the movement of infected material such as rhizomes.

It was considered that the likelihood of spread from infected plants in home gardens to other locations would be between 70–90% in grower areas and between 30–50% in other areas. The likelihood of spread from amenity plants would be greater than from remote wild plants. For plants in other plant communities, the likelihood of spread was taken to be between 5–30% in grower areas and between 3–20% in other areas (see Table 9.14). Uniform distributions with these ranges were used.

**Table 9.14**      **The probability of spread after establishment**

<b>Exposure group</b>	<b>Grower areas</b>	<b>Other areas</b>
commercial crops	1	1
home gardens	U(0.7, 0.9)	U(0.3, 0.5)
other plant communities	U(0.05, 0.3)	U(0.03, 0.2)

### 9.13 Probability of entry, establishment and spread

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.6 and Table 5.7. Table 9.15 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation, 105,000 tonnes, is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively).

**Table 9.15** Probability of entry, establishment and spread

	50,000 tonnes	105,000 tonnes	160,000 tonnes
<b>Scenario A – Insect transmission to <i>Musa</i> spp. and <i>Heliconia</i> spp.</b>			
5th percentile	1.53E-10	3.27E-10	4.97E-10
Median	1.90E-09	3.95E-09	6.03E-09
95th percentile	6.84E-09	1.42E-08	2.16E-08
<b>Scenario A – Insect transmission to asymptomatic carrier hosts</b>			
5th percentile	5.37E-09	1.10E-08	1.70E-08
Median	5.72E-08	1.20E-07	1.82E-07
95th percentile	1.95E-07	4.07E-07	6.23E-07
<b>Scenario B – Leaching to <i>Musa</i> spp. and <i>Heliconia</i> spp.</b>			
5th percentile	6.63E-04	1.43E-03	2.17E-03
Median	9.10E-03	1.88E-02	2.86E-02
95th percentile	3.34E-02	6.80E-02	1.02E-01
<b>Scenario B – Leaching to asymptomatic carrier hosts</b>			
5th percentile	5.26E-03	1.09E-02	1.68E-02
Median	5.75E-02	1.17E-01	1.73E-01
95th percentile	1.88E-01	3.52E-01	4.85E-01
<b>Scenario C – Transmission by machinery, vehicles and implement</b>			
5th percentile	8.62E-05	1.82E-04	2.70E-04
Median	7.22E-04	1.51E-03	2.31E-03
95th percentile	1.71E-03	3.59E-03	5.47E-03
<b>Scenario D – Transmission by cutting, mowing and slashing</b>			
5th percentile	8.76E-04	1.82E-03	2.79E-03
Median	8.39E-03	1.76E-02	2.66E-02
95th percentile	2.64E-02	5.45E-02	8.21E-02

Rather than showing the individual PEES value for each waste point and exposure group combination, Table 9.16 shows the proportion of overall PEES attributable to each waste point and exposure group combination.

**Table 9.16** Proportion of overall PEES attributable to each waste point and exposure group combination

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0.00%	0.09%	0.00%
home gardens	0.00%	85.93%	0.01%
other plant communities	0.00%	5.66%	0.04%
<b>Other areas</b>			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	7.71%	0.00%
other plant communities	0.00%	0.56%	0.01%

## 9.14 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of Moko by considering, on a range of direct and indirect criteria, its potential impact at the local district, regional and national level. At each level, the impact of Moko was assessed on the basis of its potential effect on the entire local district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was obtained by combining the direct and indirect impacts of Moko using the decision rules discussed in Chapter 3.

Consideration of the direct and indirect impacts is provided in the following text.

### 9.14.1 Direct impact

#### *Plant life or health – F*

This criterion describes the direct effects on plants and their health, including production losses associated with Moko in commercial banana plantations. The direct effects of Moko have to be considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of indirect impacts at Section 9.14.2 below.

Moko disease is one of the most important economically damaging diseases of bananas and plantains worldwide (Sequeira 1998). Moko is highly contagious and rapidly kills infected plants (PCARRD 1988). The pathogen is rapidly spread by contaminated tools, insects and water (PCARRD 1988). Wounds caused by standard banana production practices, including frequent de-leafing and de-suckering, promote the spread of the disease, particularly in the absence of ongoing rigorous control measures (Stover 1972).

Infection with the pathogen causes premature ripening and fruit rot and ultimately leads to the death of plants (Stover 1972; Wardlaw 1972; Raymundo et al 1998; BPI 2001). There are no cultivars of commercial crops known to be resistant to Moko (Buddenhagen 1987; Sequeira 1998). Once the Moko pathogen has become established in banana plantations it is unlikely that it could be eradicated. This would result in permanent changes in plantation management practices and ongoing production losses in Australia.

High losses in Cavendish production have been reported where new plantations were established in forest clearings among heliconias that showed symptoms of Moko infection (Sequeira and Avere 1961; Black and Delbeke 1991).

A Moko disease incident in Australia is likely to have a significant impact, as there has been no previous experience of bacterial disease affecting banana production. Disease recognition and management practices would need to be developed and implemented. Current plantation management practices in the Australian banana production industry differ significantly from production systems that are based on a much larger manual labour force, such as in Central and South America and the Philippines. The higher level of mechanisation of the Australian banana industry is expected to result in a more rapid and widespread impact on plant life or health, compared to plantations managed predominantly with manual labour.

The ability of the Moko pathogen to persist in asymptomatic hosts, and its spread by irrigation and flood water, would exacerbate the effects of a potential incursion in Australia's banana production areas, given that the major production area of Far North Queensland is subject to periodic flooding (Peasley 2006a).

Favourable climatic conditions for the establishment and spread of Moko occur all year round in almost all Australian commercial banana and heliconia cut flower production areas. Banana and heliconia regions in south-eastern Queensland and northern New South Wales are the exception, as favourable conditions for the establishment and spread of Moko may only occur for part of the year.

Overall, the likely direct impact of Moko in terms of plant production losses is considered 'highly significant' at the regional level. The rating assigned to this criterion is therefore **F**.

#### *Human life or health – A*

The direct impacts on human life or health are unlikely to be discernible at all levels and the rating assigned to this criterion is therefore **A**.

#### *Any other aspects of the environment not covered above – C*

This criterion addresses the possible direct impact of pests on 'other aspects' of the natural or built environment, such as the physical and biological environment.

Although native banana species (*M. acuminata* subsp. *banksii*, *M. jackeyi* and *M. fitzalanii*) could potentially become infected with Moko, the impact of infection is unknown. However, a reduction in the number of native banana plants may occur if Moko was to become established in an area. Native bananas in Australia are generally disease free, either due to their low density and isolation from commercial banana plantations or some level of resistance or tolerance to disease. In comparison, plant production based on monoculture is more likely to experience pest and disease epidemics.

Overall, the likely direct impact of Moko on other aspects of the environment is considered to be 'Significant' at the local level and the rating assigned to this criterion is therefore **C**.

### **9.14.2 Indirect impact**

#### *Control or eradication – E*

An eradication program for Moko could be initiated when first detected under the Emergency Plant Pest Deed. Eradication programs and associated costs would involve joint participation from all levels of government and industry. Costs of an eradication campaign will depend on the severity and duration of an outbreak, and are likely to run into tens of millions of dollars per year for a number of years if the incursion is not detected immediately. Peasley (2006a) suggests that a successful eradication or control program for the pathogen in the Far North Queensland production area would

likely be unsuccessful, due to the high mechanisation of Australian production. If Moko disease occurred in Queensland, the controls that are likely to be applied are prescribed under the *Plant Protection Regulation 2002*. These controls currently include restrictions on the movement of *Musa* species planting material and fruit.

Moko is managed in overseas Cavendish plantations using an integrated approach. This consists of de-belling and covering the developing fruit with bunch covers, together with sanitation, fallowing, weed control and chemical control for spot eradication, and regular monitoring and surveillance visually checking for disease symptoms. These combined practices for the management and control of Moko in commercial Cavendish export plantations are employed in Central America (Stover and Simmonds 1987) and the Philippines (BPI 2002b).

In Philippine banana plantations, Moko-infected mats are dug up and destroyed, including those within a 5 m radius of the infected plant. The site then is fenced and may be left fallow for 6–12 months, or fumigated (under tarpaulins) and replanted after three weeks or more (BPI 2001).

Regular crop monitoring and surveillance activities associated with the control or eradication of Moko would result in significant costs to the Australian banana industry, considering the small size of Australian operations coupled with higher labour and consultancy costs. In the event of an incursion, production costs are likely to increase that would therefore affect the long-term economic viability of the majority of plantation holdings. A change in production systems is also likely to be required due to increase in plantation hygiene and regular sanitation for both banana fruit and heliconia cut flower production.

Abdalla and Sheales (2005) demonstrated that commodities with low demand-elasticity (such as bananas) experience a higher economic impact on the industry, especially in the short-term, with increased production costs. The direct impact of the disease on heliconias is difficult to estimate.

Overall, the indirect control or eradication consequences program for Moko is considered ‘highly significant’ at the district level. The rating assigned to this criterion is therefore **E**.

#### ***Domestic trade – D***

Almost all banana fruit (99.9%) produced in Australia is sold domestically (HAL 2004). There are currently standard interstate movement requirements applied to the movement of banana fruit and heliconia cut flowers and planting material between all states and territories. An incursion of the Moko bacterium in Australia near Cairns in 1989 resulted in quarantine restrictions on the movement of heliconia plants and cut flowers from the affected nursery (Akiew and Hyde 1993).

The presence of Moko in commercial plantations may result in the restriction of the sale and movement of banana fruit. These restrictions are already prescribed for Queensland under the *Plant Protection Regulation 2002*. Restrictions currently apply to planting material infected with banana diseases, such as Panama disease and bunchy top, and could be used for Moko. Similar restrictions are likely to apply to the sale and movement of heliconia planting material and to the heliconia cut flower industry.

The banana industry is important to the economies of local areas in New South Wales, Queensland, Western Australia and the Northern Territory – most notably in northern Queensland. In the event of an incursion the restriction on the sale and movement of banana fruit from infected areas would reduce the income of directly-affected producers and have a flow-on effect to rural communities, such as increased unemployment (refer to *Communities*, below).

The indirect consequences on domestic trade are considered to be ‘significant’ at the district level. The rating assigned to this criterion is therefore **D**.



### *International trade – A*

Australia exports only small quantities of banana fruit to specialty markets (HAL 2004). The presence of Moko is therefore unlikely to impact on international trade and is unlikely to be discernible at all levels. The rating assigned to this criterion is therefore **A**.

### *Environment – A*

Commercial banana production uses intensive cultivation practices. Although additional pesticide applications may be required for the control or eradication of Moko in commercial banana plantations (including weed management), it is unlikely that additional usage would impact on the environment. Measures to control Moko in heliconias would be the same as for bananas.

Overall, the indirect impacts on the environment are unlikely to be discernible at all levels. The rating assigned to this criterion is therefore **A**.

### *Communities – D*

One of the considerations within this criterion is the potential indirect impact of Moko on rural economic viability, due to the persistent nature of Moko and the effect on plant life or health. The effects of Moko on changes to horticultural practices have already been considered under new or modified controls (see above).

Bananas are grown as a high intensity crop. In 2002–03 approximately 265,000 tonnes of bananas were grown on 14,000 hectares Australia-wide, of which 90% were produced in northern Queensland. The remaining 10% were produced in New South Wales, south-eastern Queensland, Western Australia (Carnarvon and Kununurra) and the Northern Territory (Darwin). The gross value of the Australian banana industry in 2003–04 was \$286 million (DAFF 2005; refer to Section 2.3.6).

The north Queensland banana industry is concentrated in the Tully and Innisfail areas which are within the Cardwell and Johnstone shires. These shires account for 90% of the north Queensland banana production and gross value, and generate about 30% (~1500 people) and 25% (~1900 people) of all employment in the agricultural sector in the Cardwell and Johnstone shires, respectively (OGS 2005b, 2005c).

An incursion of Moko is likely to result in irreversible effects on the banana industry, as eradication of the pathogen, once it has established, is almost impossible to achieve. Growers will experience higher costs and lower returns which may result in industry restructuring. This would have a negative impact on agriculturally related employment within the local community where bananas are grown.

Gross regional product multipliers in the range of 1.5–2 for banana growing areas in north-eastern Australia suggest that a downturn in banana production will have a flow-on effect on other local industries and their employees (CEPM 2002; OGS 2002; Growcom 2004). A downturn in banana production would have a substantial economic and social impact on the Johnstone and Cardwell shires where agricultural production constitutes the dominant industry (Cummings 2002).

Overall, the indirect effects on communities are considered to be ‘highly significant’ at the local level. The rating assigned to this criterion is therefore **D**.

## **9.14.3 Overall consequences of Moko**

*The overall consequences to the Australian community of the entry, establishment and spread of Moko as a result of trade in mature hard green bananas from the Philippines: **High**.*

Table 9.17 provides a summary of the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of Moko within Australia.

The direct and indirect impacts of Moko shown in Table 9.17 were combined using the decision rules discussed in Chapter 6. It follows from these decision rules that where the consequences of a pest with respect to one or more criteria are F, the overall consequences are considered to be ‘high’. Therefore, the overall consequences of Moko are considered to be ‘high’.

**Table 9.17 Consequence assessment for Moko is high**

Criteria	National	Regional	District	Local	Impact
Plant life or health	Significant	Highly significant	Highly Significant	Highly significant	F
Human life or health	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Any other aspects of the environment	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
Control or eradication	Minor	Significant	Highly significant	Highly significant	E
Domestic trade	Unlikely to be discernible	Minor	Significant	Highly significant	D
International trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Communities	Unlikely to be discernible	Minor	Significant	Highly significant	D

## 9.15 Unrestricted risk

The median PEES values for each scenario were added to give an indication of the overall PEES and the relative contribution of the individual scenarios, as shown in the top half of Table 9.18. The overall estimate of PEES was obtained by combining the six scenarios into a single model and re-running the simulation. The resultant PEES of  $1.60E-01$  was combined with the overall consequence (‘high’) using the decision rules in Table 6.2. The conclusion was that the unrestricted risk for Moko associated with the importation of mature hard green bananas from the Philippines exceeds Australia’s ALOP.

**Table 9.18 Unrestricted risk for Moko**

Probability of entry, establishment and spread	Unrestricted scenario	Proportion of PEES
(A) Insects, bananas and heliconias	$3.95E-09$	<0.01%
(A) Insects, asymptomatic carriers	$1.20E-07$	<0.01%
(B) Leaching, bananas and heliconias	$1.88E-02$	12.16%
(B) Leaching, asymptomatic carriers	$1.17E-01$	75.50%
(C) Machinery, vehicles and implements	$1.51E-03$	0.98%
(D) Cutting, mowing and slashing	$1.76E-02$	11.36%
All scenarios total	$1.55E-01$	100.00%
Overall PEES	$1.60E-01$	
Consequence	High	
Risk	Exceeds ALOP (Moderate)	

## 9.16 Risk management for Moko

The unrestricted risk of Moko exceeds Australia's ALOP when the overall probability of entry, establishment and spread (PEES) is combined with the overall consequence. Risk mitigation measures would therefore be required to lower this rating to achieve Australia's ALOP.

The risk mitigation measures will need to be effective in the areas of Mindanao proposed for export of Cavendish bananas to Australia.

The pathways considered in this analysis showed that Moko could enter, establish and spread in Australia from imported banana fruit that have been infected with the Moko bacterium.

A range of potential phytosanitary risk management measures at various steps in the import pathway may be considered to reduce the risk to an acceptable level.

The Philippines Government will be required to demonstrate to Australia's satisfaction that the strength of the proposed phytosanitary risk management measures, or of a combination of phytosanitary risk management measures (a systems approach), will reduce the number of Moko bacteria infecting banana fruit waste.

The efficacy of any treatment(s) to reduce the number of bacteria would need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

The Philippines Government will be required to prove and verify the effectiveness of measures, as indicated in this section and Chapter 20. All proposed measures must be monitored, verified and audited by trained BPI and AQIS staff as specified in Chapter 20.

### *Summary of scenarios*

The risk scenarios used to determine the unrestricted probability of entry, establishment and spread of Moko in this analysis considered the number of bacteria infecting banana fruit and relate to the successful transfer of Moko bacteria from infected banana fruit waste to suitable host plants:

Scenario A: Insects – transfer of Moko bacteria by insects from banana waste to host plants

Scenario B: Leaching – transfer of Moko bacteria in free water (including irrigation and floodwater) from banana waste through soil to host plants

Scenario C: Movement of machinery, vehicles and implements – transfer of Moko bacteria by vehicles and implements from banana waste to host plants

Scenario D: Cutting, mowing and slashing – transfer of Moko bacteria by mowing, cutting and slashing that carries bacteria from waste to host plants.

The IRA team, taking into consideration the best available information and taking account of expert judgement, determined the values that were used in the model to aid the evaluation of the unrestricted probability of entry, establishment and spread of Moko in this analysis (Table 9.18).

The analysis of unrestricted risk determined that in the order of  $10^6$  bacteria cells/gram of infected banana tissue (Section 9.2.4) would be associated with banana fruit imported from the Philippines. Any risk management measure would only have an effect on the Importation steps (Imp2, Imp4 and Imp5) and have no effect on any of the transfer scenarios of the analysis. Risk mitigation measures would need to reduce the proportion of infected clusters.

### *Pest threshold to achieve Australia's ALOP*

If the unrestricted risk exceeds Australia's ALOP, the risk assessment then considers what risk management measures might be available to reduce the risk to achieve Australia's ALOP (Section

6.3). Because the overall consequences rating is ‘high’ the PEES would be required to be less than 0.001 (Table 6.2).

The use of a quantitative approach to determining PEES allows the restricted PEES to be expressed in terms of a pest threshold which is the maximum number of pests and/or the maximum level of disease associated with mature hard green Cavendish bananas imported into Australia from the Philippines that would achieve Australia’s ALOP.

The overall restricted PEES were calculated for a pest threshold, as shown in Table 9.19. Any measures that would reduce the level of infected clusters after packing to below 2.5 per million ( $2.50\text{E}-06$ ) would achieve Australia’s ALOP.

**Table 9.19 Probability of entry, establishment and spread when the pest threshold is met.**

(The table is based on there being  $10^6$  bacterial cells/gram of infected banana fruit tissue.)

Proportion of clusters that remain infected after processing	PEES
2.50E-06	0.00099

Because the consequences of Moko were rated as ‘High’, to achieve Australia’s ALOP any proposed phytosanitary risk management measures (or system of measures) will need to reduce the PEES to less than 0.001 (giving the restricted PEES).

The calculation of the restricted PEES for the importation pathway used values for Imp2, Imp4 and Imp5 that would result in the specified threshold level being presented after processing and was done by combining the six individual simulations into a single simulation.

The value shown in Table 9.19 would, when inserted in the model with all values in the relevant sections of Part B of the report, considered in the context of the report as a whole, and combined with the consequences of “High” (Section 9.14), achieve Australia’s ALOP.

#### ***Standard commercial practice and phytosanitary risk management***

Much of the key information provided by the Philippines Government is based on standard commercial agronomic practice in the Philippines. Some aspects of standard agronomic practice are discussed further in the sections on operational requirements (Chapter 20 and Part C). One of the aims of standard commercial agronomic practice is that bananas for export are to be free of leaf and floral material and meet commercial export standards.

Where compliance with standard commercial practises is required, by Australia, for the effective implementation of phytosanitary risk management measures, such practises will be made mandatory and be required to be verifiable and auditable.

#### **9.16.1 Potential phytosanitary risk management measures**

A range of potential phytosanitary risk management measures may be considered if they can be demonstrated, to Australia’s satisfaction, to reduce the unrestricted risk and achieve Australia’s ALOP. Potential phytosanitary risk management measures may include, but are not limited to:

- pest free areas, pest free places of production and pest free production sites
- areas of low pest prevalence
- visual inspection for discolouration of the pseudostem and peduncle followed by corrective action
- post-harvest chlorine treatment.

#### *Pest free areas, pest free places of production and pest free production sites*

Sourcing bananas for export from areas established, maintained and verified free from Moko (pest free areas or pest free places of production or pest free production sites), in accordance with the guidelines outlined in ISPM 4: *Requirements for the establishment of pest free areas* (FAO 1996), ISPM 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO 1999) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007), would reduce the values associated with several steps on the importation pathway and achieve Australia's ALOP.

It may be difficult to demonstrate pest free areas, pest free places of production and pest free production sites to Australia's satisfaction given that Moko is reported to be widely distributed throughout the Cavendish export plantations on Mindanao Island. Extensive detection and delineating surveys, including inspection of alternative host plants, would be required to confirm the pest free status of these risk management options.

Currently, the establishment and maintenance of pest free areas, pest free places of production and pest free production sites may not represent a technically feasible management option, given that there are no restrictions on, for example, the movement of planting material, banana fruit or contaminated machinery within the Philippines (BPI 2002b). As well, there is no means of restricting insect transmission.

#### *Areas of low pest prevalence*

An area of low pest prevalence (ALPP) could be established and maintained following the guidelines described in ISPM 22: *Requirements for the establishment of areas of low pest prevalence* (FAO 2005a) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007). An area of low Moko disease prevalence could be a place of production (a banana plantation managed as a single unit) or a production site (a designated block within a plantation) for which low prevalence of Moko is established, maintained and verified by BPI and audited by AQIS. This measure would reduce the values associated with several steps on the import pathway and thereby mitigate the risk.

When establishing an ALPP, the Philippines would have to meet a number of requirements, including:

- establishing the specified level of the relevant pest to sufficient precision
- recording and maintaining surveillance and control activities for a sufficient number of years
- identifying and demonstrating that potential infection/infestation pathways have been regulated to maintain the ALPP.

#### *Visual inspection for discolouration of pseudostem and peduncle followed by corrective action*

Inspection of harvested banana bunches for vascular discolouration of the pseudostem and peduncle, and for premature ripening of fruit, at either harvesting or processing could be used to identify Moko-infected fruit in the export pathway. Subsequent corrective action of immediately removing bunches showing visible signs of vascular discolouration would constitute a risk mitigation measure.

Moko infection causes vascular discolouration irrespective of whether external disease symptoms develop. However, the degree of discolouration varies from cream or yellow through to reddish-brown, brown and black. This colour variation is likely to depend on the time elapsed since infection and the severity of the infection. Consequently, there will be instances when there is no evident

vascular discolouration of infected plants because of the ‘lag period’ between when infection with Moko occurs and when the first signs of vascular discolouration become evident. It is acknowledged that there are other diseases and physiological conditions that may cause similar discoloration. This could result in the rejection of some bunches that are not infected with Moko.

While quality assurance staff may not detect all occurrences of discolouration, it is considered that visual inspection for vascular discolouration of the pseudostem and peduncle would reduce the risk of processing ‘symptomless infected’ bunches.

### ***Post-harvest chlorine treatment***

Washing fruit in chlorinated water is a widely used post-harvest treatment to reduce the external microbial load of fruit and vegetables. The use of chlorinated water in wash tanks and flotation tanks during processing of banana fruit would reduce some of the risk associated with new fruit infections through the cushions of freshly separated clusters.

Chlorine is known to have strong biocidal properties against a wide range of organisms (Dychdala 1991; USEPA 1999). However, the efficacy of chlorinated wash solutions can reduce quickly in the presence of high organic matter content and sub-optimal pH levels (Ecowise Environmental 2005).

As described under the Moko risk scenario in Section 9.2.5, all fruit passing through the wash tanks and flotation tanks at the packing station (Imp5) could be exposed to infection through the severed cushion ends if the tank water becomes contaminated with Moko bacteria from the immersion of previously infected fruit. Reducing the Moko bacterial load in wash water and flotation water during processing would reduce the risk.

Water treated with chlorine would reduce the risk of new Moko infections through the cushions of freshly separated clusters or hands that are immersed into potentially contaminated water. However, it is acknowledged that chlorine has poor penetrating powers. Chlorine treatment would not be fully effective to prevent bacteria being taken up into the vascular tissue of cushions and would have no effect against pre-existing symptomless infection of fruit.

Having taken all of the above information into consideration, the IRA team concluded that water treated with chlorine may reduce the risk of new fruit infection. This proposed measure would be subject to BPI demonstrating the efficacy of the proposed treatment at both their fixed and mobile packing stations. To date, the efficacy of chlorine treatment of banana fruit has not been demonstrated under commercial conditions.

### ***Systems approach***

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve the ALOP, as described in ISPM 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.

### ***Other potential risk management measures***

The IRA team acknowledges that there are potentially other possible risk management measures, including testing methods for the detection of asymptomatic fruit infection. Based on the available information relevant to Moko, the IRA team was unable to adequately assess the feasibility of these alternatives. If additional relevant information is provided that suggests alternative measures may be capable of reducing the risks to achieve Australia’s ALOP, the supporting evidence will be considered on a case-by-case basis.

### 9.16.2 Application of potential risk management measures

The IRA process requires the consideration, and recommendation, of whether there are risk mitigation measures, used either alone or in combination that would reduce any risk that exceeds Australia's ALOP, identified through pest risk analysis, to a level that achieves ALOP. This section considers what effect the measures proposed in the previous section might have on the proportion of clusters infected with Moko.

To achieve Australia's ALOP, the pest threshold in Table 9.19 must be met. Since the pest threshold is specified as a proportion of clusters, the reduction in pest levels required to meet the threshold will depend on the level of disease present. Efficacy percentages have been included in this section as indicative examples and were developed considering the pest prevalence in the Philippines as described in this report.

Based on the average level of infected clusters determined earlier in this chapter (approximately 5 per 10,000 for the unrestricted value), in order to achieve Australia's ALOP, measures must reduce the number of banana clusters infected with Moko after processing by at least 99.5% (from approximately 505 per million for the assessed unrestricted value to below 2.5 per million). The precise reduction needed would depend on the actual pest levels occurring in the Philippines.

The Philippines Government would be required to demonstrate that any proposed measures would be able to achieve the specified efficacy under commercial conditions.

**Table 9.20 Example effects of mitigation measures on pest levels**

(The table shows example efficacies of measures considered feasible at reducing the proportion of infected clusters determined in the analysis of unrestricted risk. In this example the combination of ALPP and visual inspection (followed by corrective action) reduces the pest level to 1.2 infected clusters per million bunches which achieves Australia's ALOP.)

Measure	Example efficacy	Pest level (number of infected clusters per million)	Effect
No Measure		505	-
Pest free areas, pest free places of production and pest free production sites		-	Not considered feasible
Post-harvest chlorine treatment			Minimal effect
Areas of Low Pest Prevalence (ALPP)	0.03 plants infected per ha per year	6.1	Exceeds ALOP
Visual inspection for discolouration of the pseudostem and peduncle followed by corrective action (visual inspection)	80%	101	Exceeds ALOP
ALPP and visual inspection	As above	1.2	Achieves ALOP

#### *Pest free areas, pest free places of production and pest free production sites*

Given the wide distribution of Moko in the Philippines, the IRA team considered that mitigation based on disease freedom in pest free areas, pest free places of production and pest free production sites would be extremely difficult to implement.

Also, the early stages of Moko infection on banana plants are difficult to detect and are easily confused with other disease symptoms such as fusarium wilt. Similarly, the establishment and maintenance of pest free status would need to be relevant to the biology of Moko, including its means of spread.

As noted above, the establishment and maintenance of pest free areas, pest free places of production and pest free production sites are unlikely to represent a technically feasible management option, given that there are no restrictions on, for example, the movement of planting material, banana fruit or

contaminated machinery within the Philippines (BPI 2002b). As well, there is no means of restricting insect transmission.

Without precluding this measure as an option, the Philippines Government may use the measure was not considered feasible by the IRA team.

#### *Areas of low pest prevalence*

The IRA team considered that ALPP would be a risk mitigation measure that could be implemented and would reduce the level of pests. ALPP would be expected to reduce the number of infected banana fruit.

Inspection of Cavendish export plantations would need to be done at regular specified intervals throughout the year. Recognition of an ALPP would have an influence on the values for Imp2 and Imp5 on the importation pathway.

Sourcing of bananas from low pest prevalence areas would reduce the proportion of infected clusters, the evaluation of which is described at the Imp2 step of Section 9.3.2. An ALPP would also reduce the number of infected clusters contaminated at step Imp 5.

In the example given in Table 9.20 the ALPP is based on 0.03 cases per hectare per year.

#### *Post-harvest chlorine treatment*

The IRA team considered that a post-harvest chlorine treatment may reduce number of bacteria in the wash tank and available for uptake (Imp5).

As noted above, washing fruit in chlorinated water is a widely used post-harvest treatment to reduce the external microbial load of fruit and vegetables. The use of chlorinated water in wash tanks and flotation tanks during processing of banana fruit would reduce some of the risk associated with new fruit infections through the cushions of freshly separated clusters.

BPI (2002b) proposed to treat the water held in wash tanks and flotation tanks with chlorine. BPI provided results from an *in vitro* study reporting on the efficacy of chlorine as a post-harvest treatment of banana fruit. All treatment rates (from 1 ppm–16 ppm of chlorine) killed Moko bacteria and no bacterial growth was observed in comparison to non-chlorinated water (BPI 2002b).

Having taken all of the information presented in this section regarding post harvest chlorine treatment into consideration, the IRA team concluded that water treated with chlorine may reduce the risk of new fruit infection. This proposed measure would be subject to BPI demonstrating the efficacy of the proposed treatment at both their fixed and mobile packing stations. To date, the efficacy of chlorine treatment of banana fruit has not been demonstrated under commercial conditions.

Post-harvest chlorine treatment would only reduce bacteria levels due to contamination in the wash tank at step Imp5. Since this contamination only contributes a small fraction to the overall pest level, the IRA team considers that this measure, without precluding it as an option the Philippines Government may use, to be of minimal benefit.

#### *Visual inspection for discolouration of pseudostem and peduncle followed by corrective action*

Inspection of harvested banana bunches for vascular discolouration of the pseudostem and peduncle, and for premature ripening of fruit, at either harvesting or processing could be used to identify Moko-infected fruit in the export pathway. Subsequent corrective action of immediately removing bunches showing visible signs of vascular discolouration would constitute a risk mitigation measure.

As noted above, it was considered that examinations of the cut pseudostem and the cut peduncle of banana bunches when harvested for export to Australia would be a means of detecting at least a



proportion of Moko-infected banana bunches that are not expressing externally visible symptoms, and thus be a means of reducing the likelihood of importing asymptomatic fruit. Inspection for internal Moko symptoms in freshly cut cross-sections of the pseudostem and peduncle could be conducted in the field at bunch harvest (Imp2) and for the peduncle again within the packing station (Imp4). All bunches that show visible signs of vascular discolouration would be required to be immediately removed from the export pathway, either in the field or before de-handing. These inspections would be in addition to the routine quality assurance regime targeted at ensuring the removal of fruit with blemishes, obvious distortion in shape, premature ripening and visible splits. There will be a corresponding reduction to the value of Imp5.

In the example given in Table 9.20 visual inspection for discolouration of pseudostem and peduncle followed by corrective action reduces the proportion of infected clusters at Imp2 (and Imp5) by 80%.

### *Systems approach*

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve Australia's ALOP. The concept of systems approaches are more fully described in ISPM 14: *The use of integrated measures in a systems approach for pest risk management* (FAO 2002).

Possible systems approaches include:

- Area of Low Pest Prevalence and visual inspection for vascular discolouration of the pseudostem and peduncle followed by corrective action
- Area of Low Pest Prevalence and post-harvest chlorine treatment
- visual inspection for vascular discolouration of the pseudostem and peduncle followed by corrective action and post harvest chlorine treatment
- Area of Low Pest Prevalence, visual inspection for vascular discolouration of the pseudostem and peduncle followed by corrective action and post harvest chlorine treatment.

### *Conclusion*

Example pest reduction levels for those measures considered feasible are provided in Table 9.20. The values given, which are based on the level of pest assessed to be currently present in the Philippines, as contained in the report, are included as examples and do not imply that such a level of reduction will be achieved. The strength of any mitigation measure will depend on how the measure is implemented. As mentioned previously, the Philippines Government would be required to demonstrate the effect of any proposed mitigation measures using laboratory and/or field trials and under commercial conditions. Table 9.20 suggests that no single feasible measure would be adequate to reduce the risk sufficiently, but that there could be combinations of measures that would achieve Australia's ALOP.

### **9.16.3 Risk management conclusion**

The Philippines Government would be required to provide evidence to Australian authorities on the efficacy of any phytosanitary risk management measures proposed to reduce the level of the proportion of banana clusters infected with Moko bacteria to levels that would achieve Australia's ALOP.

Any proposed phytosanitary risk management measures would be required to be demonstrated, to Australia's satisfaction, by laboratory experiments and/or field trials and under commercial conditions and would need to be completed to provide supporting evidence, including that:

- The strength of proposed phytosanitary risk management measures, or combinations of phytosanitary risk management measures (a systems approach), is sufficient to reduce the proportion of clusters infected with Moko bacteria to the levels required to meet Australia's ALOP

- Procedures for visual inspection for vascular discolouration of the pseudostem and peduncle including the detection and examination of cut pseudostem and peduncles are effective
- Areas of Low Pest Prevalence are effective and the level of efficacy can be measured by procedures such as sampling.

Other evidence may also be required, depending on the specific risk management measures proposed for consideration.

Further details of the proposed risk management regime are provided in Chapter 20.

## 10. Black Sigatoka

### 10.1 Introduction

Black Sigatoka is a leaf spot disease of bananas and plantains caused by the ascomycete fungus *Mycosphaerella fijiensis* (Carlier et al 2000). It occurs in both the Philippines and Australia but whereas it is widespread in the Philippines (Carlier et al 2000; BPI 2002b) its distribution in Australia is limited to remote areas in Torres Strait and Cape York Peninsula (Allen and Peterson 1999; Peterson et al 2003). It is not present in any areas of Australia where bananas are produced commercially. The disease is under official control in all banana-growing areas of Australia and measures are in place to restrict the marketing of fruit should the need arise.

Cavendish bananas cannot be grown commercially in wet tropical areas unless black Sigatoka is controlled. This is achieved by a combination of leaf pruning to remove diseased leaf tissue and the application of fungicides at regular intervals. In the Philippines, these activities are carried out routinely throughout the year. Between 30–45 fungicide sprays are applied per year, depending on weather conditions and the results of disease monitoring. It is generally accepted (Carlier et al 2000) that the degree of control required for black Sigatoka is greater than that for yellow Sigatoka disease (*M. musicola*), which is already established in Australia (Peterson et al 2003). In contrast to tropical areas, it is not clear how black Sigatoka would affect bananas in subtropical areas of Australia, as it is often out-competed by yellow Sigatoka in these situations (Carlier et al 2000).

### 10.2 Biology

#### 10.2.1 Host plants

Black Sigatoka infects a range of *Musa* species and cultivars in the Eumusa group of edible bananas and plantains in many countries (Meredith and Lawrence 1970; Gauhl 1994; Carlier et al 2000). It has also been reported to infect *Heliconia psittacorum* in Brazil (Gasparotto et al 2005).

The pathogen is capable of germination and growth on the surface of many *Musa* species, but its entry through stomates and growth in tissues is restricted by a hypersensitive-like response in most *Musa* species (Meredith and Lawrence 1970; Fouré 1994). It causes disease on Cavendish bananas, which is the main variety in Australian commercial plantations and on Lady Finger and Ducasse bananas, which are the main varieties in home gardens.

Two cultivars of the native species *M. acuminata* subsp. *banksii* have been recorded as susceptible in Cameroon (Carlier et al 2000) and in Papua New Guinea (ABGC 2007). It appears that this species would be susceptible in Australia. The susceptibility of native *M. jackeyi* and *M. fitzalanii* in Australia is not known but these two species are also considered susceptible in this analysis.

Species such as *M. textilis* (abacá), *M. coccinea* and *M. velutina*, and *Ensete ventricosum* or other species in the order Zingiberales are not affected (Gauhl 1994).

On the basis of available evidence, *M. fijiensis* present in the Philippines is considered to affect bananas, plantains and some native *Musa* and *Heliconia* species.

#### 10.2.2 Disease symptoms and effects on infected host plants

Black Sigatoka primarily infects the leaf lamina, and to a lesser extent the midrib tissue. It has been found to cause symptoms to a limited extent on fruit skin of plantain (Cedano et al 2000) and Cavendish bananas (Fullerton 2006), but has not been reported to produce pseudothecia in infected fruit skin. The pathogen has not been reported to infect the flowers, flower bracts, pseudostem, corm

or roots of Cavendish bananas (Carlier et al 2000), although there appears to have been no studies specifically directed at finding infection in these tissues. It is considered that the petals, if infected, would naturally shrivel well before infection was established (RA Fullerton, Plant Pathologist, New Zealand HortResearch, pers comm, 10 May 2001).

Six different stages of disease development have been identified (Meredith and Lawrence 1969; Fouré 1987):

- initial symptoms of white marks to red-brown specks on the lower surface of the leaf (stage 1)
- streaks of 20 × 2 mm that change in colour from red-brown to dark brown (stages 2, 3 and 4)
- spot stages in which the symptoms appear on the upper leaf surface, the lesion colour changes to black and the centre dries out (stages 5 and 6).

The fungal conidiophores and conidia are formed in stages 2, 3 and 4, followed by spermatogonia and spermatia at stage 4, and pseudothecia and ascospores in stages 5 and 6. All stages of disease development can be seen on a single leaf and, in severe cases, the lesions coalesce, causing the sudden death of large sections of the leaf surface.

In its most severe form, black Sigatoka can kill all the leaves and bunches will fail to mature (Meredith and Lawrence 1969; Carlier et al 2000). In less severe cases, the bunch size and fruit quality will be affected.

### 10.2.3 Dispersal

Black Sigatoka can be spread on infected leaves attached to banana planting material or on infected leaves used as padding for the transport of fruit (Carlier et al 2000). Infection of leaves attached to planting material is probably the main means by which the disease is introduced to new areas. However, the principal sources of inoculum within plantations are infected leaves still hanging on the plant or those recently placed on the ground. There is no mention in the literature (Carlier et al 2000) of fruit waste being a source of black Sigatoka inoculum in banana plantations but it is expected that inoculum on fruit waste would be spread by water, air and animal vectors in a manner similar to dispersal from leaves on the ground.

Two spore types are produced in black Sigatoka lesions that aid in direct dispersal of the pathogen:

- Conidia are formed at the tip of conidiophores in the early stages of disease development (stages 2-4). They stand upright initially at an angle of 45-90° (Meredith et al 1973) but lay prone on surfaces after dehiscence. There may be 13-44 conidiophores per mm<sup>2</sup> of lesion surface on leaves that have not been sprayed with fungicides (Meredith et al 1973; Fouré and Moreau 1992). Each conidiophore can produce up to 4 conidia and therefore young black Sigatoka lesions can produce 52-132 conidia per mm<sup>2</sup> of lesion surface. These conidia can survive on various surfaces for several weeks if kept dry (Gasparotto et al. 2000).
- Ascospores are formed in pseudothecia embedded in the host tissue. The pseudothecia are found in black Sigatoka lesions with necrotic centres (stages 5-6) and they become apparent from 20-40 days after infection occurs, depending on the severity of infection and the environmental conditions (Carlier et al 2000). However, they are initiated at an earlier stage of symptom development when spermatia of one mating type interact with trichogynes of a compatible mating type. The production of spermatia, and therefore the initiation of pseudothecia, reaches a peak about 14 days after infection occurs (Mourichon and Zapater 1990), and pseudothecia with ascospores are found about 35 days after fertilization (Etebu et al 2003). There may be an average of 0.3-6.7 pseudothecia formed per mm<sup>2</sup> of lesion surface area in leaves that have not been sprayed with fungicides (Carlier et al 2000) or possibly as many as 8 per mm<sup>2</sup> over both leaf surfaces (Burt et al 1999). Each pseudothecium may contain 10-27 asci (Stover 1972). Given that each ascus produces 8 ascospores, a pseudothecium may therefore produce a total of 80-216 ascospores. If it is assumed that there are 0.3-8 pseudothecia per mm<sup>2</sup>, it is expected that 24-

1728 ascospores could be produced per mm<sup>2</sup> of necrotic leaf tissue. Although ascospores released from aged pseudothecia may not germinate (Stover 1971), it is assumed in this analysis that ascospores survive for a time similar to conidia.

Evidence for the transport and deposition of ascospores and conidia is reviewed in Part C. Both spore types can be disseminated in wind or water. A summary of relevant information appears below.

In the case of dispersal by wind

- *Conidia* are dislodged from conidiophores by strong winds (Gauhl 1994; Aylor 1990). They are transported by the prevailing wind and settle on any surface by direct impaction or by becoming involved with a falling water droplet (Aylor 1990). However, in the case of conidia on imported fruit and associated materials, it is considered that all spores would be laying prone on the surface and therefore not liable to uptake by wind.
- *Ascospores* are propelled 1-7 mm directly into the air following a thorough wetting of the pseudothecium (Aylor and Anagnostakis 1991). Release occurs in the early morning hours following dew at night or at any time of day following rain or irrigation (Meredith et al 1973; Gauhl 1994). The spores drift upwards through the leaf canopy and impact on any surface either directly or by becoming involved with a falling water droplet (Aylor and Sutton 1992). Ascospores can disperse effectively over many kilometres when they are released in vast numbers (Gregory 1968; Aylor 1990; Carlier et al 2000). The release of spores over a short time period from a small amount of waste lying at ground level is significantly different from that relating to the release from heavily infected leaves hanging on plants. Carlier (2004) studied the dispersal of *M. fijiensis* ascospores over a single sexual cycle and observed that the dispersal range was about 30 m. A similar result was obtained by Cox and Scherm (2001), who studied primary infections in blueberry caused by *Monilinia vaccinii-corymbosi* ascospores released from a small amount of inoculum buried in the ground. They found more than 95% of primary infections within 20 m of the source. This analysis assumes that 99% of spores released from waste on the ground will settle within a radius of 30 m from the source and considered that only very occasionally would spores travel further than 90 m from the source. It is also expected that most spores will rise to a height of less than 1 m within this distance (Aylor and Qiu 1996) but, for the purposes of this analysis, it is assumed that all surfaces within the impaction zone are subject to exposure.

In the case of dispersal by water –

- *Conidia* can be washed off surfaces and contaminate other surfaces (Stover 1972). Contamination may occur on lower canopy leaves and bunches in the field or fruit in flotation tanks at the packing station. The spores are also subject to water splash, in which falling water droplets pick up spores as they impact on wet surfaces and transport them in one or two secondary impaction events (Meredith 1973; Fitt et al 1989). Water splash dispersal is expected to transport conidia over distances of up to 2 metres in still air, or up to 10 metres downwind, but to a height of no more than 1 m. For the purposes of this analysis, the area of the impaction zone is considered to remain constant at 12.5 m<sup>2</sup>, while the impaction zone involves surfaces only within 1 m of the ground surface.
- *Ascospores* are expected to be washed off surfaces and splashed by water droplets in the same way as conidia. For the purposes of this analysis, the impaction zone is considered to be the same as conidia, that is, 12.5 m<sup>2</sup> by 1 m high.

Other means of spread during the initial entry of the disease involve transfer by insects and small animal vectors, or transfer on contaminated packaging materials.

#### 1) Insects and small animal vectors.

Conidia and ascospores could be translocated by insects and small animals as they move between contaminated surfaces and nearby host surfaces. Flying insects attracted to banana waste might carry spores over considerable distances, but the likelihood of an insect being attracted to banana

waste and subsequently alighting on susceptible host surface is considered to be quite remote. For the purposes of this analysis, the extent of secondary dispersal from fruit waste (including associated plant material) on small animal vectors is considered to be the same as dispersal by water above.

## 2) Contaminated packaging materials.

Spores may contaminate packaging materials and be dispersed subsequently as a result of rain splash or other vectors. However, the likelihood of this dispersal mechanism becoming significant is limited by the ultimate disposal of packaging through controlled waste systems. Infected plant material that becomes associated with packaging materials after banana fruit are packed is also subject to controlled waste management systems, although some may enter the environment directly. Although a large proportion of these packaging materials may be discarded through controlled waste facilities, it is assumed in this analysis that the spore contamination remains with the fruit and is discarded in the same manner as any banana fruit waste.

The various dispersal mechanisms will be considered under the risk scenarios described below.

### 10.2.4 Risk scenarios

Two scenarios are considered relevant to the entry, establishment and spread of black Sigatoka as a result of importing Philippine bananas. These are:

#### **Scenario A: contamination with infected plant material**

This scenario is associated with contamination of fruit clusters and packaging materials by pieces of leaf and floral tissue bearing fertile *M. fijiensis* pseudothecia. A fertile pseudothecium is defined as one capable of producing ascospores. It will become infertile after it has released the spores or been treated to prevent spore production. The contaminant plant material will eventually become waste lying on the ground or buried beneath other waste. It is expected that fertile pseudothecia can survive for at least 21 weeks in leaves hanging on plants, but for only 4–8 weeks when placed on the ground (Gauhl 1994).

#### *Leaf material*

The association of leaf material with banana fruit exported from the Philippines has been confirmed by observations in New Zealand. In September 2005, two pieces of leaf material were found in a randomly-selected carton of Grade 1 Philippine bananas offered for sale at Taupo, New Zealand (Figure 10.1). In December 2005, 351 cartons of Philippine bananas were examined at a wholesale outlet in Christchurch, New Zealand (Peterson et al 2006). Two pieces of leaf material were found in 30 cartons from one supplier and 16 pieces of leaf material were found in 321 cartons from a second supplier. One carton had six pieces of leaf material, one had two pieces and seven cartons had one piece each. The pieces of leaf material varied in size between 1–3 mm by 2–25 mm (assumed to be an average of 25 mm<sup>2</sup> in area) and were generally found between the fingers of the packed clusters of fruit. A total of 3597 clusters were packed in the cartons from the second supplier, indicating an average of 4.00E–03 leaf pieces per cluster. No other information has been found on how this estimate might vary between suppliers and different times of the year.

Mycelia of *M. fijiensis* were found to be associated with four of eleven pieces of the detected leaf material (Fullerton 2006) but no information was provided regarding the prevalence of *M. fijiensis* pseudothecia. It is expected that contaminant leaf material would have either no black Sigatoka infection or a range of symptoms depending on the degree of disease control in the plantation and recent infection history. Necrotic leaf tissue (Stages 5 and 6) would have pseudothecia at various stages of maturity, including some that had lost fertility as a result of having already released their ascospores. Material from recently infected leaves (stages 1 or 2) could develop fructifications post-harvest and particularly after the fruit arrives in Australia. The development of pseudothecia in leaf tissue with Stage 1, 2 or 3

lesions at the time that contamination occurs will depend on the presence of compatible mating types, and an environment suitable for spermatogonial development, recombination and pseudothecial development.

Some leaf litter present on the fruit at the time of packing will become detached during subsequent handling and transport, but will remain in the carton until the fruit is removed for display at the retail outlet (Figure 10.1). While much of the extraneous material in cartons is discarded at this stage through controlled waste facilities, the conservative assumption used in this analysis that the leaf litter is discarded in the same manner as any banana fruit waste.

#### *Floral material*

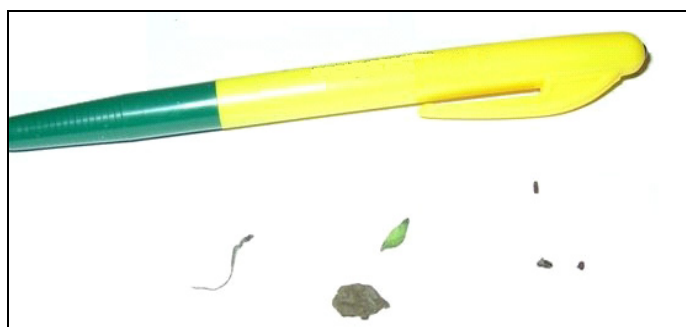
The Christchurch study (Peterson et al 2006) found floral remnants in 148 of the 351 examined cartons. A considerable, although unquantified, proportion of floral tissue had become detached and was found within the polythene liner at the base of the carton. A couple of floral remnant pieces were found wedged between fingers in fruit clusters. No information was provided on the prevalence of *M. fijiensis* pseudothecia on floral material detected in this study.

### **Scenario B: contamination with spores**

This scenario is associated with contamination of fruit clusters and packaging materials with conidia and ascospores of *M. fijiensis*.

It is possible that conidia and ascospores are washed off fruit during routine processing and subsequently contaminate cartons and plastic liners. As indicated above, a large proportion of these packaging materials may be discarded through controlled waste facilities but the conservative assumption used in this analysis that the spore contamination remains with the fruit and is discarded in the same manner as any banana fruit waste. It is expected that there will be several thousand conidia and ascospores on each finger at the time of harvest, possibly as high as 11,000 spores per finger as reported by Gasparotto et al (2000) for fruit from plants that were not subject to fungicide spraying. However, depending on the degree of disease control and the protection provided by bunch covers, it is expected that there will be considerable variability in the number of contaminant spores on fruit surfaces.

No evidence has been found to indicate that infection of fruit leads to the production of pseudothecia. The extent to which conidia are produced from endophytic infections in fruit has not been determined but it is considered that any production of conidia from endophytic infections would be subject to the same epidemiological factors as other conidia on the surface of fruit. As in Scenario A above, the remains of contaminated fruit clusters will eventually become waste lying on the ground or buried beneath other waste.



**Figure 10.1 Waste material from Philippine bananas in New Zealand**

*Extraneous material found in a randomly selected carton of 'Grade 1' Philippine bananas on sale at Taupo, New Zealand, on 23 September 2005, including a slice of fruit peel, two pieces of leaf material, a flower end and particles of soil (D Peasley, Horticultural Consultant, pers comm 10 October 2005).*

### **Excluded scenarios**

The role of insects and other animals in the spread of black Sigatoka was considered by the IRA team. Larger animals might move the waste to another location. Such a movement was considered to be part of the random disposal of the waste.

It is possible that insects and other animals might inadvertently pick up spores when coming in contact with waste and then carry the spores to a host. However, this was considered to be much less likely to spread the disease than Scenarios A and B above. This view is supported by the conclusions drawn for other diseases in this analysis. While the transfer of Moko bacteria by insects from a banana flower to a banana plant is a successful method of transmission, Table 9.6, Table 9.7 and Table 9.8 show that the likelihood of insects transmitting Moko from banana waste is extremely small and several orders of magnitude less than the other scenarios considered for Moko. In addition, this report shows that the likelihood of transmission of BBTV and BBrMV by aphids from waste is also extremely small, despite both viruses being dependant on aphids to transmit the disease from plant to plant. It was also considered that spores that were eaten by insects and animals would have an even smaller chance of causing infection than spores carried on external surfaces.

In light of these conclusions, the transfer of black Sigatoka spores by insects and animals was not considered further.

## **10.3 Importation – contamination with infected plant material (Scenario A)**

Importation starts with the sourcing of banana fruit from a plantation in the Philippines and finishes with the release of imported fruit at the Australian border. It is analysed in eight steps, as described in Section 5.2 (Chapter 5, Part B). This section provides the available evidence supporting the likelihood assessments for each step for scenario A.

Scenario A considers the likelihood of entry, establishment and spread resulting from infected plant material being attached to clusters of bananas.

Plant material is defined as pieces of leaf and floral tissue and the term 'infected' means that pseudothecia are present in the plant material. Whether or not these pseudothecia are capable of producing ascospores is considered at the point where host plants are exposed to the pathogen (Transfer considerations, Section 10.6).



### 10.3.1 The proportion of plantations where the pest is present

*Imp1: The proportion of plantations in which black Sigatoka is present is 1.*

Black Sigatoka occurs in Cavendish bananas throughout the Mindanao region from which export bananas are to be sourced (Carlier et al 2000; BPI 2002b). No information has been provided to indicate that any banana plantation is free of black Sigatoka, so it is assumed that black Sigatoka is certain to be present in a plantation from which a cluster of fruit is sourced.

Imp1 was therefore assigned a value of 1 for black Sigatoka infection.

### 10.3.2 Contamination level within an infected plantation

*Imp2: The proportion of clusters of harvested fruit contaminated with plant material bearing fertile pseudothecia of black Sigatoka is Uniform (min.  $2.00E-05$ ; max.  $3.42E-03$ ).*

In estimating the likelihood that clusters of banana fruit will be contaminated with plant material infected with black Sigatoka and also bearing pseudothecia, the following factors were considered:

1. the proportion of bunches contaminated with any plant material at harvest
2. the proportion of clusters contaminated with any plant material within contaminated bunches
3. the proportion of plant material pieces on contaminated clusters that are infected with black Sigatoka
4. the proportion of plant material pieces infected with black Sigatoka that contain fertile pseudothecia.

The proportions relevant to leaf and floral tissue were assessed separately at first and the estimates of Imp2 for each were then combined.

#### *Leaf material*

#### **Factor 1 – The proportion of bunches contaminated with any leaf material at harvest**

For infected leaf tissue to become associated with harvested fruit, pieces of leaf tissue need to be transferred to the bunch by contact, wind or vectors (such as rodents) and become lodged within the bunch. These pieces of leaf would not be readily detected by field workers, as bunches are covered with polythene bags until they reach the packing station.

The frequency with which leaf pieces become associated with banana bunches has not been quantified, but general observations of IRA team members in Australia and the Philippines indicate that it occurs with a low frequency: not more than 1 in 5 bunches and possibly as few as 1 in 20 bunches.

Factor 1 is estimated to be  $5.00E-02$  to  $2.00E-01$ .

#### **Factor 2 – The proportion of clusters contaminated with any leaf material within contaminated bunches**

It is unlikely that all clusters in a harvested bunch would be contaminated with leaf litter.

The frequency with which clusters are contaminated within bunches has not been quantified, but it is considered that the three top hands would be more prone to contamination with leaf tissue from rodent nests than the lower hands but there would be some residual leaf material lodging between fingers in lower hands. Other hands could be subject to contact with leaves from other stems on the plant.

The IRA team considered, based on observations in Australia and the Philippines, that 1–5 in 30 clusters in a harvested bunch would be contaminated.

A range of  $3.00E-02$  to  $1.70E-01$  was used for Factor 2.

### **Factor 3 – The proportion of leaf material pieces on contaminated clusters that are infected with black Sigatoka**

Leaf tissue from both young and old leaves could contaminate bunches prior to harvest. Young leaves would have black Sigatoka infections at an early stage of development or, in some cases, be free of infection. Old leaves would have black Sigatoka at all stages of development, especially those present on fruit-bearing pseudostems. Fullerton (2006) found *M. fijiensis* to be present in 4 of 11 (36%) of leaf fragments detected by Peterson et al (2006) in Philippine bananas exported to New Zealand.

Information provided by Philippine authorities (BPI 2002) indicates that a high degree of disease control is achieved throughout the year. An average of 10 to 12 of the youngest leaves remain free of black Sigatoka leaf spots (stages 4, 5 or 6) on unbunched stems. It is expected that early symptoms (stages 1, 2 or 3) could be present on younger leaves, although the youngest leaves could be free of infection.

Recommended measures for controlling black Sigatoka in the Philippines involve removal of parts of diseased leaves with less than 50% of the leaf area affected, and the whole leaf if more than 75% of the leaf area is affected (PCARRD 1988). On the basis of general observations in Australia and the Philippines (BA 2002a), it is expected that leaves with more than 20% of the leaf with symptoms of Stage 3 or above would be removed from the plant and placed on the soil surface. It is also expected that nearly all leaves will have at least 10% of the leaf area infected by the time that the leaf dies naturally.

On this basis, Factor 3 is expected to be 1.00E–01 to 2.00E–01.

### **Factor 4 – The proportion of leaf pieces infected with black Sigatoka that contain fertile pseudothecia.**

This factor concerns the likelihood that an infected leaf piece would contain at least one fertile pseudothecium. Studies made on Philippine banana fruit exported to New Zealand (Peterson et al 2006; Fullerton 2006) did not report the occurrence of pseudothecia in leaf fragments.

Pseudothecia are found in black Sigatoka lesions at the second leaf spot stage and beyond (Part C, Appendix 6) but these pseudothecia are initiated at a much earlier stage of disease development. Under Philippine conditions, it is expected pseudothecia would be formed from 3-4 weeks after infection occurs, depending on rainfall intensity and the severity of infection. Pseudothecia would continue to mature for a considerable time after their first appearance in diseased tissue, even after the leaf becomes detached from the plant. Some of the leaf pieces present in banana clusters at harvest could have been from leaves killed by disease in the plantation and therefore very likely to have formed mature pseudothecia before contaminating the bunch. Other leaf pieces may be from leaves that contaminated the bunch around the time of harvest. This leaf tissue may not develop pseudothecia for several weeks, depending on temperature and moisture, or not at all if the infection does not include compatible mating types. It is expected that pseudothecia will be initiated pre-harvest. Consequently the total number that develop in waste material post-harvest will not exceed the number that are initiated pre-harvest (Burt et al 1999).

The number of pseudothecia on leaf fragments will depend on the surface area of the leaf fragment, the age of the leaf tissue, the stage of disease development pre-harvest, and the effectiveness of routine disease control measures pre-harvest.

- Area of necrotic leaf tissue. The area of each leaf fragment is about 25 mm<sup>2</sup> (Peterson et al 2006) and, as outlined in the dispersal section above, it is expected that necrotic tissue on leaves that have not been sprayed with fungicides will develop an average of 0.3-8 pseudothecia per mm<sup>2</sup> of lesion area (Burt et al 1999; Carlier et al 2000). This yields an estimate of 7.5-200 pseudothecia in each leaf fragment of this type if the leaf fragment was fully infected with black Sigatoka.
- Age of lesion. Mature pseudothecia present in necrotic leaf tissue (stage 6 lesions) would have

been subject to repeated wetting and drying prior to harvest and many would have become infertile as a result of releasing their ascospores (Stover 1971). Most of the remaining pseudothecia would be immature, especially those in leaf fragments with early disease symptoms (stages 1-4). It is expected that pseudothecia in these leaf fragments would continue to develop during shipment and especially after disposal as waste.

- Effect of routine control measures. The number of pseudothecia that develop pre-harvest and possibly post-harvest would be considerably reduced by the effects of routine leaf pruning and fungicide treatment. Opportunities for fertilization would be reduced (Mourichon and Zapater 1990) and fungicides would delay both the development of symptoms and pseudothecia (Stover and Dickson 1985; Guzmán and Romero 1998).

When these factors are taken into account, it was considered that the density of pseudothecia in leaf fragments could be less than 10% of that observed in unsprayed leaves. It is therefore considered that between 50–90% of the infected leaf pieces would bear no fertile pseudothecia at this stage, while the remainder would bear from one to 20 fertile pseudothecia each.

Factor 4 is expected to be between  $1.00E-01$  to  $5.00E-01$ .

#### *Floral material*

##### **Factor 1 – The proportion of bunches that are contaminated with any floral material at harvest**

All bunches have floral tissue that eventually dries out before harvest. While much of this dried tissue is removed manually during routine field operations (BPI 2002a) there is no evidence to indicate that it is all removed before harvest. General observations of IRA team members in Australia and the Philippines indicate that it occurs to some extent in every bunch.

Factor 1 is estimated to be 1.

##### **Factor 2 – The proportion of clusters contaminated with any floral material within contaminated bunches**

It is unlikely that all clusters in a harvested bunch would be contaminated with floral material. The frequency with which clusters are contaminated with floral material within bunches at harvest has not been quantified, but on the basis of general observations of IRA team members in Australia and the Philippines, it is expected that from 5–10 clusters in a harvested bunch yielding 30 clusters would be contaminated.

Factor 2 is between  $1.67E-01$  and  $3.33E-01$ .

##### **Factor 3 – The proportion of floral material pieces on contaminated clusters that are infected with black Sigatoka**

There is no published information on infection of floral tissue by *M. fijiensis* (Carlier et al 2000). However, the IRA team considered that floral tissue could be exposed to spore contamination and that infection could occur.

Factor 3 is considered to be between  $3.00E-01$  to  $7.00E-01$ .

##### **Factor 4 – The proportion of floral material infected with black Sigatoka that contain fertile pseudothecia**

There is no information on the occurrence of pseudothecia in floral material. While floral tissue may be exposed to contamination with black Sigatoka spores and some infection could occur, it is doubtful that the tissue would be viable for a sufficient period of time for pseudothecia to be initiated. The IRA team considered that pseudothecial production in floral tissue is most unlikely.

Factor 4 is expected to be no more than  $1.00E-04$ .

### *Leaf and floral material combined*

After multiplying the estimates of Factors 1–4 above, it was considered that the likelihood of a cluster of fruit being contaminated with material bearing at least one fertile pseudothecium (Imp2) would be within the range of  $1.50\text{E}-05$  to  $3.40\text{E}-03$  for leaf material and between  $5.00\text{E}-06$  to  $2.33\text{E}-05$  for floral material.

The estimates of Imp2 for both leaf and floral material are each extremely small, but dominated by the estimate for leaf material. The combined value was assessed as being in the range of  $2.00\text{E}-05$  to  $3.42\text{E}-03$ . There are insufficient data to suggest any central tendencies, so it is considered that the proportion would have a Uniform distribution.

### **10.3.3 Contamination by infected plant material during harvest and transport**

*Imp3a: The proportion of clean clusters from infected plantations that become contaminated with plant material bearing fertile pseudothecia of black Sigatoka during harvest and transport to the packing station is 0.*

Polythene bunch covers remain on harvested bunches until arrival at the packing station. When bunch covers are applied, a gap about two fingers wide is commonly left between the top of the bunch and the peduncle so that excessive heat that builds up under the covers can escape. They may tear during maturation of the fruit. While it is possible for contamination to occur in the plantation (see Imp2 above), there is virtually no opportunity for pieces of plant material with black Sigatoka to contaminate clusters during harvest and transport to the packing station. A value of 0 was assigned to this step.

*Imp3b: The proportion of clean clusters from clean plantations that become contaminated with plant material infected with pseudothecia of black Sigatoka during harvest and transport to the packing station is 0.*

As in Imp3a, the IRA team considered that clean clusters from clean plantations would not become contaminated with plant material infected with black Sigatoka during harvesting and transport to the packing station. A value of 0 was assigned to this step.

### **10.3.4 Infected plant material remaining after the packing procedures**

*Imp4: The proportion of contaminated clusters that remain contaminated with plant material bearing fertile pseudothecia of black Sigatoka after routine processing in the packing station is Uniform (min. 0.1; max. 0.5).*

On arrival at the packing station, polythene covers are removed from bunches, fruit is washed to remove soil, extraneous material and insects. It is then de-handled and immersed in water for up to 25 minutes while sap exudes and clusters are inspected for imperfections.

The degree to which plant material is removed during these processes has not been quantified. It is considered that obvious sources of contamination would be removed with high efficiency, but that small pieces of plant material (Figure 10.1) would not be removed if they were caught between the fingers in a cluster or glued to the fruit surface with dried sap.

Overall, the IRA team considered that the likelihood that plant material infected with black Sigatoka would remain with clusters of fruit would be no more than 1 in 2 instances and possibly as low as 1 in 10 instances, ranging therefore from 10–50%. There are insufficient data to suggest any central tendencies, so it is considered the frequency would have a Uniform distribution.

### 10.3.5 Contamination by infected plant material during packing

*Imp5: The proportion of clean clusters that become contaminated with plant material bearing fertile pseudothecia of black Sigatoka during processing at the packing station is Uniform (min.  $1.00E-06$ ; max.  $1.00E-05$ ).*

For clean clusters to become contaminated with plant material infected with black Sigatoka at the packing station, a piece of leaf or floral tissue has to be dislodged from one cluster and become attached to another. If there is only one piece of tissue per cluster, there is no net gain in the level of contamination. On rare occasions, clusters may be contaminated with external sources of leaf litter present in the packing station, although the dilution effects of washing and flotation in water tanks would render this contamination insignificant. On other rare occasions, some clusters may be contaminated with more than one piece of tissue. On this basis, Imp5 was assigned a value between  $1.00E-06$  and  $1.00E-05$ . Insufficient data were available to suggest any central tendencies, so a Uniform distribution was applied.

### 10.3.6 Contaminated plant material remaining after post-packing processes

*Imp6: The proportion of clusters contaminated with plant material bearing fertile pseudothecia of black Sigatoka that remain contaminated during handling and transport to Australia is 0.9.*

Clusters contaminated with plant material infected with black Sigatoka would be packed in banana cartons lined with polythene during transport to Australia. They would be wet at the time of packing and remain wet throughout the voyage to Australia.

The transport temperature of 13–14 °C may inhibit maturation of pseudothecia during the voyage, but the priming effect of being wet for several days would ensure that any mature pseudothecia discharge their ascospores when there is a change in water potential. The effect of premature spore release would be to render some pseudothecia infertile. The degree to which this occurs has not been quantified but it is considered that up to 10% of the most lightly infected plant fragments would become totally infertile at this stage and the remaining plant fragments would typically retain 1–18 fertile pseudothecia per fragment. Imp6 was therefore assigned a value of 0.9.

### 10.3.7 Contamination by infected plant material during post-packing procedures

*Imp7: The proportion of clean clusters contaminated with plant material bearing pseudothecia of black Sigatoka during handling and transport to Australia is 0.*

Clean clusters would be contained within cartons lined with polythene during the voyage to Australia. Any contamination of clean clusters with plant material would occur as a result of transfer from a contaminated cluster, so there would be no net increase in the level of contamination. Some clean clusters may become contaminated with ascospores released during transport, but this is considered under Scenario B. Imp 7 was assigned a value of 0.

### 10.3.8 Plant material remaining after border procedures

*Imp8: The proportion of contaminated clusters with plant material bearing fertile pseudothecia of black Sigatoka that remain contaminated after on arrival minimal border procedures is 1.*

Minimal border procedures take no account of fruit contaminated by black Sigatoka. A value of 1 was therefore assigned to this step.

The estimate of the proportion of banana clusters contaminated with leaf material made after border procedures in New Zealand by Peterson et al (2006) can be compared with the estimates made in this analysis by multiplying the means of Imp2 (factors 1 and 2) by Imp4. The estimates given above were

in the ranges of (0.05-0.2), (0.03-0.17) and (0.10-0.50), respectively. The product of the mean values of these three ranges (assuming a Uniform distribution) is 3.75E-03, which is consistent with the value of 4.00E-03 reported by Peterson et al (2006).

## 10.4 Distribution (Scenario A)

Distribution within Australia starts with the release of imported fruit at the port of entry and ends with the disposal of waste material under controlled or uncontrolled conditions. The two steps associated with distribution are outlined in Section 5.3. As mentioned in Section 7.2, distribution occurs through established wholesale and retail outlets and includes processes to store fruit at 13–14 °C and ripen it at 14.5–21 °C over a period of 14–21 days.

During this period, some plant material will become dislodged from clusters as a result of vibration and gradual shrinkage of the fruit as it loses moisture. Such material will become part of the waste packaging material discarded by retailers but, as indicated in the discussion of scenarios above, it is assumed that this plant material will be discarded in the same way as any other fruit waste. Other effects on plant material contaminating clusters of fruit during the distribution process are assessed as follows.

### 10.4.1 Infected plant material remaining after distribution

*Dist1: The proportion of clusters of bananas contaminated with plant material bearing fertile pseudothecia of black Sigatoka remaining contaminated throughout the distribution pathway is 0.9.*

Immature pseudothecia are expected to remain dormant until the plant material is exposed to ambient temperatures, either after the fruit is ripened or when waste is discarded by wholesalers. Pseudothecia that are mature at the time of packing the fruit will be exposed to extended periods of moisture and high humidity during transport to Australia and are therefore likely to discharge ascospores during this time. The effect of premature spore release would be to render these mature pseudothecia infertile. This would reduce the total numbers of pseudothecia on leaf material and also render some of the older infected tissues entirely infertile. The degree to which this occurs has not been quantified but the IRA team considered that up to 10% of the most lightly infected plant fragments would become totally infertile at this stage and the remaining plant fragments would typically retain 1–16 fertile pseudothecia per fragment. Dist1 was therefore assigned a value of 0.9.

### 10.4.2 Contamination by infected plant material during distribution

*Dist2: The number of clean clusters that will become contaminated with plant material bearing pseudothecia of black Sigatoka during the distribution process is 0.*

For reasons outlined under Imp7 above (see Section 10.3.7), any contamination of clean clusters (or packaging materials) with plant material will occur as a result of transfer from a cluster already contaminated. There will be no net gain in the level of contamination. Dist2 was therefore assigned a value of 0.

### 10.4.3 The number of clusters with infected plant material at each waste point

Table 10.1 summarises how infected banana waste will be divided between the three waste categories in the two areas. The number of infected clusters bearing fertile pseudothecia is based on 105,000 tonnes of bananas being imported. This indicates that about one in 2,500 of clusters distributed (0.04%) would have infected leaf material.

**Table 10.1** Estimated number of clusters with infected plant material distributed to each waste point from 105,000 tonnes of imported bananas

Areas	Waste category					
	controlled		uncontrolled consumer		other uncontrolled	
Grower areas	4,938	11.1%	3,528	8.0%	49	0.1%
Other areas	20,976	47.3%	14, 629	33.0%	235	0.5%

## 10.5 Exposure – proximity considerations (Scenario A)

As outlined in Section 5.1.1, the unit for assessing the likelihood of transfer of the pest from waste to a host is based on an individual banana finger. However, in the case of this particular scenario, leaf fragments are considered to be discrete units of inoculum attached to a single finger in a banana cluster.

Determining the probability of exposure is done in two parts. The first part (the proximity considerations covered in this section) determines how likely it is that waste from an infected finger would be close enough to a host to infect it, if conditions are favourable. The second part (the transfer considerations covered in the next section) determines how likely it is that an infection would be initiated on the host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a likelihood greater than zero of transfer of *M. fijiensis* to a host plant to occur. In turn, the likelihood of banana waste being disposed of sufficiently close to a suitable host plant depends both on the method of waste disposal and on the category of the host plant exposure group.

A suitable host is a plant of the genus *Musa* or *Heliconia*. Species of these genera are considered to occur independently in Australia, although they may occur together in some exposure groups such as in home gardens.

The likelihood of at least one suitable host plant occurring in proximity to discarded banana waste depends both on the method of waste disposal and on the exposure group. The dispersal range of black Sigatoka ascospores released from waste on the ground is considered to decrease at an exponential rate so that 99% of the spores would no longer be airborne after 30 m (reference to black Sigatoka datasheet in Part C). For some combinations of waste type and exposure group in this scenario, proximity of the waste to the exposure group was based on a distance of 90 m, corresponding to the distance at which only one in a million spores released at ground level would still be airborne. However, there was no absolute distance cut off when using the exponential rate of deposition to determine transfer values (Table 10.3).

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 10.2. For each combination in the table, the value given is calculated as the proportion of waste discarded at a waste point that is near the exposure group.

The data used for these calculations are given in Sections 7.4 and 7.5 (Chapter 7, Part B), with specific points summarised below.

### 10.5.1 Proportion of waste near each exposure group

The proportion of each type of waste that is within 90 m of the nearest exposure group is based on the information about the general distribution of waste given in Section 7.4.

### **Controlled waste**

Data indicate that no commercial host crops or home gardens occur within 90 m of any controlled waste facility. Although there are no banana plants growing at controlled facilities in other areas, there are some at controlled waste facilities in grower areas. The IRA team considered that no more than 7.5% of controlled waste in grower areas would be sent to facilities that had plants within or around the perimeter of the facility. There would be no such facilities in other areas.

### **Uncontrolled consumer waste**

Uncontrolled consumer waste is generated by consumers and most of it will be discarded in a home environment, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other environments such as public parks, roadsides, farmlands and bushland. It is very unlikely that uncontrolled consumer waste will be discarded within 90 m of a commercial banana plantation. A value of  $5.60E-06$  was considered appropriate.

### **Other uncontrolled waste**

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. It may be fed to livestock, used directly as organic mulch, or disposed of in areas not subject to controlled waste management.

Most of the other uncontrolled waste is discarded in other environments such as public parks, farmlands, roadsides and bushland. It was considered that about 5% of other uncontrolled waste is discarded or used near households. It is very unlikely that other uncontrolled waste will be discarded within 90 m of a commercial banana plantation. A value of  $1.00E-06$  was considered appropriate.

## **10.5.2 Probability of plants within the proximity area**

Because there is no absolute distance cutoff when using an exponential rate of deposition of spores, the impact of host density is considered entirely in the transfer section (Table 10.3) and so, unlike other analysis in this report, the probability of plants being within the proximity zone was not calculated.

## **10.5.3 Summary of proximity values**

Table 10.2 summarises the details given in Section 10.5.1 for the proportion of each type of waste discarded near each type of exposure group. The data were insufficient to suggest any central tendencies and so Uniform distributions were used.



**Table 10.2 Summary of proximity values for black Sigatoka (Scenario A)**

Exposure Groups	Controlled Waste	Uncontrolled Household Waste	Other Uncontrolled Waste
<b>Grower areas</b>			
commercial crops	0	5.60E-06	1.00E-06
home gardens	0	1	5.00E-02
other plant communities	7.50E-02	U(1.00E-02, 5.00E-02)	1
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	1	5.00E-02
other plant communities	0	U(1.00E-02, 5.00E-02)	1

## 10.6 Exposure – transfer considerations (Scenario A)

Section 5.4 describes the considerations required when determining the second value needed to determine the probability of exposure – the likelihood of transfer. Given that waste bearing fertile black Sigatoka pseudothecia has been discarded in proximity to a susceptible host plant, the transfer considerations concern the likelihood that black Sigatoka will be carried from the waste to an infection site on the host plant. Because this scenario concerns trash lodged in a cluster, the assessment of the likelihood of transfer of the pest from waste to host is based on a cluster rather than a finger. A transfer event will occur when an ascospore released from a fertile pseudothecium in the waste material is carried to the infection site.

The following sequence of factors must occur for black Sigatoka to be successfully transferred:

1. the waste must be exposed to the air so that ascospores may disperse
2. fertile pseudothecia must be present in the waste and produce ascospores
3. ascospores must be released and become airborne
4. dispersed ascospores must settle on a host plant surface.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of Factors 1, 2, 3, 4 was calculated to give the minimum value for the likelihood of at least one transfer event. A similar calculation was done to determine the maximum value. These values are presented in Table 10.3. The likelihood values associated with these factors are assessed as follows.

### Factor 1 – Waste presentation

Factor 1 concerns the likelihood that waste will be discarded in such a way that ascospores can be discharged into the air stream. This will be affected by the manner in which waste is discarded, but will be similar for both grower and other areas.

Ascospores have the ability to be released into the airstream from infected plant material on the ground (Meredith 1973; Aylor 1990). This is achieved in part by a process of propulsion from the parent ascus and also by the production of vast numbers of spores. In the case of *Venturia inaequalis*, for example, ascospores are propelled from 1-7 mm into the air (Aylor and Anagnostakis 1991). The potential ascospore dose in infected apple leaf litter on the floor of apple orchards has been estimated to be approximately  $10^9$  per  $m^2$ , of which 80-95% became airborne over a period of 40 days in the presence of grass swards 60 and 25 cm deep, (Aylor and Qiu 1996). *Mycosphaerella fijiensis* also releases large numbers of ascospores that can be readily detected in proximity to infected host plants throughout the year but differs from *V. inaequalis* in that ascospores are released from leaves hanging on the plant or from leaves that have been placed recently on the ground (Gauhl 1994).

In a controlled waste facility, waste is generally buried or contained in plastic bags. The waste is diluted with general household waste and is heavily compacted in the waste disposal process. The time that it is exposed to the air is limited by the rate that other waste is brought to the facility and also by the frequency with which waste is covered. Data are not available to quantify Factor 1 but it is considered that the proportion of controlled waste exposed to the air, and therefore capable of releasing ascospores for a significant time, is  $1.00E-06$ .

Most uncontrolled consumer waste is disposed in compost bins or discarded on compost heaps or into vegetation that prevents the dispersal of spores. The waste is subject to being buried under other waste material within a few days or otherwise overgrown with weeds and vegetation. Data are not available to quantify Factor 1 further, but the IRA team's best judgment was that only 5–10% of waste would be exposed to the air for a sufficient period to allow ascospore dispersal. For uncontrolled consumer waste, Factor 1 would have a value between  $5.00E-02$  and  $1.00E-01$ .

Other uncontrolled waste is discarded on the soil surface in heaps and a large proportion of spores would be trapped in these heaps. Data are not available to quantify Factor 1 but the IRA team considered that, like uncontrolled consumer waste, only 5–10% of other uncontrolled waste would be exposed to the air for a significant period of time. For other uncontrolled waste, Factor 1 would have a value between  $5.00E-02$  and  $1.00E-01$ .

### **Factor 2 – Pest availability**

Factor 2 concerns the likelihood that fertile pseudothecia on a plant fragment will mature and produce ascospores. As outlined in Imp2, Imp6 and Dist1, plant fragments with stage 6 lesions are expected to retain progressively fewer fertile pseudothecia as they pass along the import pathway. However, immature pseudothecia are expected to continue their development in stage 2-5 lesions until the leaf fragment decays. On average, infected plant fragment is estimated to have only 1–16 fertile pseudothecia at exposure (this transfer step). Between 80–3456 ascospores could be produced per plant fragment at this time.

The potential for fertile pseudothecia to mature in the period leading up to disposal at a waste point will depend to a large extent on the temperature during transport and handling, and then at the waste point for the first few weeks after disposal occurs and before the leaf fragment decays. This would apply especially to immature pseudothecia in stage 1-4 lesions. Given the effects of temperature on black Sigatoka (refer to Part C black Sigatoka datasheet *Effects of temperature*) it is expected that only 50% of fertile pseudothecia would mature in 4–8 weeks at average temperatures in grower areas. In other areas of Australia, it is expected that a smaller proportion would mature because temperatures would be too low for any development for several months of the year and the leaf fragment would decay before maturation was complete.

The IRA team considered that some of the plant fragments with the fewest number of fertile pseudothecia would not produce ascospores in the time available, and so the number of fertile pseudothecia with ascospores in the remaining plant fragments could be as few as 1–8 in grower areas and 1–3 in other areas, each with a potential to release 80–1728 or 80–648 ascospores per fragment, respectively.

Given the uncertainties concerning the likelihood that plant fragments with fertile pseudothecia would mature and produce ascospores, Factor 2 was considered to have a value of  $5.00E-01$  in grower areas and  $2.00E-01$  in other areas.

### **Factor 3 – Release of spores**

Factor 3 concerns the likelihood that ascospores produced in mature pseudothecia in the waste material will be released. While Factor 1 has considered macro-environmental effects on the potential for ascospores to become airborne, Factor 3 considers the micro-environmental effects about each pseudothecium.

The IRA team considered that ascospores will be released over a short time period when mature pseudothecia have been primed with suitable moisture. A single priming event may occur in association with rain, supplementary irrigation or even heavy dew and is regarded as sufficient to enable discharge of all ascospores once the pseudothecium is mature. Given general information on rainfall and dew events and on irrigation practice in Australia, the IRA team considered that it is almost certain that a significant wetting event will occur in the 4–8 week period when waste material contains fertile pseudothecia.

Factor 3 was assigned a value of 1.0.

#### **Factor 4 – Spores settle on host**

Factor 4 concerns the likelihood that an airborne ascospore will settle on and adhere to a susceptible part of a host surface. This is determined by the number of released ascospores that become airborne, the distance to host plants, the deposition rate, the surface area of a host plant, and the efficiency with which ascospores adhere to the host surface on settling.

##### *4A – Number of ascospores that become airborne from each plant fragment*

*Mycosphaerella fijiensis* releases large numbers of ascospores that can be readily detected in proximity to infected host plants throughout the year (Gauhl 1994). Given the numbers of ascospores that could potentially be released per plant fragment (Factor 2 above) and the uncertainties involved in release from banana waste on the ground, the number of ascospores that become airborne from each plant fragment is estimated to be 80–1728 in grower areas or 80–648 in other areas.

##### *4B – Likelihood that an ascospore lands on a host*

The host surfaces in this instance are the leaf tissues of *Musa* and *Heliconia* species. In considering the growth habits of *Musa* and *Heliconia* cultivars, it is expected that the area occupied by each host plant would average 5 m<sup>2</sup>, based on a host diameter of 2.5 m. The proportion of area occupied by susceptible host tissue is reduced by the area of non-susceptible leaf tissue relative to the total area. Deposition of spores on the highly susceptible tissue on the under surface of leaves is expected to decrease with increasing age because the leaves assume a more horizontal position than when they are newly-emerged. It is therefore expected that about 70% of the area occupied by a plant is host leaf surface on which spores may deposit. The likelihood that ascospores will land on a host will depend on the density of hosts, the distance to the nearby hosts, and the deposition rate of airborne spores.

##### *Commercial crops:*

It is very unlikely that banana waste will be discarded within a commercial banana plantation. It is more likely that it will be discarded at locations where workers or visitors at the plantation consume bananas or where a banana peel is discarded on access routes near the plantation boundaries. If an airborne spore from banana waste reached the edge of the plantation, it was assumed that the spore would land in the plantation. On this basis, Factor 4B was considered to be in the range of 1.38E–02 and 8.33E–02 for uncontrolled waste in proximity to commercial crops. If there were a commercial plantation adjacent to a controlled waste facility, the distance between the hosts and the waste in the tipping area would result in a value of Factor 4B between 2.00E–07 and 4.86E–06.

##### *Home Gardens:*

The average density of home garden banana and heliconia plants is 360–520 mats per km<sup>2</sup> in grower areas and 4.2–25.2 mats per km<sup>2</sup> in other areas (Table 7.6). After taking into account the deposition rate, and density, Factor 4B was considered to have values between 1.26E–03 to 1.82E–03 in grower areas and between 1.47E–06 to 8.82E–05 other areas for uncontrolled waste in proximity to home gardens. If there were home gardens adjacent to a controlled waste facility, the distance from the area where waste is randomly being disposed and the perimeter of the facility would give a value for Factor 4B of between 1.57E–07 and 4.06E–06.

**Other plant communities:**

The average density of banana and heliconia plants in other plant communities is 0.4–4.0 mats per km<sup>2</sup> and 0.005 mats per km<sup>2</sup> in grower and other areas, respectively (Table 7.6). For uncontrolled waste, Factor 4B would have a value between 1.40E–06 and 1.40E–05 in grower areas and a value of 1.75E–08 in other areas. Where there is an isolated host within or along the perimeter of a controlled waste facility, Factor 4B would have a value of between 2.13E–05 and 1.15E–04.

**4C – Efficiency with which ascospores adhere to host plant surfaces on settling**

In order for an ascospore to initiate infection, it must first adhere to the host surface so that it is not dislodged by rain or water that may occur at the time of spore release. It is expected that rainfall would continue to occur on about 30% of days following spore release, so that about 70% of spores would remain on the surfaces on which they settled. Factor 4C therefore has a value of 7.00E–01.

Factor 4 is then calculated by combining the number of ascospores becoming airborne from each plant fragment (4A), the proportion of target area in the proximity zone (4B) and the efficiency of spore adherence (4C) by calculating  $Factor\ 4 = 1 - (1 - 4B \times 4C)^{4A}$ .

**Summary of transfer values**

To estimate the likelihood that at least one transfer event will occur, values of the four factors are combined as indicated above. Table 10.3 summarises the values for each combination of waste point and exposure group.

**Table 10.3 Summary of transfer values for black Sigatoka (Scenario A)**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(5.60E–12, 2.93E–09)	U(1.35E–02, 5.00E–02)	U(1.35E–02, 5.00E–02)
home gardens	U(4.40E–12, 2.45E–09)	U(1.70E–03, 4.45E–02)	U(1.70E–03, 4.45E–02)
other plant communities	U(5.96E–10, 6.49E–08)	U(1.96E–06, 8.40E–04)	U(1.96E–06, 8.40E–04)
<b>Other areas</b>			
commercial crops	U(2.24E–12, 4.40E–10)	U(5.40E–03, 2.00E–02)	U(5.40E–03, 2.00E–02)
home gardens	U(1.76E–12, 3.68E–10)	U(8.23E–07, 7.84E–04)	U(8.23E–07, 7.84E–04)
other plant communities	U(2.38E–10, 1.02E–08)	U(9.80E–09, 1.59E–07)	U(9.80E–09, 1.59E–07)

## 10.7 Establishment (Scenario A)

The initiation point for establishment of *M. fijiensis* is the exposure of a suitable host plant to an ascospore. As outlined in Section 10.6, each completed transfer event is expected to result in inoculation with one ascospore. The end point is the development of black Sigatoka lesions in which conidia or ascospores are consistently produced on the host plant. Section 5.5 gives the ISPM 11 criteria that need to be considered.

The following factors were identified as influencing the establishment of *M. fijiensis*:

1. infection efficiency of spores
2. surface moisture and ambient temperature
3. host susceptibility
4. routine horticultural practices.

The likelihood values associated with these factors are assessed as follows.

### **Factor 1 – infection efficiency of spores**

It is theoretically possible for a single viable ascospore to establish an asexual population of *M. fijiensis* on a host plant, or for two ascospores to establish a population capable of sexual recombination. However, there is only a limited chance that a single spore will initiate an infection under field conditions. This chance will increase with increasing numbers of spores. Experiments in growth cabinets under apparently ideal conditions of temperature and moisture indicate an infection efficiency of 0.34-0.78% for viable conidia of *M. fijiensis* on banana leaves (Jacome and Schuh 1992). The conidia in this case were produced in culture. Ascospore infection is apparently more dependent on free water than conidial infection (Jacome and Schuh 1992) but no information on their infection efficiency has been found. In the case of growth cabinet experiments on apple leaves with naturally produced *Venturia inaequalis* ascospores, Sanogo and Aylor (1997) reported infection efficiencies of 6-21%. The ascospores involved in these experiments are of a similar size and shape to those of *M. fijiensis*. However, it is not known how these estimates relate to field conditions because growth cabinet conditions may not be representative of the fluctuating light and moisture conditions that facilitate penetration of stomatal pores (Leach 1946; Goos and Tschirch 1963).

A second consideration in the infection efficiency of spores is their germinability. It is expected that the germinability of ascospores released from freshly matured pseudothecia would be high, while that of ascospores released from old pseudothecia would be much reduced (Stover 1971). It is expected that the germinability of ascospores released from pseudothecia in banana waste would be affected by their storage history and factors that delay the release of ascospores.

For the purposes of this analysis, it is assumed that the infection efficiency for *M. fijiensis* ascospores is in the range of 1.00E-02 to 1.00E-01.

### **Factor 2 – surface moisture and ambient temperature**

Under optimal conditions of temperature and moisture, black Sigatoka spores germinate within 2-3 hours of deposition. Penetration of host tissue occurs after 2–3 day's growth of the epiphytic mycelia (Carrier et al 2000). Further epiphytic growth and penetration occurs over the following 2–3 weeks before symptoms appear and sporulation occurs. The processes also occur under sub-optimal conditions but at a slower rate (Jacome and Schuh 1992). The degrees of line and tip spotting reflecting the abundance of conidia and ascospores of *M. musicola*, respectively, follow a seasonal pattern with the greatest intensity at the end of the tropical wet season (Leach 1946; Pont 1960a).

Infection events can be described by arbitrary rules such as the occurrence of three consecutive wet days (>1mm rain) with a minimum temperature greater than 18 °C. Peterson et al (2005) reported an average of 1–3 infection events per month in the years 2001–2005 at Tully (North Queensland). These criteria were applied to meteorological data from South Johnstone (representing exposure groups in north Queensland), Alstonville (representing exposure groups in south-eastern Queensland and north-eastern New South Wales), Sydney (representing exposure groups in the northern parts of other areas of Australia), and Melbourne (representing the southern parts of other areas). The data were recorded over the 11 years from 1996 to 2006, inclusive. The numbers of infection events for each year and average numbers of infection events per month are presented in the black Sigatoka datasheet (Appendix 6 of Part C).

There was an average of 79.5 potential infection events per year at South Johnstone (range 56–110 between years), 9.3 at Alstonville (range 3–18) and 2.5 at Sydney (range 1–5). There were no infection events at Melbourne during the period analysed. At South Johnstone, most infection events were recorded in April (16.6 per month) and the least in August (0.2 per month). At Alstonville, infection events were recorded from October to May, with a maximum of 3.2 per month in February. At Sydney, infection events were recorded from January to March, with a maximum of 1.6 per month in January.

In estimating Factor 2, it is necessary to take account of the environments at the various exposure groups.

- In grower areas, approximately 90% of the home gardens and other plant communities occur in the south (represented by Alstonville) whereas 90% of commercial crops are in northern areas (represented by South Johnstone). The estimates of Factor 2 for home garden and other plant community groups would be an average of 90% Alstonville and 10% South Johnstone, whereas the estimates for commercial crops would be 10% Alstonville and 90% South Johnstone.
- In other areas of Australia, any commercial crops are in northern areas (represented by Sydney) whereas home gardens and other plant communities occur almost equally in the north and south. Minimum overnight temperatures are sometimes conducive to infection in northern areas (represented by Sydney) but rarely in southern areas (represented by Melbourne and Hobart, for example). The estimates of Factor 2 for home garden and other plant community groups are assumed to be 50% of Sydney and 50% of Melbourne, whereas the estimates for commercial crops are those for Sydney.

As mentioned under Factor 3 in Section 10.6, ascospores will be released over a short time period when mature pseudothecia have been primed with suitable moisture. It was considered that such a 'priming event' would occur on any day for which there was recorded rain and on half the remaining days due to dew or supplementary irrigation. The number of such days was used to determine the likelihood that a priming event would be followed by a period suitable for infection.

Estimates of Factor 2 for each of the six exposure groups, weighted according to the distribution of exposure group environments, are presented in Table 10.4. The minimum and maximum values are based on annual estimates while the modal values are based on 11-year averages.

**Table 10.4** Estimates of Factor 2 for black Sigatoka (Scenario A)

	Grower areas	Other areas
Commercial crops	Min: 1.85E-01; mode: 2.53E-01; max: 3.38E-01	Min: 3.89E-03; mode: 9.89E-03; max: 2.07E-02
Home gardens	Min: 3.07E-02; mode: 5.92E-02; max: 9.30E-02	Min: 1.95E-03; mode: 4.95E-03; max: 1.03E-02
Other plant communities	Min: 3.07E-02; mode: 5.92E-02; max: 9.30E-02	Min: 1.95E-03; mode: 4.95E-03; max: 1.03E-02

### Factor 3 – host susceptibility

It is considered that almost all *Musa* species in Australia would be susceptible to black Sigatoka, although some resistant ornamental bananas might occur in home gardens and other plant communities. Apart from the report by Gasparotto et al (2005) in Brazil, the susceptibility of various cultivars of *H. psitticorum* or of other *Heliconia* species to strains of black Sigatoka present in the Philippines has not been investigated. The susceptibility of *Heliconia* spp. under Australian conditions is unknown, although it is noted that their occurrence as wild and amenity plants in the Tully Valley did not appear to provide a reservoir of black Sigatoka infection (P Whittle, Principal Scientist, QDPIF, pers comm 8 January 2008).

After taking into account the relative numbers of *Musa* and *Heliconia* species, the IRA team considered that the proportion of susceptible host plants would be 95–100% in commercial crops but, for both home gardens and other plant communities, would be 50–70% in grower areas and 80–90% in other areas.

Factor 3 was therefore assigned values of 9.50E-01 to 1.00 for commercial crops and 5.00E-01 to 7.00E-01 for home gardens and other plant communities in grower areas. For other areas, Factor 3 had values of 8.00E-01 to 9.00E-01 for home gardens and other plant communities.

#### Factor 4 – routine horticultural practices

Routine horticultural practices are likely to affect establishment of black Sigatoka in commercial banana plantations since infection would be inhibited by fungicides used for the control of yellow Sigatoka (*M. musicola*) and leaf speckle (*M. musae*). It is known that fungicides are used throughout the year in north Queensland and for six months of the year in subtropical banana growing areas (BA 2002b). The effectiveness of these fungicides in preventing founder events on commercial bananas has not been quantified but the IRA team considered that fungicides would reduce the degree of ascospore infection by 80-85%. Routine horticultural practices are unlikely to affect establishment of black Sigatoka in home gardens and other plant communities.

Factor 4 was therefore assigned a value between 1.50E-01 and 2.00E-01 in commercial crops and 1.0 in home gardens and other plant communities.

For each exposure group, the product of the minimum value for the likelihood of Factors 1, 2, 3 and 4 occurring was calculated to give the minimum likelihood of establishment. A similar calculation was done to determine the mode and maximum value. These values are presented in Table 10.5. The data had a central tendency and a Triangular distribution was used.

**Table 10.5 Probability of establishment for black Sigatoka after exposure**

Exposure group	Grower areas	Other areas
commercial crops	T(2.63E-04, 2.37E-03 6.77E-03)	T(5.54E-06, 9.28E-05, 4.13E-04)
home gardens	T(1.54E-04, 1.95E-03 6.51E-03)	T(1.56E-05, 2.31E-04 9.30E-04)
other plant communities	T(1.54E-04, 1.95E-03 6.51E-03)	T(1.56E-05, 2.31E-04 9.30E-04)

## 10.8 Spread (Scenario A)

Spread could occur as a result of infected material being transferred for planting purposes. This means of spread is subject to official control in grower areas but may still occur to a limited extent in both grower and other areas.

Secondary spread could occur by both conidia and ascospores, although the extent and speed will depend on whether or not compatible mating types become established. Establishment on a host involving both mating types will result in a population capable of sexual reproduction whereas establishment from a single conidium or ascospore will result in an asexual population without pseudothecia. Secondary spread will therefore occur only by conidia and the outbreak will remain relatively localised until the pathogen encounters another population with a compatible mating type. It is also possible that mycelia and conidia in leaf spot lesions will die out over winter, especially if the leaves are chilled or cut down.

In grower areas, it is almost inevitable that spread will occur because leaf spot lesions will persist on infected plants and other susceptible hosts occur in the vicinity. On this basis, a value of 1.0 was assigned. However, in other areas, black Sigatoka may not overwinter successfully unless pseudothecia are formed in the tissue. The likelihood of spread would therefore be reduced, especially in home gardens and other plant communities. On this basis, a value of 0.7 was assigned. Table 10.6 summarises these values.

**Table 10.6 The Probability of Spread (Scenario A)**

Exposure group	Grower areas	Other areas
commercial crops	1.0	1.0
home gardens	1.0	0.7
other plant communities	1.0	0.7

## 10.9 Probability of entry, establishment and spread (Scenario A)

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.7. Table 10.7 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation, 105,000 tonnes, is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively).

Rather than showing the individual PEES values for each waste point and exposure group combination, Table 10.8 shows the relative contribution the individual values make to the overall PEES.

**Table 10.7 Probability of entry, establishment and spread of black Sigatoka via contaminated plant material (Scenario A)**

	50,000 tonnes	105,000 tonnes	160,000 tonnes
5 <sup>th</sup> percentile	5.05E-03	1.06E-02	1.54E-02
Median	6.35E-02	1.30E-01	1.90E-01
95 <sup>th</sup> percentile	3.16E-01	5.53E-01	7.03E-01

**Table 10.8 Apportioning the PEES by waste point and exposure group**

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	99.18%	0.07%
other plant communities	0.00%	0.05%	0.02%
<b>Other areas</b>			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	0.67%	0.00%
other plant communities	0.00%	0.00%	0.00%

## 10.10 Importation – contaminated bananas (Scenario B)

Importation starts with the sourcing of banana fruit from a plantation in the Philippines and finishes with the release of imported fruit at the Australian border. It is analysed in eight steps, as described in Section 5.2. This section provides the available evidence supporting the likelihood assessments for each step for scenario B.



Scenario B considers the likelihood of entry, establishment and spread from clusters of bananas contaminated by black Sigatoka spores.

### 10.10.1 The proportion of plantations where black sigatoka is present

*Imp1: The proportion of plantations in which black Sigatoka present is 1.*

Black Sigatoka occurs in Cavendish and local banana cultivars throughout the Mindanao region from which export bananas are to be sourced (Carlier et al 2000; BPI 2002b). No information has been provided to indicate that any banana plantation is free of black Sigatoka, so it is assumed that it is certain that black Sigatoka will be present in a plantation from which a cluster of fruit is sourced.

Imp1 was therefore assigned a value of 1 for black Sigatoka infection.

### 10.10.2 Level of black Sigatoka spores within a plantation

*Imp2: The proportion of clusters of harvested fruit contaminated with black Sigatoka spores is 1.*

It is expected that conidia and ascospores of *M. fijiensis* would be abundant in the air around Philippine banana plantations throughout the year as they are in Costa Rica (Gauhl 1994). These spores would be expected to settle on all surfaces in the plantation, including the fruit surfaces. The spores can also be distributed by rain splash and wind-driven droplets (Carlier et al 2000) and therefore extend the level of contamination. On this basis, Imp2 was assigned a value of 1.

### 10.10.3 Contamination by black Sigatoka during harvest and transport

*Imp3a: The proportion of clean clusters from infected plantations that become contaminated with spores of black Sigatoka during harvest and transport to the packing station is 1.00E-03.*

Polythene bunch covers remain on harvested bunches until they arrive at the packing station. These covers are open at the bottom and also manufactured with perforations to allow gas exchange. They may tear during maturation of the fruit. While it is possible for contamination to occur over an extended time in the plantation (see Imp2 above) and in the packing station (see Imp5 below), there is relatively little opportunity for black Sigatoka spores to contaminate clusters during harvest and transport to the packing station.

On this basis, Imp3a was assigned a value of 1.00E-03.

*Imp3b: The proportion of clean clusters from clean plantations that become contaminated with spores of black Sigatoka during harvest and transport to the packing station is 1.00E-03.*

As in Imp3a, there is little opportunity for *M. fijiensis* spores to contaminate fruit surfaces during this process, although it is possible. On this basis, Imp3a was assigned a value of 1.00E-03.

### 10.10.4 Survival of spores during packing procedures

*Imp4: The proportion of contaminated clusters that remain contaminated with spores of black Sigatoka during routine processing in the packing station is 1.*

On arrival at the packing station, polythene covers are removed from bunches, fruit is washed to remove extraneous material and insects. The bunches are then de-handled and immersed in water for up to 25 minutes while sap exudes and clusters are inspected for imperfections.

It is possible that spores would be washed from fruit surfaces during this process and contaminate the water in the flotation tanks. It was not considered likely that all spores would be washed off a cluster. On this basis, Imp4 was assigned a value of 1.

### 10.10.5 Contamination by black Sigatoka during packing

*Imp5: The proportion of clean clusters that become contaminated with spores of black Sigatoka during routine processing in the packing station is 1.*

As outlined in Imp4, it is possible that spores would be washed from fruit surfaces during routine processing in the packing station and that many of them would contaminate the water in the flotation tanks, therefore contaminating all fruit passing through the process. On this basis, Imp5 was assigned a value of 1.

### 10.10.6 Infected clusters remaining after post-packing processes

*Imp6: The proportion of clusters contaminated with spores of black Sigatoka that remain contaminated during handling and transport to Australia is 1.*

Clusters contaminated with black Sigatoka spores would be packed in banana cartons lined with polythene during transport to Australia. They would be wet at the time of packing and remain wet throughout the journey to Australia. The effects of water films on spore survival are considered under Exposure – transfer considerations (Section 10.13) and will not be considered here. On this basis, a value of 1 was assigned to Imp6.

### 10.10.7 Contamination by black Sigatoka during post-packing procedures

*Imp7: The proportion of clean clusters contaminated with spores of black Sigatoka during handling and transport to Australia is  $1.00E-06$ .*

Some clean clusters may become contaminated with ascospores released during transport (see Scenario A) and some spores may be transferred in water droplets that trickle from fruit surfaces. The IRA team considered that this process would contaminate fingers mostly within each cluster and rarely any clean clusters in the rest of the carton when there was an infected leaf fragment present. Imp7 was assigned a value of  $1.00E-06$ .

### 10.10.8 Contaminated clusters remaining after border procedures

*Imp8: The proportion of contaminated clusters that remain contaminated with spores of black Sigatoka after on arrival minimal border procedures is 1.*

Routine border procedures would not detect black Sigatoka spores on banana fruit. A value of 1 was therefore assigned to this step.

## 10.11 Distribution (Scenario B)

Distribution within Australia starts from the release of imported fruit at the port of entry and ends with the disposal of waste material under controlled or uncontrolled conditions. The two steps associated with distribution are outlined in Section 5.3. As mentioned in Section 7.2, distribution occurs through established wholesale and retail outlets and includes processes to store fruit at 13–14 °C and ripen it at 14.5–21 °C over a period of 14–21 days.

During this period, fruit would be removed from cartons and polythene liners and sold to consumers. The cartons and polythene liners would be discarded mainly as controlled waste and any contaminating black Sigatoka spores would be removed from the pathway. As indicated in the discussion of scenarios, it is assumed that packaging materials would be discarded in the same way as any other fruit waste. Other effects on black Sigatoka spores contaminating clusters of fruit during the distribution process are assessed as follows.

### 10.11.1 Pest survival during distribution

**Dist1:** *The proportion of clusters of bananas contaminated with spores of black Sigatoka remaining contaminated throughout the distribution pathway is 1.*

Black Sigatoka spores will continue to be inhibited by low storage temperatures during the early stages of distribution and by low humidity as the fruit is ripened and displayed at the retail outlet. The effects of water films on spore survival are considered under Exposure – transfer considerations (Section 10.13) and will not be considered here. The net effect is that no contaminated clusters of bananas are expected to become totally clean at this step. On this basis, Dist1 was assigned a value of 1.

### 10.11.2 Contamination by black Sigatoka during distribution

**Dist2:** *The number of clean clusters that become contaminated with black Sigatoka spores during the distribution process in Australia is 0.*

As outlined under Dist1 above, black Sigatoka spores are likely to be inhibited by low temperatures and humidity during the distribution process. Cross-contamination could still occur as in Imp7, but it is considered that the number of additional clean clusters in each carton that would become contaminated at Dist2 is extremely small. A value of 0 was therefore assigned to this step.

### 10.11.3 The number of contaminated clusters at each waste point

Table 10.9 summarises how infected banana waste will be divided between the three waste categories in the two areas. The number of contaminated clusters is based on 105,000 tonnes of bananas being imported. It is evident that all clusters would be contaminated.

**Table 10.9 Estimated number of infected clusters distributed to each waste point from 105,000 tonnes of imported bananas**

Areas	Waste category					
	controlled		uncontrolled consumer		other uncontrolled	
<b>Grower areas</b>	11,688,908	11.1%	8,351,143	8.0%	114,826	0.1%
<b>Other areas</b>	49,657,320	47.3%	34,632,295	33.0%	555,508	0.5%

## 10.12 Exposure – proximity considerations (Scenario B)

Determining the probability of exposure is done in two parts. The first part (the proximity considerations covered in this section) determines how likely it is that waste from an infected finger would be close enough to a host to infect it, if conditions are favourable. The second part (the transfer considerations covered in the next section) determines how likely it is that an infection would be initiated on the host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a likelihood greater than zero of transfer of black Sigatoka spores to a host plant to occur. The likelihood of banana waste being discarded sufficiently close to a suitable host plant is dependent both on the method of waste disposal and on the category of the host plant exposure group.

For the purposes of this part of the assessment, the dispersal range of a splash-dispersed black Sigatoka spore is assumed to be 2 m (see discussion under dispersal above). A suitable host is a plant of the genus *Musa* or *Heliconia*.

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 10.10. For each combination in the table, the value is found by multiplying the following two probabilities together:

- the proportion of waste discarded at a waste point that is near the exposure group
- the likelihood that a host plant in an exposure group would be within 2 m of the waste.

The data used for these calculations are given in Sections 7.4 and 7.5, with specific features summarised below.

### **10.12.1 Proportion of waste near each exposure group**

Section 7.4 discusses the proportion of each type of waste that is near each exposure group.

#### **Controlled waste**

Data indicate that no commercial host crops or home gardens occur within 2 m of any controlled waste facility. Although there are no banana plants growing at controlled facilities in other areas, there are some at controlled waste facilities in grower areas. Averaged over all facilities in grower areas, the IRA team considered that no more than  $1.00\text{E}-10$  of the waste might be within 2 m of plants at the facility.

#### **Uncontrolled consumer waste**

Uncontrolled consumer waste is generated by consumers and most of it will be discarded in a home environment, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other environments such as public parks, farmlands, roadsides and bushland. It is very unlikely that uncontrolled consumer waste will be discarded within 2 m of a commercial banana plantation. A value of  $3.10\text{E}-06$  was considered appropriate.

#### **Other uncontrolled waste**

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. It may be fed to livestock, used directly as organic mulch, or tipped in areas not subject to controlled waste management.

Most of the other uncontrolled waste is discarded in other environments such as public parks, farmlands, roadsides and bushland. It was considered that about 5% of other uncontrolled waste is discarded or used near households. It is very unlikely that other uncontrolled waste will be discarded within 2 m of a commercial banana plantation. A value of  $1.00\text{E}-06$  was considered appropriate.

### **10.12.2 Probability of plants within the proximity area**

For any circle, the likelihood of a plant being within it is equal to the area of the circle multiplied by the planting density (Table 7.6).

#### **Commercial crops**

There would be about two banana plants in a circle of a 2 m radius in a banana plantation in grower areas. There are no commercial banana and heliconia plantations in other areas.

### Home gardens

There is a likelihood of between  $4.51\text{E-}03$  and  $6.51\text{E-}03$  that there would be bananas and heliconia plants in a random circle of a 2 m radius in a home garden for grower areas. The corresponding figures for other areas are  $5.28\text{E-}05$  and  $3.17\text{E-}04$ .

### Other plant communities

The likelihood that there are wild, volunteer or amenity banana or heliconia plants in a random circle of a 2 m radius in other environments is between  $5.03\text{E-}06$  and  $5.03\text{E-}05$  for grower areas and about  $6.28\text{E-}08$  for other areas.

### 10.12.3 Summary of proximity values

The proportion of waste near an exposure group is multiplied by the probability that there will be banana plants in a 2 m circle to give the proximity value. Table 10.10 summarises these values for each combination of waste point and exposure group. Where values were expressed as a range, the minimum values are multiplied together, as are the maximum values. The data were insufficient to suggest any central tendencies and so a Uniform distribution was used.

**Table 10.10 Summary of proximity values for black Sigatoka (Scenario B)**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	$3.10\text{E-}06$	$1.00\text{E-}06$
home gardens	0	U( $4.51\text{E-}03$ , $6.51\text{E-}03$ )	U( $2.26\text{E-}04$ , $3.26\text{E-}04$ )
other plant communities	$1.00\text{E-}10$	U( $5.03\text{E-}08$ , $2.51\text{E-}06$ )	U( $5.03\text{E-}06$ , $5.03\text{E-}05$ )
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	U( $5.28\text{E-}05$ , $3.17\text{E-}04$ )	U( $2.64\text{E-}06$ , $1.58\text{E-}05$ )
other plant communities	0	U( $6.28\text{E-}10$ , $3.14\text{E-}09$ )	$6.28\text{E-}08$

### 10.13 Exposure – transfer considerations (Scenario B)

Section 5.4 describes the considerations required when determining the second value needed to determine the probability of exposure: the likelihood of transfer. Given that waste contaminated with conidia and ascospores has been discarded in proximity to a susceptible host plant, the transfer considerations concern the likelihood that black Sigatoka will be carried from the waste to an infection court on the host plant. It is considered that black Sigatoka would be dispersed by rain splash or transport on small animals/insects. The following sequence of factors must occur for black Sigatoka to be successfully transferred:

1. the waste must be exposed to falling water or to animal vectors so that spores may disperse
2. there must be spores present on the waste material
3. spores must be released and become airborne or dispersed by animal vectors
4. dispersed spores must settle on a host plant surface.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of Factors 1, 2 and 3 occurring was calculated to give the minimum values for the likelihood of a transfer event. These values were then adjusted for the total number of spores involved in transfer events (Factor 4) to provide an estimate of the likelihood that at least one spore would be

transferred to a suitable host plant. A similar calculation was done to determine the maximum values. The adjusted values are presented in Table 10.11.

The likelihood values associated with these factors are assessed as follows.

### **Factor 1 – waste presentation**

The same considerations apply to Factor 1 in Scenario B as for Scenario A, although animal vectors would gain access to waste that is partially buried. The IRA team considered that a value of  $1.00E-05$  would apply to controlled waste and between  $7.00E-02$  and  $2.00E-01$  for uncontrolled consumer and other waste.

### **Factor 2 – pest availability**

Factor 2 concerns the likelihood that spores are present on the waste surface. As outlined in the description of Scenario B, the available evidence indicates that there may be in the order of 11,000 spores on each fruit finger (Gasparotto et al 2000). Many of these spores would be removed during washing processes or at least transferred to other fruit or packaging surfaces. Some additional contamination may occur from ascospores released post-harvest (Scenario A). There is likely to be considerable variation in the degree of spore contamination depending on the degree of disease control in the plantation and the efficiency with which bunch covers prevent contamination.

Many of the spores on the fruit surface would be removed during washing processes or at least transferred to other fruit or packaging surfaces. It is expected that many of the spores that contaminated the fruit pre-harvest would germinate ineffectively before harvest, while others would germinate similarly on wet fruit surfaces post-harvest. It is also expected that germinated spores would be firmly attached to the substrate or subject to microbial degradation and therefore not amenable to further dispersal. No information is available to quantify the total number of spores present at this time, but the IRA team's best judgment was that there may be only 100 viable spores on each fruit finger that are available for dispersal when waste material is discarded.

It was therefore considered certain that there would be spores on the waste surface and so Factor 2 was assigned a value of 1.

### **Factor 3 – release of spores**

Factor 3 concerns the likelihood that spores on the surface of fruit will be lifted into the air by rain splash or moved from the waste material by animal vectors. This could occur over a period of 4–8 weeks while the waste material is still intact but the likelihood of release will decrease with time as a result of physical and biological degradation.

Dispersal by animal vectors will require them to have contact with the waste to acquire a level of spore contamination and then move it from the waste to another site. The number of animal vectors that might contact banana waste would be small relative to the number of rain droplets but this dispersal could occur at times when there has been little rainfall. The efficiency with which animal vectors will move spores from banana waste surfaces is probably low and considered to be comparable to that of splash dispersal.

Dispersal of spores by rain splash can occur during periods of rainfall or supplementary irrigation. It is expected that the degree of splash-dispersal will be directly proportional to the amount of rainfall or irrigation received, and indirectly to the frequency of intense rainfall. On average, over 1 mm of rain in a day occurs on 73–106 days a year in grower areas and other areas of Australia (Allen 2008). Rainfall of over 5 mm in a day occurs on an average of 49–73 days a year in grower areas and 39–49 days a year in other areas. Supplementary irrigation may increase the likelihood that splash dispersal occurs in horticultural situations to a limited extent. It was considered that rainfall of over 1 mm would almost always occur during the 4–8 week period that the waste was intact.

Huber et al (2006) provide evidence that the proportion of rainfall splashed from wet surfaces varies with the type of leaf surface, the intensity of rain and rain droplet size. With tobacco leaves, about 0.1% of incident rain splashed when falling at 10 mm/hour as small (2mm diameter) drops and about 10% with large (4mm diameter) drops. With oilseed rape leaves, the corresponding proportions were about 3% and 20%. The proportion of water splashed was about 10-times lower when rain fell at 1 mm/hour but not significantly greater when rain fell at 100 mm/hr. On this basis, the IRA team considered that the proportion of spores becoming airborne from banana waste would be about 1% on average.

As outlined in Factor 2, there may be only 100 spores on each fruit finger that are available for dispersal when it is discarded. Consequently no spores would be lifted from about 35% of waste. From the remaining 65%, one or two spores would be lifted. This will be taken into account under Factor 4.

After considering the uncertainties associated with the release of spores, Factor 3 had a value of 6.50E-01 for all exposure groups.

#### **Factor 4 – spores settle on host**

Factor 4 concerns the likelihood that dispersed spores will settle on a host surface within the proximity zone. This is determined by the number of spores lifted from the waste surface, by the area of host surface relative to that of the proximity zone, and by the efficiency with which spores can adhere to the host surface upon settling.

##### *4A – Number of spores lifted*

As mentioned under Factor 3, only about one or two spores would be lifted.

##### *4B – Area of host surface as a proportion of the area of the proximity zone*

The host surfaces in this instance are the leaf tissues of *Musa* and *Heliconia* species. In considering the growth habits of *Musa* and *Heliconia* cultivars in both commercial and non-commercial situations, it is expected that the area occupied by each host plant would average 5 m<sup>2</sup> but only 10% of this area would be host leaf surface in the area where spores are dispersed. The combination of these two proportions represents 4% of the 2 m dispersal zone around the discarded waste material.

The value of 4% would be applicable for both home plantings and other plant communities, where there is likely to be only one host plant in the 2 m proximity zone for waste discarded. However, for commercial crops, there could be up to three plants within 2 m of the banana waste, and the host surface would make up 4–12% of the proximity zone.

##### *4C – Efficiency with which spores adhere to host plant surfaces*

In order for a spore to initiate infection, it must first adhere to the host surface so that it is not dislodged by rain or water. It would be expected that ascospores and conidia subject to secondary dispersal, as in this scenario, would not adhere to host surfaces to the same degree as spores freshly released from asci and conidiophores. No data have been found to quantify the efficiency with which spores adhere to the surface, but the IRA team considered that it will not be more than 10%.

Factor 4 is then calculated by combining the number of ascospores becoming airborne from each plant fragment (4A), the proportion of target area in the proximity zone (4B) and the efficiency of spore adherence (4C) by calculating  $Factor\ 4 = 1 - (1 - 4B \times 4C)^{4A}$ .

#### **Summary of transfer values**

To estimate the likelihood that at least one transfer event from a waste unit will occur, values of the four factors are combined as indicated above. Table 10.11 summarises the values for each combination of waste point and exposure group.

**Table 10.11 Summary of transfer values for black Sigatoka (Scenario B)**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(2.60E-08, 1.55E-07)	U(1.82E-04, 3.10E-03)	U(1.82E-04, 3.10E-03)
home gardens	U(2.60E-08, 5.19E-08)	U(1.82E-04, 1.04E-03)	U(1.82E-04, 1.04E-03)
other plant communities	U(2.60E-08, 5.19E-08)	U(1.82E-04, 1.04E-03)	U(1.82E-04, 1.04E-03)
<b>Other areas</b>			
commercial crops	U(2.60E-08, 1.55E-07)	U(1.82E-04, 3.10E-03)	U(1.82E-04, 3.10E-03)
home gardens	U(2.60E-08, 5.19E-08)	U(1.82E-04, 1.04E-03)	U(1.82E-04, 1.04E-03)
other plant communities	U(2.60E-08, 5.19E-08)	U(1.82E-04, 1.04E-03)	U(1.82E-04, 1.04E-03)

## 10.14 Establishment (Scenario B)

The factors pertaining to the establishment of black Sigatoka under Scenario B are similar to those in Scenario A (Section 10.7). As explained in the Section 10.6 (transfer), spores that were on the fruit pre-harvest or had entered the pathway at the time of packing would have pre-germinated during transport and handling and are not expected to be transferred from banana waste. The remaining spores would be mainly those that had been released during shipment or produced from endophytic mycelia. It is considered that the infection efficiency (Factor 1) of these remaining spores would be the same as in Scenario A.

Factor 2 is calculated in the same way as for Scenario A. It was considered that the same weather conditions (3 successive days for which there was at least 1 mm of rain and the temperature was greater than 18 °C) would be required for infection to occur. However, Scenario B requires a greater amount of moisture to initiate spore production and transfer via splashing than the moisture required to prime pseudothecia under Scenario A. It was considered that transfer by splashing could occur if there was at least 1 mm of rain. If the temperature was adequate, this day would form the first day of a possible infection period. The number of such days was used to determine the likelihood that a transfer event would be followed by a period suitable for infection. The estimates of Factor 2 are shown in Table 10.12.

**Table 10.12 Estimates of Factor 2 for black Sigatoka (Scenario B)**

	Grower areas	Other areas
Commercial crops	Min: 3.40E-01; mode: 4.42E-01; max: 5.31E-01	Min: 9.35E-03; mode: 2.81E-02; max: 6.67E-02
Home gardens	Min: 5.98E-02; mode: 1.18E-01; max: 1.68E-01	Min: 4.67E-03; mode: 1.40E-02; max: 3.33E-02
Other plant communities	Min: 5.98E-02; mode: 1.18E-01; max: 1.68E-01	Min: 4.67E-03; mode: 1.40E-02; max: 3.33E-02

Factors 3 and 4 are considered to have the same values as in Scenario A. The probability of establishment for Scenario B was calculated for each exposure group as described in Section 10.7. The values are presented in Table 10.13.



**Table 10.13 The probability of establishment values for black Sigatoka (Scenario B)**

Exposure group	Grower areas	Other areas
commercial crops	T(4.84E-04, 4.15E-03, 1.06E-02)	T(1.33E-05, 2.63E-04, 1.33E-03)
home gardens	T(2.99E-04, 3.88E-03, 1.18E-02)	T(3.74E-05, 6.56E-04, 3.00E-03)
other plant communities	T(2.99E-04, 3.88E-03, 1.18E-02)	T(3.74E-05, 6.56E-04, 3.00E-03)

### 10.15 Spread (Scenario B)

The likelihood of spread is the same for Scenario B as for Scenario A and the values are therefore re-presented in Table 10.14.

**Table 10.14 The probability of spread after establishment has occurred**

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	0.7
other plant communities	1	0.7

### 10.16 Probability of entry, establishment and spread (Scenario B)

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.6 and Table 5.7. Table 10.15 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation, 105,000 tonnes, is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively). Rather than showing the individual PEES values for each waste point and exposure group combination, Table 10.16 shows the relative contribution the individual values make to the overall PEES.

**Table 10.15** Probability of entry, establishment and spread of black Sigatoka from contaminated fruit (Scenario B)

	50,000 tonnes	105,000 tonnes	160,000 tonnes
5 <sup>th</sup> percentile	1.15E-01	2.27E-01	3.24E-01
Median	3.54E-01	6.01E-01	7.53E-01
95 <sup>th</sup> percentile	6.88E-01	9.13E-01	9.76E-01

**Table 10.16** Apportioning the PEES by waste point and exposure group

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0.00%	0.14%	0.00%
home gardens	0.00%	97.56%	0.07%
other plant communities	0.00%	0.02%	0.01%
<b>Other areas</b>			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	2.20%	0.00%
other plant communities	0.00%	0.00%	0.00%

## 10.17 Consequences

The consequences to the Australian community of the entry, establishment and spread of black Sigatoka are assessed by considering, on a range of direct and indirect criteria, its potential impact at the local district, regional and national level.

At each level, the impact of black Sigatoka was assessed on the basis of its potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was obtained by combining the direct and indirect impacts of black Sigatoka using the decision rules discussed in Chapter 6.

While black Sigatoka can infect *Heliconia* species, it is unlikely to cause discernible impacts on their production and therefore such impacts were not considered further in the consequences assessment.

Consideration of the direct and indirect impacts is provided in the following text.

### 10.17.1 Direct Impact

#### *Plant life or health – E*

This criterion describes the production losses associated with black Sigatoka in commercial bananas, as well as any loss in productivity of other susceptible species. The direct effects of black Sigatoka have to be considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of ‘indirect impacts’.

In summarising the literature on direct impacts of black Sigatoka, Carlier et al (2000) note that black Sigatoka:

...does not kill plants immediately, but crop losses increase gradually with the age of the plantings. The decrease in functional leaf area caused by the disease results in a reduction in the quality and quantity of fruit. Fruit from affected plants ripen prematurely and do not fill properly. Bananas for export are sometimes harvested at a lower grade (younger age) in order to reduce the risks of premature ripening in transit to overseas markets.

They also note that black Sigatoka is a major constraint to banana production and that, after the first occurrence in an area, the disease builds up and often reaches epidemic proportions. The speed of build-up depends on:

- the environmental conditions
- the degree to which other leaf diseases are established in the area
- the degree to which fungicides are already used
- the virulence of the introduced *M. fijiensis* to the local banana cultivars.

In Australia, black Sigatoka is expected to be most significant in the tropical parts of north Queensland, and less significant in subtropical temperate, or arid areas. Its effects will be minimised by fungicide sprays and leaf sanitation measures already used against established diseases such as yellow Sigatoka (*M. musicola*) and leaf speckle (*M. musae*). However, the disease is likely to spread within a short time to all banana farms in a production district, and to affect these farms to various degrees, depending on the management systems in place. In household situations, fruit production and fruit quality would be reduced and the growing of susceptible lines would be impractical in most tropical areas for most householders.

The severity of black Sigatoka on native Australian *Musa* species (*M. acuminata* subsp. *banksii*, *M. jackeyi*, *M. fitzalanii*) is unknown. However, given their limited distribution in Australia and their isolation from other amenity and commercial bananas, it is very unlikely that they would be infected. This is the case for infection of *M. acuminata* subsp. *banksii* by *M. musicola* in north Queensland (Pont 1960b).

Marín et al (2003) note that black Sigatoka is considered the most damaging disease of bananas and plantains. It has been estimated that the disease causes 38 percent yield loss on plantains and even greater losses may occur on banana when control measures fail. The disease destroys the foliage rapidly if control measures are not applied. Plant growth and fruit yield are affected due to the reduction in photosynthetic area. The greatest loss probably results from premature ripening of fruit in the field, and during transport and storage.

Overall, the likely direct impact of black Sigatoka in terms of plant production losses is considered 'significant' at the regional level. The rating assigned to this criterion is therefore **E**.

#### ***Human life or health – A***

There are no known direct impacts of black Sigatoka on human life or health and the rating assigned to this criterion is therefore **A**.

#### ***Any other aspects of the environment not covered above – C***

This criterion addresses the possible direct impact of pests on 'other aspects' of the natural or built environment, such as the physical and biological environment.

Although native banana species (*M. acuminata* subsp. *banksii*, *M. jackeyi* and *M. fitzalanii*) could potentially become infected with black Sigatoka, the impact of infection is unknown. However, a reduction in the number of native banana plants may occur if black Sigatoka was to become established in an area. Native bananas in Australia are generally disease free, either due to their low density and isolation from commercial banana plantations or some level of resistance or tolerance to

disease. In comparison, plant production based on monoculture is more likely to experience pest and disease epidemics.

Overall, the likely direct impacts of black Sigatoka on other aspects of the environment is considered to be 'significant' at the local level and the rating assigned to this criterion is therefore **C**.

### **10.17.2 Indirect impact**

#### *Control or eradication – E*

On first detection, an eradication program could be initiated under the Emergency Plant Pest Deed. The cost is likely to be several million dollars per year over a number of years. This was the case when black Sigatoka was found in the Tully district in April 2001. This eradication program cost over \$20million, and additional indirect costs were borne by affected banana growers (C Adriaansen, General Manager, Plant Biosecurity, QDPIF, pers comm 22 March 2006).

If eradication fails, black Sigatoka would require on-going fungicide spraying and leaf sanitation measures additional to those required for control of endemic leaf diseases such as yellow Sigatoka. Currently, 20 to 24 fungicide sprays are applied to control yellow Sigatoka in tropical north Queensland and 4 to 8 in the subtropical parts. The number of spray and de-leafing cycles would probably double, leading to an increase in the cost of production in the order of \$1650 per hectare, which represents approximately \$2 per carton or \$36 million across the industry each year (Allen 2000). In addition, more intensified de-leafing programs will be required for the control of black Sigatoka than those currently used for yellow Sigatoka.

Marín et al (2003) notes that black Sigatoka is very costly to control in both bananas and plantains and accounts for 27% of the total production costs in these production systems.

Overall, the indirect impact of *M. fijiensis* on the cost of pest control programs is considered 'significant' at the regional level. The rating assigned to this criterion is therefore **E**.

#### *Domestic trade – C*

Domestic trade effects associated with the introduction and spread of black Sigatoka are likely to result from intrastate and interstate trading restrictions on planting materials, leaf material and fruit. The effects on planting materials would be no greater than already apply to other pests and diseases. The restrictions on leaf and bell materials would be minor to the few producers affected by the restrictions.

However, restrictions on fruit could disrupt national marketing arrangements for a short time after the initial detection of the disease in an area, but would be no more than currently exist for outbreaks of black Sigatoka that have occurred previously. Overall, the indirect impact on domestic trade is considered 'significant' at the local level. The rating assigned to this criterion is therefore **C**.

#### *International trade – A*

Australia exports only small quantities of bananas that go to a specialty organic market. The presence of black Sigatoka would not disturb these trade arrangements. However, production would be significantly reduced and may threaten the viability of the enterprise. The rating assigned to this criterion is therefore **A**.

#### *Environment – C*

An effect of black Sigatoka would be to increase the use of fungicidal chemicals and associated spraying practices. These chemicals and spraying practices have been used in banana growing areas for many years and there are already concerns over any further increase in their use.

It is considered that the effect would be ‘significant’ at the local level. The rating assigned to this criterion is therefore **C**.

### ***Communities – C***

One of the considerations within this criterion is the potential indirect impact of black Sigatoka on rural economic viability. The effects of black Sigatoka on changes to horticultural practices have already been considered under new or modified controls (see above).

An incursion of black Sigatoka will be more difficult and costly to control than the existing yellow Sigatoka pathogen. Growers will experience higher costs and lower returns that may result in some industry readjustment. This would have a negative impact on agriculturally related employment within the local community (refer to Section 9.14.2).

Gross regional product multipliers in the range of 1.5–2 for banana growing areas in north-eastern Australia suggest that a downturn in banana production will have a flow-on effect on other local industries (CEPM 2002; OGS 2002; Growcom 2004). A downturn in banana production would have a significant economic and social impact on the Johnstone and Cardwell shires where agricultural production constitutes the dominant industry (Cummings 2002).

Overall, the indirect effects of black Sigatoka on communities are likely to be ‘significant’ at the local level. The rating assigned to this criterion is therefore **C**.

### **10.17.3 Overall consequences for black Sigatoka**

*The overall consequences to the Australian community of the entry, establishment and spread of black Sigatoka as a result of trade in mature hard green bananas from the Philippines: **Moderate**.*

Table 10.17 provides a summary of the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of black Sigatoka within Australia.

The direct and indirect impacts of black Sigatoka shown in Table 10.17 were combined using the decision rules discussed in Chapter 6. It follows from these decision rules that 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 black Sigatoka are considered to be ‘moderate’.

**Table 10.17 Consequences assessment for black Sigatoka is moderate**

Criteria	National	Regional	District	Local	Impact
Plant life or health	Minor	Significant	Highly significant	Highly significant	E
Human life or health	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Any other aspects of the environment	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
Control or eradication	Minor	Significant	Highly significant	Highly significant	E
Domestic trade	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
International trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Environment	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
Communities	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C

## 10.18 Unrestricted risk

The risk associated with black Sigatoka in Scenario A is determined by combining the median value of PEES ( $1.30E-01$ ) with the consequence (“Moderate”) according to Table 6.2. The same calculation was done for Scenario B ( $6.01E-01$ ). Simulating Scenarios A and B together gives a median value of  $6.84E-01$  for the PEES. The risk from infected leaf pieces and floral material (Table 10.18; Scenario A) and the risk from contaminated bananas (Table 10.19; Scenario B) in both instances exceeds Australia’s ALOP and therefore risk management would be required for both infected plant fragments and contaminated banana fruit with black Sigatoka.

**Table 10.18 Unrestricted risk (Scenario A)**

Probability of entry, establishment and spread	$1.30E-01$
Consequence	Moderate
Risk	Exceeds ALOP (Low)

**Table 10.19 Unrestricted risk (Scenario B)**

Probability of entry, establishment and spread	$6.01E-01$
Consequence	Moderate
Risk	Exceeds ALOP (Moderate)

## 10.19 Risk management for black Sigatoka

The unrestricted risk of black Sigatoka exceeds Australia’s ALOP when the overall probability of entry, establishment and spread (PEES) is combined with the overall consequence. Risk mitigation measures would therefore be required to lower this rating to achieve Australia’s ALOP.

The risk mitigation measures will need to be effective in the areas of Mindanao proposed for export of Cavendish bananas to Australia.

The pathways considered in this analysis showed that black Sigatoka could enter, establish and spread in Australia from imported banana fruit that have pseudothecia of black Sigatoka embedded in infected leaf and floral plant material (Scenario A), and spores of black Sigatoka on the surfaces of fruit (Scenario B).

A range of potential phytosanitary risk management measures at various steps in the import pathway may be considered to reduce the risk to an acceptable level.

The Philippines Government will be required to demonstrate to Australia's satisfaction that the strength of the proposed phytosanitary risk management measures, or of a combination of phytosanitary risk management measures (a systems approach), will reduce the number of fertile pseudothecia in leaf and floral plant material (Scenario A) and the number of fertile spores on the surfaces of fruit (Scenario B).

The efficacy of any treatment(s) to reduce the numbers of fertile spores and pseudothecia would need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

The Philippines Government will be required to prove and verify the effectiveness of measures, as indicated in this section and Chapter 20. All proposed measures must be monitored, verified and audited by trained BPI and AQIS staff as specified in Chapter 20.

### *Summary of scenarios*

The risk scenarios used to determine the unrestricted probability of entry, establishment and spread of black Sigatoka in this analysis considered the number of ascospores released from fertile pseudothecia embedded in infected leaf and floral plant material (Scenario A) and surface contamination of packed fruit with spores of black Sigatoka (Scenario B).

The IRA team, taking into consideration the best available information and taking account of expert judgement, has determined the values that were used in the model to aid the evaluation of the unrestricted probability of entry, establishment and spread of black Sigatoka in this analysis (Table 10.7 and Table 10.15).

The analysis of unrestricted risk for Scenario A determined that in the order of 1 in 2000 clusters (or 50 per 100,000) would have trash with between 1–20 pseudothecia after being subjected to standard commercial practices in the Philippines. Each piece of infected trash could release between 80–1728 ascospores, depending on the degree of infection and the environmental conditions to which the infected material is exposed. Risk mitigation measures would need to reduce the number of viable ascospores released by reducing, for example, the number of clusters with trash and/or the number of fertile pseudothecia on the trash.

Scenario B considered that there will be spores on each banana finger. The unrestricted risk scenario determined that an average of 100 fertile spores would be present on the surface of each banana finger when the waste is disposed of. Risk mitigation measures for Scenario B would need to reduce the number of fertile spores at waste disposal. The Philippines Government would be required to demonstrate an appropriate reduction in spore numbers following post harvest treatment, and under standard transport and storage conditions.

### *Pest thresholds to achieve Australia's ALOP*

If the unrestricted risk exceeds Australia's ALOP, the risk assessment then considers what risk management measures might be available to reduce the risk to achieve Australia's ALOP (Section 6.3) because the overall consequences rating is 'moderate' the PEES would be required to be less than 0.05 (Table 6.2).

The use of a quantitative approach to determining PEES allows the restricted PEES to be expressed in terms of a pest threshold which is the maximum number of pests and/or the maximum level of disease

associated with mature hard green Cavendish bananas imported into Australia from the Philippines that would achieve Australia's ALOP.

Because black Sigatoka can enter by two pathways (infected trash and spores on the skin), two thresholds need to be specified:

- (Scenario A) the proportion of clusters that, after processing, have trash bearing pseudothecia and the number of fertile pseudothecia on trash.
- (Scenario B) the number of viable spores that would be on a finger when it is disposed of.

There are many pairs of these thresholds that, when combined, give a PEES that would achieve Australia's ALOP.

The overall restricted PEES was calculated for a number of combinations of thresholds, as shown in Table 10.20. The shaded combinations in the table have a PEES that is less than 0.05. Any measures that would meet those thresholds would achieve Australia's ALOP.

**Table 10.20 Probability of entry, establishment and spread when pest thresholds are met.**

The table is based on there being 1–20 fertile pseudothecia on contaminated trash under Scenario A. Similar tables can be calculated if risk management measures reduce the number of fertile pseudothecia on trash.

Scenario A		Probability of entry, establishment and spread						
Number of clusters after processing with contaminated trash per 100,000 clusters.	14	0.051	0.059	0.069	0.078	0.087	0.095	0.103
	12	0.044	0.053	0.062	0.071	0.080	0.088	0.097
	10	0.037	0.046	0.056	0.065	0.073	0.082	0.089
	8	0.029	0.039	0.048	0.058	0.066	0.075	0.082
	6	0.022	0.032	0.041	0.050	0.059	0.067	0.075
	4	0.015	0.024	0.034	0.042	0.050	0.058	0.066
	2	0.007	0.017	0.026	0.034	0.042	0.050	0.057
	0	0.000	0.008	0.017	0.025	0.033	0.041	0.048
	Scenario B		0	1	2	3	4	5
		Average number of fertile spores on a discarded finger						

Because the consequences of black Sigatoka were rated as 'moderate' to achieve Australia's ALOP, any proposed phytosanitary risk management measures (or system of measures) will need to reduce the PEES to less than 0.05 for both Scenario A and Scenario B combined (giving the restricted PEES).

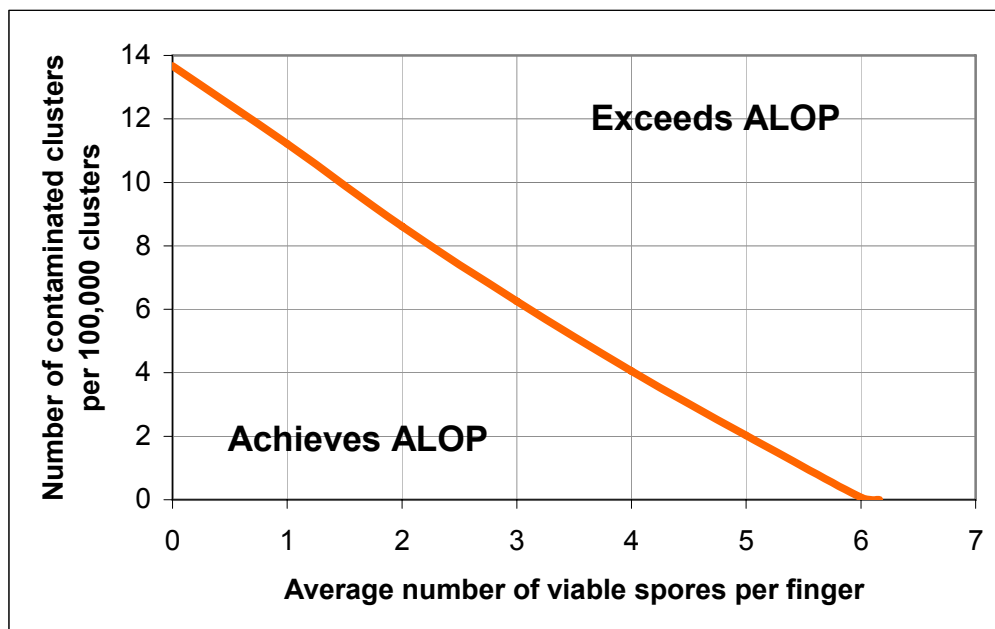
The calculation for the restricted PEES for Scenario A in the table used values for Imp2, Imp4 and Imp5 that would result in the specified threshold level being present after processing. It is assumed that the level of fertile pseudothecia on contaminated trash would have the range (1–20) used in this analysis. Similar tables could be calculated if different levels of fertile pseudothecia could be demonstrated.

For Scenario B, the threshold value was used instead of the value 100 for the number of fertile spores at Factor 2 of the transfer values (Section 10.13). The left-most column of Table 10.20 gives the PEES for Scenario A considered by itself and the bottom row of the table does the same for Scenario B. The median PEES of the two combined scenarios is slightly greater than the sum of the median PEES values for each scenario taken alone.

The effect of any phytosanitary risk management measures would need to be considered for both scenarios. There will be a number of different combinations of risk management measures that would achieve Australia's ALOP.



Figure 10.2 illustrates the range of thresholds that would achieve Australia's ALOP. Those values in the portion of the chart under the line would, when inserted in the model together with the other values in the relevant sections of Part B of the report, considered in the context of the report as a whole, and combined with the consequence of "moderate" (Section 10.17.3), achieve Australia's ALOP.



**Figure 10.2** Combination of required pest thresholds that achieves Australia's ALOP

#### *Standard commercial practice and phytosanitary risk management*

Much of the key information provided by the Philippines Government is based on standard commercial agronomic practice in the Philippines. Some aspects of standard agronomic practice are discussed further in the sections on operational requirements (Chapter 20 and Part C). One of the aims of standard commercial agronomic practice is that bananas for export are to be free of leaf and floral material and meet commercial export standards.

Where compliance with standard commercial practices is required by Australia for the effective implementation of phytosanitary risk management measures, such practices will be made mandatory and be required to be verifiable and auditable.

#### **10.19.1 Potential phytosanitary risk management measures**

A range of potential phytosanitary risk management measures may be considered if they can be demonstrated, to Australia's satisfaction, to reduce the unrestricted risk and achieve Australia's ALOP. Potential phytosanitary risk management measures may include, but are not limited to:

- pest free areas, pest free places of production and pest free production sites
- areas of low pest prevalence
- trash minimisation
- post-harvest fungicide treatment
- post-harvest inspection and corrective action.

#### ***Pest free areas, pest free places of production and pest free production sites***

Sourcing bananas for export from areas established, maintained and verified free from black Sigatoka in accordance with the guidelines outlined in ISPM 4: *Requirements for the establishment of pest free areas* (FAO 1996), ISPM 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO 1999) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007) would reduce the values associated with several steps on the importation pathway and achieve Australia's ALOP.

It would be difficult to demonstrate pest free areas, pest free places of production and pest free production site to Australia's satisfaction given the subtle symptom expression of the disease in its early stages and the presence of the pathogen may be masked by other foliar diseases, including yellow Sigatoka (*M. musicola*) and cordana leaf spot (*Cordana musae*).

#### ***Areas of low pest prevalence***

Areas of low pest prevalence could be established and maintained following the guidelines described in ISPM 22: *Requirements for the establishment of areas of low pest prevalence* (FAO 2005a) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007).

An area of low black Sigatoka prevalence could be a place of production (a banana plantation managed as a single unit) or a production site (a designated block within a plantation) for which low prevalence of black Sigatoka is established, maintained and verified by BPI and audited by AQIS. This measure would reduce the number of fertile pseudothecia and spores on the import pathway and thereby mitigate the risk.

Individual banana plantations in the Philippines could be maintained at a very low disease prevalence for black Sigatoka disease symptoms through the use of various management practices, including regular fungicide applications and other horticultural practices, such as regular de-leafing as soon as initial fleck or streak symptoms of the disease are observed on leaves in weekly inspections. Plantations where such measures are implemented are known to have lower black Sigatoka disease prevalence.

An area of low pest prevalence would ensure the degree of infection of plant material and spore contamination associated with export bananas would be lower than those indicated in the unrestricted risk assessment.

The IRA team acknowledges that the prevalence of black Sigatoka is lower in the drier areas of Mindanao than in wetter areas. It may be practical to establish areas of low pest prevalence in parts of Mindanao where the disease pressure is relatively low. Even in these areas, it would be necessary to avoid areas where 'hot spots' are likely to occur due to microclimatic factors or physical barriers to aerial fungicide application.

#### ***Trash minimisation***

Trash minimisation procedures would reduce the level of leaf and floral material in export bananas and hence reduce the proportion of infected clusters. Trash minimisation procedures may be applied in the banana plantation and in the pack house.

Trash minimisation procedures in banana plantations may include:

- covering of bunches without placing the flag leaf in the bunch cover
- regularly replacing bunch covers showing tears
- rodent control
- rejecting bunches with rodent or bird nests or other visible trash
- rejecting bunches that fall on the ground
- removing pruned leaves from a plantation used for growing export bananas.

Trash minimisation procedures at the pack house may include:

- high pressure washing
- removal of trash during de-handing
- brushing and/or wiping of clusters
- visual quality control systems including the removal of visible trash.

It is expected that the degrees of infection of plant material and spore contamination associated with export bananas contaminated with lower levels of plant material would be lower than those indicated in the unrestricted risk assessment.

#### *Post-harvest fungicide treatment*

Post-harvest fungicide treatments are already used in packing stations in the Philippines (BPI 2000) and the principles and practices of application are well understood.

As development of fungicide resistance in black Sigatoka is a problem, this issue will need to be addressed by testing the sensitivity of spores from an export plantation to the nominated fungicide(s) prior to applying the post-harvest fungicide treatment.

While post-harvest fungicide treatment of export bananas in the packing station would reduce the level of spores on the fruit surface, it may not be sufficiently effective against fertile pseudothecia embedded in plant material.

#### *Post-harvest inspection followed by corrective action*

Post harvest inspection would be followed by corrective action if the number of pieces of trash exceeds a predefined level. This would reduce the proportion of infected clusters and the level of leaf and floral material in export bananas. It may be applied either at the pack house or during the BPI inspection process prior to presenting the consignment to AQIS inspectors as part of any pre-clearance program.

Considering the small proportion of clusters that would be contaminated with leaf or floral material, a relatively large sample size would be required at inspection to enable detection of potentially contaminated leaf and floral material.

Taking the corrective action of removing leaf and floral material from export bananas would constitute a phytosanitary risk management measure (Scenario A).

However, visual inspection would be ineffective in detecting surface contamination of export bananas with black Sigatoka spores (Scenario B). Therefore post harvest inspection followed by corrective action could not achieve Australia's ALOP by itself.

#### *Systems approach*

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve the ALOP, as described in ISPM 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.

### *Other potential risk management measures*

The IRA team acknowledges that there are potentially other possible risk management measures. If additional relevant information is provided that suggests alternative measures may be capable of reducing the risks to achieve Australia's ALOP, the supporting evidence will be considered on a case-by-case basis.

#### **10.19.2 Application of potential risk management measures**

The IRA process requires the consideration, and recommendation, of whether there are risk mitigation measures, used either alone or in combination that would reduce any risk that exceeds Australia's ALOP, identified through pest risk analysis, to a level that achieves ALOP. This section considers what effect the measures proposed in the previous section might have on the number of clusters contaminated with infected trash (Scenario A) and the number of fertile spores on banana waste at disposal (Scenario B).

To achieve Australia's ALOP, one of the combinations of pest threshold set out in Table 10.21 must be met. As an example, the combination of less than 6 clusters having pieces of infected leaf material per 100,000 clusters with 2 fertile spores on waste from a banana finger at disposal achieves Australia's ALOP. Since the pest thresholds are specified as a number, the reduction in pest levels required to meet the thresholds will depend on the level of disease present. Efficacy percentages have been included in this section as indicative examples and were developed considering the pest prevalence in the Philippines as described in this report.

Based on the level of pests determined earlier in this chapter, in order to achieve Australia's ALOP, a combination of measures must reduce the proportions of clusters with infected leaf material by at least 88% (from 50 per 100,000 for the assessed unrestricted value to below 6 per 100,000) and the number of spores by at least 98% (from 100, the assessed unrestricted value, to below 2 fertile spores per finger at disposal). The precise reduction needed for the individual scenarios would depend on the actual pest levels occurring in the Philippines.

The Philippines Government would be required to demonstrate that any proposed measures would be able to achieve the specified efficacy under commercial conditions.

**Table 10.21 Example effects of mitigation measures on pest levels**

The table shows example efficacies of measures considered feasible at reducing the level of infected trash (Scenario A) and fertile spores (Scenario B) from the pest levels determined in the analysis of unrestricted risk.

Measure	Example efficacy		Pest levels		Effect
	Scenario A	Scenario B	Scenario A	Scenario B	
No Measure			<b>50</b>	<b>100</b>	
Pest free areas, pest free places of production and pest free production sites	-	-	-	-	Not considered feasible
Post harvest inspection followed by corrective action	-	-	-	-	Not considered feasible
Areas of Low Pest Prevalence (ALPP)	95.00%	90.00%	2.50	10.00	Exceeds ALOP
Trash minimisation	75.00%	85.00%	12.50	15.00	Exceeds ALOP
Post-harvest fungicide treatment	0.00%	90.00%	50.00	10.00	Exceeds ALOP
Trash minimisation and post-harvest fungicide treatment	75.00%	98.50%	12.50	1.50	Exceeds ALOP
ALPP and trash minimisation	98.75%	98.50%	0.62	1.50	Achieves ALOP
ALPP and post-harvest fungicide treatment	95.00%	99.00%	2.50	1.00	Achieves ALOP
ALPP, trash minimisation and post-harvest fungicide treatment	98.75%	99.85%	0.62	0.15	Achieves ALOP

#### *Pest free areas, pest free places of production and pest free production sites*

Given the ubiquitous nature of black Sigatoka in the Philippines, the IRA team considered that mitigation based on disease freedom in pest free areas, pest free places of production and pest free production sites may be extremely difficult to implement.

Demonstrating pest freedom would be difficult given the subtle symptom expression of the disease in its early stages and the presence of the pathogen may be masked by other foliar diseases, including yellow Sigatoka (*M. musicola*) and cordana leaf spot (*Cordana musae*).

Without precluding this measure as an option the Philippines Government may use, the measure was not considered feasible by the IRA team.

#### *Areas of low pest prevalence*

The IRA team considered that ALPP would be a risk mitigation measure that could be implemented and would reduce the level of pests. ALPP would be expected to reduce both the level of infected trash in exported clusters (Scenario A) and the level of fertile spores on fruit (Scenario B).

Sourcing of bananas from low pest prevalence areas would reduce the proportion of infected clusters, the evaluation of which is described at the Imp2 step of Scenario A in Section 10.3.2. While ALPP would not alter the values of the first two of the four factors that make up Imp 2 (the proportion of clusters contaminated with any leaf material at harvest and the proportion of clusters contaminated with any leaf material within contaminated bunches), ALPP would reduce the third and fourth factors. The third factor, the proportion of leaf material pieces on contaminated clusters that are infected by black Sigatoka, should decrease because measures to achieve ALPP would reduce the level of disease.

The fourth factor, the proportion of leaf pieces infected with black Sigatoka that contain fertile pseudothecia, should also reduce because the earlier detection of disease needed to achieve ALPP would mean that any disease lesions would be less advanced. An ALPP would also reduce the spore levels in the plantation, on fruit, and in the wash tank.

In the example given in Table 10.21 ALPP reduces the value of Imp2 for Scenario A by 95% and spore levels for Scenario B by 90%.

#### *Trash minimisation*

The IRA team considered that trash minimisation would be a risk mitigation measure that would reduce the level of pests. Trash minimisation procedures have the potential to reduce the proportion of contaminated clusters on the plantation (which is considered at Imp2) and during processing (which is considered at Imp4).

The determination of the value for Imp2 follows the method described in Section 10.3.2. Trash minimisation would reduce the first two factors (that is, the proportion of clusters contaminated with any leaf material at harvest and the proportion of clusters contaminated with any leaf material within a contaminated bunch). The remaining two factors would remain the same as for the unrestricted scenario. Effective trash minimisation procedures at the plantation and/or pack house may result in a decrease of the number of fertile spores of black Sigatoka on the surface of the banana fingers at the point of disposal (Scenario B).

In the example given in Table 10.21 trash minimisation reduces the value of Imp2 for Scenario A by 75% and spore levels for Scenario B by 85%.

#### *Post-harvest fungicide treatment*

The IRA team considered that a post-harvest fungicide treatment would reduce fertile spore levels.

The major effect of a post-harvest disinfestation treatment will be on the number of fertile spores for Scenario B, with only a minor effect on the number of fertile pseudothecia on trash for Scenario A. Because the unrestricted risk from Scenario A exceeds the ALOP, it seems unlikely that post-harvest treatment would provide sufficient risk mitigation to achieve Australia's ALOP by itself. The efficacy of post-harvest treatment would need to be demonstrated by the Philippines Government for Scenario B and, if it was claimed that there was an effect, for Scenario A.

In the example given in Table 10.21 post harvest fungicide treatment reduces spore levels for Scenario B by 90%.

#### *Post-harvest inspection followed by corrective action*

Post-harvest inspection and corrective action was not considered to be a practical method for reducing trash level under Scenario A since effective visual inspection for minute particulate trash would be difficult. In addition, visual inspection would be ineffective in detecting surface contamination of export bananas with fertile spores of black Sigatoka (Scenario B).

Without precluding this measure as an option the Philippines Government may use, the measure was not considered feasible by the IRA team.

#### *Systems approach*

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve Australia's ALOP. The concept of systems approaches are more fully described in ISPM 14: *The use of integrated measures in a systems approach for pest risk management* (FAO 2002).

Possible systems approaches include:

- ALPP and trash minimisation
- ALPP and post harvest fungicide treatment
- Trash minimisation and post harvest fungicide treatment
- ALPP, trash minimisation and post harvest fungicide treatment

### *Conclusion*

Example pest reduction levels for those measures considered feasible are provided in Table 10.21. The values given, which are based on the level of pest assessed to be currently present in the Philippines, as contained in the report, are included as examples and do not imply that such a level of reduction will be achieved. The strength of any mitigation measure will depend on how the measure is implemented. As mentioned previously, the Philippines Government would be required to demonstrate the effect of any proposed mitigation measures using laboratory and/or field trials and under commercial conditions. Table 10.21 suggests that no single feasible measure would be adequate to reduce the risk sufficiently, but that there could be combinations of measures that should achieve Australia's ALOP.

### **10.19.3 Risk management conclusion**

The Philippines Government would be required to provide evidence to Australian authorities on the efficacy of any phytosanitary risk management measures proposed to reduce the level of contamination of banana clusters by black Sigatoka to levels that would achieve Australia's ALOP.

Any proposed phytosanitary risk management measures would be required to be demonstrated, to Australia's satisfaction, by laboratory experiments and/or field trials and under commercial conditions and would need to be completed to provide supporting evidence, including that:

- The strength of proposed phytosanitary risk management measures, or combinations of phytosanitary risk management measures (a systems approach), is sufficient to reduce the proportion of clusters contaminated with leaf and floral plant material bearing fertile pseudothecia (Scenario A) and the number of fertile spores on the surfaces of fruit (Scenario B) to the levels required to meet Australia's ALOP.
- Procedures for fruit inspection including the detection and examination of leaf and floral material for infection by black Sigatoka are effective.
- Post-harvest disinfestation treatments are effective and the level of efficacy can be measured by procedures such as incubation tests.

Other evidence may also be required, depending on the specific risk management measures proposed for consideration.

Further details of the proposed risk management regime are provided in Chapter 20.





## 11. Freckle

### 11.1 Introduction

Freckle is a leaf and fruit spotting disease of bananas and plantains caused by the ascomycete fungus *Guignardia musae* (Chuang 1981; Jones 2000). It occurs in both the Philippines and Australia. It is widespread in the Philippines on local and Cavendish banana cultivars (Lee 1922), but its occurrence in Australia is restricted to non-Cavendish cultivars (Jones and Alcorn 1982; Jones 2000; Condé 2001). The disease is under official control in all banana-growing areas of Australia. Measures are in place to restrict the marketing of fruit should the need arise.

Cavendish bananas cannot be produced commercially in wet tropical or subtropical areas unless freckle disease is controlled, at least at a quality suitable for market. This is achieved by a combination of leaf pruning to remove diseased leaf tissue and the application of fungicides at regular intervals. In the Philippines, these activities are carried out routinely throughout the year in association with disease control for black Sigatoka disease (*Mycosphaerella fijiensis*). Between 30–45 fungicide sprays are applied per year, depending on weather conditions and the results of disease monitoring. In subtropical Taiwan, freckle has become the dominant leaf pathogen over black Sigatoka and requires control with sanitation and multiple fungicide applications (Tsai et al 1993).

Fruit severely affected by freckle disease is excluded from export under standard quality assurance procedures in the Philippines. These measures prevent the harvesting of bunches with obvious disease symptoms and reject severely diseased clusters during processing at the packing station.

### 11.2 Biology

#### 11.2.1 Host plants

Freckle infects a range of *Musa* species and cultivars in many countries (Meredith 1968; Tsai et al 1993; Jones 2000). It is known that the native species *M. acuminata* subsp. *banksii* is susceptible, but the susceptibility of native *M. jackeyi* and *M. fitzalanii* in Australia is not known. *Guignardia musae* has been reported to infect *Heliconia* spp. in Venezuela (Madriz et al 1991) and *Ensete superbum* in India (Nag Raj 1993) but these reports appear not to have been substantiated by pathogenicity tests. The pathogen has not been observed on hosts other than *Musa* spp. in the Philippines or Australia.

Strains of freckle present in the Philippines are considered to affect only edible bananas, plantains, and some native *Musa* spp. In the Philippines, freckle causes disease on Cavendish (AAA) bananas whereas the strains present in Australia do not affect Cavendish (Jones 2000).

#### 11.2.2 Symptoms and effects on host plants

Freckle infects and causes disease on leaves and fruit although symptoms are rarely seen on fruit unless the leaves are also infected (Meredith 1968). Freckle can affect the lamina and mid-rib tissues on leaves and the surface (skin), cushion, bunch stem and flower bracts associated with fruit. It penetrates the host tissue directly and spreads from cell to cell in the outer layers of the surface tissues.

It has been shown in inoculation experiments that fruit tissues are susceptible to infection from the time the floral bract rolls back until a late stage of maturity (Chuang 1984). The symptoms appear as reddish-brown flecks, 4–6 days after inoculation (Meredith 1968, Chuang 1981 and Pu et al 2008). Each fleck lesion has a characteristic dark green halo of water-soaked tissue and develops into a brown to black spot 1–4 mm in diameter over the following three to four weeks. Pycnidia form in the centre of the spots giving the surface a rough texture. There may be up to 40 pycnidia per cm<sup>2</sup> of diseased

areas in the rainy season but more often only 7–8 pycnidia per cm<sup>2</sup> (Chuang 1984). In severe cases, the entire surface of leaves and fruit can be covered with freckle lesions and pycnidia (Meredith 1968).

Symptoms on leaves and fruit become visible to the naked eye within 10–30 days of inoculation under ideal conditions of temperature and moisture, and abundant inoculum (Meredith 1968; Chuang 1981, 1984). The severity of disease increases as a result of secondary infection from spores produced in older lesions as the leaf and fruit tissues age (Meredith 1968). Conidia from overhanging leaves may be splashed on to young fruit before the bunch is covered, or may be carried in water trickling down the bunch stem. Water trickling under covered bunches could lead to significant infection on the cushion tissue. Inoculum can also come from lesions that developed from earlier infections. This may occur even after the fruit is harvested, as indicated by the results from inoculation experiments (Meredith 1968; Chuang 1984).

In Taiwan, Chuang (1984) reported that, while most leaves developed symptoms within 17–30 days of emergence, disease symptoms did not appear on some leaves until up to 69 days after their emergence. These observations were made in periods of cool, dry weather. There is no indication of when infection first occurred on newly emerged leaves, so it cannot be concluded that the incubation period (that is, the period from infection to appearance of disease symptoms) could be as long as 69 days.

Meredith (1968) found that appressorium formation did not occur if the host surface dried out within 12 hours of spore germination. Keeping the fruit surface wet for 48 hours provided optimum conditions for infection. He also found that the development of symptoms was enhanced when there were multiple infections within a small area, whereas infections from a single appressorium could lead to symptoms visible only at the microscopic level.

Pu et al (2008) report that spore germination and appressorium formation occur on detached banana leaves at temperatures of 15–35 °C and optimally at 25 °C. Research on *G. bidwellii* (black rot of grapes) (Spotts 1980) has found that the minimum leaf wetness duration required for light infection of grape leaves was 12 hours at 13 °C, compared with 6 hours at the optimum temperature of 26.5 °C. Spotts (1980) reported that the incubation period of black rot on grape leaves was 13.5 days at 15 °C, compared with 7.5 days at 26.5 °C and that pycnidia were observed after 19 and 12 days, respectively. The observations by Spotts (1980) were similar to those made by Meredith (1968) at the optimum temperature for freckle. They indicate that freckle may potentially develop on packed bananas during the 10–14 day period that fruit are transported at 13–14 °C and the following 7–10 day period at which the fruit are ripened, presented for retailing and eventually stored in households at ambient temperature prior to consumption.

No information has been found on the numbers of *G. musae* conidia that can be produced in a pycnidium. It has been reported that large numbers of conidia exude in long tendrils of mucilage when the pycnidia become wet (Meredith 1968). Apparently dormant pycnidia can resume the production of conidia on being re-wetted and it is possible that spore production will continue for as long as the pycnidium survives. Estimates from the closely related fungus, *G. bidwellii*, indicate that about 120 conidia are released per pycnidium after 4 hours of continuous rain. This process is expected to recur after intervening periods of recovery until nutritional reserves in the pycnidium or banana waste are exhausted. Given the close similarities between the pycnidia of *G. bidwellii* and *G. musae*, it is considered that freckle could produce up to 2,000 conidia per pycnidium over the 4–8 week period that banana waste remains intact on the soil surface. This represents about 16 cycles of spore release and recovery.

In the Philippines, freckle disease can be found all year round (BPI 2002b; refer to Part C, Appendix 7 *Disease severity in the Philippines*). However, in Taiwan and Hawaii the disease develops most severely in the rainy summer months (Meredith 1968; Chuang 1984). Freckle hastens the death of older leaves and may affect the productivity of host plants if it is severe. However, the main commercial effect is to cause blemish on fruit surfaces that is unacceptable in export markets such as

Japan (Jones 2000). It is expected similarly that Australian consumers would not accept fruit with blemish caused by freckle.

### 11.2.3 Dispersal

Infection of leaves attached to planting material is probably the main means by which the disease is introduced to new areas. It is very likely that freckle can be spread on infected leaves attached to banana planting material or used as padding in the transport of fruit and also on infected leaf fragments associated with fruit packed in cartons. In the context of this analysis leaves are not used for padding fruit in transport and the quantity of inoculum associated with leaf fragments associated with fruit is insignificant compared with the inoculum carried on fruit. However, the spread of freckle on infected plant material is relevant when estimating the probability of spread after establishment has occurred.

Freckle can also be spread by spores. Two types of spores are known:

- *Conidia* are formed internally in pycnidia that occur abundantly in all freckle lesions. They exude from pycnidia in long tendrils under wet conditions, and they disperse in water that trickles over the infected surfaces. Meredith (1968) reported that run-off water from infected leaves contained 500,000 conidia per ml and that these spores germinated readily. The spores are also subject to water splash, in which falling water droplets pick up spores as they impact on wet surfaces and transport them in one or two secondary impaction events (Meredith 1973; Fitt et al 1989). Meredith (1968) detected up to 50 conidia in splashed water droplets. Water splash dispersal is expected to transport conidia over distances of up to two metres in still air, or up to ten metres downwind, but to a height of no more than 1 m (Meredith 1973; Fitt et al 1989). The effect of wind will distort the shape of the deposition zone without necessarily increasing its area. Apart from rain splash, it is possible that small animals/insects could act as vectors as they move about wet banana waste on the ground and subsequently onto host plants in the vicinity. Conidia are not readily brushed off dry surfaces and do not become air-borne independently of water (Meredith 1968). After taking these factors into account, the IRA team considered that conidia of *G. musae* would disperse on average up to 2 m horizontally and 1 m vertically, giving a deposition zone of 12.5 m<sup>2</sup> in area and up to 1 m above the ground surface.

*Ascospores* are formed internally in ascomata that develop within freckle lesions. Their role in the epidemiology of freckle disease is unclear (Jones 2000). They were originally found on leaves of *Musa paradisiaca* in Indonesia (van der Aa 1973) and have been observed in the cooler, drier months of the year in Taiwan but to a much lesser extent in the warmer, wetter months (CP Chao, Pathologist, Taiwan Banana Research Institute, pers comm 14 February 2006). The ascomata appear to be associated with freckle lesions on very old leaf tissue, such as the older leaves that persist under subtropical conditions for more than six months. They have not been found on fruit, possibly because fruit are harvested and consumed before ascomata can develop. In Hawaii, Carpenter (1919) reported that a relatively small number of spermogonia were associated with freckle pycnidia. However, neither Carpenter (1919) nor Meredith (1968) made comment on the occurrence of ascomata in Hawaii. Ascomata and ascospores have not been found in the tropical areas of the Philippines where Cavendish bananas are grown. Although there appear to be no published reports of surveys for the teleomorph in the Philippines, plant pathologists have studied freckle disease in both commercial and non-commercial Philippine bananas dating back to Lee (1922). However, if ascospores were produced, it is expected that their dispersal would be similar to that of *M. fijiensis* ascospores (see Part B Chapter 10, *Black Sigatoka*).

### 11.2.4 Survival

No information has been found on the survival of freckle in leaf or fruit litter. However, it is expected that the survival of *G. musae* fruiting bodies is similar to that of *M. fijiensis* pseudothecia (see

Appendix 6 of Part C), that is, in the order of 4–8 weeks depending on where the litter was discarded and on the environmental conditions at the site. There is no evidence that *G. musae* has a saprophytic phase outside of the host plant, although it can be cultured and will grow slowly on microbial media (Chuang 1981). Similar fungi, such as *G. citricarpa* (citrus blackspot) (Kiely 1949) and *G. bidwellii* (black rot of grapes) (Ramsdell and Mulholland 1994), are considered to have a strong overwintering capacity on infected leaf and stem tissue but a weak saprophytic potential external to host tissue. It is therefore expected that pycnidia would remain intact and release spores until the litter is overcome by microbial activity or nutritional reserves are exhausted.

### 11.2.5 Risk scenario

The risk scenario considered in this analysis concern freckle pycnidia that develop from pre-harvest and post-harvest infection.

With pre-harvest infection, freckle symptoms that have not been detected during standard quality assurance procedures may give rise to the development of pycnidia in packed fruit. Based on the observations on bananas by Meredith (1968) and Chuang (1984) and supported by the research on black rot of grapes with a similar biology (Spotts 1977) it is also expected that recent pre-harvest infections, which may not have developed symptoms at the time of packing or even by the time that fruit arrive in Australia 7–10 days later, may develop pycnidia during the period of distribution in Australia, or even after waste material is discarded. Small numbers of freckle lesions have been observed on ripened Philippine bananas on sale in New Zealand supermarkets (Allen, pers comm., 16 May 2006). The disease was identified on the basis of lesions with raised, black centres that are indicative of pycnidia being present (Meredith 1968). The numbers of lesions varied from 1–23 per finger and it is reasonable to expect that each lesion contained at least one pycnidium. These symptoms may not have been evident on mature hard green fruit at the time of its arrival in New Zealand.

Coincident with pre-harvest infection of fruit, it is expected that pycnidia could also occur on leaf litter that may be associated with fruit clusters. It is possible that this material could become detached from fruit during transport and handling in Australia and contaminate plastic liners of cartons. This would be managed separately to fruit but, in this analysis, it is assumed that all leaf litter remains with the fruit.

With post-harvest infection, fruit may become contaminated with freckle conidia produced in pycnidia on fruit or leaf litter prior to harvest. Much of this contamination will occur as the fruit passes through the flotation tanks at the packing station. These spores are expected to germinate in the water films that persist on fruit from the time of packing in the Philippines until the polythene liners are opened to facilitate ethylene gassing at a ripening facility in Australia. The results of experiments on freckle (Meredith 1968; Chuang 1984) and black spot of grapes (Spotts 1977; Spotts 1980) indicate that post-harvest infection can result in the formation of pycnidia on intact fruit within 21 days under ideal temperature conditions. However, the rate at which pycnidia are formed under sub-optimal temperatures is likely to be significantly slower (Spotts 1980). It is very unlikely that symptoms of post-harvest infection would be evident on arrival of mature hard green fruit in Australia, or even on ripened fruit at retail outlets. It is more likely that post-harvest infections will develop pycnidia in banana waste from 4–6 weeks after harvest and therefore from 1–3 weeks after it is discarded in the Australian environment. It is expected that this development will depend on environmental conditions at the place of disposal and will be subject to competition from other fruit infecting organisms, such as *Colletotrichum musae*, *Lasiodiplodia theobromae* and *Fusarium* spp. (Jones 2000).

A further scenario concerns the occurrence of ascomata on leaf litter associated with fruit clusters. Leaf litter has been found to be associated with an average of 1.3% of Philippine banana cartons marketed in New Zealand (Peterson et al 2006) indicating that the proportion of fruit clusters contaminated with leaf litter would be approximately 0.3% (Part C). A proportion of this litter is

derived from relatively young leaf tissue. It is expected that this would carry relatively young infections of freckle that would not develop ascomata during the 4–8 weeks that it might remain intact in the Australian environment. However, a proportion of the leaf litter could be derived from aged leaf tissue in which ascomata could develop in the Australian environment. However, in considering this scenario, it was noted that the leaf tissue likely to contaminate fruit in the Philippines, and indeed the fruit tissue itself, would not be old enough at the time of disposal to bear ascomata. Consequently, this scenario was not investigated further.

### Excluded scenarios

The role of insects and other animals in the spread of freckle was considered by the IRA team. Larger animals might move the waste to another location. Such a movement was considered to be part of the random disposal of the waste.

It is possible that insects and other animals might inadvertently pick up spores when coming in contact with waste and then carry the spores to a host. However, this was considered to be much less likely to spread the disease than in the scenarios above. This view is supported by the conclusions drawn for other diseases in this analysis. While the transfer of Moko bacteria by insects from a banana flower to a banana plant is a successful method of transmission, Tables 9.6, 9.7 and 9.8 show that the likelihood of insects transmitting Moko from banana waste is extremely small and several orders of magnitude less than the other scenarios considered for Moko. In addition, this report shows that the likelihood of transmission of BBTV and BBrMV by aphids from waste is also extremely small, despite both viruses being dependant on aphids to transmit the disease from plant to plant. It was also considered that spores that were eaten by insects and animals would have an even smaller chance of causing infection than spores carried on external surfaces.

## 11.3 Importation

Importation starts with the sourcing of banana fruit from a plantation in the Philippines and finishes with the release of imported fruit by at the Australian border. It is analysed in eight steps, as described in Section 5.2. This section provides the available evidence supporting the likelihood assessments for each step.

### 11.3.1 The proportion of plantations where the pest is present

*Imp1: The proportion of plantations in which freckle is present is 1.*

Freckle occurs in Cavendish bananas throughout the Mindanao Province from which export bananas are to be sourced. It has been claimed that the disease is present in only some plantations (BPI 2002b) but no information has been provided to indicate that any banana plantation is free of freckle. It is therefore assumed that all Cavendish banana plantations will be infected by freckle at least to a minor degree. Imp1 was therefore assigned a value of 1.

### 11.3.2 Incidence of freckle within an infected plantation

*Imp2: The proportion of clusters coming from infected plantations that are actually infected with freckle at harvest is Uniform (min. 1.00E-02; max. 3.00E-01).*

*Guignardia musae* is known to infect fruit, especially when symptoms are apparent on the leaves overhanging the bunch (Meredith 1968; Chuang 1984). Disease monitoring data provided by Philippine authorities (BPI 2002b) indicate that freckle occurs on Cavendish banana plants throughout the year. The youngest leaf affected with freckle varied from the 9<sup>th</sup> (most severe) to 12<sup>th</sup> in the period from August 1997 to March 2002. However, freckle is often unevenly distributed within banana plantations, with some production blocks being more severely affected than others (BA 2001). It is

also evident that normal plantation practices such as leaf sanitation and fungicide application would minimise opportunities for fruit to become infected.

A significant proportion of fruit clusters must escape infection, as large quantities of apparently unblemished fruit are exported to Japan each year (BA 2002c). No information has been found on symptom development on Philippine fruit in Japan or other countries after it has been cleared at the port of entry. However, inspections at these ports would be made on mature hard green and not ripened bananas or banana waste.

Freckle lesions have been found in 2 of 4 lots of Philippine banana fruit on sale in New Zealand supermarkets (Allen, pers comm., 16 May 2006). In one lot, two of 25 clusters had 1–5 lesions each. In the other lot, all clusters had from 1–23 lesions per finger. The lesions are considered to have occurred before harvest (see Appendix 7 of Part C *Disease severity in the Philippines*).

No other quantitative data on the occurrence of freckle in Philippine banana fruit have been found. On the basis of available evidence, the likelihood of a cluster being infected with freckle at harvest is considered to be in the range of 1–30%, that is,  $1.00E-02$  to  $3.00E-01$ .

### 11.3.3 Contamination by freckle during harvest and transport

*Imp3a: The proportion of clean clusters from infected plantations that become infected with freckle during harvest and transport to the packing station is 0.*

Polythene bunch covers remain on harvested bunches until they arrive at the packing station. These covers are open at the bottom and some are manufactured with perforations to allow gas exchange. They may tear during maturation of the fruit. It is possible that significant contamination with freckle conidia may occur in wet weather as a result of the physical forces during handling. However, the effect of the flotation tank at the packing station would redistribute any such contamination, and so the issue of infection by these contaminating spores will be considered at step Imp 5. On this basis, Imp 3a was assigned a value of 0.

*Imp3b: The proportion of clean clusters from clean plantations that become infected with freckle during harvest and transport to the packing station is 0.*

The comments about harvesting and transport to the packing station are the same as for Imp3a, except that the possibility that some clean clusters will become contaminated with conidia of *G. musae* as a result of contact with leaves or bunches from infected plantations would be smaller. As mentioned under Imp 3a, the issue of infection by these contaminating spores will be considered at step Imp5. On this basis, Imp 3b was assigned a value of 0.

### 11.3.4 Proportion of freckle infection surviving packing procedures

*Imp4: The proportion of infected clusters that remain infected with freckle after routine processing in the packing station is Uniform (min 0.3; max 0.9).*

On arrival at the packing station, polythene covers are removed from bunches and fruit is washed free of extraneous material and insects. It is then de-handled and finally immersed in water for a period of up to 25 minutes, prior to packing in new cartons with polythene liners. Throughout this process, fruit are inspected for quality assurance purposes and any fruit with severe blemish, such as severe freckle infection, would be removed. Similarly, much of the infected leaf litter would be removed as a result of the washing and flotation, but some small pieces are expected to remain with the fruit.

The proportion of fruit clusters infected with freckle that remain infected at the end of this process has not been quantified. The washing process will not remove pycnidia, as these are embedded in the diseased tissue. The quality inspection process is expected to remove some fruit clusters with visible

symptoms, but not all. However, it will not be capable of removing infected fruit that has not yet displayed disease symptoms.

It is noted that all fruit passing through the flotation tanks at the packing station are liable to be contaminated with freckle spores and this is considered under the step Imp5.

Overall, the IRA team considered that the proportion of infected clusters that would remain infected with freckle after routine processing in the packing shed could be as high as 0.9 and possibly no less than 0.3. However, it is recognised that the infected fruit that remained after processing in the packing station would not be severely diseased at this time. There are insufficient data to suggest any central tendencies, so it is considered the proportion would have a Uniform distribution.

### 11.3.5 Contamination during packing

*Imp5: The proportion of clean clusters that become contaminated with freckle spores during processing at the packing station that would subsequently develop pycnidia is 1.00E-04.*

As described under the freckle scenario section above, all fruit passing through the flotation tanks at the packing station are liable to be contaminated with freckle spores. This contamination is expected to be more pronounced when the fruit comes from plantation blocks with severe freckle symptoms than from blocks where the symptoms are mild.

Freckle is not generally known as a post-harvest disease of bananas (Jones 2000). However, a proportion of the fruit contaminated in the packing station would be expected to develop pycnidia after fruit ripens or while waste material is exposed to the environment. Freckle symptoms have been observed on ripened Philippine banana fruit in New Zealand and, while some of this infection could have occurred pre-harvest (see discussion under Imp2 above), some of the observed infection could have occurred post-harvest.

The water present in the flotation tank and in the packed carton during transit to Australia is expected to stimulate spore germination and facilitate infection. Appressorium formation has been reported to occur at 17–21 °C in the presence of water (Chuang 1984) and these temperature and moisture conditions will occur for several hours immediately after the fruit is packed. Some appressoria could develop in this period (Meredith 1968).

Following this initial period, the fruit is shipped at a temperature of 13–14 °C. Pu et al (2008) found that appressoria develop slowly on leaf surfaces at 15 °C and it is very likely that appressoria will develop at even lower storage temperatures. Spore germination could resume at temperatures encountered during subsequent periods of ripening, marketing and waste disposal but moisture films may not always be present to facilitate infection. Without moisture, germinated spores that have not formed an appressorium are expected to die (Meredith 1968).

Once infection is established, it is expected that pycnidia will develop on intact banana fruit after three weeks or more, depending on the incubation temperature (Meredith 1968; Chuang 1984). On grape leaves, pycnidia of *G. bidwellii* were detected after 19 days' incubation at 15 °C, approximately six days later than at the optimum temperature of 26.5 °C (Spotts 1977). It is therefore very likely that pycnidia will develop on banana fruit waste once post-harvest infection is established.

After reviewing the uncertainties associated with post-harvest infection, the IRA team considered that the proportion of clean clusters developing pycnidia as a result of post-harvest infection would not exceed 0.01%. Imp5 was therefore assigned a value of 1.00E-04.

### 11.3.6 Pest level surviving post-packing processes

*Imp6: The proportion of clusters infected with freckle that remain infected during handling and transport to Australia is 1.*

Clusters infected with freckle would be packed in banana cartons lined with polythene during transport to Australia. They would be wet at the time of packing and remain wet throughout the voyage to Australia. This environment would not reduce the prevalence of existing infections on fruit. On this basis, the proportion of clusters infected with freckle that would remain infected during transport to Australia would be 1.

### 11.3.7 Contamination by the pest during post-packing procedures

*Imp7: The proportion of clean clusters that become infected with freckle during handling and transport to Australia is 0.*

As outlined in the Biology and Scenario sections above, some pre-harvest infections may develop symptoms and even some pycnidia during handling and transport to Australia. These infections have already been considered under Imp2. It is also possible that contaminant spores will germinate and infect fruit during handling and transport to Australia. These have been accounted for under Imp5. No further contamination will occur during handling and transport, and so Imp7 has a value of 0.

### 11.3.8 Pest level remaining after border procedures

*Imp8: The proportion of clusters that remain infected with freckle after on arrival minimal border procedures is 1.*

None of the minimal on arrival procedures (Section 7.2.6) directly affects freckle infection of banana fruit and none of the procedures affect the survival of freckle in infected tissue.

A value of 1 was therefore assigned to this step.

## 11.4 Distribution

Distribution within Australia starts from the release of imported fruit at the port of entry and ends with the disposal of waste material under controlled or uncontrolled conditions. The two steps associated with distribution are outlined in Section 5.3. As mentioned in Section 7.2, distribution occurs through established wholesale and retail outlets and includes processes to store fruit at 13–14 °C and ripen it at 14.5–21 °C over a period of 14–21 days. During this period, some infections that occurred pre-harvest will develop into freckle lesions and some pycnidia will develop in immature lesions. The effect on freckle during the distribution process is assessed below.

### 11.4.1 Pest survival during distribution

*Dist1: The likelihood of clusters of bananas infected with freckle remaining infected throughout the distribution process is 1.*

The environment during the distribution of bananas in Australia is not considered to be harmful to the survival of freckle in infected fruit. A value of 1 was therefore assigned to Dist1.



### 11.4.2 Contamination by freckle during distribution

**Dist2:** *The number of clean clusters of bananas that become infected with freckle during the distribution process is 0.*

It is possible that spores released from pycnidia may be disseminated within packed cartons of fruit as a result of the movement of water within the carton. While these conidia may germinate and infect fruit, it is not expected that the infection will result in the formation of pycnidia. Dist2 was therefore assigned a value of 0.

### 11.4.3 The number of infected clusters at each waste point

Table 11.1 summarises how infected banana waste will be divided between the three waste categories in the two areas. Approximately 9% of imported clusters are expected to be infected. The number of infected clusters is based on 105,000 tonnes of bananas being imported and excludes contaminated clusters that will not develop pycnidia.

**Table 11.1** Estimated number of clusters with infected plant material distributed to each waste point from 105,000 tonnes of imported bananas

Areas	Waste category					
	controlled		uncontrolled consumer		other uncontrolled	
<b>Grower areas</b>	1,088,056	11.1%	777,362	8.0%	10,689	0.1%
<b>Other areas</b>	4,622,327	47.3%	3,223,730	33.0%	51,709	0.5%

## 11.5 Exposure – proximity considerations

As outlined in Section 5.1.1, the unit for assessing the likelihood of transfer of the pest from waste to a host is based on an individual banana finger.

Determining the probability of exposure is done in two parts. The first part (done in this section) determines how likely waste from an infected finger would be close enough to a host to be able to infect it if conditions are favourable. The second part (done in the next section) determines how likely the pest would transfer to a host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a non-zero likelihood of transfer of *G. musae* to a host plant to occur. The likelihood of banana waste being disposed of sufficiently close to a suitable host plant is dependent both on the method of waste disposal and on the category of the host plant exposure group.

For freckle derived from the Philippines, a suitable host is a plant of the genus *Musa*. For the purposes of this part of the assessment, the dispersal range for splash-dispersed conidia is considered to be 2 m (refer to Section 11.2.3 *Dispersal* and to the corresponding section in Appendix 7 of Part C).

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 11.2. For each combination in the table, the likelihood was found by multiplying the following two probabilities together:

- the proportion of waste discarded at a waste point that is near the exposure group
- the likelihood that a host plant in an exposure group would be within 2 m of the waste.

The data used for these calculations are given in Sections 7.4 and 7.5, with specific points summarised below.

### **11.5.1 Proportion of waste near each exposure group**

The proportion of each type of waste that is within 2 m of each exposure group is based on the information about the general distribution of waste given in Section 7.4.

#### **Controlled waste**

Data indicate that no commercial host crops or home gardens occur within 2 m of any controlled waste facilities. Although there are no banana plants growing at controlled facilities in other areas, there are some at controlled waste facilities in grower areas. Averaged over all facilities in grower areas, the IRA team considered that no more than a proportion of  $1.00\text{E}-10$  of the waste could be within 2 m of plants at the facility.

#### **Uncontrolled consumer waste**

Uncontrolled consumer waste is generated by consumers and most of it will be discarded in a home environment, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other environments such as public parks, roadsides, farmlands and bushland. It is very unlikely that uncontrolled consumer waste will be discarded within 2 m of a commercial banana plantation. A value of  $3.00\text{E}-06$  was considered appropriate.

#### **Other uncontrolled waste**

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. It may be fed to livestock, used directly as organic mulch, or tipped in areas not subject to controlled waste management.

Most of the other uncontrolled waste is discarded in other environments such as public parks, farmlands, and along roadsides. It was considered that about 5% of other uncontrolled waste is discarded or used near households. It is very unlikely that other uncontrolled waste will be discarded within 2 m of a commercial banana plantation. A value of  $1.00\text{E}-06$  was considered appropriate.

### **11.5.2 Probability of plants within the proximity area**

The average number of plants within a random circle of 2 m radius is equal to the area of the circle multiplied by the planting density (Table 7.6). The average number is then used to determine the probability that there would be at least one host plant within the circle.

#### **Commercial crops**

There would be about two banana plants in a circle of a 2 m radius in a banana plantation in grower areas. There are no commercial banana and heliconia plantations in other areas.

#### **Home gardens**

There is a likelihood of between  $1.13\text{E}-03$  and  $1.63\text{E}-03$  that there would be banana plants in a random circle of 2 m radius in a home garden for grower areas. The corresponding figures for other areas are  $3.77\text{E}-05$  and  $2.26\text{E}-04$ .

#### **Other plant communities**

The likelihood that there are wild, volunteer or amenity banana plants in a random circle of 2 m radius in other environments is between  $1.26\text{E}-06$  and  $1.26\text{E}-05$  for grower areas and  $6.28\text{E}-08$  for other areas.

### **11.5.3 Summary of proximity values**

The proportion of waste near an exposure group is multiplied by the probability that there will be banana plants in a 2 m circle to give the proximity value. Table 11.2 summarises these values for each

combination of waste point and exposure group. Where values were expressed as a range, the minimum values are multiplied together. The same is done for the maximum values. The data was insufficient to suggest any central tendencies and so Uniform distributions were used.

**Table 11.2 Summary of proximity values for freckle**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	3.00E-06	1.00E-06
home gardens	0	U(1.13E-03, 1.63E-03)	U(5.65E-05, 8.16E-05)
other plant communities	1.00E-10	U(1.26E-08, 6.28E-07)	U(1.26E-06, 1.26E-05)
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	U(3.77E-05, 2.26E-04)	U(1.88E-06, 1.13E-05)
other plant communities	0	U(6.28E-10, 3.14E-09)	6.28E-08

## 11.6 Exposure – transfer considerations

Section 5.4 describes the considerations required when determining the second value needed to determine the probability of exposure – the likelihood of transfer. Assuming that waste infected with freckle has been discarded within 2 m of a susceptible host plant, this section estimates the likelihood that freckle will be carried from the waste to an infection court on the host plant.

The following sequence of factors must occur for freckle to be successfully transferred:

1. the waste must be exposed to the air or animal vectors so that spores may disperse
2. conidia must be produced within pycnidia on the waste
3. conidia must be released and become airborne or attach to animals
4. dispersed conidia must settle on a host plant surface.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of Factors 1, 2, 3, 4 were calculated to give the minimum values for the likelihood of at least one transfer event. Similar calculations were done to determine maximum values. These values are presented in Table 11.2. The likelihood values associated with these factors are assessed as follows.

### Factor 1 – Waste presentation

Factor 1 concerns the likelihood that waste will be discarded in such a way that conidia can be dispersed. This will be affected by the manner in which waste is discarded but will be similar for both grower and other areas.

Waste in a controlled waste facility is generally buried or contained in plastic disposal bags. The waste is diluted with general household waste and has been heavily compacted in the waste disposal process. The time that it is exposed to the air is limited by the rate that other waste is brought to the facility and also by the frequency with which waste is covered with overburden. However, the presence of animal vectors may enhance exposure. Data are not available to quantify Factor 1 but the IRA team considered that the proportion of controlled waste exposed to the air, and therefore capable of releasing conidia for a significant time, is 1.00E-05.

Most uncontrolled consumer waste is disposed in compost bins or discarded on compost heaps or into vegetation that prevents the dispersal of spores. The waste is subject to being buried under other waste material within a few days or otherwise overgrown with weeds and vegetation. Small animals/insects

may gain access to this waste but exposure to rain droplets would be limited. Data are not available to quantify Factor 1 but the IRA team's best judgment was that only 7–20% of waste would be exposed for a significant period of time. For uncontrolled consumer waste, Factor 1 would have a value of  $7.00E-02$  to  $2.00E-01$ .

Other uncontrolled waste is discarded on the soil surface in heaps and a large proportion of spores would be trapped in these heaps. Data are not available to quantify Factor 1 but it is considered that only 7–20% of waste would be exposed for a significant period of time. For other uncontrolled waste, Factor 1 would have a value of  $7.00E-02$  to  $2.00E-01$ .

### **Factor 2 – Production of spores**

Factor 2 concerns the potential for pieces of banana waste with pycnidia on their surface to produce conidia. Pycnidia must be present, or at least develop in the waste, before the waste is consumed by other organisms.

In the case of infections by freckle that have occurred pre-harvest, it is considered that infected clusters will have 1–23 pycnidia per finger as observed in New Zealand (assuming that there was at least one pycnidium per lesion). The number of pycnidia that develop from post-harvest infection is considered to be much smaller. As outlined in the Introduction (Section 11.1), the IRA team considered that each freckle pycnidium could produce 2,000 conidia before reserves are exhausted.

Spore production could occur at any time in the 4-8 week period that pycnidia are expected to develop or survive in banana waste. Pycnidia that are already mature at the time of waste generation will begin to produce spores as soon as environmental conditions are conducive. However, immature pycnidia will need additional time to develop before producing spores.

Appendix 7 of Part C outlines information leading to the definition of criteria for a freckle sporulation event. These criteria were:

- one day with >5 mm rainfall and an overnight minimum temperature of >20 °C; or
- two consecutive days with >5 mm rainfall per day and an overnight minimum temperature of >10 °C.

These criteria were applied to meteorological data from South Johnstone (representing exposure groups in north Queensland, Alstonville (representing exposure groups in south-eastern Queensland and north-eastern New South Wales), Sydney (representing exposure groups in the northern parts of other non-banana growing areas of Australia), and Melbourne (representing the southern parts of other areas). The data were recorded over eleven years from 1996 to 2006, inclusive. There was an average of 107.1 sporulation events per year at South Johnstone (range 80–145), 35.4 at Alstonville (range 20–61), 18 at Sydney (range 10–27), and 1.8 at Melbourne (range 0–3).

In estimating Factor 2, it was necessary to take account of the environments at the various exposure groups.

- In grower areas, approximately 90% of the home gardens and other plant communities occur in the south (represented by Alstonville) whereas 90% of commercial crops are in northern areas (represented by South Johnstone). The estimates of Factor 2 for home garden and other plant community groups combine the data from Alstonville and South Johnstone in the ratio 9:1, whereas the estimates for commercial crops were combined in the ratio 1:9.
- In other areas of Australia, any commercial crops are in northern areas (represented by Sydney) whereas home gardens and other plant communities occur almost equally in the north and south. Minimum overnight temperatures are sometimes conducive to infection in northern areas (represented by Sydney) but rarely in southern areas (represented by Melbourne and Hobart, for example). The estimates of Factor 2 were based on those for Sydney for commercial crops but combined the Sydney and Melbourne values in equal proportions for home garden and other plant community groups.

These data showed there is a high likelihood that weather conditions suitable for a sporulation event would occur in grower regions in the 4–8 weeks that the waste is on the ground and capable of producing *G. musae* conidia. Considering the weather data cited above, between 93–99% of waste discarded near commercial plantations and 82–95% of waste near home gardens and other environments would experience a sporulation event. The likelihood is lower in other areas; between 53–77% of waste discarded near commercial plantations and 32–50% of waste near home gardens and other areas would experience a sporulation event. These values were used for Factor 2.

### **Factor 3 – Release of spores**

Factor 3 concerns the likelihood that spores on the surface of fruit or packaging materials will be uplifted into the air by rain splash or moved from the waste material by animal vectors.

Dispersal by animal vectors will require contact with the waste to acquire a level of spore contamination and then movement from the waste to another site. The number of animal vectors that might contact banana waste would be small relative to the number of rain droplets, but could occur at times when there has been little rainfall. The efficiency with which animal vectors will uplift spores from banana waste surfaces was considered by the IRA team to be small and considered to be comparable to that of splash dispersal.

Dispersal of spores by rain splash can occur during any period of rainfall or supplementary irrigation. This rain or irrigation would most probably be associated with the same event that provided conditions for spore production as considered under Factor 2 above, and will not be considered directly here. However, with regard to spore release rainfall of 5 mm would wet each piece of discarded waste with about 600 rain drops or 30 ml of water. This could uplift at least some of any spores on the surface of waste material in batches of up to 50 spores at a time (Meredith 1968). However, a large proportion of the rain will simply wash spores onto the ground surface where secondary dispersal will not occur. Huber et al (2006) provide evidence that the proportion of rainfall splashed from wet surfaces varies with the type of leaf surface, the intensity of rain and rain droplet size. With tobacco leaves, about 0.1% of incident rain splashed when falling at 10 mm/hour as small (2 mm diameter) drops and about 10% with large (4mm diameter drops). With oilseed rape leaves, the corresponding proportions were about 3% and 20%. The proportion of water splashed was about 10-times lower when rain fell at 1 mm/hour but not significantly greater when rain fell at 100 mm/hour. On this basis, the IRA team considered that the proportion of any spores becoming airborne from banana waste would be about 1% on average.

As outlined above, there are expected to be 2,000 spores produced per pycnidium under optimal conditions and 1–23 pycnidia per unit of infected waste material. Since only 1% of the spores would be uplifted, it is estimated that between 20–460 spores would be dispersed by rain splash or animal vectors from each unit of infected banana waste on which spores had been produced. A droplet might have between 25–50 spores, so there would be between 1–10 uplift events.

Although most of the spores will be washed off the waste, it was considered almost certain that some spores would be dispersed. Hence Factor 3 was assigned a value of 1.

#### **Factor 4 – Spores settle on host**

Dispersed spores must settle on a host plant surface. The likelihood of at least one of the vectored conidia settling on a host is determined firstly by the number of conidia dispersed, secondly by the target area of host plant surfaces relative to the total surface area of the proximity zone and thirdly by the efficiency with which conidia adhere to the host plant surface.

##### *A – Number of uplift events*

As outlined under Factor 3, there would be between 1–10 uplift events.

##### *B – Relative target area*

The host surfaces in this instance are the leaf tissues of *Musa* spp within 1 m of the ground surface. In considering the growth habits of *Musa* cultivars, it is expected that the area occupied by each host plant would average 5 m<sup>2</sup> but only 10% of this area would be host leaf surface in the area where spores are dispersed. The combination of these two proportions represents 4% of the 2 m radial dispersal zone around the discarded waste material.

The value of 4% would be applicable for both home plantings and other plant communities, where there is likely to be only one host plant within 2 m of discarded banana waste. However, for commercial crops, there could be up to three plants within this range, and the host surface would make up 4–12% of the proximity zone.

##### *C – Efficiency with which conidia adhere to host plant surfaces*

In order for a conidium of *G. musae* to initiate infection, it must first adhere to the host surface so that it will not be dislodged by rain or irrigation associated with spore dispersal. It is thought that adhesion involves a Ca<sup>++</sup> mediated attachment process, as for *G. bidwellii* (Kuo and Hoch 1995), and therefore not favoured by continuous rainfall. No data have been found to quantify the degree to which spores adhere to plant surfaces, but the IRA team considered that it will not be more than 10%.

Factor 4 was then calculated by combining the number of uplift events being dispersed from each waste unit (A), the proportion of target area in the proximity zone (B) and the efficiency with which spores adhere to the host surface (C) using Factor 4 = 1-(1-4Bx4C)<sup>4A</sup>.

#### **Summary of transfer values**

As already mentioned, the values of the Factors 1, 2, 3 and 4 are multiplied together to give the likelihood that spores will be dispersed to a host plant in a transfer event. Table 11.3 summarises the values for each combination of waste point and exposure group.

**Table 11.3 Summary of transfer values for freckle**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	U(3.72E-08, 1.13E-06)	U(2.60E-04, 2.25E-02)	U(2.60E-04, 2.25E-02)
home gardens	U(3.28E-08, 3.73E-07)	U(2.30E-04, 7.46E-03)	U(2.30E-04, 7.46E-03)
other plant communities	U(3.28E-08, 3.73E-07)	U(2.30E-04, 7.46E-03)	U(2.30E-04, 7.46E-03)
<b>Other areas</b>			
commercial crops	U(2.12E-08, 8.76E-07)	U(1.48E-04, 1.75E-02)	U(1.48E-04, 1.75E-02)
home gardens	U(1.28E-08, 1.96E-07)	U(8.96E-05, 3.93E-03)	U(8.96E-05, 3.93E-03)
other plant communities	U(1.28E-08, 1.96E-07)	U(8.96E-05, 3.93E-03)	U(8.96E-05, 3.93E-03)

## 11.7 Establishment

The initiation point for establishment is the exposure of a suitable host plant to a *G. musae* spore. The end point is the development of freckle lesions in which spores are consistently produced on the host plant. Section 5.5 includes the ISPM 11 criteria to be considered for the establishment of freckle. The following factors were identified as influencing the establishment of freckle:

1. infection efficiency of spores
2. surface moisture and ambient temperature
3. host susceptibility
4. routine horticultural practices.

The likelihood values associated with these factors are assessed as follows.

### Factor 1 – infection efficiency of spores

It is theoretically possible for a single spore to establish an asexual population of *G. musae* on a host plant. However, there is a limited chance that a single spore will initiate an infection in practice. This chance will increase with increasing numbers of transferred spores.

Most of the spores transferred from banana waste are expected to have been freshly produced, so their germinability would be high. However, both Meredith (1968) and Pu et al (2008) note that not all conidia germinate to produce appressoria or progress to a successful penetration of host tissue. The proportion is estimated to be about 60% after 36 hours incubation. It is also possible that not all infections will develop pycnidia, although the likelihood of pycnidia being formed is expected to increase with time (Pu et al 2008). However as outlined in Section 11.6 – Factor 3, it is considered that a host would be inoculated with up to 50 spores from each transfer event. The likelihood of at least one of the spores associated with a transfer event infecting a susceptible host plant is therefore high. On this basis, a value of 1.0 was assigned to Factor 1.

### Factor 2 – surface moisture and ambient temperature

Under optimal conditions of temperature and moisture, conidial germination commences about 2 hours after inoculation and continues over a period of at least 96 hours (Meredith 1968; Chuang 1984) or 120 hours (Pu et al 2008) while the surface is wet. Appressorium formation and penetration of host tissue follows in due course.

There is no published criterion for defining a freckle infection event similar to that used by Peterson et al (2005) for black Sigatoka. However, the following information is considered relevant to defining appropriate criteria for freckle.

- Meredith (1968) found that no infection occurred if the leaf surface dried out within 12 hours of

inoculation. Much more infection occurred if the leaf surface was kept wet for 48 hours or more. The incubation temperature was reported as 24 °C.

- Chuang (1984) found that the most suitable incubation temperature was 21°C and that appressoria were formed at 17–21°C. Inoculated leaves and fruit were kept wet for 96 hours.
- Pu et al (2008) found that the optimum temperature for spore germination and appressorium formation on banana leaves was 25 °C and the rates at 15 °C and 35 °C were about half of those at 20–30 °C. Appressorium formation lagged about 6 hours behind germination on average but reached a maximum of about 80% of inoculated conidia after 36 hours incubation in a damp chamber at optimum temperature. The rate of germination and appressorium formation at 15 °C was about half that at the optimum temperature.
- Spotts (1980) found that the minimum period of wetness required for infection of grape leaves by *G. bidwellii* increased more than 2-fold when the incubation temperature was <13°C, compared with 15–33°C, although infection still occurred at 10 °C.
- Allen (2008) found that there was a correlation between the amount of rainfall and the duration of surface wetness. Days with more than 18 hours of surface wetness received more than 5 mm rain per day. Given that there needs to be a period of at least 12 hours wetness per day (Meredith 1968), it is expected that a period of 5 mm of rain would constitute a day with moisture adequate for growth and survival of *G. musae* on a host surface.

Given that an infection event must follow immediately after a sporulation event as defined in Section 11.6 – Factor 2, the above observations suggest the following criteria for a freckle infection event:

- a sporulation event followed by two consecutive days with >5mm rainfall per day and an overnight minimum temperature of >20°C; or
- a sporulation event followed by three consecutive days with >5mm rainfall per day and an overnight minimum temperature of >14°C; or
- a sporulation event followed by four consecutive days with >5mm rainfall per day and an overnight minimum temperature of >10°C.

These criteria reflect the necessity for the leaf surface to remain moist during development and the lower development rate in cooler weather. The criteria were applied to meteorological data from South Johnstone (representing exposure groups in north Queensland), Alstonville (representing exposure groups in south-eastern Queensland and north-eastern New South Wales), Sydney (representing exposure groups in the northern parts of other (non-banana growing) areas of Australia and Melbourne (representing the southern parts of other areas). The data were recorded over eleven years from 1996 to 2006, inclusive.

The average number of days that could result in infection events over the 11-year period at South Johnstone was 48.1 per year (range 27–79). At Alstonville the average was 3.6 per year (range 1–8) and at Sydney it was 1.1 per year (range 0–4). There were no such days at Melbourne during the period. Further details are given in Part C, Appendix 7, *Sporulation and infection events*.

The ratio of the number of such days to the number of days that could result in sporulation events is used to determine Factor 2, which is the proportion of sporulation events that are followed by an infection event. The likelihood that there is a sporulation event has already been considered in Factor 2 of the Transfer calculations (Section 11.6).

In estimating Factor 2, it was necessary to take account of the environments at the various exposure groups and the weather data from the three locations above were combined in the same ratios as outlined in Section 11.6. The minimum and maximum values for Factor 2 took into account the minimum and maximum yearly values of the data, and the mode took into account the average of the 11 years of data. Estimates of Factor 2 for each of the six exposure groups are presented in Table 11.4.



**Table 11.4 Estimates of Establishment Factor 2 for freckle**

	<b>Grower areas</b>	<b>Other areas</b>
<b>Commercial crops</b>	Min: 0.30; Mode:0.40; Max: 0.55	Min: 0.01; Mode:0.06; Max: 0.15
<b>Home gardens</b>	Min: 0.08; Mode:0.13; Max: 0.22	Min: 0.01; Mode:0.03; Max: 0.08
<b>Other plant communities</b>	Min: 0.08; Mode:0.13; Max: 0.22	Min: 0.01; Mode:0.03; Max: 0.08

**Factor 3 – host susceptibility**

The host must be susceptible to infection in that it must not resist penetration of the epidermal cells or provision of suitable nutrients to the establishing mycelial thallus. It is considered that almost all *Musa* host plants in Australia would be susceptible to infection by freckle from the Philippines. Factor 3 was therefore assigned a value of 1.

**Factor 4 – routine horticultural practice**

Routine horticultural practices are likely to affect establishment of freckle in commercial banana plantations since infection would be inhibited by fungicides used for the control of yellow Sigatoka (*Mycosphaerella musicola*) and leaf speckle (*M. musae*). It is known that fungicides are used throughout the year in north Queensland and for six months of the year in subtropical banana growing areas (BA 2002b) but the effects of these fungicides on host penetration and fungal establishment have not been quantified for freckle. Evidence from Hawaii (Meredith 1968), Taiwan (Tsai et al 1993) and the Philippines (BPI 2002b) suggests that fungicides are reasonably effective in preventing infection, with possibly only 5% of spores being able to infect host tissues. Horticultural practices are unlikely to influence establishment of freckle in home gardens and other plant communities.

The product of the various estimates of the likelihood of Factors 1, 2, 3 and 4 was used to estimate the probability of establishment in each of the exposure groups. These estimates are summarised in Table 11.5.

**Table 11.5 Probability of establishment for freckle after exposure has occurred**

<b>Exposure group</b>	<b>Grower areas</b>	<b>Other areas</b>
commercial crops	T(1.50E-02, 2.00E-02, 2.75E-02)	T(5.00E-04, 3.00E-03, 7.50E-02)
home gardens	T(8.00E-02, 1.30E-01, 2.20E-01)	T(1.00E-02, 3.00E-02, 8.00E-02)
other plant communities	T(8.00E-02, 1.30E-01, 2.20E-01)	T(1.00E-02, 3.00E-02, 8.00E-02)

**11.8 Spread**

Spread could occur by the transfer of infected plants or by dispersal of conidia. It is unlikely that an infected plant would die as a result of infection and the formation of pycnidia in infected tissue would facilitate survival between seasons. Freckle would therefore persist for an indefinite period after freckle became established.

It was considered certain that spread of freckle in Australia would occur from infected plants. A value of 1.0 was therefore used (Table 11.6).

**Table 11.6** The probability of spread for freckle after establishment has occurred

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	1
other plant communities	1	1

## 11.9 Probability of entry, establishment and spread

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.6 and Table 5.7. Table 11.7 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation, 105,000 tonnes, is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively). Rather than showing the individual PEES values for each waste point and exposure group combination, Table 11.8 shows the relative contribution the individual values make to the overall PEES.

**Table 11.7** Probability of entry, establishment and spread for freckle

	50,000 tonnes	105,000 tonnes	160,000 tonnes
<b>5th percentile</b>	1.56E-01	3.00E-01	4.21E-01
<b>Median</b>	7.74E-01	9.56E-01	9.91E-01
<b>95th percentile</b>	9.98E-01	1.0000E+00	1.0000E+00

**Table 11.8** Apportioning the PEES by waste point and exposure group

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0.00%	0.09%	0.00%
home gardens	0.00%	94.36%	0.06%
other plant communities	0.00%	0.02%	0.01%
<b>Other areas</b>			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	5.45%	0.00%
other plant communities	0.00%	0.00%	0.00%

## 11.10 Consequences

The consequences to the Australian community of the entry, establishment and spread of freckle are assessed by considering, on a range of direct and indirect criteria, its potential impact at the local district, regional and national level.

At each level, the impact of freckle was assessed on the basis of its potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: 'unlikely to be discernible', 'minor', 'significant' and 'highly significant'.

An overall assessment of consequences was obtained by combining the direct and indirect impacts of freckle using the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

### 11.10.1 Direct impact

#### *Plant life or health – C*

This criterion describes the production losses associated with freckle in commercial bananas, as well as any loss in productivity of other susceptible species. The direct effects of freckle were considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of indirect impacts.

Freckle is a disease of *Musa* species only, and thus there is no direct impact on other plant or animal species. On Cavendish bananas, freckle is not considered a disease that leads to the death of plants. Rather, freckle symptoms reduce the photosynthetic tissues of the banana leaves and disfigure fruit. Freckle is generally restricted to the older leaves and becomes severe on fruit when young fruit is in close contact with severely diseased leaves (Meredith 1968).

In some tropical areas overseas freckle is listed as a minor disease, while in others it is reported as following black Sigatoka in importance. Freckle is a major problem in subtropical Taiwan (Chuang 1984). It is expected that in Australia, the severity of freckle will be reduced by existing control programs against yellow Sigatoka disease caused by *Mycosphaerella musicola* and other fruit diseases such as speckle, caused by *Deightoniella torulosa* (Jones and Stover 2000). However, freckle hot spots are likely to emerge in managed plantations depending on microclimatic conditions and the degree of coverage of plant surfaces with fungicide sprays. According to Chuang (1984) the longevity of infected leaves is reduced to half that of healthy leaves. Increased de-leafing would be required to control freckle. Severe de-leafing will adversely affect plant vigour and lead to reduction in fruit size.

The severity of freckle infection on native Australian *Musa* spp. is unknown. *Musa acuminata* subsp. *banksii* is reported to be susceptible to freckle (Jones 2000) but the susceptibilities of the other two native bananas in Australia (*M. jackeyi* and *M. fitzalanii*) have not been assessed. In any event, freckle does not kill infected plants. Rather, as explained above, freckle reduces the photosynthetic area of the plant generally on the older leaves. Severe freckle infections can cause premature death of older leaves in some cultivars (Jones 2000).

The main impact of freckle is on the quality of the fruit produced in terms of surface blemishing. This will result in downgrading of fruit for discerning markets and the impact for producers is that a considerable quantity of fruit will be discarded at the packing station.

Overall, the likely direct impact of freckle in terms of plant production losses is considered as 'significant' at the local level. The rating assigned to this criterion is therefore C.

#### *Human life or health – A*

There are no known impacts of freckle on human life or health, and the rating assigned to this criterion is therefore A.

#### *Any other aspects of the environment not covered above – C*

Although native banana species (*M. acuminata* subsp. *banksii*, *M. jackeyi* and *M. fitzalanii*) could potentially become infected with freckle, the impact of infection is unknown. However, a reduction in the number of native banana plants may occur if freckle was to become established in an area. Native bananas in Australia are generally disease free, either due to their low density and isolation from commercial banana plantations or some level of resistance or tolerance to disease. In comparison, plant production based on monoculture is more likely to experience pest and disease epidemics.

Overall, the likely direct impacts of freckle on other aspects of the environment is considered to be ‘significant’ at the local level and the rating assigned to this criterion is therefore **C**.

### **11.10.2 Indirect impact**

#### *Control or eradication – D*

It is unlikely that an eradication program would be conducted in Australia if freckle were identified on Cavendish bananas. Such a program was conducted in 2001 following an outbreak of freckle in a remote settlement in Western Australia. Eradication programs can be very expensive if an outbreak is not detected early, and involve cooperation from all levels of government and industry. The cost could amount to several million dollars over 2–3 years. This cost could be shared between the Australian Government, the governments of banana-producing states or territories, and the banana industry.

Additional requirements for the control of freckle in Australia are unknown due to conflicting reports from overseas and the likelihood, as discussed under the section on direct impacts above, that existing disease control programs for yellow Sigatoka disease will also control freckle. In the Philippines, fungicide control programs for black Sigatoka also control freckle. The Philippines presently applies up to 45 sprays per year for black Sigatoka, compared to the 20–22 sprays per year presently used in north Queensland for yellow Sigatoka (caused by a similar fungus *Mycosphaerella musicola*). In subtropical areas of Australia, only 4–6 sprays per year are presently applied for yellow Sigatoka. However, it is expected that freckle could be controlled by fungicide sprays and de-leafing programs similar to those already used for yellow Sigatoka in Australia, although some fungicides may have to be applied more frequently.

An increase in the intensity of de-leafing is expected due to loss of leaf area by freckle infections, particularly in conjunction with yellow Sigatoka. Freckle eradication programs will be complicated by difficulties in inspecting for small lesions in the upper canopy and on portions of petiole bases close to the pseudostem. De-leafing programs will not remove all infections, including those on the remaining petiole bases.

Overall, the indirect impact of freckle on the cost of pest control programs is considered as ‘significant’ at the district level. The rating assigned to this criterion is therefore **D**.

#### *Domestic trade – D*

As previously noted, freckle is primarily a disease affecting the presentation quality of fruit. Australian consumers have a very low tolerance for blemished fruit. Any fruit expressing freckle symptoms would likely be downgraded or rejected in the Australian marketplace. It is possible that embargoes could be installed on fruit, as occurred after the discovery of black Sigatoka in the Tully district in 2001. This embargo disrupted Australian markets for a short period until the disease was brought under control.

Overall, the impact of freckle on domestic trade and industry was considered as ‘significant’ at the district level. The rating assigned to this criterion is therefore **D**.

#### *International trade – A*

Australia exports only small quantities of bananas that go to a specialty market. The presence of freckle is unlikely to disturb bilateral trade agreements. The rating assigned to this criterion is therefore **A**.

### *Environment – A*

An effect of freckle would be to increase the use of fungicidal chemicals and associated spraying practices. It is expected that fungicide sprays and de-leafing programs similar to that already used for yellow Sigatoka in Australia could control freckle.

It is considered that the effect is unlikely to be discernible and the rating assigned to this criterion is therefore **A**.

### *Communities – C*

One of the considerations within this criterion is the potential indirect impact of freckle on rural economic viability. The effects of freckle on changes to horticultural practices have already been considered under new or modified controls (see above).

An incursion of freckle would require an increase in the use of fungicidal chemicals and associated spraying activities. Growers will experience higher costs and lower returns that may result in some industry readjustment. This would have a negative impact on agriculturally related employment within the local community (refer to Section 9.14.2).

Gross regional product multipliers in the range of 1.5–2 for banana growing areas in north-eastern Australia suggest that a downturn in banana production will have a flow-on effect on other local industries (CEPM 2002; OGS 2002; Growcom 2004). A downturn in banana production would have a significant economic and social impact on the Johnstone and Cardwell shires where agricultural production constitutes the dominant industry (Cummings 2002).

Overall, the indirect impact of freckle on communities is likely to be ‘significant’ at the local level. The rating assigned to this criterion is therefore **C**.

### **11.10.3 Overall consequences for freckle**

*The overall consequences to the Australian community of the entry, establishment and spread of freckle as a result of trade in mature hard green bananas from the Philippines: **Low**.*

Table 11.9 provides a summary of the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of freckle within Australia.

The direct and indirect impacts of freckle shown in Table 11.9 were combined using the decision rules discussed in Chapter 6. It follows from these decision rules that 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 freckle are considered to be ‘low’.

**Table 11.9 Consequence assessment for freckle is low**

Criteria	National	Regional	District	Local	Impact
Plant life or health	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
Human life or health	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Any other aspects of the environment	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C
Control or eradication	Unlikely to be discernible	Minor	Significant	Highly significant	D
Domestic trade	Unlikely to be discernible	Minor	Significant	Highly significant	D
International trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Communities	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C

### 11.11 Unrestricted risk

The risk associated with freckle is determined by combining the median value of PEES ( $9.56E-01$ ) with the consequence (“Low”) according to Table 6.2. The result is that the unrestricted risk exceeds Australia’s ALOP (Table 11.10) and therefore risk management would be required for banana fruit with freckle.

**Table 11.10 Unrestricted risk for freckle**

Probability of entry, establishment and spread	9.56E-01
Consequence	Low
Risk	Exceeds ALOP (Low)

### 11.12 Risk management for freckle

The unrestricted risk of freckle exceeds Australia’s ALOP when the overall probability of entry, establishment and spread (PEES) is combined with the overall consequence. Risk mitigation measures would therefore be required to lower this rating to achieve Australia’s ALOP.

The risk mitigation measures will need to be effective in the areas of Mindanao proposed for export of Cavendish bananas to Australia.

The pathways considered in this analysis showed that freckle could enter, establish and spread in Australia from imported banana fruit that have pycnidia of freckle infecting the surface of bananas.

A range of potential phytosanitary risk management measures at various steps in the import pathway may be considered to reduce the risk to an acceptable level.

The Philippines Government will be required to demonstrate to Australia’s satisfaction that the strength of the proposed phytosanitary risk management measures, or of a combination of phytosanitary risk management measures (a systems approach), will reduce the number of pycnidia on banana fruit.

The efficacy of any treatment(s) to reduce the number of pycnidia would need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

The Philippines Government will be required to prove and verify the effectiveness of measures, as indicated in this section and Chapter 20. All proposed measures must be monitored, verified and audited by trained BPI and AQIS staff as specified in Chapter 20.

### *Summary of scenarios*

The risk scenario used to determine the unrestricted probability of entry, establishment and spread of freckle in this analysis considered the number of pycnidia infecting banana fruit imported into Australia.

The IRA team, taking into consideration the best available information and taking account of expert judgement, has determined the values that were used in the model to aid the IRA team in determining the unrestricted probability of entry, establishment and spread of freckle in this analysis (Table 11.7).

The analysis of unrestricted risk for freckle determined that an infected cluster would have between 1 – 23 pycnidia per finger and 2000 conidia per pycnidium after being subjected to standard commercial practices in the Philippines and that conidia would be released over 4–8 weeks depending on the environmental conditions to which the infected material is exposed. Risk mitigation measures would need to reduce the number of pycnidia.

### *Pest threshold to achieve Australia's ALOP*

If the unrestricted risk exceeds Australia's ALOP, the risk assessment then considers what risk management measures might be available to reduce the risk to achieve Australia's ALOP (Section 6.3). Because the overall consequence rating is low, the PEES would be required to be less than 0.3 (Table 6.2).

The use of a quantitative approach to determining PEES allows the restricted PEES to be expressed in terms of a pest threshold which is the maximum number of pests and/or the maximum level of disease associated with mature hard green Cavendish bananas imported into Australia from the Philippines that would achieve Australia's ALOP.

The overall restricted PEES was calculated for a pest threshold, as shown in Table 11.11. Any measures that would reduce the level of infected clusters after packing to below 7.5 per thousand (7.50E–03) would achieve Australia's ALOP.

**Table 11.11 Probability of entry, establishment and spread when pest threshold is met.**

Proportion of clusters that remain infected after processing	PEES
7.50E–03	0.288

The calculation for the restricted PEES for the importation scenario in the table used values for Imp2, Imp4 and Imp5 that would result in the specified threshold level being present after processing. It is assumed that the level of pycnidia would have the range (1–23) used in this analysis. The effect of any phytosanitary risk management measures would need to be considered for the scenario.

The value shown in Table 11.11 would, when inserted in the model with all values in the relevant sections of Part B of the report, considered in the context of the report as a whole, and combined with the consequence of “low” (Section 11.10.3) achieve Australia's ALOP.

### ***Standard commercial practice and phytosanitary risk management***

Much of the key information provided by the Philippines Government is based on standard commercial agronomic practice in the Philippines. Some aspects of standard agronomic practice are discussed further in the sections on operational requirements (Chapter 20 and Part C). One of the aims of standard commercial agronomic practice is that bananas for export are to be free of leaf and floral material and meet commercial export standards.

#### **11.12.1 Potential phytosanitary risk management measures**

A range of potential phytosanitary risk management measures may be considered if they can be demonstrated, to Australia's satisfaction, to reduce the unrestricted risk and achieve Australia's ALOP. Potential phytosanitary risk management measures may include, but are not limited to:

- pest free areas, pest free places of production and pest free production sites
- areas of low pest prevalence
- fungicide bunch sprays
- trash minimisation
- post-harvest fungicide treatment
- post-harvest inspection followed by corrective action.

#### ***Pest free areas, pest free places of production and pest free production sites***

Sourcing bananas for export from areas established, maintained and verified free from freckle in accordance with the guidelines outlined in ISPM 4: *Requirements for the establishment of pest free areas* (FAO 1996), ISPM 10: *Requirements for the establishment of pest free places of production and pest free production sites* (FAO 1999) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007) would reduce the values associated with several steps on the importation pathway and achieve Australia's ALOP.

However, these options were not considered feasible, given that freckle is widely distributed in banana growing areas in the Philippines and there is no feasible option to verify whether Cavendish export plantations are free from the pathogen. The pathogen can occur at very low levels in obscure places such as the bases of leaf petioles, where it can remain undetected by visual field inspection. In addition, subtle freckle symptoms may be masked by other foliar diseases, particularly speckle (*Deightoniella torulosa* (Syd.) Ellis).

#### ***Areas of low pest prevalence***

Areas of low pest prevalence could be established and maintained following the guidelines described in ISPM 22: *Requirements for the establishment of areas of low pest prevalence* (FAO 2005a) and ISPM 29: *Recognition of pest free areas and areas of low pest prevalence* (FAO 2007). An area of low freckle prevalence could be a place of production (a banana plantation managed as a single unit) or a production site (a designated block within a plantation) for which low prevalence of freckle is established, maintained and verified by BPI and audited by AQIS. This measure would reduce the number of pycnidia on the import pathway and thereby mitigate the risk.

Individual banana plantations in the Philippines could be maintained at a very low disease prevalence for freckle disease symptoms through the use of various management practices, including regular fungicide applications and other horticultural practices such as regular de-leafing, covering of banana bunches with polythene bunch covers, improving drainage to reduce build up of relative humidity, avoiding overlapping of leaves by maintaining appropriate plant density and the use of tissue cultured planting material. Plantations where such measures are implemented are known to have lower disease prevalence.



An area of low pest prevalence would ensure the degree of infection of clusters on export bananas would be lower than those indicated in the unrestricted risk assessment.

The IRA team acknowledges that prevalence of freckle is lower in the drier areas of Mindanao than in wetter areas. It would be more practical to establish areas of low pest prevalence in parts of Mindanao where the disease pressure is relatively low. Even in these areas, it would also be necessary to avoid areas where 'hot spots' are likely to occur due to microclimatic factors or physical barriers to aerial fungicide application.

Literature on infestation of bananas sourced from plantations with low prevalence of freckle symptoms provides examples of measures that may reduce freckle symptoms. Meredith (1968) and Jones (2000) reported that fruit symptoms are particularly severe when the young bunch is in contact with severely diseased leaves, while little or no disease develops on fruit when the pathogen is absent on leaves of the same plant, or when fruit is covered with a paper bag. The disease may also be symptomless during the incubation period for about four weeks.

The lower freckle incidence from ALPP would also reduce the likelihood that clean fruit is contaminated during processing in the packing station (Imp5).

#### *Fungicide bunch sprays*

A further risk mitigation measure is the use of fungicide bunch sprays to provide protection against freckle infection. Pesticide sprays are already used in banana plantations in the Philippines (BPI 2000, 2001, 2002b) including fungicide bunch sprays against fruit spots (BPI 2001) and therefore the principles and practices of application are well understood. Non-perforated bags would be required to be attached in a manner that would minimise the risk of pathogen entry into bagged bunches. Any damaged bags would be required to be replaced.

With lower freckle incidence in fungicide treated bananas, the proportion of clean clusters that may be contaminated during processing in the packing station (Imp5) would be reduced.

#### *Trash minimisation*

As previously mentioned, the unrestricted risk estimate has been based on the assumption that all leaf and floral trash remnants would remain with the fruit throughout the pathway. It is recognised that this would overestimate the risk if inoculum in the trash was high relative to that in the fruit. The assumption is reasonable in the case of freckle because the level of trash contamination in export quality bananas is relatively low and because a high proportion of inoculum is expected to be associated with the skin of fruit. However, any reduction in trash will only have a marginal effect on Imp2 and Imp5.

Without precluding this measure as an option the Philippines Government may use, the measure was not considered effective by the IRA team.

#### *Post-harvest fungicide treatment*

Post-harvest fungicide treatments are already used in packing stations in the Philippines (BPI 2000) and the principles and practices of application are well understood.

Post-harvest fungicide treatment of export bananas at the Imp4 step would reduce the level of conidia on fruit surfaces. However, such treatments would not be effective against pycnidia embedded in fruit tissue and leaf trash. There are currently no practical post-harvest fungicide treatment measures available that sufficiently address the risk of pycnidia present in fruit tissue.

Post-harvest fungicide treatment of export bananas in the packing station would reduce the level of conidia on the fruit surface, but may not be sufficiently effective against pycnidia embedded in the banana skin.

Post-harvest fungicide treatment would affect Imp 5, which is small compared to Imp2, and have a marginal effect on Imp 4.

Without precluding this measure as an option the Philippines Government may use, it was not considered that this measure, by itself, would be effective in achieving Australia's ALOP.

#### *Post-harvest inspection followed by corrective action*

Post harvest inspection would be followed by corrective action if the number of pieces of trash exceeds a predefined level. This would reduce the proportion of infected clusters. It may be applied either at the pack house or during the BPI inspection process prior to presenting the consignment to AQIS inspectors as part of any pre-clearance program.

Taking the corrective action of removing leaf and floral material from export bananas may constitute a phytosanitary risk management measure.

Standard quality control procedures will already remove many fruit that show the symptoms of freckle. A greater intensity of inspection may further reduce the proportion of infected clusters. However, visual inspection would be ineffective in detecting surface contamination of export bananas with conidia and recent infection. Therefore, post harvest inspection followed by corrective action could not achieve Australia's ALOP by itself.

#### *Systems approach*

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve the ALOP, as described in ISPM 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.

#### *Other potential risk management measures*

The IRA team acknowledges that there are potentially other possible risk management measures. If additional relevant information is provided that suggests alternative measures may be capable of reducing the risks to achieve Australia's ALOP, the supporting evidence will be considered on a case by case basis.

### **11.12.2 Application of potential risk management measures**

The IRA process requires the consideration, and recommendation, of whether there are risk mitigation measures, used either alone or in combination that would reduce any risk that exceeds Australia's ALOP, identified through pest risk analysis, to a level that achieves ALOP. This section considers what effect the measures proposed in the previous section might have on the number of pycnidia on a banana finger.

The pest threshold for the risk scenario have been inserted into the relevant section(s) of the model with all values in the relevant sections of Part B of the report, considered in the context of the report as a whole, and combined with the consequence of "low" (Section 11.10) to ensure that the pest thresholds achieve Australia's ALOP.

Any proposed phytosanitary risk management measures would require evaluation by Australia of the evidence provided by the Philippines Government (including methodology, laboratory trial, field trials, demonstrated under commercial conditions, commercial application, etc) prior to their implementation.

Based on the average level of infected clusters determined earlier in this chapter (approximately 9.31% for the unrestricted value), in order to achieve Australia's ALOP, measures must reduce the

number of banana clusters infected with freckle pycnidia after processing by at least 92% (from approximately 93 per 1,000 clusters for the assessed unrestricted value to below 7.5 per 1,000 clusters). The precise reduction needed would depend on the actual pest levels occurring in the Philippines.

The Philippines Government would be required to demonstrate that any proposed measures would be able to achieve the specified efficacy under commercial conditions.

**Table 11.12 Example effects of mitigation measures on pest levels**

(The table shows example efficacies of measures considered feasible at reducing the proportion of clusters infected with pycnidia from the pest levels determined in the analysis of unrestricted risk. In this example the combination of ALPP and fungicide bunch sprays reduces the number of infected clusters to a level that achieves Australia's ALOP.)

Measure	Example Efficacy	Pest levels (infected clusters per 1,000)	Effect
No Measure		93.1	
Pest free areas, pest free places of production and pest free production sites			Not considered feasible
Post harvest inspection followed by corrective action			Not considered effective
Trash minimisation			Not considered effective
Post-harvest fungicide treatment	90%		Only effective on a small proportion of infection
Areas of Low Pest Prevalence (ALPP)	90%	9.3	Exceeds ALOP
Fungicide bunch sprays	70%	27.9	Exceeds ALOP
ALPP (90%) and fungicide bunch sprays (70%)	97%	2.8	Achieves ALOP

#### *Pest free areas, pest free places of production and pest free production sites*

Given the wide distribution of freckle in the Philippines, the IRA team considered that mitigation based on disease freedom in pest free areas, pest free places of production and pest free production sites would be extremely difficult to implement.

Demonstrated freedom would be difficult given that subtle freckle symptoms may be masked by other foliar diseases, particularly speckle (*Deightoniella torulosa* (Syd.) Ellis).

Without precluding this measure as an option the Philippines Government may use, the measure was not considered feasible by the IRA team.

#### *Areas of low pest prevalence*

The IRA team considered that ALPP would be a risk mitigation measure that could be implemented and would reduce the level of pests. ALPP would be expected to reduce the proportion of infected clusters.

Sourcing of bananas from low pest prevalence areas would reduce the proportion of infected clusters, the evaluation of which is described at the Imp2 step (Section 11.3.2) and reduce the cross contamination during processing (Imp 5).

In the example given in Table 11.12 ALPP reduces the value of Imp 2 by 90%.

#### *Fungicide bunch sprays*

The IRA team considered that the use of fungicide bunch sprays to provide protection against freckle infection would reduce the level of pests. Pesticide sprays are already used in banana plantations in the Philippines (BPI 2000, 2001, 2002b), including fungicide bunch sprays against

fruit spots (BPI 2001), and therefore the principles and practices of application are well understood. The level of symptomless infection of banana fruit could be reduced by regular fungicide bunch sprays.

In the example given in Table 11.12 fungicide bunch sprays reduces the value of Imp 2 by 70%.

#### *Trash minimisation*

The IRA team considered that any reduction in trash will only have a marginal effect on Imp2 and Imp5 because the level of trash contamination in export quality bananas is relatively low and because a high proportion of inoculum is expected to be associated with the skin of fruit.

Without precluding this measure as an option the Philippines Government may use, the measure was not considered effective by the IRA team.

#### *Post-harvest fungicide treatment*

The IRA team considered that a post-harvest fungicide treatment would reduce the level of conidia on the surface of the fruit. Post-harvest fungicide treatments are already used in packing stations in the Philippines (BPI 2000) and the principles and practices of application are well understood.

While post-harvest fungicide treatment of export bananas would reduce the level of conidia on fruit surfaces, such treatments would not be effective against pycnidia embedded in fruit tissue and leaf trash. There are currently no practical measures available that sufficiently address the risk of pycnidia present in fruit tissue.

Without precluding this measure as an option the Philippines Government may use, the IRA team considered that this measure would only have a marginal ability to reduce pest levels.

#### *Post-harvest inspection followed by corrective action*

Post-harvest inspection and corrective action was not considered to be a practical because visual inspection would be ineffective in detecting surface contamination of export bananas contaminated with conidia. Without precluding this measure as an option the Philippines Government may use, the measure was not considered feasible by the IRA team.

#### *Systems approach*

Systems approaches comprise the integration of different risk management measures, at least two of which act independently, and which cumulatively achieve Australia's ALOP. The concept of systems approaches are more fully described in ISPM 14: *The use of integrated measures in a systems approach for pest risk management* (FAO 2002).

Possible systems approaches include:

- Area of Low Pest Prevalence (ALPP) and fungicide bunch sprays
- ALPP and post harvest fungicide treatment
- ALPP, fungicide bunch sprays and post harvest fungicide treatment

#### *Conclusion*

Example pest reduction levels for those measures considered feasible are provided in Table 11.12. The values given, which are based on the level of pest assessed to be currently present in the Philippines, as contained in the report, are included as examples and do not imply that such a level of reduction will be achieved. The strength of any mitigation measure will depend on how the measure is implemented. As mentioned previously, the Philippines Government would be required to demonstrate the effect of any proposed mitigation measures using laboratory and/or field trials and under commercial conditions. Table 11.12 suggests that possibly no single feasible measure would be

adequate to reduce the risk sufficiently, but that there could be combinations of measures that should achieve Australia's ALOP.

### **11.12.3 Risk management conclusion**

The Philippines Government would be required to provide evidence to Australian authorities on the efficacy of any phytosanitary risk management measures proposed to reduce the level of contamination of banana clusters by freckle to levels that would achieve Australia's ALOP.

Any proposed phytosanitary risk management measures would be required to be demonstrated, to Australia's satisfaction, by laboratory experiments and/or field trials and under commercial conditions and would need to be completed to provide supporting evidence, including that:

- the strength of proposed phytosanitary risk management measures, or combinations of phytosanitary risk management measures (a systems approach), is sufficient to reduce the number of pycnidia on banana fruit to the levels required to meet Australia's ALOP
- procedures for fungicide bunch sprays are effective and the level of efficacy can be measured by procedures such as incubation tests
- post-harvest disinfestation treatments are effective and the level of efficacy can be measured by procedures such as incubation tests.

Other evidence may also be required, depending on the specific risk management measures proposed for consideration.

Further details of the proposed risk management regime are provided in Chapter 20.



## 12. Banana bract mosaic virus

### 12.1 Introduction

*Banana bract mosaic virus* (BBrMV) is a potyvirus (Bateson and Dale 1995; Thomas et al 1997) that is not known to occur in Australia. It infects plants of the genus *Musa* in the Philippines (Magnaye and Espino 1990; Muñoz 1992; Thomas et al 2000). BBrMV is declared as a notifiable pest under the *Plant Protection Regulation 2002* in Queensland and is listed as an emergency plant pest in the Emergency Plant Pest Deed.

BBrMV developed in epidemic proportions in several export Cavendish plantations on Mindanao Island in the Philippines before the cause of the disease was discovered and appropriate control measures were introduced in the late 1980s (Thomas 1993). Effective control is now maintained by the use of healthy planting material, weekly inspection of plantations for disease symptoms and the removal of diseased plants, as well as any plants within 5 m of a diseased plant.

### 12.2 Biology

#### 12.2.1 Host plants

Studies on the host range of BBrMV are not comprehensive (Dale 2004) and it is difficult to predict from general knowledge of other potyviruses (Shukla et al 1994) whether BBrMV has a broad or narrow host range. There is no evidence to suggest that BBrMV infects hosts of genera other than *Musa* under natural conditions (Thomas et al 2000). Potential *Musa* host species occur in tropical and subtropical areas of Australia and include a range of native and feral bananas, as well as commercial bananas of all cooking and dessert varieties.

#### 12.2.2 Symptoms and effects on infected plants

Like other potyviruses, BBrMV is expected to spread systemically through all parts of an infected plant including the fruit, and is expected to survive until the plant tissue dies (Shukla et al 1994).

Virus infection leads to a range of symptoms depending upon the plant part affected, the variety of banana, the mode of transmission, and the strain of BBrMV (Thomas et al 2000). Mosaic patterns on flower bracts are distinct from all other symptoms caused by other known viruses of banana (Thomas et al 2000), but may not always be displayed on the bracts when disease symptoms are present on other plant parts (Rodoni et al 1999). The expression of BBrMV symptoms is subject to seasonal influences (Kenyon et al 1997) and may be suppressed under bright, sunny conditions (Muñoz 1992). Reliable detection of BBrMV requires investigation using molecular methods (Thomas et al 1997; Sharman et al 2000a; Dale 2004).

The severity of disease in banana fruit is correlated with the stage of plant growth at the time of infection by BBrMV (Thomas et al 2000).

If a plant of a Cavendish cultivar is infected when the fruit fingers are only three weeks old, symptoms may include spindle-shaped brown streaks on the fruit and a distorted shape. The bunch will not develop normally and is generally unsaleable.

If a plant of a Cavendish cultivar is infected when the fruit fingers are several weeks old, symptoms may not be evident or may be limited to dark green streaks and minor distortion of the fingers. Some bunches may be saleable.

If a plant of a Cavendish cultivar is infected when the fruit fingers are fully developed, there will be no symptoms on the fruit and the bunch will meet export quality standards.

In the Philippines, a high incidence of BBrMV in commercial Cavendish banana plantations has been correlated with a high rejection rate for malformed bunches and low hand-class ratings (Thomas 1993). Yield losses of up to 40% have been reported in Saba and Cardaba cooking bananas (Roperos and Magnaye 1991).

### 12.2.3 Transmission

BBrMV is transmitted by aphid vectors, of which *Aphis gossypii*, *Rhopalosiphum maidis* and *Pentalonia nigronervosa* are recognised in the Philippines (Magnaye and Espino 1990; Muñoz 1992). These aphid species are widespread and common in both the Philippines and Australia. Evidence from studies on other potyviruses (Shukla et al 1994) indicates there is potential for BBrMV transmission by many additional aphid vector species. In the absence of data to the contrary, it is assumed that the aphid species present in Australia would have a similar biology and be as efficient in transmitting BBrMV as those in the Philippines.

Transmission is considered to be non-persistent, in that aphids acquire the virus quickly by probing the epidermal cells of an infected host plant and subsequently probing the epidermal cells of another host plant. Probing times of a minute are considered sufficient to acquire and subsequently transmit the virus (Muñoz 1992). The ability of an aphid to transmit potyviruses such as BBrMV is generally lost within minutes once it settles to feed on a host plant, or if it probes the surface of a non-host plant or any inanimate surface (Shukla et al 1994). Infectivity is generally lost within a few hours of acquiring the virus, regardless of the probing behaviour.

An aphid vector does not need to colonise the host plant or feed extensively to transmit BBrMV (Muñoz 1992), but the aphid needs to carry an infective dose of the virus.

#### *Dispersal mechanisms*

Dispersal is associated primarily with alates (winged forms) of the aphid vectors. It is expected that these would be attracted to green and yellow coloured surfaces (such as newly discarded banana tissue) and would transmit BBrMV to nearby hosts with a frequency decreasing exponentially with increasing distance (Shukla et al 1994).

For the banana aphid (*P. nigronervosa*), Allen (1987) estimated that the mean spread distance of *banana bunchy top virus* (BBTV) in New South Wales, Australia, was 15.2 m. However, BBTV is persistent in the banana aphid vector and the average distance that BBTV has been spread in this instance reflects the total of a number of successive intermediate flights. Unlike BBTV, BBrMV is transmitted in a non-persistent manner and some infectivity is lost each time an aphid probes a surface after each intermediate flight.

The other aphid species known to be able to vector BBrMV may have different flight characteristics. For this analysis, the IRA team considered that the average flight distance of aphid vectors involved in BBrMV transmission is considerably less than 15.2 m and that each vector retains infectivity for no more than 2–3 successive flights. While it is possible that spread may occur over much greater distances (Shukla et al 1994), the effective dispersal range for the small numbers of aphids attracted to waste banana peel is considered to be 30 m (Part C).

Philippine bananas would be imported into Australia at any time of year and be distributed as described in Section 7.2. The potential aphid vectors of BBrMV are not necessarily present in high numbers or active throughout the year. *Pentalonia nigronervosa* is present on bananas and a range of hosts that grow in banana growing areas throughout the year, but populations of alates vary considerably depending on climatic conditions.



### 12.2.4 Risk scenarios

The scenario considered relevant to the entry, establishment and spread of BBrMV is associated with infected banana fruit being harvested when the symptoms are not displayed, are temporarily masked, or are too mild to be readily detected. Such infection would occur internally in the tissue and would not be detected by standard quality inspection. The presence of BBrMV in trash materials such as dead leaf and floral tissue is not considered to pose any risk because the virus rapidly deteriorates in dead and rotting tissue and is inaccessible to aphid vectors.

A second scenario suggested by some stakeholders concerned the infestation of fruit or packaging materials with aphid vectors. These vectors may be present on infected fruit at harvest or may feed on infected fruit during shipment to Australia. This scenario was not considered feasible for the following reasons:

- The aphid vectors known to transmit BBrMV in the Philippines are already dispersed widely in Australia and are active throughout the year at populations far in excess of any possible contamination of imported banana fruit.
- Aphids that might be carrying the virus as a result of feeding on infected plants before harvest, or on infected fruit during shipment to Australia, would lose their ability to transmit BBrMV during the three-week period that the fruit are in transit, being stored and ripened. There is no evidence that aphids can re-acquire the virus without feeding on an infected host.
- A large proportion of individual aphids that might infest fruit in the Philippines or during shipment would be subject to natural mortality before the cartons are opened in Australia and they have an opportunity to disperse.
- Any nymphs produced by aphid species during shipment to Australia would most likely be wingless forms given that the majority of generations are free of winged individuals, and in generations when they do occur, they are rare. Consequently, they have very limited potential to disperse to susceptible host plants in Australia.

## 12.3 Importation

Importation starts with the sourcing of banana fruit from a plantation in the Philippines and finishes with the release of imported fruit at the Australian border. It is analysed in eight steps, as described in Section 5.2. This section provides the available evidence supporting the likelihood assessments for each step.

### 12.3.1 Plantations where BBrMV is present

*Imp1: The proportion of plantations exporting Cavendish bananas from the Philippines that are infected with BBrMV is 1.*

Infection is considered to be widespread among plantations of local banana cultivars on small holdings in Mindanao (Magnaye and Espino 1990; Thomas et al 2000). BBrMV is also known to occur in commercial Cavendish plantations from which export quality fruit is to be sourced (Thomas 1993). BBrMV infestation was noted to spread in commercial Cavendish plantations during the period from 1985 to 1990 (Thomas 1993).

Philippine authorities have commented that virus control measures have been routinely practised in plantations producing Cavendish bananas for many years, to the extent that from the end of 1997 to the present, symptoms caused by BBrMV have been rarely encountered. However, no data have been provided to demonstrate BBrMV freedom in any Cavendish plantation, nor is it expected that the disease control measures practiced in the Philippines would eradicate infection from any banana plantation where the disease is known to occur.

Dale (2004) considered that the evidence from field surveys may underestimate the incidence of infection because:

- the ability to identify infected plants is usually quite specialised
- there is good evidence that the symptoms induced by this virus are quite variable and therefore difficult to identify
- there are symptomless strains of the virus.

Masking of BBrMV symptoms has been noted in glasshouse experiments (Muñez 1992) and symptomless infection by BBrMV has also been recognised in germplasm collections (Thomas 1993; Diekmann and Putter 1996), particularly when other viruses such as *Cucumber mosaic virus* were present (Rodoni et al 1997; Caruana and Galzi 1998).

After considering the occurrence of BBrMV, the widespread use of virus control measures and the possibility that BBrMV may exist as mild strains, Imp1 was assigned a value of 1.

### 12.3.2 Incidence of BBrMV within an infected plantation

*Imp2: The proportion of clusters of banana fruit coming from infected plantations that are actually infected with BBrMV at harvest is Uniform (min. 8.27E-06; max. 7.89E-03).*

The proportion of banana clusters infected with BBrMV is expected to be correlated with the proportion of banana plants infected in the field at the time of harvest. It is also recognised that the symptoms of BBrMV in banana plants are ephemeral (Muñez 1992), so that the incidence of infection in a plantation may be greater than that indicated by inspection for disease symptoms.

Philippine authorities submit that BBrMV has been rarely encountered in commercial plantations since 1997. They consider that the incidence of disease in harvested fruit is reduced to insignificance because:

- all plant parts are subject to weekly inspection throughout the year and the removal of any plant displaying disease symptoms (including any plant within 5 m of that plant)
- only 3% of plants will have harvestable bunches in any week
- each plant with a bunch is inspected many times before harvest, both by specialist surveyors and by other staff engaged in bagging, that is the covering of developed bunches with polythene sleeves and de-belling.

No recent survey data were provided to support this claim made by Philippine authorities. Historical data are available from disease surveys conducted from 1985–1993 on 12 commercial Cavendish plantations near Davao City, covering a total area of 5300 ha (Thomas 1993). These surveys found BBrMV symptoms on between 0.04–0.14% of mats each year<sup>7</sup>. The average annual incidence peaked in 1987, decreased progressively to 0.04% in 1990 and was then maintained at that level at least until 1993. Thomas (1993) also reported that 94% of BBrMV found in 1990 occurred in only two of the 12 plantations surveyed. At that time also, Muñez (1992) reported an incidence of 5.26 mats/ha in a four-week survey period in one of these plantations (equivalent to 2.63 mats/ha at any weekly harvest time if allowance is made for the fact that the eradication of all plants within 5 m of any diseased plant would remove at least one additional infected plant).

Kenyon et al (1997) found that the incidence of BBrMV disease in Lakatan bananas varied seasonally from 0–7 infected plants per four-week period, with no obvious symptoms being present from September–December in two years (1996 and 1997). However, in October 1997 they noted that at least 100 of the 600 plants in the observation block had mild symptoms suggestive of BBrMV infection. Therefore, the proportion of plants infected at that time may have been as high as 17%. It is

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<sup>7</sup> The 2004 RDIRA misquoted Thomas (1993) by indicating incidences of from 4% to 14%.

noted that the Lakatan bananas in this study were not routinely subject to eradication measures in the same way as commercial Cavendish bananas.

From the late 1980s onwards, Cavendish banana plantations in the Philippines have been subject to a control program involving selection of symptom-free planting material, micro-propagation of plantlets, weekly field inspections and the prompt eradication of diseased mats. However, virus indexing technologies have not been widely adopted and there have been no recent surveys to establish disease incidence. In interpreting the historical evidence above, some allowance has to be made for the fact that the prevalence of disease found at each field inspection reflects only the proportion of plants that are displaying symptoms at that time. The results of inoculation experiments (Muñez 1992) indicate that some infected plants may have been infected only recently (within six weeks), while others may have previously displayed symptoms and have since recovered. The degree to which this happens in the field has not been quantified. Nor has its relevance to the infectiousness of the fruit been established.

In considering the uncertainties surrounding an estimate for Imp2 and the possibilities for symptomless or mild infection as outlined under Imp1 above, it was concluded that the proportion of clusters infected with BBrMV at harvest would be Uniform with:

- a maximum reflecting six times the incidence noted by Muñez (1992), which equates to 15.78 mats/ha at any weekly harvest or a proportion of  $7.89\text{E}-03$
- a minimum reflecting the lowest annual incidence of 0.86 mats/ha/year as recorded by Thomas (1993), which equates to a prevalence of  $8.27\text{E}-06$  at any weekly harvest.

As there are no data to suggest a central tendency, a Uniform distribution was assumed.

### 12.3.3 Contamination during harvesting

*Imp3a and Imp3b: The proportion of clean clusters that become infected with BBrMV during harvest and transport to the packing station is 0 for both infected and non-infected plantations.*

The movement of fruit from the point of harvest to the packing station involves a series of operations (Section 7.2) that take no more than one to two hours to complete, which is a very small proportion of the total time for which fruit is exposed to the environment.

It is not known if BBrMV can infect a cluster of harvested fruit directly. However, from general knowledge of the infection process for potyviruses (Shukla et al 1994), it is expected that harvested banana fruit would not be susceptible to infection by BBrMV, even if it was probed by a virus-carrying aphid vector during transport to the packing station. This is due mainly to the fact that harvested fruit would not provide a suitable means for BBrMV to move through the phloem from the point of inoculation to a metabolic sink where it could replicate and affect cell development. This reasoning also applies to the other steps that relate to post-harvest contamination (Imp5, Imp7 and Dist2).

Given that harvested green fruit is considered not susceptible to infection by BBrMV, both Imp3a and Imp3b were assigned a value of zero.

### 12.3.4 Survival during processing and packing

*Imp4: The proportion of infected clusters that remain infected with BBrMV after routine processing in the packing station is 1.*

Export clusters are washed and inspected for basic quality parameters before being packed into 13 kg cartons (see Section 7.2). Some fruit showing symptoms of BBrMV might be removed. However, as previously noted, the scenario being considered relates to symptomless infection and thus it is clear that fruit of this sort would not be removed during the packing process.

Given that the scenario concerns BBrMV infection that is internal, symptomless and not subject to post-harvest shed treatments or quality procedures, Imp4 was assigned a value of 1.

### **12.3.5 Contamination during processing and packing**

*Imp5: The proportion of clean clusters infected by BBrMV during processing at the packing station is 0.*

BBrMV is not readily sap-transmitted and therefore the mechanical handling processes at the packing stations would not lead to infection. Further, the immersion in water during these processes would not favour probing by aphid vectors, inoculation by which, as outlined in Section 12.3.3, would not lead to infection of harvested fruit.

Consequently Imp5 was assigned a value of zero.

### **12.3.6 Survival during handling and transport**

*Imp6: The proportion of clusters infected with BBrMV that remain infected during handling and transport to Australia is 1.*

The process of handling and transporting cartons of bananas to Australia is described in Section 7.2 and would take 10–14 days.

BBrMV infection is carried internally within the fruit and is expected to remain viable until the fruit tissue rots or dies. Given that BBrMV would be unaffected by the transport environment, Imp6 was assigned a value of 1.

### **12.3.7 Contamination during handling and transport**

*Imp7: The proportion of clean clusters infected by BBrMV during handling and transport to Australia 0.*

For clean clusters to become infected with BBrMV, aphids present within the sealed cartons would need to move from cluster to cluster and probe the epidermal cells. The virus would then need to replicate at the site of inoculation and move through the phloem tissue to a metabolic sink. For reasons described in Step Imp3, such conditions are not attainable on harvested fruit and harvested green bananas are not regarded as susceptible to BBrMV infection.

Consequently, Imp7 was assigned a value of zero.

### **12.3.8 Survival during border procedures**

*Imp8: The proportion of infected clusters that remain infected with BBrMV after on arrival minimal border procedures is 1.*

Minimal border procedures take no account of fruit infection by BBrMV. A value of 1 was therefore assigned to this step.

## **12.4 Distribution**

Distribution within Australia starts with the release of imported fruit at the port of entry and ends with the disposal of waste material under controlled or uncontrolled conditions. The two steps associated with distribution are outlined in Section 5.3. As mentioned in Section 7.2, distribution occurs through established wholesale and retail outlets over a period of 14–21 days and includes processes to store fruit at 13–14 °C and ripen it at 14.5–21 °C. The effect on BBrMV during the distribution process is assessed below.

### 12.4.1 Survival during distribution

*Dist1: The proportion of infected fruit that will remain infected during transport and handling in Australia is 1.*

Infection by BBrMV occurs internally in the fruit and is not affected by these processes. Therefore, the proportion of infected clusters that remain infected during these processes was assigned a value of 1.

### 12.4.2 Contamination during distribution

*Dist2: The number of clean fruit that will become infected with BBrMV from an infected cluster during transport and handling in Australia is 0.*

For reasons outlined for step Imp3 above, the conditions do not favour transmission of BBrMV from infected to non-infected clusters. Therefore the number of clean clusters that are infected with BBrMV during distribution was assigned a value of zero.

### 12.4.3 The number of clusters with BBrMV at each waste point

Table 12.1 summarises how infected banana waste will be divided between the three waste categories in the two areas. The number of infected clusters is based on 105,000 tonnes of bananas being imported.

**Table 12.1** Estimated number of infected clusters of imported bananas at waste points from 105,000 tonnes

Areas	Waste category					
	controlled		uncontrolled consumer		other uncontrolled	
Grower areas	46,161	11.1%	32,980	8.0%	453	0.1%
Other areas	196,103	47.3%	136,768	33.0%	2,194	0.5%

## 12.5 Exposure – proximity

Determining the probability of exposure is done in two parts. The first part (this section) determines how likely it is that waste from an infected finger would be close enough to a host to be able to infect it, if conditions are favourable. The second part (Section 12.6) determines how likely it is that the infection would be transferred to a host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a non-zero likelihood of transfer of virus to a host plant to occur. The likelihood of banana waste being disposed of sufficiently close to a suitable host plant is dependent both on the method of waste disposal and on the category of the host plant exposure group.

For BBrMV strains from the Philippines, a suitable host is any plant of the genus *Musa*. For the purposes of this part of the assessment, as discussed in the biology section, the flight range of an aphid vector is assumed to be 30 m.

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 12.2. For each combination in the table, the likelihood was found by multiplying the following two probabilities together:

- the proportion of waste discarded at a waste point that is near the exposure group
- the likelihood that a host plant in an exposure group would be within 30 m of the waste.

The data used for these calculations are given in Sections 7.4 and 7.5, with specific points summarised below.

### **12.5.1 Proportion of waste near an exposure group**

The proportion of each type of waste that is within 30 m of each exposure group is based on the information about the general distribution of waste given in Section 7.4.

#### *Controlled waste*

Data indicate that no commercial host crops or home gardens occur within 30 m of any controlled waste facility. Although there are no banana plants growing at controlled facilities in other areas, there are some at controlled waste facilities in grower areas. Averaged over all controlled waste facilities in grower areas, the IRA team considered that no more than a proportion of  $8.74\text{E}-05$  of the waste could be within 30 m of the banana plants at each of the facilities.

#### *Uncontrolled consumer waste*

Uncontrolled consumer waste is generated by consumers and most of it will be discarded in a home environment, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other environments such as public parks, farmlands and bushland, and along roadsides. It is very unlikely that uncontrolled consumer waste will be discarded within 30 m of a commercial banana plantation. A value of  $5.50\text{E}-06$  was considered appropriate.

#### *Other uncontrolled waste*

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. It may be fed to livestock, used directly as organic mulch, or tipped in areas not subject to controlled waste management.

Most of the other uncontrolled waste is discarded in other environments such as public parks, roadsides, farmlands and bushland. It was considered that about 5% of other uncontrolled waste is discarded or used near households. It is very unlikely that other uncontrolled waste will be discarded within 30 m of a commercial banana plantation. A value of  $1.00\text{E}-06$  was considered appropriate.

### **12.5.2 Probability of plants within a 30-metre circle**

The average number of plants within a random circle of 30 m radius is equal to the area of the circle multiplied by planting density (Table 7.6). The average number is then used to determine the probability that there would be at least one banana plant within the circle.

#### *Commercial crops*

There would be 566 banana plants in a circle of 30 m radius in a banana plantation in grower areas. By definition, there are no commercial banana plantations in other areas.

#### *Home gardens*

Although on average for grower areas there would be between  $2.54\text{E}-01$  and  $3.68\text{E}-01$  banana plants within a 30 m radius of the waste in home gardens, there may occasionally be no plants. The probability that there would be at least one plant within the circle is between  $2.25\text{E}-01$  and  $3.08\text{E}-01$ . The corresponding probabilities for other areas are  $8.45\text{E}-03$  and  $4.96\text{E}-02$ .

### Other plant communities

The probability that there are wild, volunteer and amenity banana plants in a circle of 30 m radius in other environments is between  $2.83\text{E-}04$  and  $2.82\text{E-}03$  for grower areas and about  $1.41\text{E-}05$  for other areas.

### 12.5.3 Summary of proximity values

The proportion of waste near an exposure group is multiplied by the probability that there will be banana plants in a circle of 30 m radius to give the proximity value. Table 12.2 summarises these values for each combination of waste point and exposure group. Where values were expressed as a range, the minimum values are multiplied together. The same was done for the maximum values. The data were insufficient to suggest any central tendencies and so Uniform distributions were used.

**Table 12.2 Summary of proximity values for BBrMV**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
Grower areas			
commercial crops	0	$5.50\text{E-}06$	$1.00\text{E-}06$
home gardens	0	U( $2.25\text{E-}01$ , $3.08\text{E-}01$ )	U( $1.12\text{E-}02$ , $1.54\text{E-}02$ )
other plant communities	$8.74\text{E-}05$	U( $2.83\text{E-}06$ , $1.41\text{E-}04$ )	U( $2.83\text{E-}04$ , $2.82\text{E-}03$ )
Other areas			
commercial crops	0	0	0
home gardens	0	U( $8.45\text{E-}03$ , $4.96\text{E-}02$ )	U( $4.22\text{E-}04$ , $2.48\text{E-}03$ )
other plant communities	0	U( $1.41\text{E-}07$ , $7.07\text{E-}07$ )	$1.41\text{E-}05$

## 12.6 Exposure – transfer considerations

Section 5.4.4 describes the considerations required when determining the second value needed to determine the probability of exposure: the likelihood of transfer.

Given that waste banana peel infected with BBrMV has been discarded within 30 m of a susceptible host plant, the transfer considerations concern the likelihood that BBrMV will be carried from the waste peel to an infection court on the host plant.

The following sequence of factors must occur for BBrMV to be successfully transferred:

1. the waste must be accessible to aphid vectors
2. the waste must have a sufficient virus concentration for aphid acquisition
3. an aphid must find the waste and probe it momentarily
4. the aphid must find a host within a few hours and probe it momentarily.

For each combination of waste point and exposure group, the product of the minimum values for the likelihood of Factors 1, 2, 3 and 4 occurring was calculated to give the minimum values for the transfer value. A similar calculation was done to determine the maximum value. These values are presented in Table 12.3. The data were insufficient to suggest any central tendencies, so it was assumed the values had a Uniform distribution. The likelihood values associated with these factors are assessed as follows.

### *Factor 1 – Waste accessibility*

The waste material must be presented in a way that is accessible to aphid vector movement to and from the waste material – that is, the material must not be buried or contained in plastic bags. This is dependent on the method of waste disposal.

Most of the waste received in controlled waste facilities is contained in garbage bags or buried under other waste. It is greatly diluted by mixture with other household waste and heavily compacted in the waste collection process. The degree to which burial reduces the ability of aphid vectors to access banana waste has not been quantified, but it is considered highly unlikely that the waste would be accessible to aphids in controlled waste facilities. Factor 1 was therefore assigned a value of  $1.00E-06$  for controlled waste.

A significant proportion of uncontrolled consumer waste may be buried or contained in compost heaps, but some of this waste is discarded on the soil surface as litter. The degree to which burial reduces the ability of aphid vectors to access banana waste has not been quantified, but the IRA team's best judgment was that not more than 30% of the waste would be accessible. Factor 1 was therefore assigned a value of  $3.00E-01$  for uncontrolled consumer waste.

Uncontrolled other waste may be taken to agricultural land and discarded in heaps or otherwise be subject to some containment. The degree to which this disposal method reduces the ability of aphid vectors to access banana waste has not been quantified, but it is considered that not more than 30% of the waste would be accessible. Factor 1 was therefore assigned a value of  $3.00E-01$  for other uncontrolled waste.

### *Factor 2 – Virus availability*

The waste material must have sufficient virus concentration for an aphid vector to acquire an infective dose of BBrMV. There is no information on the concentrations of BBrMV in the peel and cushion material that constitutes banana waste. Given that BBrMV infects a host plant systemically and may occur in the tissue whether or not disease symptoms are evident, the IRA team considered that the virus would be present in all fingers of an infected cluster and would remain viable for up to five days after the waste is discarded. On this basis, Factor 2 was assigned a value of 1.

### *Factor 3 – Virus acquisition*

An aphid vector must be attracted to probe the banana waste material for a minute or so in order to acquire BBrMV particles. The efficiency with which an individual aphid can acquire BBrMV under ideal conditions is 12–26% (Part C). Under field conditions it is expected that Factor 3 will also depend on aphid activity at the time of waste disposal and the condition of the waste tissue at the time aphid probing occurs. This will vary between exposure groups.

#### **Condition of plant tissue**

Aphids can only acquire BBrMV while the plant tissue remains fresh. Both uncontrolled consumer waste and other uncontrolled waste are usually fresh when discarded and, therefore, may be suitable for BBrMV acquisition for up to five days. This component of Factor 3 would have a value of 1.0. However, controlled waste will have already been stored in garbage bins for up to seven days before collection and a large proportion will have rotted by the time it is exposed. For controlled waste, this component of Factor 3 was assigned a value of  $1.00E-01$ .

#### **Aphid activity**

The likelihood that an aphid finds the waste will depend on the number of aphids, which in turn will depend on the number of host plants in the proximity zone.



Data, based on yellow sticky traps, reported by Kenyon et al (1997) indicate that the likelihood of *P. nigronervosa* being attracted to waste discarded in a commercial banana plantation over a period of five days may be in the order of  $5.00\text{E}-02$  to  $2.10\text{E}-01$  (see BBrMV data sheet in Part C). However, because of the size of a banana peel compared to the traps used and other considerations, the likelihood of an aphid finding waste would be no more than 10% of these values.

In addition, as a result of seasonal variations in temperature, aphid activity in Australia is expected to be less than that in the Philippines. For *P. nigronervosa*, the activity in grower areas could be 70% of that in the Philippines (Allen 1978a, 1987). The corresponding figure for other areas is 10%. Hence values ranging between  $3.50\text{E}-03$  to  $1.47\text{E}-02$  were used in grower areas and  $5.00\text{E}-04$  to  $2.10\text{E}-03$  in other areas for the likelihood that an aphid would find the waste in a commercial plantation.

The activity of *P. nigronervosa* is expected to be greater in commercial banana plantations than in home garden plantings or other plant communities, as a result of greater host plant density. However, the activity of other potential aphid vectors is expected to compensate for the relative inactivity of *P. nigronervosa* in these exposure groups, since the other aphid species have alternative hosts. It will be assumed, therefore, that the activity of alternative vectors will be similar to that of *P. nigronervosa* outlined above.

The estimates for aphid activity and the effects on virus acquisition of the condition of plant tissue were multiplied to provide estimates of Factor 3 for each waste point and exposure group.

#### **Factor 4 – Virus transmission**

Having acquired an infective dose of BBrMV, the aphid vector must move from the waste material, locate a suitable host and probe its surface for a minute or two in order to transmit BBrMV. This must be achieved within a few hours of acquiring the virus, otherwise infectivity will be lost. The aphid activity associated with virus transmission has already been considered under Factor 3 above and will not be considered further in Factor 4.

When aphids are transferred to a host under ideal conditions, the transmission efficiency of individual aphid vectors has been found to be 12–26% (Part C). However, in a field situation, aphids may probe a range of non-host surfaces before finding a host, thereby reducing their ability to transmit BBrMV before they find a suitable host plant.

The likelihood of an aphid making a flight after acquiring BBrMV from banana waste has not been quantified. It is unlikely to be 100% as the aphid may remain to feed on the waste material and thereby lose infectivity. The aphid may also be subject to unfavourable environmental conditions or predation. Taking account of these factors, the IRA team considered that no more than 30% of aphids that had acquired BBrMV would make a transmission flight.

Their ability to find a suitable host plant is governed largely by the host surface target area within their flight range. The flight range of an aphid vector is 30 m, so the proximity zone is  $2829\text{ m}^2$ . A banana plant will occupy an area of  $5\text{ m}^2$ , which represents about 0.18% of the proximity zone. The opportunity to locate a host plant would be increased by the aphid making a number of secondary flights and probing alternative host surfaces, although it is unlikely to make more than two flights before it loses infectivity.

It will be assumed, therefore, that Factor 4 will have a value between  $6.37\text{E}-05$  and  $1.38\text{E}-04$  if there is one suitable host plant in the 30 m proximity zone. This would be the case for home plantings and other plant communities, where plant density estimates (Table 7.6) indicate there would not be more than one banana plant in the proximity zone. However, there may be many plants in the proximity zone for commercial crops, depending on the position that the waste is discarded in. It is expected that a large proportion of waste in proximity to commercial crops will be discarded outside the boundaries of the cropping area. Given that banana plantations have 2000 plants/ha, it is therefore expected that

the number of host plants in the proximity zone will be between 1–283. The value of Factor 4 in commercial crops will therefore be between  $6.37E-5$  and  $3.90E-02$ .

### Summary of transfer values

As already mentioned, the values of Factors 1, 2, 3 and 4 are multiplied together to give the transfer value. Table 12.3 summarises the values for each combination of waste point and exposure group.

**Table 12.3 Summary of transfer values for BBrMV**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
Grower areas			
commercial crops	U(2.67E–15, 1.49E–11)	U(8.02E–09, 4.48E–05)	U(8.02E–09, 4.48E–05)
home gardens	U(2.67E–15, 5.27E–14)	U(8.02E–09, 1.58E–07)	U(8.02E–09, 1.58E–07)
other plant communities	U(2.67E–15, 5.27E–14)	U(8.02E–09, 1.58E–07)	U(8.02E–09, 1.58E–07)
Other areas			
commercial crops	U(3.82E–16, 2.13E–12)	U(1.15E–09, 6.39E–06)	U(1.15E–09, 6.39E–06)
home gardens	U(3.82E–16, 7.53E–15)	U(1.15E–09, 2.26E–08)	U(1.15E–09, 2.26E–08)
other plant communities	U(3.82E–16, 7.53E–15)	U(1.15E–09, 2.26E–08)	U(1.15E–09, 2.26E–08)

## 12.7 Establishment

The initiation point for establishment of BBrMV is the exposure of a suitable host plant following probing by a virus-carrying aphid. The end point is the development of a systemic infection within the host plant, to the extent that infectious BBrMV particles are present in sufficient concentration for aphid vectors to acquire them subsequently for spread to other host plants in Australia. Section 5.5 gives the ISPM 11 criteria that need to be considered.

If exposure occurred in a *Musa* sp., it is expected that there would be no resistance to establishment of BBrMV. The virus would replicate initially at the point of inoculation and then move from this point through the phloem tissue to a metabolic sink. The virus would continue to replicate in the growing plant tissues and eventually reach a concentration at which it could be acquired by an aphid vector or spread in plant material. It is expected that establishment of BBrMV would not be dependent upon adaptation to local varieties of *Musa* sp. or any horticultural practices.

After considering the uncertainties regarding establishment of BBrMV at each of the exposure points, it was concluded that exposure of a suitable host plant (as defined under the distribution steps above) would certainly lead to establishment. The establishment potential was therefore assigned a value of 1. Table 12.4 summarises these values.

**Table 12.4 The probability of establishment after exposure has occurred**

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	1
other plant communities	1	1

## 12.8 Spread

The probability of spread after establishment has occurred examines factors relevant to the movement of BBrMV from a point of establishment in an exposed plant or group of plants, to susceptible plants in the endangered areas throughout Australia. The initiation point for spread is acquisition of BBrMV by an itinerant aphid species from a plant in Australia on which the virus has established, and the end point is the distribution of an effective dose of BBrMV to other host plants. Section 5.5 gives the ISPM 11 criteria that need to be considered.

BBrMV does not kill infected plants directly and will persist as long as the host survives. Bananas are perennial hosts and it is therefore inevitable that BBrMV will spread to other plants from an infected banana plant.

Viruses do not have natural enemies as such, and it is clear that aphids are able to sustain stable populations in Australia despite predation. The relative abundance of aphid vectors in Australia would favour spread. The spread of *cucumber mosaic virus* throughout Australia by non-persistently infected aphid vectors illustrates that this mechanism is effective. BBrMV is known to be carried long distances through the movement of infected planting or propagation material.

A value of 1 was therefore assigned to the spread potential (see Table 12.5).

**Table 12.5 The probability of spread after establishment has occurred**

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	1
other plant communities	1	1

## 12.9 Probability of entry, establishment and spread

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.6 and Table 5.7. Table 12.6 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation, 105,000 tonnes, is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively). Rather than showing the individual PEES values for each waste point and exposure group combination, Table 12.7 shows the relative contribution the individual values make to the overall PEES.

**Table 12.6 Probability of entry, establishment and spread for BBrMV**

	50,000 tonnes	105,000 tonnes	160,000 tonnes
5th percentile	1.77E-04	3.76E-04	5.54E-04
Median	2.01E-03	4.29E-03	6.48E-03
95th percentile	6.90E-03	1.44E-02	2.18E-02

**Table 12.7 Apportioning the PEES by waste points and exposure group**

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
Grower areas			
commercial crops	0.00%	0.52%	0.00%
home gardens	0.00%	93.35%	0.06%
other plant communities	0.00%	0.03%	0.01%
Other areas			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	6.03%	0.00%
other plant communities	0.00%	0.00%	0.00%

## 12.10 Consequences

The consequences to the Australian community of the entry, establishment and spread of BBrMV are assessed by considering, on a range of direct and indirect criteria, its potential impact at the local district, regional and national level.

At each level, the impact of BBrMV was assessed on the basis of its potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was obtained by combining the direct and indirect impacts of BBrMV using the decision rules discussed in Chapter 6.

Consideration of the direct and indirect impacts is provided in the following text.

### 12.10.1 Direct impact

#### *Plant life or health – D*

This criterion describes the production losses associated with BBrMV in commercial bananas. The direct effects of BBrMV have to be considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of indirect impacts.

The direct impact of BBrMV on commercial bananas will be determined by the stage of development at which infection occurs, and the speed and extent to which the disease spreads to other farms. At the start of this risk assessment, the following points were made:

- Three-week-old fingers from Cavendish cultivars have spindle-shaped brown streaks and a distorted shape. The bunch will not develop normally and is generally unsaleable.
- When fully-developed Cavendish bananas are infected, symptoms may not be evident or may be limited to dark green streaks and minor distortion of the fingers.
- Commercial companies noted a strong correlation between a high incidence of BBrMV and a high rejection rate for malformed bunches and low hand-class ratings.
- In the Philippines, yield losses have been estimated to be as high as 40% in the popular Cardaba and Saba (ABB) cultivars.
- In 1988, the disease reached epidemic proportions around General Santos City (South Cotabato), where 25,000 mats of Cavendish bananas (CAB International 2006) were destroyed.
- In Australia, BBrMV would cause this spectrum of effects, including the possibility of serious outbreaks in some years.

Overall, the likely direct impact of BBrMV in terms of plant production losses is considered to be ‘significant’ at the district level. The rating assigned to this criterion is therefore **D**.

#### *Human life or health – A*

There are no known direct impacts of BBrMV on human life or health and the rating assigned to this criterion is therefore **A**.

#### *Any other aspects of the environment not covered above – A*

This criterion addresses the possible direct impact of pests on other aspects of the natural or built environment, such as the physical and biological environment. There are no known direct impacts of BBrMV in these directions, and the rating assigned to this criterion is therefore **A**.

### **12.10.2 Indirect impact**

#### *Control or eradication – D*

On first detection, an eradication program could be initiated under the Emergency Plant Pest Deed. The cost is likely to be several million dollars per year over a number of years. For BBrMV disease in Queensland, the controls that may be applied in the event of an incursion are already prescribed under the *Plant Protection Regulation 2002*. These controls do not currently include restrictions on fruit movement.

Overseas experience with other potyvirus infections in perennial or continuously cultivated crops suggests that eradication may not be possible where the crop is widely grown. It is more likely that banana growers would be faced with an ongoing control and containment program, using a combination of preventative and sanitation measures. These would include use of disease-free planting material, early detection surveys, and eradication of infected plants, plus surrounding mats within a 5 m radius.

In addition to this, individual banana farmers may need to target the aphid vectors using pesticide applications. Pesticides are costly, and additional applications may alter the economic viability of some crops and affect existing integrated pest management programs. In addition, it is possible that with a ceiling on the number of pesticide applications tolerated by consumers, sprays targeting aphids would need to be used in the place of those previously targeting other pests. This might lead to an increase in other insect populations, a decrease in productivity and a further indirect loss associated with BBrMV.

Overall, the indirect impact of BBrMV on the cost of pest control programs is considered likely to be ‘significant’ at the district level. The rating assigned to this criterion is therefore **D**.

#### *Domestic trade – B*

There would be effects on intrastate and interstate movement of planting materials, but these would be similar to those that already apply to other pests and diseases.

There are currently no proposals to restrict the intrastate or interstate movement of fruit should there be an incursion of BBrMV in Australia. Nevertheless, it is likely that such movement controls would be introduced at least for a short time, thereby disrupting marketing arrangements for a short time after the initial discovery of BBrMV.

The indirect impact on domestic trade is considered ‘minor’ at the local level and the rating assigned to this criterion is therefore **B**.

### *International trade – A*

Australia exports only small quantities of bananas that go to a specialty market. The presence of BBrMV would not therefore disturb bilateral trade agreements. The rating assigned to this criterion is therefore **A**.

### *Environment – A*

Although additional pesticide applications may be required to control aphids on commercial banana plantations, this is unlikely to impact on the environment as it is not considered to be distinguishable from day-to-day variation in current pesticide use. The rating assigned to this criterion is therefore **A**.

### *Communities – C*

One of the considerations within this criterion is the potential indirect impact of BBrMV on rural economic viability. The effects of BBrMV on changes to horticultural practices have already been considered under new or modified controls (see above).

The banana industry provides continuous employment for more than 4000 workers nationally, most of whom are employed in two shires in Far North Queensland (OGS 2005b, 2005c). The initial effects of BBrMV could lead to removal of banana plantations and loss of jobs until the plants could be replaced with virus-tested stock. These losses would impact on agricultural employment within the affected local communities until adjustments were made to horticultural systems.

Gross regional product multipliers in the range of 1.5–2 for banana growing areas in north-eastern Australia suggest that a downturn in banana production will have a flow-on effect on other local industries (CEPM 2002; OGS 2002; Growcom 2004). A downturn in banana production would have a significant economic and social impact on the Johnstone and Cardwell shires where agricultural production constitutes the dominant industry (Cummings 2002).

The indirect effects on communities are likely to be ‘significant’ at the local level. The rating assigned to this criterion is therefore **C**.

## **12.10.3 Overall consequences for BBrMV**

*The overall consequences to the Australian community of the entry, establishment and spread of BBrMV as a result of trade in mature hard green bananas from the Philippines: Low.*

Table 12.8 provides a summary of the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of BBrMV within Australia.

The direct and indirect impacts of BBrMV shown in Table 12.8 were combined using the decision rules discussed in Chapter 6. It follows from these decision rules that 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 BBrMV are considered to be ‘low’.

**Table 12.8 Consequence assessment for BBrMV is low**

Criteria	National	Regional	District	Local	Impact
Plant life or health	Unlikely to be discernible	Minor	Significant	Highly significant	D
Human life or health	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Any other aspects of the environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Control or eradication	Unlikely to be discernible	Minor	Significant	Highly Significant	D
Domestic trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Minor	B
International trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Communities	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C

## 12.11 Unrestricted risk

The unrestricted risk associated with BBrMV is determined by combining the median value of PEES ( $4.29E-03$ ) with the consequence (“Low”) according to Table 6.2.

The unrestricted risk is within Australia’s ALOP (Table 12.9) and risk management is not required provided that standard practices are maintained in the Philippines.

**Table 12.9 Unrestricted risk for BBrMV**

Probability of entry, establishment and spread	$4.29E-03$
Consequence	Low
Risk	Achieves ALOP (Negligible)





## 13. Banana bunchy top virus

### 13.1 Introduction

*Banana bunchy top virus* (BBTV) is a nanovirus (Wu and Su 1990a; Burns et al 1995) that occurs in both the Philippines and Australia. Whereas it is widespread in the Philippines (Thomas 1993; Magnaye and Valmayor 1995), in Australia, it is limited in distribution to subtropical areas in south-eastern Queensland and north-eastern New South Wales. The disease is under active official control in all banana-growing areas of Australia (Newly 2000; QDPIF 2005). However, Western Australia restricts the entry of fruit infested with the banana aphid (*P. nigronervosa*), partly because this aphid is apparently not present in some areas of that state and partly because of the potential of this aphid to be a virus vector.

There are significant genetic differences between the isolates of BBTV in Australia (the so-called South Pacific strains) and those that occur in the Philippines, Vietnam and Taiwan (Karan et al 1994). The Asian BBTV strains are associated with satellite viruses that do not occur in Australia and may infect without causing disease symptoms (Dale 2004). There is no information about the relative pathogenicity of various strains within the two BBTV groups or, if they were to coexist, how this would affect their virulence. The possibility of introducing additional genetic variability into Australian strains of BBTV is a matter for concern.

A second nanovirus has recently been characterised and named provisionally as abacá bunchy top virus (J Thomas, Principal Plant Virologist, QDPIF, pers comm 25 July 2006). This virus primarily infects abacá but to some extent also infects bananas. It has previously been regarded as a strain of BBTV with similar epidemiological features (Magee 1939, 1953b). In this assessment, abacá bunchy top virus has been considered as part of the assessment for BBTV. This new virus is known to occur in the Philippines but not in Australia (J Thomas, Principal Plant Virologist, QDPIF, pers comm 25 July 2006).

### 13.2 Biology

#### 13.2.1 Host plants

BBTV infects a range of *Musa* species and cultivars in the Eumusa and Australimusa series of edible bananas, and also *Ensete ventricosum* (Thomas and Iskra-Caruana 2000). In both Australia and the Philippines, the hosts of BBTV include native and feral bananas, as well as commercial bananas of all cooking and dessert varieties. In Australia, BBTV is not known to infect hosts other than *Musa* spp. (Geering and Thomas 1997) but there have been reports of BBTV infection on non-*Musa* plants in Taiwan and India (Thomas and Iskra-Caruana 2000).

BBTV spreads from the point of inoculation through the phloem tissue towards areas of cell differentiation where it affects the phloem and associated parenchyma tissues that develop subsequently (Magee 1939; Hafner et al 1995). It can spread to the buds of infected propagation material (Magee 1927) and survive in detached leaf tissue for at least 12 days if kept fresh (Magee 1940). It can be detected by PCR and ELISA in all tissues of infected plants, including fruit rind, but is not thought to be present in tissue that develops before infection to any great extent (Magee 1939; Thomas and Iskra-Caruana 2000).

#### 13.2.2 Effects on infected host plants

In its most severe form, BBTV causes banana leaves to be bunched, with chlorotic margins that tend to turn necrotic (Magee 1927; Thomas and Iskra-Caruana 2000). These symptoms are most commonly

seen when infected planting material is taken from severely diseased plants or when a plant has been infected for a long time. Early symptoms are seen as green streaks in a small number of veins of the first or second leaf to emerge after inoculation (Magee 1927). This is associated with derangement of the phloem tissue in which meristematic cells that would otherwise develop into sieve tubes or companion parenchyma are modified into large, thin walled cells with a high chloroplast content (Magee 1939). Symptoms increase in severity with the production and bunching of successive leaves as the phloem is increasingly affected. Streaks may also be found in the floral bracts. There are no histological or visible symptoms in leaves that develop before BBTV becomes systemic on an infected plant. Banana bunches can be distorted in the advanced stages of the disease.

The severe strains of BBTV that were originally common in Australia in the 1920s (Magee 1929) were gradually selected out under a relentless control program by using the so-called leaf-by-leaf inspection system (Eastwood 1946). Mild strains of BBTV have been identified in which symptoms are difficult to see or in which the host has apparently recovered (Magee 1948; Magee 1953b; Thomas and Iskra-Caruana 2000). In some of these instances, BBTV can be detected by ELISA or PCR (Thomas and Iskra-Caruana 2000).

While it has been stated that bunches can be deformed by BBTV infection (Magee 1927; Thomas and Iskra-Caruana 2000) evidence for the development or otherwise of visible symptoms in the skin of banana fruit has not been provided, nor has evidence been provided on whether aphids can acquire BBTV from fruit tissue. In the absence of evidence to the contrary, it was the IRA team's view that the skin of a fruit from an infected plant could potentially be a source of BBTV that aphids could acquire and transmit. For this to be of significance, the plant would need to become infected several weeks before harvest and escape detection during routine control operations. There would also need to be some replication of BBTV in the phloem and associated parenchyma, resulting in at least mild symptoms at the microscopic level.

### 13.2.3 Dispersal

#### *Aphid transmission*

BBTV is transmitted vegetatively in banana plant material (Magee 1927), the movement of which is controlled in all banana-producing states of Australia.

It is also transmitted by the banana aphid, *Pentalonia nigronervosa*, which is present in banana plantations in both Australia (Magee 1927) and the Philippines (Kenyon et al 1997). All life stages of this aphid are able to transmit BBTV, including adults and nymphs of both winged and wingless forms. Transmission occurs in a persistent manner (Thomas and Iskra-Caruana 2000). The virus passes through moults of an individual aphid but not to offspring (Magee 1940). No other insect vectors of BBTV are known.

Magee (1940) estimated that nymphs transmitted BBTV with an efficiency of 46% under experimental conditions. The aphids required a feeding time of at least 17 hours to acquire BBTV and preferably up to 24 hours before full infective potential was attained. Hu et al (1996) confirmed the high efficiency with which nymphal aphids acquire BBTV, given an acquisition feeding time of 17–24 hours, but also noted that 20% of individual aphids acquired BBTV after feeding for only three hours.

The banana aphid transmits BBTV by feeding on the phloem of a healthy plant for a relatively short time. Under experimental conditions, Hu et al (1996) found that infective aphids averaged 27% transmission after an inoculation feeding time of 15 minutes, rising to 80% after two hours. Aphids can retain their infective power for at least 13 days (Magee 1940) and possibly for life (Hu et al 1996). This may be from 10–20 days, depending on its age at virus acquisition.

Allen (1987) estimated the rate at which BBTV spread within Cavendish banana plantations in New South Wales. The basic infection rate varied from a maximum of 0.064 new infections per infectious

plant per day in summer to a minimum of 0.0044 new infections per infectious plant per day in winter. The infection rates in tropical north Queensland would be expected to have a similar maximum but a higher minimum value than in subtropical New South Wales. These rates are indicative of banana aphid activity in Cavendish bananas under field conditions.

### *Vector biology and behaviour*

According to Magee (1927), *P. nigronervosa* has both winged and wingless adult forms, each of which is preceded by four nymphal stages. When first introduced to a host plant, an aphid spends some time walking and repeatedly probing the surface. It then settles to feed on succulent tissue in a protected position such as under a leaf base, on the heart-leaf at the apex of the pseudostem, or under the floral bract. Females immediately start to produce from 1–3 live nymphs a day while continuing to feed. The nymphs settle to feed close by and maintain a close colony for several weeks before crowding induces them to produce wing buds. Winged aphids disperse from the colony when they become adults. Aphids live about 30 days, with the adult stage lasting about 20 days. The factors that induce winged aphids to fly from a host plant are unclear, but their initial instinct is to head for bright light.

Magee (1964) noted that the banana aphid (*P. nigronervosa*) became inactive during the cool months of the year (temperatures below 15 °C). They stopped feeding and producing offspring. He correlated this behaviour with seasonal rates of BBTV infection, which Allen (1987) subsequently confirmed in studies of disease outbreaks in New South Wales. Hu et al (1996) confirmed this low temperature sensitivity of the banana aphid under experimental conditions.

The banana aphid (*P. nigronervosa*) has a worldwide distribution with a host range that includes *Musa* spp. and other species in the Musaceae. Species in several closely related plant families including the Araceae, Cannaceae, Heliconiaceae, Strelitziaceae and Zingiberaceae are also colonised (Wardlaw 1961). Aphids do exhibit host preferences and so they may not transfer readily between host species.

There are two sources of information on the activity of the banana aphid. In the first, Allen (1987) estimated the basic infection rate of BBTV outbreaks in New South Wales banana plantations as varying from 4.40E–03 new infections per infectious plant per day in winter to 6.40E–02 new infections per infectious plant per day in summer. The values for a five-day period would be 2.20E–02 to 3.20E–01.

In the second, Kenyon et al (1997) estimated aphid activity under Philippine conditions using yellow sticky traps installed at the edge of commercial banana plantations. The likelihood that a banana aphid would be attracted to waste material from a cluster of bananas discarded in a commercial banana plantation in the five days the waste material remains green or yellow and not flaccid or moribund has been estimated to range from 5.00E–02 to 2.00E–01. (For further details on this estimate see the BBTV datasheet in Part C). The similarity between the estimates of Allen (1987) for the summer in New South Wales and Kenyon et al (1997) is immediately apparent.

The above data were obtained in commercial banana plantations where host plant density was 1100–2000 mats per hectare. It is expected that the likelihood of an aphid landing on waste material discarded in home garden plantings or other plant communities would be lower than this estimate by a factor proportional to the density of host plants. The likelihood that an aphid would settle to feed on this material is further reduced because it walks and probes the surface for a considerable period before settling (Facundo and Sumalde 1998).

The distances alates fly while transmitting BBTV were found by Allen (1978b, 1987) to be distributed as a negative exponential function characterised by a mean of 15.2 m (Allen 1987). In this analysis, the flight range of a banana aphid is assumed to be 70 m (see the BBTV datasheet in Part C).

### 13.2.4 Risk scenarios

One scenario considered relevant to the entry, establishment and spread of BBTV is associated with mild or symptomless infection of the vascular tissues of banana fruit. Such infection would occur internally in the tissue, but would not have developed to the stage of visible symptoms. It would occur several weeks before harvest, when the phloem of the fruit is still developing. This form of infection would not be detected by visual inspection, nor would it be affected by postharvest treatments or during handling and transport. The presence of BBTV in trash materials such as dead leaf and floral tissue is not considered to pose any risk because the virus rapidly deteriorates in dead and rotting tissue and is inaccessible to aphid vectors.

A second scenario raised by some stakeholders is that associated with contamination of fruit surfaces by virus-bearing banana aphid specimens of the winged form. It was argued that adult alate aphids or advanced nymphs with wing buds may be on the fruit at harvest or infest the fruit or cartons post-harvest. In considering this scenario, it was noted that colonies of the banana aphid are found only rarely on banana bunches and that alate forms (adult or nymphs) would be found only after the colony had been present for several generations. It became apparent that the likelihood of virus-bearing aphids being present on the fruit at harvest (Imp2) was extremely remote, the likelihood of aphids feeding during transport or even surviving the transport and handling processes (Imp6 and Dist1) was small, and that the likelihood of an alate moving from banana waste to a suitable host plant in Australia was also remote. Under these circumstances, this scenario was not considered to represent a viable pathway.

## 13.3 Importation

### 13.3.1 The proportion of plantations where BBTV is present

*Imp1: The proportion of plantations in which BBTV is present is 1.*

BBTV occurs in Cavendish and local banana cultivars throughout Mindanao Island region from where export bananas are to be sourced. No information has been provided to indicate that any banana plantation is free of BBTV, so it is assumed that it is certain that BBTV will be present in a plantation from which a cluster of fruit is sourced. It is considered that banana aphids are ubiquitous in banana plantations and would be present on the fruit.

Imp1 was therefore assigned a value of 1 for BBTV infection.

### 13.3.2 Incidence of BBTV within an infected plantation

*Imp2: The proportion of clusters coming from infected plantations that are actually infected with BBTV at harvest is Uniform (min 1.00E-05; max 1.00E-03).*

BBTV invades bananas systemically and may be found in all phloem tissues produced after infection has occurred (Magee 1940; Haffner et al 1995). In the absence of data to the contrary, it is assumed that this includes the phloem tissues in harvested banana fruit.

All Cavendish banana plantations on Mindanao Island from where export bananas are sourced are subject to weekly inspections for bunchy top disease. Any diseased mats, as well as any located within 5 m of a diseased mat, are sprayed with an insecticide and destroyed (BPI 2001).

Survey data provided by BPI (BPI 2002a) indicates that in the years from 1998–2001, the incidence of BBTV varied from 0.08–0.471 cases (infected mats) per hectare per 4-week period. The average incidence was 0.185 new cases per hectare per 4-week period, with a modal value of 0.13 cases per hectare per 4-week period. No information has been provided on how these data were derived other than that they were from Cavendish banana plantations from which export fruit was harvested.

Smith et al (1998) examined survey records for a 220 hectare area at the edge of a large export Cavendish banana plantation near Davao City. This area bordered banana plantations that were heavily infested with BBTV. The export area was subject to a BBTV control program involving inspections every 1–2 weeks, eradication of BBTV-infected plants and replacement with healthy plants over a three year period from 1993. The highest incidence recorded was 0.14% in April 1996. This equates to 3.18 cases per hectare per 4-week period. However, the incidence of BBTV decreased exponentially with increasing distance from the border adjacent to BBTV-infested bananas. The incidence of new infections in the 100 m-wide block nearest the border was seven cases per hectare per month, or 0.32% of the plants per month.

Smith et al (1998) also examined survey records for a large export Cavendish plantation from 1983–1996. No details were provided on the area of this plantation, but there was a consistent annual periodicity in BBTV detection, with twice as many plants detected in May as in November. Disease incidence also increased with time, in spite of control measures. It was more than 12 times greater in 1996 than 1983. Considering the seasonal effect, together with the extreme value recorded above, it is possible that the incidence of new infections could reach as much as 0.5% of the plants per month under routine control measures when there is an external source of BBTV.

The likelihood that a bunch harvested from a diseased mat will show symptoms, and be in a potentially infectious state, was considered in relation to the developmental stage of the banana plant and the likelihood of the mat escaping detection in the period leading up to harvest.

The last stage in the development of the phloem tissue at which symptoms could develop in the fruit coincides with bunch emergence (Simmonds 1966).

Symptoms will appear on the fruit as the bracts dehisce and the fruit expands.

Approximately seven weeks will elapse from the time all the fruit has fully developed, and the time when the fruit is ready for harvest. Symptoms will also appear on other parts of the mat during this period and the mat will be inspected for BBTV symptoms at weekly intervals.

As mentioned in Section 13.2.2, it is expected that a plant would need to become infected several weeks before harvest for the skin of a fruit from an infected plant to be a source of BBTV for aphid transmission. Based on estimates of detection efficiency under Australian conditions (Allen 1978a, 1987), it is estimated that the likelihood that a diseased mat would escape detection over a seven week period would be no more than 5%. Detection efficiency for plants infected with mild or symptomless strains of BBTV would be lower than this estimate, so the number of mats escaping detection would be correspondingly higher. However, no data have been presented concerning the incidence of mild or symptomless strains.

After considering:

- the uncertainties of field incidence
- the effectiveness of continuing field sanitation measures
- the efficiencies of disease detection measures with both severe and mild strains of BBTV
- the time for disease symptoms to develop after initial infection
- the effects of external sources of infection on disease incidence in commercial Cavendish plantations,

it was concluded that the proportion of clusters infected with BBTV at any weekly harvest time would be between  $1.00E-05$  and  $1.00E-03$ . As no data are available to suggest any central tendencies, a Uniform distribution was assumed.

### **13.3.3 Contamination by BBTV during harvest and transport**

*Imp3a and Imp3b: The proportion of clean clusters from both infected and non-infected plantations that become infected or infested with BBTV during harvest and transport to the packing station is 0.*

On the basis of evidence on BBTV infection of tissues formed before infection (Magee 1940; Hafner et al 1995), it is expected that mature Cavendish fruit would not be susceptible to infection by BBTV during harvest and transport. A value of 0 was assigned to these steps.

### **13.3.4 Proportion of infested clusters remaining after packing procedures**

*Imp4: The proportion of infected clusters that remain infected with BBTV after routine processing in the packing station is 1.*

BBTV carried internally in the fruit will not be affected by treatments in the packing station or detected by routine quality standard inspections. A value of 1 was therefore assigned to this step.

### **13.3.5 Contamination by BBTV during packing**

*Imp5: The proportion of clean clusters infected by BBTV during processing at the packing station is 0.*

As in Imp3, it is expected that mature Cavendish fruit would not be susceptible to infection by BBTV during packing. A value of 0 was assigned to this step.

### **13.3.6 Proportion of infected clusters remaining after post-packing procedures**

*Imp6: The proportion of clusters infected by BBTV that remain infected during handling and transport to Australia is 1.*

It is observed that BBTV remains in infected leaf tissue for at least 12 days if kept fresh (Magee 1940) and it is expected that BBTV will remain in the fruit until the tissue decomposes. Handling and transport conditions are not considered to affect BBTV. On this basis, a value of 1 was assigned to this step.

### **13.3.7 Contamination by BBTV during post-packing procedures**

*Imp7: The proportion of clean clusters infected by BBTV during handling and transport to Australia is 0.*

As in Imp3, it is expected that mature Cavendish fruit would not be susceptible to infection by BBTV during post-packing procedures. A value of 0 was assigned to this step.

### **13.3.8 Proportion of infected clusters remaining after border procedures**

*Imp8: The proportion of infected clusters that remain infected with BBTV after on-arrival minimal border procedures is 1.*

Minimal border procedures take no account of fruit infection by BBTV. A value of 1 was therefore assigned to this step.

## **13.4 Distribution**

The starting point for distribution in Australia is the release of imported fruit at the port of entry. The end point of this process is the disposal of waste material under controlled or uncontrolled conditions.

Distribution occurs through established wholesale and retail outlets and includes processes to store fruit at 13–14 °C and ripen it at 14.5–21 °C over a period of 14–21 days. The effect on BBTV during the distribution process is assessed below.

### 13.4.1 BBTV survival during distribution

*Dist1: The likelihood that infected fruit will remain infected during transport and handling in Australia is 1.*

Infection by BBTV occurs internally in the fruit and is not affected by these treatments. Therefore, the proportion of infected clusters that remain infected during these processes is 1.

### 13.4.2 Contamination by BBTV during distribution

*Dist2: The number of clean fruit that become infected with BBTV from an infected cluster during transport and handling in Australia is 0.*

For reasons outlined under Imp3a above, the conditions do not favour transmission of BBTV from infected to non-infected clusters. Therefore, the number of clean clusters that are infected with BBTV during the distribution process is 0.

### 13.4.3 The number of infected clusters at each waste point

Table 13.1 summarises how infected banana waste will be divided between the three waste categories in the two areas. The number of infected clusters is based on 105,000 tonnes of bananas being imported.

**Table 13.1 Estimated number of infected clusters of imported bananas at waste points from 105,000 tonnes**

Areas	Waste category					
	controlled		uncontrolled consumer		other uncontrolled	
Grower areas	5,903	11.1%	4,217	8.0%	58	0.1%
Other areas	25,077	47.3%	17,489	33.0%	281	0.5%

## 13.5 Exposure – proximity considerations

Determining the probability of exposure is done in two parts. The first part (this section) determines how likely it is that waste from an infected finger would be close enough to a host to be able to infect it, if conditions are favourable. The second part (the next section) determines how likely it is that the infection would be transferred to a host (see Section 5.4).

The term ‘proximity’ in this report refers to the likelihood that banana waste will be discarded sufficiently close to a host plant to allow for a likelihood greater than zero of transfer of virus to a host. The likelihood of banana waste being disposed of sufficiently close to a suitable host plant depends both on the method of waste disposal and on the category of the host plant exposure group.

For BBTV strains from the Philippines, a suitable host is any plant of the genus *Musa*. For *P. nigronevosa* derived from banana plants in the Philippines, there are other less-preferred host plants than the genus *Musa* in Australia but none of these are hosts of BBTV.

For the purposes of this part of the assessment, the flight range of an aphid vector is assumed to be 70 m.

Estimates of the proximity values for the 18 waste point and exposure group combinations are presented in Table 13.2. For each combination in the table, the value was found by multiplying the following two probabilities together:

- the proportion of waste discarded at a waste point that is near the exposure group
- the likelihood that a host plant in an exposure group would be within 70 m of the waste.

The data used for these calculations are given in Sections 7.4 and 7.5, with specific points summarised below.

### **13.5.1 Proportion of waste near each exposure group**

The proportions of each type of waste that is within 70 m of each exposure group are based on the information about general waste given in Section 7.4.

#### **Controlled waste**

Data indicate that no commercial host crops or home gardens occur within 70 m of any controlled waste facility. Although there are no banana plants growing at controlled facilities in other areas, there are some at controlled waste facilities in grower areas. Averaged over all facilities in grower areas, the IRA team considered that no more than a proportion of  $2.00\text{E}-04$  of the waste could be within 70 m of banana plants at each of the facility.

#### **Uncontrolled consumer waste**

Uncontrolled consumer waste is generated by consumers and most of it will be discarded in a home environment, generally for composting. A small proportion (between 1–5%) of uncontrolled consumer waste is discarded in other environments such as public parks, roadsides, farmlands and bushland. It is very unlikely that uncontrolled consumer waste will be discarded within 70 m of a commercial banana plantation. A value of  $5.50\text{E}-06$  was considered appropriate.

#### **Other uncontrolled waste**

Other uncontrolled waste is banana waste generated by wholesalers, retailers, food processors and food services. It may be fed to livestock, used directly as organic mulch, or tipped in areas not subject to controlled waste management.

Most of the other uncontrolled waste is discarded in other environments such as public parks, roadsides, farmlands and bushland and along roadsides. As mentioned in Section 7.4, about 5% of other uncontrolled waste is discarded or used near households. It is very unlikely that other uncontrolled waste will be discarded within 70 m of a commercial banana plantation. A value of  $1.00\text{E}-06$  was considered appropriate.

### **13.5.2 Probability of plants within a 70-metre circle**

The average number of plants within a random circle of 70 m radius is equal to the area of the circle multiplied by the planting density (Table 7.6). The average number is then used to determine the probability that there would be at least one banana plant within the circle.

#### **Commercial crops**

There would be 3080 banana plants in a circle of 70 m radius in a banana plantation in grower areas. By definition, there are no commercial banana plantations in other areas.

#### **Home gardens**

Although on average there would be between 1.39–2.00 banana plants in a circle of 70 m radius for home gardens in grower areas, there may occasionally be no plants. The probability that there would



be at least one plant within the circle is between  $7.50E-01$  and  $8.65E-01$ . The corresponding probabilities for other areas are  $4.51E-02$  and  $2.42E-01$ .

### Other plant communities

The probability that there are wild, volunteer and amenity banana plants in a circle of 70 m radius in other environments is between  $1.54E-03$  and  $1.53E-02$  for grower areas and  $7.70E-05$  for other areas.

### 13.5.3 Summary of proximity values

The proportion of waste near an exposure group is multiplied by the probability that there will be banana plants in a 70 m circle to give the proximity value. Table 13.2 summarises these values for each combination of waste point and exposure group. Where the proximity values were expressed as a range, the minimum values are multiplied together. The same was done for the maximum values. The data were insufficient to suggest any central tendencies and so a Uniform distribution was used.

**Table 13.2 Summary of proximity values for BBTV**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
<b>Grower areas</b>			
commercial crops	0	$5.50E-06$	$1.00E-06$
home gardens	0	U( $7.50E-01$ , $8.65E-01$ )	U( $3.75E-02$ , $4.32E-02$ )
other plant communities	$2.00E-04$	U( $1.54E-05$ , $7.64E-04$ )	U( $1.54E-03$ , $1.53E-02$ )
<b>Other areas</b>			
commercial crops	0	0	0
home gardens	0	U( $4.51E-02$ , $2.42E-01$ )	U( $2.26E-03$ , $1.21E-02$ )
other plant communities	0	U( $7.70E-07$ , $3.85E-06$ )	$7.70E-05$

## 13.6 Exposure – transfer considerations

Section 5.4.4 describes the considerations required when determining the second value needed to determine the probability of exposure: the likelihood of transfer.

The most likely vector of the virus in the Australian environment is the banana aphid (*P. nigronervosa*). It is considered that although nymphs and apterous individuals have the capacity to walk to the site and feed on host plants, the effective range of these forms is extremely limited and therefore their role in field transmission is not significant.

Assuming that waste banana peel infected with BBTV has been discarded in proximity to a susceptible host plant, the transfer considerations concern the likelihood that BBTV will be carried from the waste peel to an infection site on the host plant.

The following sequence of factors must occur for BBTV to be successfully transferred:

- the waste must be accessible to aphid vectors
- the virus must be present in sufficient concentration for aphid acquisition
- an aphid must find and feed on the waste
- the aphid must find and feed on a host.

For each combination of waste point and exposure group, the minimum transfer value is the product of the minimum values for Factors 1, 2, 3 and 4. A similar calculation was done to determine each maximum value. These values are presented in Table 13.3. The data were insufficient to suggest any

central tendencies, so it was assumed the values had a Uniform distribution. The likelihood values associated with these factors are assessed as follows:

### **Factor 1 – waste accessibility**

The waste material must be presented in a way that is accessible to aphid vector movement to and from the waste material, that is, the material must not be buried or contained in plastic bags. This is dependent on the method of waste disposal.

Most of the waste received in controlled waste facilities is contained in garbage bags or buried under other waste. It is greatly diluted by mixture with other household waste and heavily compacted in the waste collection process. The degree to which burial reduces the ability of aphid vectors to access banana waste has not been quantified, but it is considered highly unlikely that the waste would be accessible to aphids in controlled waste facilities. Factor 1 was therefore assigned a value of  $1.00E-06$  for controlled waste.

A significant proportion of uncontrolled consumer waste may be buried or contained in compost heaps, but some of this waste is discarded on the soil surface as litter. The degree to which burial reduces the ability of aphid vectors to access banana waste has not been quantified, but the IRA team's best judgment was that not more than 30% of the waste would be accessible. Factor 1 was therefore assigned a value of  $3.00E-01$  for uncontrolled consumer waste.

Uncontrolled other waste may be taken to agricultural land and discarded in heaps or otherwise be subject to some containment. The degree to which the disposal method reduces the ability of aphid vectors to access banana waste has not been quantified, but it is considered that not more than 30% of the waste would be accessible. Factor 1 was therefore assigned a value of  $3.00E-01$  for other uncontrolled waste.

### **Factor 2 – virus availability**

The waste material must have sufficient virus concentration for an aphid vector to acquire an infective dose of BBTV. Given that BBTV is found principally in phloem tissue with visible disease symptoms (Hafner et al 1995) and that export quality Cavendish bananas are likely to have only mild disease symptoms at most, it is unlikely that many fruit will have sufficient BBTV concentration for aphids to acquire an effective dose. The proportion has not been quantified, but the IRA team considered that the likelihood of infected waste having a virus concentration sufficient for BBTV acquisition would be not more than  $1.00E-03$  when it is discarded.

### **Factor 3 – virus acquisition**

An aphid vector must be attracted to feed on the banana waste material for several hours. Factor 3 will depend on the condition of plant material and aphid activity at the time of waste disposal. Some relevant observations in the literature are listed below.

#### *Condition of plant material*

Aphids can only acquire BBTV while the plant tissue is fresh. Both uncontrolled consumer waste and other uncontrolled waste are usually fresh when discarded and therefore may be suitable for BBTV acquisition for up to five days while the tissue is relatively fresh. This component of Factor 3 would have a value of 1. However, controlled waste will have already been stored in garbage bins for up to seven days before collection and a large proportion will be unsuitable for acquisition at the time of exposure. For controlled waste, this component of Factor 3 was assigned a value of  $1.00E-01$ .

#### *Aphid activity*

The likelihood that an aphid finds the waste will depend on the number of aphids, which in turn will depend on the number of host plants in the proximity zone.

Data based on yellow sticky traps, reported by Kenyon et al (1997), indicate that the likelihood of *P. nigronevosa* being attracted to waste discarded in a commercial banana plantation over a period of five days may be in the order of  $5.00E-02$  to  $2.10E-01$  (see Part C). However, because of the size of a banana peel compared to the traps used and other considerations, the likelihood of an aphid finding waste would be no more than 10% of these values.

In addition, as a result of seasonal variations in temperature, aphid activity in Australia is expected to be less than that in the Philippines. For *P. nigronevosa*, the activity in grower areas could be 70% of that in the Philippines (Allen 1978a, 1987). The corresponding figure for other areas is 10%. Hence values ranging between  $3.50E-03$  to  $1.47E-02$  were used in grower areas and  $5.00E-04$  to  $2.10E-03$  in other areas for the likelihood that an aphid would find the waste in a commercial plantation.

For home garden grower areas, there would be between one to four plants in the proximity zone of 70 m. There would be only one plant in the proximity zone for home garden plantings in other areas and for other environments. Taking into account the small area of the waste relative to the area of the proximity zone and the number of aphids, the IRA team considered that the probability that aphids from a single plant would find the waste would be no more than  $1.00E-04$  in grower areas and  $2.50E-05$  in other areas. The probabilities would be four times greater for four plants.

Not all aphids will settle to feed on discarded waste material for the required time. The banana aphid tends to walk and probe the plant surface for a considerable time after first landing (Facundo and Sumalde 1998) and some aphids will leave after probing the surface and finding the material unsuitable for feeding. Other aphids may be attacked by predators. This issue has not been quantified, but it is considered that not more than 10% of aphids that probe the banana waste will settle to feed.

The various components were multiplied to provide estimates of Factor 3 for each waste point and exposure group combination.

#### **Factor 4 – virus transmission**

Having acquired an infective dose of BBTV, the aphid vector must disperse, locate a suitable host and feed for 0.25–3 hours on that host to transmit the virus. Determining the likelihood of finding a host and transmitting the virus is based on the following considerations.

The transmission efficiency of an infective aphid is 80% under ideal conditions when the aphid is placed directly on the host plant for the required inoculation feeding time (Part C). It is expected that this efficiency will be reduced by external factors under field conditions.

Once a banana aphid has settled to feed (Factor 3) it is normally reluctant to leave the feeding site until the tissue rots or a dense aphid colony develops (Magee 1927). During the feeding period, the aphid may be subject to predation and mortality from desiccation and adverse environmental conditions. The ability of aphids to leave the feeding site has not been quantified but the IRA team considered that not more than 30% of aphids would leave banana waste once they have settled to feed.

Having left the feeding site, a banana aphid will make one or more successive flights in search of a suitable host and often spend considerable time walking and probing any surface on which it lands, sometimes until it dies (Magee 1964; Facundo and Sumalde 1998). It is considered that it will eventually settle to feed for the required inoculation feeding time if it finds a suitable host.

The flight range of an aphid vector is 70 m, so the proximity zone is  $15,400 \text{ m}^2$  in area. The target area presented by each host plant is approximately  $5 \text{ m}^2$ , which represents a proportion of about 0.032% of the area within the proximity zone. An aphid is not expected to be attracted to a banana plant more than any other plant in the vicinity.

The ability of an aphid vector to find a host plant also depends on the number of host plants in the proximity zone. This number will vary between exposure groups as follows:

#### *Commercial crops*

Commercial bananas are planted at 2000 plants per hectare (Section 7.5) and there may be up to 3080 plants within the 70 m proximity zone. However, only a very small proportion of waste discarded near commercial crops will be discarded within the cropping area. Under these circumstances, the IRA team considered that there would be 1–1540 plants in the proximity zone.

#### *Home gardens*

There could be between one and four home garden host plants present in the proximity zone in grower areas. In other areas, it is unlikely that there will be more than one home garden host plant in the proximity zone.

#### *Other plant communities*

It is unlikely that there will be more than one host plant in other plant communities in the proximity zone.

The various components were multiplied to provide estimates of Factor 4 for each waste point and exposure group combination.

#### **Summary of transfer values**

As already mentioned, the values of Factors 1, 2, 3 and 4 are multiplied to give the transfer value. Table 13.3 summarises the values for each combination of waste point and exposure group.

**Table 13.3 Summary of transfer values for BBTV**

Exposure groups	Controlled waste	Uncontrolled household waste	Other uncontrolled waste
Grower areas			
commercial crops	U(2.73E-18, 1.76E-14)	U(8.19E-12, 5.29E-08)	U(8.19E-12, 5.29E-08)
home gardens	U(7.80E-20, 1.25E-18)	U(2.34E-13, 3.74E-12)	U(2.34E-13, 3.74E-12)
other plant communities	7.80E-20	2.34E-13	2.34E-13
Other areas			
commercial crops	U(3.90E-19, 2.52E-15)	U(1.17E-12, 7.56E-09)	U(1.17E-12, 7.56E-09)
home gardens	1.95E-20	5.85E-14	5.85E-14
other plant communities	1.95E-20	5.85E-14	5.85E-14

## **13.7 Establishment**

The starting point for establishment of BBTV is the exposure of a suitable host plant to an infected aphid. The end point is the development of a systemic infection within the host plant. Section 5.5 gives the ISPM 11 criteria that need to be considered.

If exposure of a *Musa* species occurred, it is expected that there would be no resistance to establishment of BBTV. The virus would replicate initially at the point of inoculation and then move from this point through the phloem tissue to a metabolic sink. The virus would continue to replicate in the meristematic tissues and eventually reach a concentration at which it could be acquired by an aphid vector or spread in vegetative propagation material. It is expected that establishment of BBTV would not be dependent on adaptation to local varieties of *Musa* species, nor would it be affected by the other factors listed above.

After considering the uncertainties relating to the establishment of BBTV at each of the exposure points, the IRA team concluded that exposure of a suitable host plant (as defined under the distribution steps above) would lead to establishment. The establishment potential was therefore assigned a value of 1 for each exposure group (refer to Table 13.4).

**Table 13.4 Probability of establishment for BBTV after exposure**

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	1
other plant communities	1	1

## 13.8 Spread

The probability of spread examines the movement of BBTV from the establishment point in an exposed plant or group of plants to susceptible plants in the endangered area throughout Australia. The starting point for spread is acquisition of BBTV by an itinerant aphid species from a plant in Australia on which the virus has established. The end point is the distribution of an effective dose of BBTV to other host plants. Section 5.5 gives the ISPM 11 criteria that need to be considered.

BBTV does not kill infected plants directly and will persist as long as the host survives. Bananas are perennial hosts and it is therefore inevitable that BBTV will spread to other plants from an infected banana plant, whether or not this occurs as a result of aphid vector activity or the transfer of infected vegetative planting material.

Viruses do not have natural enemies as such and it is clear that aphids are able to sustain stable populations in Australia despite predation. This virus is also known to be carried long distances through the translocation of infected planting or propagation materials.

A value of 1 was therefore assigned to the spread potential for each exposure group (Table 13.5).

**Table 13.5 The probability of spread of BBTV after establishment**

Exposure group	Grower areas	Other areas
commercial crops	1	1
home gardens	1	1
other plant communities	1	1

## 13.9 Probability of entry, establishment and spread

The probability of entry, establishment and spread (PEES) was estimated using the values derived above and the calculations outlined in Table 5.6 and Table 5.7. Table 13.6 shows the median PEES from 100,000 simulations, together with the 5<sup>th</sup> and 95<sup>th</sup> percentile as a sensitivity analysis. The weight of imported bananas used in the simulation (105,000 tonnes) is about 40% of current wholesaler throughput. A further sensitivity analysis repeated the simulations with 50,000 and 160,000 tonnes (equivalent to 20% and 60% respectively). Rather than showing the individual PEES values for each waste point and exposure group combination, Table 13.7 shows the relative contribution the individual values make to the overall PEES.

**Table 13.6** Probability of entry, establishment and spread for BBTV

	50,000 tonnes	105,000 tonnes	160,000 tonnes
5th percentile	2.15E-09	4.44E-09	6.75E-09
Median	2.01E-08	4.21E-08	6.41E-08
95th percentile	6.44E-08	1.34E-07	2.05E-07

**Table 13.7** Apportioning the PEES by waste point and exposure group

Exposure groups	Controlled waste	Uncontrolled consumer waste	Other uncontrolled waste
Grower areas			
commercial crops	0.00%	8.15%	0.02%
home gardens	0.00%	89.80%	0.06%
other plant communities	0.00%	0.01%	0.00%
Other areas			
commercial crops	0.00%	0.00%	0.00%
home gardens	0.00%	1.96%	0.00%
other plant communities	0.00%	0.00%	0.00%

## 13.10 Consequences

The analysis examines the consequences to the Australian community of the entry, establishment and spread of BBTV by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of BBTV was assessed on the basis of their potential effect on the entire local district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

### 13.10.1 Direct Impact

#### *Plant life or health – E*

This criterion describes the production losses associated with BBTV in commercial bananas. The direct effects of BBTV have to be considered in the context of existing horticultural practices for control of pests and diseases. For BBTV, these involve the use of healthy propagation material and regular crop sanitation measures (Eastwood 1946). Costs associated with additional control measures or trade restrictions are considered within the discussion of ‘indirect impacts’.

BBTV is the most damaging virus disease of banana worldwide (Magnaye and Valmayor 1995). In Australia, Magee (1927) reported up to 90% disease incidence in southeast Queensland and northern NSW, resulting in up to 95% loss in production. A severe disease outbreak has recently caused heavy production loss in Pakistan where 100% disease incidence was recorded in some plantations (Thomas and Iskra-Caruana 2000). In managed commercial plantations the disease incidence can be reduced to below 5%.

The direct impact of BBTV on commercial bananas will be determined by the stage of development at which infection occurs, and the speed and extent to which the disease spreads to other farms. If BBTV infection first occurs late in the growth cycle of a banana bunch, the effects on production will not be

discernible on that bunch. However, subsequent bunches on that plant will be unmarketable. The effect on yield will become progressively worse over a number of years as disease incidence increases to the point that the plantation becomes uneconomic. Before that stage is reached the banana grower would replant the whole area with BBTV-free planting material.

BBTV has the potential to cause significant production losses even within the context of current horticultural practices for control of this disease. This impact is expected to be much more severe in the tropical production areas (where 90% of Australia's banana production is concentrated in two shires) than in the subtropical areas where the disease is currently restricted (Allen 1987) and occurs in scattered small holdings.

The likely direct impact of BBTV in terms of plant production losses is considered to be 'minor' at the national level. The rating assigned to this criterion is therefore **E**.

#### *Human life or health – A*

There are no known direct impacts of BBTV on human life or health and the rating assigned to this criterion is therefore **A**.

#### *Any other aspects of the environment not covered above – A*

This criterion addresses the possible direct impact of pests on other aspects of the natural or built environment, such as the physical and biological environment. There are no known direct impacts of BBTV in these directions, and the rating assigned to this criterion is therefore **A**.

### **13.10.2 Indirect impact**

#### *Control or eradication – D*

Although BBTV is not currently listed as a pest under an Emergency Plant Pest Deed, it is likely that an eradication program would be undertaken upon first detection of the Asian strain. The cost is likely to be several million dollars per year over a number of years. For BBTV disease in Queensland, the controls that may be applied in the event of an incursion are already prescribed under the *Plant Protection Regulation 2002*. These controls do not currently include restrictions on fruit movement.

Australian experience is that it is possible to eradicate BBTV from an area if the disease is detected soon after introduction, but that it is very difficult to eradicate once it becomes established in an area. Eradication when the disease is well-established in residential areas is much less probable (Peasley et al 1998). It is more likely that banana growers would be faced with an ongoing control and containment program, using a combination of preventative and sanitation measures. These would include use of disease-free planting material, early detection surveys and eradication of infected, plus surrounding, mats within a 5 m radius. It is also possible that virus-indexing procedures currently used routinely in Australia to produce healthy planting material would need to be modified or improved if Asian strains of BBTV are introduced, particularly for abacá bunchy top virus.

In addition to this, individual banana farmers may need to control the aphid vectors using pesticides. Additional applications may alter the economic viability of some crops and affect existing integrated pest management programs. In addition, it is possible that with a ceiling on the number of pesticide applications tolerated by consumers, sprays targeting aphids would need to be used in place of those targeting other pests. This might lead to an increase in other insect populations, a decrease in productivity and a further indirect loss associated with BBTV.

Overall, the indirect impact of BBTV on the cost of pest control programs is considered likely to be 'minor' at the regional level. The rating assigned to this criterion is therefore **D**.

### *Domestic trade – B*

There would be effects on intrastate and interstate movement of planting materials, but these would be similar to those that already apply to BBTV.

The indirect impact on domestic trade is considered ‘minor’ at the local level and the rating assigned to this criterion is therefore **B**.

### *International trade – A*

Australia exports only small quantities of bananas. The presence of BBTV would not therefore disturb bilateral trade agreements. The rating assigned to this criterion is therefore **A**.

### *Environment – A*

Although additional pesticide applications may be required to control aphids on commercial banana plantations, this is unlikely to impact on the environment as it is not considered to be distinguishable from day-to-day variation of pesticides used by the banana industry. The rating assigned to this criterion is therefore **A**.

### *Communities – C*

One of the considerations within this criterion is the potential indirect impact of BBTV on rural economic viability. The effects of BBTV on changes to horticultural practices have already been considered under new or modified controls (see above).

The banana industry provides continuous employment for more than about 4000 workers nationally, most of who are employed in Far North Queensland that is currently free from BBTV (OGS 2005b, 2005c). The initial effects of BBTV could lead to removal of banana plantations and loss of jobs until the plants could be replaced with virus-tested stock. These losses would impact on agricultural employment within the effected local communities until adjustments were made to horticultural systems.

Gross regional product multipliers in the range of 1.5–2 for banana growing areas in north-eastern Australia suggest that a downturn in banana production will have a flow-on effect on other local industries (CEPM 2002; OGS 2002; Growcom 2004). A downturn in banana production would have a significant economic and social impact on the Johnstone and Cardwell shires where agricultural production constitutes the dominant industry (Cummings 2002).

The indirect effects on communities are likely to be ‘significant’ at the local level. The rating assigned to this criterion is therefore **C**.

## **13.10.3 Overall consequences for BBTV**

*The overall consequences to the Australian community of the entry, establishment and spread of BBTV as a result of trade in mature hard green bananas from the Philippines: Moderate.*

Table 13.8 provides a summary of the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of BBTV within Australia.

The direct and indirect impacts of BBTV shown in Table 13.8 were combined using the decision rules discussed in Chapter 6. It follows from these decision rules that 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 BBTV are considered to be ‘moderate’.



**Table 13.8 Consequences assessment for BBTV is moderate**

Criteria	National	Regional	District	Local	Impact
Plant life or health	Minor	Significant	Highly Significant	Highly significant	E
Human life or health	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Any other aspects of the environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Control or eradication	Unlikely to be discernible	Minor	Significant	Highly Significant	D
Domestic trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Minor	B
International trade	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Environment	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	Unlikely to be discernible	A
Communities	Unlikely to be discernible	Unlikely to be discernible	Minor	Significant	C

### 13.11 Unrestricted risk

The unrestricted risk associated with BBTV is determined by combining the median value of PEES (4.21E-08) with the consequence (“Moderate”) according to Table 6.2.

The unrestricted risk is within Australia’s ALOP (Table 13.9) and risk management is not required, provided that standard practices are maintained in the Philippines.

**Table 13.9 Unrestricted risk for BBTV**

Probability of entry, establishment and spread	4.21E-08
Consequence	Moderate
Risk	Achieves ALOP (Negligible)



## 14. Fruit flies

### 14.1 Introduction

True fruit flies (Family Tephritidae) are considered to be one of the most serious pests of horticultural crops in the world (Allwood et al 1999, 2001; Clarke et al 2005). They attack commercial and wild plants by laying eggs under the surface of fruit of susceptible host plants. The larvae or maggots develop in the fruit. Fruit flies are regarded as important quarantine pests. Banana is not a favoured host plant, but some species of the *Bactrocera dorsalis* complex are capable of laying eggs in sound or damaged, ripening or ripe banana fruit in the field (Brown 1998; Miller and Chang 1998).

Drew and Hancock (1994) reported 13 species of *B. dorsalis* complex fruit flies that occurred in the Philippines, but only two of these are considered species of economic importance, in that they attack commercial host plants. They are examined in this import risk analysis and have been identified as follows:

- *Bactrocera occipitalis* (Bezzi 1913)
- *Bactrocera philippinensis* Drew and Hancock 1913

The biology of these species was considered sufficiently similar to justify their consideration in a single assessment.

In this assessment, the term ‘fruit flies’ is used to refer to these two species, unless otherwise specified.

*B. occipitalis* and *B. philippinensis* occur in tropical Asia and Palau in Micronesia (Drew and Hancock 1994; SPC 2001; Pacifly 2002a, 2002b; Sengebau et al 2005; Western Micronesia Regional Invasive Species Council 2005b). Both of these species are native to the Philippines and were introduced into Palau in the mid-1990s (Pacifly 2004; Republic of Palau 2002). They are known not to occur in Australia (Drew and Hancock 1994) although *B. philippinensis* was detected in the Northern Territory in 1997 and subsequently eradicated by 1999 (Cantrell et al 2002).

These fruit flies have not been reported as pests of bananas in the Philippines (BPI 2001), possibly due to the following:

- A comprehensive host plant survey for fruit fly in the Philippines has not been undertaken (RA Drew, Professor, International Centre for Management of Pest Fruit Flies, Australian School of Environmental Studies, Griffith University, Queensland, pers comm 4 August 2005), either in Cavendish or in local banana and plantain cultivars.
- Fruit fly infestations in banana plantations are controlled or prevented by harvesting fruit at the mature hard green stage. This stage is not attractive to the majority of fruit flies, including *B. occipitalis* and *B. philippinensis* (Armstrong 1983, 1994, 2001; Brown 1998; Pinese and De Faveri 1996).
- Insecticide sprays and insecticide-impregnated bunch covers offer considerable protection against fruit fly infestation.

However, *B. occipitalis* and *B. philippinensis* were introduced into Palau in the mid-1990s, possibly through accidental introductions with travellers (Pacifly 2004). Both species attack ripening and ripe bananas in that country (F. Sengebau, Head of Plant Protection and Quarantine Service, Bureau of Agriculture, Ministry of Resources and Development, Republic of Palau, pers comm 6 December 2005).

As described in the scope of this IRA, banana fruit from the Philippines would be imported in a mature hard green condition (see Section 2.1.2). It is accepted internationally that bananas harvested at the mature hard green stage are not hosts to fruit flies except for *B. musae*, and that fruit fly larvae do

not develop in hard green fruit under natural conditions (Armstrong 1983, 1994, 2001a; Pinese and De Faveri 1996; Heimoana et al 1997; Brown 1998; Allwood et al 2001; Cantrell et al 2002).

Armstrong (1983) found that three species of fruit fly, *B. dorsalis*, *B. cucurbitae* (melon fly) and *Ceratitis capitata* (Mediterranean fruit fly) readily laid eggs into mature green bananas. However, the eggs or the first instar larvae that hatched from these eggs did not survive. Armstrong also found that unripe bananas formed dark, hard tissue around egg-laying sites, encapsulating the eggs. Latex was also produced at the site and it surrounded the eggs, forming a sticky surface onto which eggs and first instar larvae would adhere and die. Also, as the latex hardened, it formed an adhesive cap over the site, suffocating the eggs and any first instar larvae.

Armstrong (1983, 2001) concluded that banana was not a host for *B. dorsalis*, *B. cucurbitae* and *Ceratitis capitata* when the bananas are hard green, undamaged and attached to the banana plant, or for up to 3–4 days post-harvest. Brown (1998) stated that eggs of most fruit fly species, with the exception of *B. musae* (the banana fruit fly), will not hatch if laid in hard green bananas.

Based on this information, many countries permit the importation of bananas in their mature hard green stage, as they consider ‘mature hard green’ to be an effective quarantine control measure against fruit flies (Pacifly 2002b; Biosecurity New Zealand MAF, Wellington, New Zealand 2005a; USDA 2006), including:

- New Zealand permits the importation of green bananas from Ecuador, Mexico, Niue, the Philippines, Samoa and Tonga (Pacifly 2002b; Biosecurity New Zealand MAF, Wellington, New Zealand 2005c).
- New Zealand’s import health standard for bananas from Australia also accepts that green bananas are not hosts to economically important Australian fruit flies (including *B. musae*) (Biosecurity New Zealand MAF, Wellington, New Zealand 2006).
- The United States of America permits imports of green bananas from Africa, the Caribbean, the Pacific and South America (USDA 2006).

It was thought that *B. papayae* may also infest undamaged hard green bananas, as it is a serious pest of bananas in Malaysia. Japan accepts hard green bananas from Malaysia, where *B. papayae* is endemic, for over a decade without fruit flies being detected.

Host status testing of hard green bananas during an outbreak of *B. papayae* in Australia in 1995 found that hard green bananas were not hosts for *B. papayae* fruit fly (Pinese and De Faveri 1996; Cantrell et al 2002). The work of Pinese and De Faveri (1996) was used to develop Interstate Certification Assurance (ICA) documents to enable Queensland bananas to be moved interstate (Cantrell et al 2002). ICA–06 *Hard green condition of bananas* describes the operational procedures including interstate fruit fly quarantine conditions, for interstate movement of Queensland bananas. It was selected as the most suitable for bananas from the Philippines, as it requires hard green bananas to conform to the following criteria (QDPI 2000):

- The variety is Cavendish only.
- The banana flesh is hard and not flexible, the skin is green and shows no yellow colouration except for areas towards the flower end of the fruit, in which the sun has bleached the skin to a yellow to white colour. The flesh beneath is hard.
- No single banana or banana on an outside whorl of a hand or cluster (except a wing banana or distorted banana) has a diameter that exceeds 42 mm when measured at right angles to the curvature of the fruit at a point one third from its flower end.
- The skin must be unbroken.

Inspection records for mature hard green Philippine bananas imported into New Zealand, Japan and Korea show that no *B. philippinensis* or *B. occipitalis* fruit flies have been intercepted on mature hard green bananas to date (Spence 2002; Iwaizumi 2004; Biosecurity New Zealand MAF, Wellington, New Zealand 2005a; F Kang, Senior Product Management Manager, Del Monte Fresh Produce Korea

Ltd, pers comm 16 February 2006; Biosecurity New Zealand MAF, Wellington, New Zealand, 11 January 2006).

## 14.2 Biology

These two species are typical Dacine fruit flies of the Oriental fruit fly complex with an adult body length of 7–8 mm, wing length of about 6 mm; black thorax with yellow markings; brown abdomen with black markings; transparent wings, with two dark bands on each. The abdomen of *B. occipitalis* is slightly darker than that of *B. philippinensis*.

*Bactrocera occipitalis* and *B. philippinensis* are polyphagous, attacking over 20 plant hosts in 14 plant families. Hosts include a range of mainly commercial fruits, with a few wild hosts (see fruit fly datasheet in Part C). Both species are considered important pests of mango in the Philippines and have also been reported on the following hosts: avocado, ripening and ripe banana, carambola, cashew, citrus, guava, Malay-apple, mandarin, papaya, passionfruit, sapodilla and soursop (Drew and Hancock 1994; Covacha et al 2000; Mango Information Network 2005; Sengebau et al 2005; Western Micronesia Regional Invasive Species Council 2005a, 2005b).

Fruit fly activity is centered on the host plant, which provides a site for adult resting or shelter, feeding, mating and egg-laying, as well as larval and pupal development in the soil underneath the plant. Using its egg-laying organ (ovipositor) the adult female lays its eggs in clutches under the skin of the fruit. During this process the female introduces bacteria into the fruit. These bacteria cause the fruit to break down and rot. One to two days following egg-laying, larvae (maggots) hatch out and feed on the decaying fruit flesh. The larvae develop through three stages (instars) in about 7 days. The third instar larvae escape from the fruit and burrow into the soil or organic matter and form yellowish-brown pupae. Pupal development takes about 10 days. Twenty days after the eggs are laid, the adult flies emerge from the puparium and disperse (Sengebau et al 2005; Western Micronesia Regional Invasive Species Council 2005a, 2005b).

Trapping data has confirmed that *B. occipitalis* is more abundant in forest habitats, while *B. philippinensis* is observed more in orchard and home garden habitats, suggesting that *B. philippinensis* is likely to be of more concern as a pest (White and Hancock 1997).

## 14.3 Risk scenario

The risk scenario of concern for fruit flies is that eggs laid within fine cracks in the skins of mature hard green banana fruit would not be detected during routine packing house procedures. Although this kind of infestation is unlikely, eggs in such cracks would be relatively protected during routine pre-harvest and post-harvest procedures on the importation pathway.

## 14.4 Entry, establishment and spread

The following analysis examines in detail the probabilities that fruit flies will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines. These probabilities are later combined with the estimated consequences for these pests to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

Where available, pest interception data from countries already importing Philippine bananas have been used to estimate values for the probabilities of these fruit flies entering, establishing and spreading in Australia.

### 14.4.1 Entry

The probability of entry is obtained by considering the ‘importation’ and ‘distribution’ pathways for the commodity and the probability that a given pest will remain viable and undetected as each of the component steps is completed.

#### *Probability of importation*

The likelihood that *B. occipitalis* and *B. philippinensis* fruit flies will arrive in Australia with the importation of mature hard green bananas from the Philippines: **Negligible**.

Fruit fly eggs laid in fine cracks on hard green banana fruit before harvest will fail to hatch if the bananas are kept in a mature hard green stage during harvest, packaging and transportation to Australia (a minimum period of 14 days) (Brown 1998).

Armstrong (1983, 1994, 2001a), Pinese and De Faveri (1996) and Brown (1998) found that, except for *B. musae* (banana fruit fly), hard green bananas are not natural hosts to many Tephritid fruit fly pests. This includes *B. occipitalis*, *B. philippinensis* and other Oriental fruit fly (*B. dorsalis*) complex species. Therefore, Tephritid fruit fly infestation of hard green bananas is significantly lower than for other tropical fruits.

Fruit flies, with the exception of *B. musae*, have not been reported as pests of hard green bananas in the Philippines or any other banana-producing country. Historic trade data and arthropod interception reports show that no importing countries have detected fruit fly during on-arrival inspections of mature hard green bananas from the Philippines (Spence 2002; Biosecurity New Zealand MAF, Wellington, New Zealand 2005a; Iwaizumi 2004; Biosecurity New Zealand MAF, Wellington, New Zealand, 11 January 2006).

Based on scientific literature regarding non-host status, historic trade data, interception records, and the identification of pests in fruits from the Philippines intercepted by New Zealand and Japan quarantine authorities between 2000–2005, Biosecurity Australia concludes that there is a **negligible** likelihood of hard green bananas (*Musa* spp.) being a host of *B. occipitalis* and *B. philippinensis*.

#### *Probability of distribution*

The likelihood that fruit flies will be distributed to the endangered area as a result of the processing, sale or disposal of hard green banana fruit from the Philippines: **Negligible**.

*Bactrocera occipitalis* and *B. philippinensis* eggs laid in fine cracks on hard green banana fruit prior to harvest will fail to hatch if the bananas are kept in a mature hard green stage during harvest, packaging and transportation to Australia (a minimum period of 14 days) (Brown 1998). Armstrong (1983) observed suberisation at the site of oviposition on hard green bananas, leading to encapsulation and death of eggs. Latex production at these sites also resulted in eggs and first-instar larvae suffocating in the fluid.

New Zealand and South Korea import significant quantities of mature hard green bananas. No records of consumers detecting fruit fly larvae in Philippine banana fruit distributed in both countries have been reported (F Kang, Senior Product Management Manager Del Monte Fresh Produce (Korea) Ltd. pers comm 16 February 2006 or New Zealand (Biosecurity New Zealand MAF, Wellington, New Zealand, 11 January 2006).

Therefore the likelihood is **negligible** of fruit flies being distributed to the endangered area as a result of the processing, sale or disposal of mature hard green banana fruit from the Philippines.

### *Probability of entry (importation x distribution)*

The likelihood that fruit flies will arrive in Australia as a result of trade in mature hard green banana fruit from the Philippines and be distributed to the endangered area: **Negligible**.

The overall probability of entry is determined by combining the probabilities of importation and distribution using the matrix of rules for combining descriptive likelihoods presented in Chapter 3.

### **14.4.2 Establishment**

The likelihood that fruit flies will establish if they arrive viable, 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**.

Dacine fruit flies are well-documented invaders and rank high on quarantine target lists (Clarke et al 2005) due to adult fruit fly traits that include high mobility and dispersive ability, high fecundity, and, in some species, extreme polyphagy. Many native *Bactrocera* spp. exist in Australia. Incursions of exotic fruit fly species of the *B. dorsalis* complex have previously occurred and subsequently been eradicated in Australia. *B. philippinensis* was detected in Darwin during 1997, and eradicated by 1999 (Cantrell et al 2002). This incursion into the northern suburbs of Darwin and the Northern Territory rural area of Humpty Doo during 1997 is indicative of the ability of this fruit fly species to establish in Australia (D Chin, Extension Entomologist, Entomology, Resource Protection, Northern Territory Department of Business, Industry and Resource Development, Darwin, pers comm 8 July 2005).

*B. occipitalis* and *B. philippinensis* are native to tropical areas of Asia and are polyphagous. All their recorded commercial host plants are present in Australia (for example, avocado, citrus, mango, papaya and banana). This suggests that *B. occipitalis* and *B. philippinensis* could find parts of the Australian environment suitable for their successful establishment.

Based on this information, the probability of a fruit fly colony establishing from infested fruit: **High**.

### **14.4.3 Spread**

The likelihood that fruit flies will spread within Australia based on a comparative assessment of those factors present, both in the area of origin and in Australia, considered pertinent to the expansion of the geographical distribution of the pest: **High**.

*B. occipitalis* and *B. philippinensis* are native to tropical Asia and have become established on Palau (Drew and Hancock 1994; SPC 2001; Pacifly 2002a, 2002b; Sengebau et al 2005; Western Micronesia Regional Invasive Species Council 2005b). It is clear that tropical or subtropical environments in Australia would favour the spread of these fruit fly species. While their movement with commercial bananas is likely to be limited by the harvesting of hard green fruit, it is likely that fruit flies would move with other fruit crops or into garden plants and subsequently move with these alternative fruit hosts.

As they are competent fliers, adult fruit flies do not require vectors. The incursion of *B. philippinensis* into the northern suburbs of Darwin and Humpty Doo in 1997 is indicative of the ability of this fruit fly species to spread in Australia (D Chin, Extension Entomologist, Entomology, Resource Protection Northern Territory Department of Business, Industry and Resource Development, Darwin, pers comm 8 July 2005).

Based on this information it was considered that the probability that fruit flies would spread within Australia: **High**.

#### 14.4.4 Probability of entry, establishment and spread

The overall likelihood that fruit flies will enter Australia as a result of trade in mature hard green banana fruit from the Philippines, be distributed in a viable state to suitable hosts, establish in that area or subsequently spread within Australia: **Negligible**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, establishment and spread using the matrix of rules for combining descriptive likelihoods (Table 3.1).

### 14.5 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of fruit flies by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of fruit flies was assessed on the basis of their potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was obtained by combining the direct and indirect impacts of fruit flies using the decision rules discussed in Chapter 6.

Consideration of the direct and indirect impacts is provided in the following text.

#### 14.5.1 Direct impact

##### *Plant life or health – E*

This criterion describes production losses associated with the presence of fruit flies in commercial bananas, as well as any loss in productivity of other susceptible host species. The direct impact of fruit flies was considered in the context of existing horticultural practices for control of pests and diseases in Australia. Costs associated with control measures or trade restrictions are considered within the discussion of ‘indirect impacts’.

*B. occipitalis* and *B. philippinensis* fruit flies are not considered a damaging pest of bananas, since bananas are harvested and removed from the plantation at the mature hard green stage. These fruit flies are polyphagous and are responsible for fruit damage and production losses in other horticulture industries (for example, avocado, breadfruit, carambola, cashew, citrus, guava, jackfruit, Malay-apple, mandarin, mango, papaya, passionfruit, sapodilla and soursop).

The direct impact of *B. occipitalis* and *B. philippinensis* fruit flies on plant life or health would be ‘significant’ at the regional level. This gave the pest a rating of **E** for this criterion.

##### *Human life or health – A*

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

##### *Any other aspects of the environment – C*

This criterion addresses the possible direct impact of pests on other aspects of the natural or built environment, such as the physical environment or microorganisms. *B. occipitalis* is reported to be primarily a forest-based species (White and Elson-Harris 1992). If *B. occipitalis* enters the rainforest environment, it may compete with native fruit flies and feed on the fruits of rainforest plants. However, the direct impacts of these fruit flies on any other aspects of the environment are still not known. Therefore, this criterion was considered ‘significant’ at the local level, giving a rating of **C**.



## 14.5.2 Indirect impact

### *Control or eradication – F*

A control or eradication program adds considerably to the cost of production of the host fruit. A control program would cost between \$200–\$900 per hectare, depending on the variety of fruit produced and the time of harvest (Bateman 1991). Fruit flies impose a significant cost on horticultural production every year and have become serious pests worldwide. The economic cost of fruit flies to Australia alone is estimated at \$130–\$140 million per annum (ITFNET 2003).

A papaya fruit fly outbreak in Cairns in 1995 that went undetected for about 18 months proved to be severe, with eradication costing \$34 million over four years (Cantrell et al 2002). The outbreak also caused disruption to the marketing of nearly all fruit crops from North Queensland, with a cost to growers of up to \$100 million (Agrans Research and Dawson 2005).

As a result of this incident, the National Exotic Fruit Fly Surveillance Program, consisting of a national fruit fly trapping grid, was established. This program was designed to be an ‘early warning system’ to identify and define incursions of targeted exotic fruit fly pests entering through international pathways at ports and associated urban areas (Office of the Chief Plant Protection Officer 2005). An eradication program could be initiated under the national Generic Incursion Management Plan approved by the Australian Primary Industries Standing Committee upon first detection of an exotic fruit fly.

The National Exotic Fruit Fly Surveillance Program was effective in detecting a *B. philippinensis* outbreak in Darwin, in November 1997. This outbreak was detected within several months of establishment and eradication was achieved at a much lower cost than for the Cairns outbreak (Agrans Research and Dawson 2005). *B. philippinensis* was officially declared eradicated in May 1999 after more than 17 months with no detections. Eradication cost \$5 million, compared with the cost of \$34 million for the eradication of Papaya fruit fly, due to early detection and effective response preparedness and planning (Pheloung 2005).

Therefore this criterion was considered to be ‘significant’ at the national level. Consequently, a rating of **F** was assigned to this criterion.

### *Domestic trade – E*

The presence of either of these fruit flies on a commercial fruit crop would result in intrastate and interstate restrictions on the sale or movement of a wide range of fruit. The horticulture industries are important to the economies of many rural localities and districts throughout Australia. Restrictions on the sale of fruit, and thus the viability of many producers, would be damaging to these communities.

On this basis, the indirect impact of fruit flies on domestic trade and industry was considered likely to be ‘significant’ at the regional level, which resulted in a rating of **E** for this criterion.

### *International trade – E*

Fruit flies are widely regarded as the most destructive horticultural pests in the world and are responsible worldwide for considerable restrictions on the international movement of fruit and vegetables. Market competition for horticulture crops is intense and is likely to lead to losses for Australian producers of a magnitude that would be felt throughout Australia.

The major consequence facing Australian horticultural industries would be the negative effect they have on gaining and maintaining export markets. For example, in 1995, when the papaya fruit fly outbreak occurred in Cairns, North Queensland, Australia experienced trade restrictions that affected the whole country. In the first two months of the papaya fruit fly eradication campaign, about \$600,000 worth of exports were interrupted by Australian trade partners (Cantrell et al 2002). Within a

week of the papaya fruit fly outbreak being declared, Japan ceased imports of mangoes at a cost of about \$570,000, New Zealand interrupted its \$30,000 banana trade and the Solomon Islands completely stopped importing fruit and vegetables from Queensland (Cantrell et al 2002).

Therefore, the indirect impact of fruit flies on international trade is considered to be ‘significant’ at the regional level on this basis, a rating of **E** was assigned to this criterion.

#### *Environment – D*

If *B. occipitalis* and *B. philippinensis* fruit flies entered Australian rainforest areas and fed on native fruits, native non-pest fruit fly species might be at risk of competition from these exotic species or their associated control measures. This is particularly important for *B. occipitalis*, which is reported to be primarily a forest-based species (CAB International 2006).

Presently, Australia has restricted the use of Sterile Insect Technique (SIT) for mainly Queensland fruit fly outbreaks. SIT for exotic fruit fly outbreaks would require significant expenditure of around \$30 million to establish a facility (Cantrell et al 2002). Broad-scale chemical treatments (for example, male annihilation and/or baiting) used in commercial areas would be an alternative. These treatments would have significant effects on the rainforest environment, as they would affect non-pest species of fruit flies as well as beneficial insects (Cantrell et al 2002).

Therefore, the indirect impact of fruit flies on the environment is considered to be ‘significant’ at the district level. A rating of **D** was thus assigned to this criterion.

#### *Communities – E*

Although the banana industry provides continuous employment for more than 4000 workers, mostly in Far North Queensland (refer to Section 9.14.2), the entry, establishment and spread of *B. philippinensis* or *B. occipitalis* fruit flies would not lead to the loss of jobs, since bananas are not favoured host plants.

It is acknowledged that fruit flies may attack a range of commercial hosts found in Australia (for example, citrus and mango). Although these plants are already hosts to endemic fruit flies and increased crop maintenance would not be necessary, intrastate, interstate and international quarantine restrictions would be encountered. While these quarantine restrictions would not affect the intrastate or interstate movement of hard green bananas, other commercial fruit and vegetable industries may be severely affected by quarantine restrictions. Depending on the importing country, our international trading partners would require a fruit fly free period that varies between 3 generation times or 12 months from when the last fruit fly was detected. When *B. papayae* was detected in northern Queensland in 1995, it took 4 years before the fruit fly was officially eradicated. Improved detection and emergency response procedures led to *B. philippinensis* being detected in 1997 and being eradicated in 2 years. During the eradication periods, trade in horticultural produce was suspended or required alternative fruit fly treatments and workers in these industries were severely affected due to being temporarily unemployed (Cantrell et al 2002).

Although additional temporary employment of quarantine inspectors may be necessary to establish fruit fly quarantine and suspension areas to maintain suspension zones (road blocks) and to monitor thorough inspections and eradicate through spraying, baiting and post-harvest quarantine treatment applications of these fruit flies (Cantrell et al 2002), communities are still significantly affected by the overall reduction in the regional economy.

On this basis, the indirect consequence on communities is considered to be ‘significant’ at the regional level. Consequently, a rating of **E** was assigned to this criterion.

### 14.5.3 Overall consequences

The overall consequences of the entry, establishment and spread of fruit flies as a result of trade in mature hard green bananas from the Philippines: **High**.

Table 14.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of fruit flies within Australia.

Based on the decision rules described in Chapter 6, where the consequences of a pest with respect to where one or more criteria has a rating of **F**, the overall consequences are considered to be **high**.

**Table 14.1 Consequence assessment for impact scores for fruit flies**

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

## 14.6 Unrestricted risk

An overall estimate of the unrestricted risk for fruit flies associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 14.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Negligible**.

Table 14.2 provides an estimate of the unrestricted risk of fruit flies entering Australia as a result of trade in mature hard green bananas from the Philippines.

**Table 14.2 Unrestricted risk estimation for fruit flies**

Probability of entry, establishment and spread	Negligible
Consequences	High
Risk	Negligible

The unrestricted risk for fruit flies is ‘**Negligible**’, which achieves Australia’s ALOP. Therefore, no risk management would be required for this pest for importation of Philippine mature hard green bananas into Australia subject to compliance with pre-clearance and audit measures for maintenance of standards of hard green conditions equivalent to ICA06 in Australia (QDPI 2000).



## 15. Armoured scales

### 15.1 Introduction

This unrestricted risk assessment includes the following species which are of quarantine significance to the whole of Australia:

- *Aspidiotus coryphae* Cockerell and Robinson 1915
- *Aspidiotus excisus* Green 1896
- *Pinnaspis musae* Takagi 1963a

The assessment also includes the following species that are of quarantine significance to Western Australia:

- *Abgrallaspis cyanophylli* Signoret 1896
- *Hemiberlesia palmae* Cockerall 1892
- *Pseudaulacaspis cockerelli* Cooley 1897
- *Selenaspis articulatus* (Morgan 1889)

The biology of these species was considered sufficiently similar to justify consideration of these species in a single assessment.

While similar, there are differences including host preference, reproductive behaviour and some aspects of life history, such as temperature preferences and intrinsic rate of growth (Rosen 1990). Consequently, this assessment takes into account existing policy with appropriate modifications, reflecting differences in biology.

### 15.2 Biology

All scales, adult and immature, are small (less than 5 mm) oval-shaped and with a surface covering of a hard scale (Ben-Dov 1990). Only the males, which are winged, and crawlers (newly hatched nymphs) are mobile. Adult females and later instar nymphs do not move (= 'sessile'), but remain firmly anchored by their mouthparts to the host plant (Koteja 1990b). Armoured scales feed on sap by means of long cylindrical hollow stylets which are permanently inserted into the plant. They do not secrete honeydew. The hard scale covering is hydrophobic and also gives them protection against predators (Rosen 1990). Scales can be found on all above ground parts of a plant: the stem, leaves and fruits.

Full details of the species hosts, distribution and the biology of armoured scales are provided in the datasheet for armoured scales in Part C.

As an example, *Aspidiotus excisus* is polyphagous and has a wide host list including some fruit trees (for example, papaw, citrus and mango) as well as bananas, many cultivated crops (such as coffee), orchids, palms, rhododendrons, lilies and other household and garden plants and weeds (for example, *Ipomea*) found in Australia (Williams and Watson 1988). It is considered a horticultural pest (Dekle 1976; Davidson and Miller 1990). Males of *A. excisus* have been collected, so the species reproduces sexually (G Watson, Associate Insect Biosystematist, Plant Pest Diagnostic Centre, California Department of Food and Agriculture, USA, pers comm 18 February 2006). However, other congeneric species reproduce parthenogenetically.

### 15.3 Risk scenarios

The risk scenario of concern for armoured scales in this analysis is the presence of adult females, males or nymphs in protected spaces between the fingers of harvested banana fruit.

Also of quarantine concern is the contamination of fruit or packaging materials with scales during transit. Fruit may become contaminated during shipment to Australia as a result of breeding and dispersal from infested fruit. Long-range movement of scales can occur when females are moved with vegetative material. Short-range transfer of armoured scales is generally attributed to the movement of crawlers, either actively or by vectors.

The presence of armoured scales in trash materials such as dead leaf and floral tissue would not pose any risk because the likelihood of the scale surviving transport to Australia is considered to not pose any risk, due to lack of food. Furthermore, the temperatures at which the bananas are stored and transported to Australia ranges from 13–14 °C, which is about 10 °C lower than the optimum temperature for reproduction.

### 15.4 Entry, establishment and spread

The following analysis examines in detail the probabilities that armoured scales will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines. These probabilities are later combined with the estimated consequences for these pests to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

Where available, pest interception data from countries already importing Philippine bananas have been used to estimate the likelihood of armoured scales entering, establishing and spreading in Australia.

#### 15.4.1 Entry

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the probability that a given pest will remain viable and undetected as each of the component steps is completed.

##### *Probability of Importation*

The likelihood that live armoured scales will arrive in Australia with the importation of mature hard green bananas from the Philippines: **High**.

The risk scenario of concern is the presence of adult female armoured scales and nymphs at the Australian border.

Banana plantations in the Philippines are commonly infested with armoured scales (Krishna et al 2005) so that it is probable that a proportion of harvested bunches will be infested.

The harvesting of bunches, their transport to the packing station and division into clusters is unlikely to cause scales to be dislodged from the fruit because adults and nymphs are firmly attached to the fruit (Koteja 1990b). Routine washing procedures undertaken within the packing station are likely to remove mobile insects such as crawlers from the fruit. The sessile armoured scales, especially adult females or nymphs in protected spaces between the fingers, are not easily dislodged, even by washing with a high pressure hose. Whiting et al (1998) recorded a high death rate of scales when kiwifruit were washed with a high pressure water jet. However, the authors concluded that removal of armoured scales by this method was poor. The infestation of bananas after washing with a high pressure jet is unlikely to change as there are more inaccessible crevices present on bananas than on kiwifruit.

As armoured scales hide in protected spaces (Foldi 1990), they are unlikely to be detected during the routine visual quality inspection procedures within the packing station in the Philippines. These

inspection procedures are concerned primarily with removing poor quality fruit, such as those with blemishes, premature ripening, visible splits, cracks or bruising. Although all fruit are visually inspected, the procedures are not specifically directed towards detecting small arthropod pests that may be present in the protected spaces. After fruit is packed for export it is highly likely to be still carrying them.

The evidence that scales are likely to survive storage and transportation is provided by pest interception data, which shows that live armoured scales are frequently detected by quarantine inspectors in New Zealand, Japan and South Korea on bananas imported from the Philippines (Sugimoto 1994; Spence 2002). They are found on all parts of the surface of the fruit including the protected spaces between the individual banana fingers in fruit clusters, at the cushion end of the clusters and at the very tip at the flower end of a banana finger (Biosecurity New Zealand MAF, Wellington, New Zealand 2005a; B Pinese, Queensland Department of Primary Industries and Fisheries, pers comm 16 August 2005).

Between 2000 and 2005, on average, over 50% of consignments entering New Zealand were contaminated with armoured scales (Biosecurity New Zealand MAF, Wellington, New Zealand 2005a). Another survey reported that 5% of cartons were infested with armoured scales and most specimens were identified as *A. excisus* (ANBG 2006).

Bunches are kept at 13–14 °C during shipping, which is below the optimum for development of scales. This is not lethal to the scale, although development will be very slow as the threshold is believed to be 13 °C (Greathead 1990). The data demonstrates that scale insects can tolerate cool storage of more than two weeks and there is a high likelihood that viable armoured scales present on Philippine bananas would remain viable on arrival in Australia.

Considering the information above, especially the interception data, the likelihood of importation is assessed as **high**.

#### *Probability of distribution*

The likelihood that armoured scales will be distributed to endangered areas as a result of the processing, sale or disposal of mature hard green bananas from the Philippines: **High**.

The risk scenario is that the pest survives from importation at the border and a viable population comes in close proximity to a susceptible host as the fruit passes from border to ripening to wholesale outlets and through the retail chain to waste disposal.

Adult armoured scales are likely to survive ripening and transportation, but males and crawlers that become mature during this time are unlikely to be released, as banana fruit will be kept in the dark for most of the time they are being distributed and enclosed in cartons. Once at the retail store, the higher temperatures and increase in light intensity is likely to initiate release of these stages. It is expected that maternal scales will still survive the environmental conditions in the ripening facility (see Chapter 7), further transport and exposure in a retail outlet, although there will be some natural mortality (McClure 1990a).

Crawlers can float, be blown by wind, or carried by other vectors (Greathead 1990) from the banana before or at the point of sale or after purchase by consumers, either in a retail outlet or in a household. However, waste banana skins that are stored for any length of time before being deposited into the environment are likely to be a poor food source, so that there would be high mortality for scales on these waste skins. A further risk scenario is transfer to house plants in households or to horticultural produce in supermarkets.

The next step is to consider the probability that susceptible host plants and other host fruits are close enough to a release point for crawlers (that is, the supermarket, household or waste point). *Aspidiotus excisus* is highly polyphagous (Williams and Watson 1988). Its host plants are widespread

throughout Australia and many, such as *Ipomoea violacea*, *Elephantopus mollis*, *Urena lobata*, *Euphorbia terracina* and *Piper aduncum*, are weedy invasive species covering much of Australia and likely to be found not only in home gardens, but also around waste dumps (RMBG 2006). Other host plants are common garden and house plants, such as *Euphorbia* sp., *Hoya* sp. and *Aglaonema*. Other than bananas, *A. excisus* has also been reported on economic crops such as *Carica papaya*, *Mangifera* spp., *Citrus aurantifolia* and other *Citrus* spp. (Williams and Watson 1988). Some of these plants can be found in households or gardens in all parts of Australia (RMBG 2006). Additionally, citrus can be found in temperate regions. The ability of *A. excisus* to colonise native plants is not known as the species has not been exposed to them, but it is known to colonise host plants from about 25 different angiosperm families. These families are represented in Australia and comprise nearly 13% of Australia's native flora.

The scenario of greatest risk is of susceptible hosts occurring in close proximity to where banana waste is deposited. For *A. excisus*, the risk is likely to be considerable because of the likely occurrence of susceptible hosts around waste facilities, in gardens, in retail outlets and in households.

The next step considers the possibility of transfer to a susceptible host. While *A. excisus* is known to reproduce sexually (G Watson, Associate Insect Biosystematist, Plant Pest Diagnostic Centre, California Department of Food and Agriculture, Sacramento, USA, pers comm 18 February 2006), other species of scales are known to reproduce parthenogenetically. Taking a conservative approach, at least one female must be present on the waste peel when it is discarded, or on the fruit in the supermarket or household to produce a viable population. In order to assess the risk of transfer to a host, the following points need consideration:

- the availability, quantity and distribution of hosts in the PRA area
- the persistence of armoured scales on discarded waste that is already or rapidly becoming moribund
- the ability of the crawler to reach the ground surface, given that most waste will be buried beneath other waste or in the soil
- the persistence of waste banana skins consumed by omnivorous vertebrates (including wallabies, cattle and birds such as crows or cockatoos) although these agents could also transfer crawlers
- the mechanisms by which armoured scales can move from discarded banana waste to a host
- the hazards encountered by the pest while moving from waste peel to host (such as predators, parasitoids, pesticides and environmental factors)
- the conditions needed for exposure of a suitable site on the plant.

The armoured scales associated with waste or fresh fruit are likely to be mainly adult immobile stages, but some crawlers and males could be present or be released. Although adult armoured scales and nymphs attached to a vegetative surface can persist in the environment within the protection afforded by their armour, they cannot move from their point of attachment and will die as the plant tissue to which they are attached decays (Rosen 1990). Moreover, fresh banana waste will not support a viable scale population for more than one or two days at most before it rots. Therefore, sessile adults and nymphs attached to discarded banana skins or crowns are considered to be of negligible risk in waste. Adult males are winged but short-lived. If they emerge from banana waste, they will be of no risk because there will be no live adult females close enough with which to mate. Any eggs on waste skins are unlikely to remain viable long enough to hatch.

Crawlers are the only agents of risk (Koteja 1990b). They may be discarded with waste cartons and liners, or released to the environment directly from the maternal scale once the material to which it is attached becomes waste. To survive, they need to find a susceptible host plant in close proximity and within preferably a few hours, but at least a day or so of release (Greathead 1990). Crawlers can be distributed in several ways. Shorter-range dispersal occurs readily by means of random walking. Crawlers cannot move more than a few metres using this method, but largely involuntary dispersal is possible over long distances by wind or other means of passive transport, such as biological or



mechanical vectors (Greathead 1990). The crawlers have a flattened shape and normally move towards light. They are able to walk from the surface of a banana skin and away from the immediate environment of the adult female. But for long distance dispersal, they must move above the ground in order to be caught by wind currents (Greathead 1990). Other means of long-range passive dispersal of these pests would require movement of adults and nymphs on infested vegetative material or fruit.

Mobile crawlers are extremely vulnerable and normally experience a high level of mortality (G Watson, Associate Insect Biosystematist, Plant Pest Diagnostic Centre, California Department of Food and Agriculture, Sacramento, USA, pers comm 18 February 2006). They can be killed by climatic variations such as drying conditions, extreme temperature fluctuations, rain and strong winds. Predators, parasitoids and disease also contribute to high mortality, but these agents of population control are exerted on large populations rather than small ones. Pesticides, including acaricides, are regularly applied to most commercial crops. Even under the most favourable environmental conditions, crawlers must find, within a few days after hatching, a point on a host surface for attachment so they can insert their mouthparts and start feeding. If suitable hosts in the immediate proximity of the female are abundant, wind may provide an effective means of dispersal. If hosts are not present at high density, most crawlers will die before they encounter a host plant from the factors mentioned above.

Taking into consideration that the high proximity to susceptible hosts in places where controls are absent is most significant, the probability of distribution, including transfer to hosts, is assessed as **high**.

#### *Probability of entry (importation x distribution)*

The likelihood that armoured scales will enter the PRA area as a result of trade in bananas from the Philippines and be distributed in a viable state to the endangered areas: **High**.

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 Chapter 3.

### **15.4.2 Establishment**

The probability that armoured scales 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: **Moderate**.

Establishment is defined as the ‘perpetuation for the foreseeable future, of a pest within an area after entry’ (FAO 2006). 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 initiation point for establishment of armoured scales is the colonisation of a suitable host plant by a minimum population. The end point is the development of an actively reproducing population on the host plant from which eggs, nymphs, male and female crawlers, and winged males are being produced in sufficient numbers to disperse to new hosts.

Under IPPC guidelines (FAO 2004), some factors to consider at this step are:

- availability, quantity and distribution of hosts in the PRA area
- environmental suitability of the PRA area
- potential for adaptation of the pest
- reproductive strategy of the pest
- method of pest survival
- cultural practices and control measures.

The first point has already been considered under the Probability of distribution above, and it has been shown that host plants for *A. excisus* are widespread and abundant in Australia, particularly in tropical and subtropical regions. The second point also has been partly considered under distribution and is no impediment to establishment. Adaptation will therefore not be necessary.

If reproduction occurs sexually and a host plant has been colonised by a minimum of three crawlers, it is expected that there would be some factors which hinder the establishment of an actively reproducing population of armoured scales once they have mated. A crawler will initially settle at a location, begin feeding and secreting the scale cover as it grows to maturity and eventually start reproducing (Greathead 1990). Establishment depends on the sex ratio of the crawlers. Information on this aspect of biology is lacking, but there are likely to be equal numbers of males and females (Nur 1990a). If founder populations are small and rare, the likelihood of mate encounters would be low even though males can fly some distance to find a mate.

Sexual reproduction, which appears to be the most common mode, if not the only mode, of reproduction in *A. excisus*, requires a female to survive long enough for a male of the same generation to become mature. Although details of the lifecycle are not known for *A. excisus*, development from egg to adult is expected to take 32–34 days, although it may last as long as 44 days, according to research on other species of *Aspidiotus*. The male lifecycle is slightly shorter. Each female may deposit 20–50 eggs over a few days, but in a related species, *Aspidiotus nerii* Bouché 1833, 100 eggs are laid and there are three generations a year. Fecundity is therefore fairly high.

Barriers to establishment are the natural defences and health of the host plant, predation or parasitism after settling, pesticides, disease, mortality due to adverse weather, and other environmental factors, such as the settled site not being suitable for continued survival or poor quality food. For instance, survival and fecundity are positively influenced by high foliar nitrogen (McClure 1990a). As a consequence, the food quality of the part of the host plant on which the crawlers have become established needs to be adequate, otherwise the population will not survive. Another factor operating against establishment is that the plant part on which the crawlers have settled could be subjected to damage from wind or from other herbivorous insects such as caterpillars.

As the controlling agents of predation, parasitism and disease operate most effectively on large populations, these factors are likely to be less important with small founder populations. Although predation effects are unlikely to be strong, the nymphs will still be vulnerable before an adequate scale covering has been produced. Small founder populations are more vulnerable to becoming extinct from abiotic factors such as adverse weather conditions and damage to the host plant. Furthermore, the practices used to control other scale and insect species in economic crops and gardens will act on founder populations, reducing their likelihood of survival.

Consequently, once exposure has taken place on a suitable host plant as defined above, there is a **moderate** likelihood of it leading to establishment.

### 15.4.3 Spread

The probability that armoured scales 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**.

The probability of spread examines factors relevant to the dispersal of armoured scales from a point of establishment on a plant that has been exposed to the pest, to other susceptible plants in nearby or distant parts of Australia. The initiation point for spread is production and release of crawlers from the founder population and the end point is the distribution of live propagules to other host plants leading to the establishment of new populations.

Under IPPC guidelines (FAO 2004), factors to consider at this step include:

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

Other relevant factors are the intrinsic rate of growth of a population of the pest (that is, the number of crawlers likely to be produced during the lifetime of the female at given temperatures), the pesticides applied to the PRA area, the density of susceptible hosts and movement of infested plant material. The likelihood of spread will be lower if the insect undergoes a long period of development, if there is limited access to males, if phenology is specialised, and if there are high levels of competition, predation and parasitoid activity. Alternatively, the likelihood of spread will be higher if there is resistance to insecticide and tolerance of a wide range of conditions, and movement of plant material by wind or other agents.

The armoured scale species being considered here does not normally kill any infested plant directly unless populations on a single plant are large. They persist as long as the host survives. Many of the host plants are perennial and so provide a suitable environment throughout the year.

In order for spread to take place, the established population must consist of adult females, as well as juvenile males and females. In *A. excisus*, the number of eggs produced by females is likely to be around 50 and the time taken for a crawler to develop into an adult is around 4–5 weeks, depending on temperature (Koteja 1990b). The intrinsic rate of increase is therefore moderate. There is no data for *A. excisus*, but in another scale with similar biology, *Aonidiella taxus* Leonardi, 1906, the intrinsic rate of natural increase was estimated to be 0.04/female daily at 25 °C (Watson 2005) and may be lower than that recorded in the literature if temperatures are below the optimum of 25 °C.

At optimum temperatures, the lifecycle is likely to take from 32–34 days, although it may last as long as 44 days. It is shorter for males. Eggs hatch after 7–8 days (Koteja 1990a, b). Crawlers will only be released from underneath the protection of the maternal scale when external conditions are suitable. Most crawlers find a settlement site and start to feed close to the maternal site. Assuming establishment has taken place and that natural factors affecting mortality of juveniles as documented above are operating, it can be assumed that only a small percentage of crawlers will survive release from the maternal scale, spread, establish on a new site and continue developing (Greathead 1990).

Pesticides and natural enemies – such as birds, coccinellid and other predatory beetles, hymenopteroid parasitoids and lacewings, as well as pathogens – may exert some control on the crawlers until they are able to produce a protective shell. Because small founding populations will suffer a high mortality rate (mainly due to abiotic factors) there is a reasonable probability that they will become extinct before producing offspring. However, spread involves a number of founding populations, thus reducing the risk of extinction.

The spread of *A. excisus* would be assisted by wind dispersal, vectors and the movement of plant material. All areas of Australia would be suitable for the spread of *Aspidiotus* species, because susceptible hosts have been recorded from all climatic regions of Australia.

Given the availability of favourable environments over extensive areas of Australia, the wide host range and the fecundity of the scale population, the likelihood of this pest spreading in the endangered area was considered to be **high**.

#### 15.4.4 Probability of entry, establishment and spread

The overall likelihood that armoured scales will enter Australia as a result of trade in mature hard green bananas from the Philippines, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Moderate**.

The probability of entry, establishment and spread is determined by combining the probabilities of entry, establishment and spread using the matrix of rules for combining descriptive likelihoods described in Table 3.1.

### 15.5 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of armoured scales by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of armoured scales was assessed on the basis of their potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: 'unlikely to be discernible', 'minor', 'significant' and 'highly significant'.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

#### 15.5.1 Direct impact

##### *Plant life or health – D*

*Aspidiotus excisus* has an extremely wide host range that includes the tropical crops of papaya, mango, coconut, lemon, breadfruit and banana. It also includes garden and house plants and weeds, and the scale could colonise native plants given that some host families include native species.

*Aspidiotus excisus* congeners, (*A. destructor* and *A. nerii*) have proved to be highly invasive and destructive in Australia, so it is likely that the effects of armoured scales could also be severe on a range of plants. As it is considered a serious pest of ornamental plants, its effect on house plants could also be severe. For example, a severe infestation has previously been recorded in ornamental nursery plants in Orange County, USA (Halbert 1997).

Armoured scales are likely to become new pests of commercial tropical fruits and may also colonise native plants. As a consequence it was considered that armoured scales are likely to be 'significant' at a district level and a rating of **D** was assigned to this criterion.

##### *Human life or health – A*

Armoured scales are not known to cause allergies or be a problem to plantation workers, so the effects of armoured scales are 'unlikely to be discernible' at all levels. The rating for this criterion was therefore **A**.

*Any other aspects of the environment – D*

As these scales have a wide host range which includes numerous garden plants and amenity trees in tropical, subtropical and some temperate regions, it is likely to become widespread if introduced. It could also compete with native scale species, disrupt natural biocontrol methods for other pests, and alter other aspects of the biotic environment such as birds and other predators. Impact is likely to be severe for native invertebrates if it colonises native vegetation. Its host range already includes species in families that also have native species in them.

Armoured scales are likely to have a ‘significant’ effect at the district level. The rating assigned to this criterion was therefore **D**.

**15.5.2 Indirect impact***Control or eradication – D*

On first detection, an eradication program under the Emergency Plant Pest Deed is unlikely because there are already existing control measures for scales on the commercial crops at risk. Overseas experience with scale infestations in perennial or continuously cultivated crops suggests that eradication is probably not possible because hosts tend to be too abundant and widespread. As eradication is unlikely to be successful, no attempt has ever been made to eradicate armoured scales in Australia or elsewhere.

It is more likely that growers might have to undertake an increased and ongoing regime of control and containment programs, using a combination of preventative and sanitation measures. As there are already some control measures for armoured scales in plantations, orchards and home gardens, these measures could be applied more frequently if armoured scales become established.

Armoured scales are likely to have a ‘significant’ effect at the district level. The rating assigned to this criterion was therefore **D**.

*Domestic trade – C*

Intrastate and interstate trading restrictions on planting materials and fruit may be the only domestic trade effects associated with the introduction and spread of armoured scales. Existing interstate controls do not currently include restrictions on fruit movement, except for those relating to fruit fly threats. Restrictions on planting materials would be similar to those that already apply for other pests and diseases.

Restrictions on fruit could, however, disrupt national marketing arrangements for a short time after the discovery of pest infestation and lead to longer-term changes in requirements for quarantine-sensitive markets in production areas. However, because scales in general are not considered to be among the most damaging pests of these crops, the indirect impact on domestic trade was considered to be ‘significant’ at a local level. Thus, a rating of **C** was assigned to this criterion.

*International trade – C*

The presence of armoured scales is unlikely to result in a disruption of international trade in bananas, given that Australia exports only negligible quantities of bananas.

However, armoured scales are also pests of commercial crops such as coconut, papaya, mango and citrus. These crops cover tropical, subtropical and Mediterranean climate areas of Australia. For example, Australia exports citrus from tropical areas, subtropical areas and Mediterranean climatic regions to a number of countries in Asia and the western Pacific, including an opening market to China, New Zealand and the USA. Papaya is exported to Egypt, Bahrain, Hong Kong, East Timor and Singapore. Coconuts are exported to Egypt.

While armoured scales are generally only considered in terms of fruit quality, their presence on Australian citrus and other tropical fruit orchards may affect current trade arrangements. The indirect impact of armoured scales on international trade was considered to be ‘significant’ at a local level. A rating of **C** was therefore assigned to this criterion.

#### *Environment – B*

It is not likely that many additional pesticide applications will be required to control armoured scales on commercial crops, because scales and other similar insects are already controlled with pesticides in tropical fruit orchards. Thus, pesticide levels are unlikely to differ from current levels, and are unlikely to make any larger impact on the environment. However, because garden plants may be affected in various regions, increased pesticide applications may be necessary in the horticultural industry and home gardens. Such effects are considered to be ‘minor’ at the local level. Consequently a rating of **B** was assigned to this criterion.

#### *Communities – B*

Incursions and establishment of these scale species are likely to have minor effects on farm workers or local communities. Such effects are considered to be ‘minor’ at the local level. Consequently a rating of **B** was assigned to this criterion.

### 15.5.3 Overall consequences

The overall consequences to the Australian community of the entry, establishment and spread of armoured scales as a result of trade in mature hard green bananas from the Philippines: **Low**.

Table 15.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of armoured scales within Australia.

Based on the decision rules described in Chapter 6 of this document, where the consequences of pest with respect to one or more criteria are **D**, the overall consequences are considered to be **low**.

**Table 15.1 Consequence assessment for armoured scales**

	Impact scores
<b>Direct impact</b>	
Plant life or health	D
Human life or health	A
Any other aspects of the environment	D
<b>Indirect impact</b>	
Control or eradication	D
Domestic trade	C
International trade	C
Environment	B
Communities	B

## 15.6 Unrestricted risk

An overall estimate of the unrestricted risk for armoured scales associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 15.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Low**.

Table 15.2 provides an estimate of the unrestricted risk of armoured scales entering Australia as a result of trade in mature hard green bananas from the Philippines.

**Table 15.2 Unrestricted risk estimation for armoured scales**

Probability of entry, establishment and spread	Moderate
Consequences	Low
Risk	Low

As indicated in Table 15.2 above, the unrestricted risk is **low**, which exceeds Australia’s ALOP. Therefore, risk management would be required for these pests for the importation of Philippines mature hard green bananas into Australia.

## 15.7 Risk management

Armoured scales have been assessed as having an unrestricted risk estimate of **low** (see Table 15.2) and therefore they require risk management measures.

The following risk management measures and procedures are proposed to take account of the risk identified in this PRA and reduce the risk to achieve Australia’s ALOP. For the initial trade pre-clearance will be used. However, if this requirement changes in the future AQIS would perform ‘on-arrival’ visual inspections and corrective action. It is part of the proposed final import conditions for mature hard green bananas from the Philippines that are described more fully in Chapter 20, Risk Management and Draft Operational Framework.

### 15.7.1 Pre-clearance inspection and corrective action

All bananas for export to Australia will be subjected to inspection by BPI staff or their accredited agency staff for armoured scales.

Visual inspection of each lot will be undertaken using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of armoured scales are known to contaminate packaging materials.

The inspected sample must be free from armoured scales.

Where any live armoured scales are found the lot must be subjected to an appropriate corrective action or rejected for export to Australia.

Only lots that pass the Philippines Bureau of Plant Industry or agency phytosanitary inspection may be presented for AQIS pre clearance inspection.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of armoured scales are known to contaminate packaging materials.

Under pre-clearance arrangements AQIS would be involved in the supervision of all procedures.

AQIS will undertake a documentation compliance examination for consignments pre cleared in the Philippines prior to their release from quarantine in Australia.

Under pre-clearance arrangements, 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.

### **15.7.2 On-arrival visual inspection and corrective action**

If requirements change in the future AQIS would perform ‘on-arrival’ visual inspection and corrective action. This section sets out the provisions that would apply to shipments that do not undergo pre clearance.

Visual inspection by AQIS officers will be conducted upon arrival at the first port of call in Australia.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of armoured scales are known to contaminate packaging materials.

Corrective action when armoured scales are present is proposed as an appropriate risk management measure for this pest, given that trained inspectors can readily detect armoured scales.

Consignments inspected and found to be free of live armoured scales will not require further risk management measures to be applied.

When a consignment is found to be infested with live armoured scales at on-arrival inspection in Australia, one of the following risk management options must be applied:

- re-export of the consignment from Australia
- destruction of the consignment
- treatment of the consignment to ensure that the pest is no longer viable.

### **15.7.3 Risk management conclusion**

The objective of these measures is to ensure that consignments of mature hard green banana fruit from the Philippines infested with live armoured scales can be readily identified and subjected to appropriate corrective action. It is considered that these measures will reduce the risk associated with armoured scales to achieve Australia’s ALOP.

It was considered that these measures would reduce the probability of entry from **high** to **low** and the probability of entry, establishment and spread from **moderate** to **low**. When the adjusted value of PEES is combined with an overall consequence of **low**, the risk associated with armoured scales was considered to achieve Australia’s ALOP.



## 16. Mealybugs

### 16.1 Introduction

This unrestricted risk assessment includes the following species which are of quarantine significance to the whole of Australia:

- *Dysmicoccus neobrevipes* Beardsley 1959
- *Nipaecoccus nipae* (Maskell 1893)
- *Pseudococcus jackbeardsleyi* Gimpel and Miller 1996

This analysis also considers the following species which is of quarantine significance to Western Australia:

- *Planococcus minor* (Maskell 1897).

The biology of these species was considered sufficiently similar to justify combining them into a single assessment. In this assessment, the term ‘mealybug’ is used to refer to these species unless otherwise specified.

### 16.2 Biology

Most of the information in this introduction is taken from ‘Introduction to Mealybugs’ (North Carolina State University 2005) and ‘Mealybugs of Southern Asia’ (Williams 2004). Differences between the mealybugs are, where relevant, discussed.

Mealybugs are one of the most destructive insect pests in the world and many species are cosmopolitan pests (Williams 2004). Typical characteristics of mealybugs are:

- small size (1–6 mm long)
- oval shape
- soft bodies
- covered in a white floury, cottony or mealy-like substance
- adult females retain the oval-shaped, mealy look
- 300–1000 offspring produced
- eggs hatch into nymphs
- adult males look like small flies (Figure 16.1)
- prefer sheltered or cryptic sites
- slow moving or sessile, especially when a suitable feeding site is found.

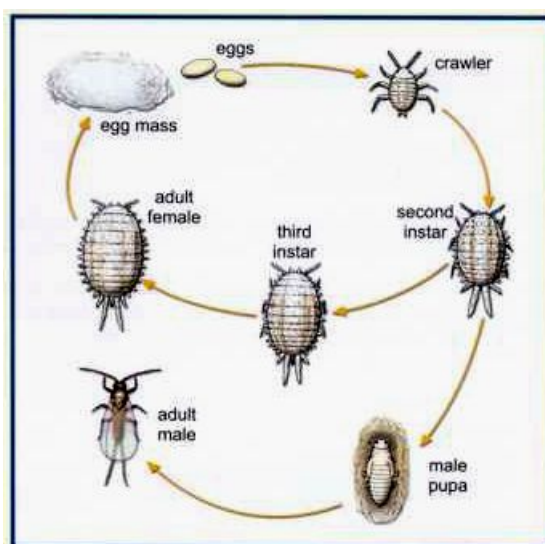


**Figure 16.1 Adult mealybug females and male (winged)**

Source: <http://vinemealybug.uckac.edu/>

Mealybugs are described as either long or short-tailed, depending on the length of their posterior filaments. In short-tailed mealybugs, the posterior filaments do not exceed one quarter of the body length (for example, *P. jackbeardsleyi*). Long-tailed mealybugs have posterior filaments about half of the body length (for example, *D. neobrevipes*).

The lifecycles of mealybugs, shown in Figure 16.2, are very similar. The main difference is that short-tailed mealybugs lay eggs (these hatch into first instars called 'crawlers'), while eggs hatch inside the body of female long-tailed mealybugs and they give birth to live crawlers.



**Figure 16.2 Short-tailed mealybug lifecycle**

Source: South Australian Research and Development Institute

Generally, mealybugs have three nymphal stages or instars. The first and second instar male and female mealybugs look similar in that they are small, oval-shaped and covered in a mealy white wax. Females go through a third instar stage before becoming adults. Adult females are larger versions of

the instar stages and they can live for up to 90 days. Male mealybugs go through a pupal stage after their second instar. Adult male mealybugs emerge with wings and look like small flies (North Carolina State University 2005). Adult males have no mouthparts, so they cannot feed. They disperse, find a female mealybug and mate. Adult male mealybugs live for 1–2 days.

After mating, mealybugs produce between 300–1000 offspring (eggs or live young) that will remain under the female for 1–2 days. The first instars, called ‘crawlers’ are the most mobile and fragile stage of development as they have not yet produced their waxy coating. First instars will crawl to new feeding sites on the same host plant or move to other suitable host plants. They can also be dispersed to new areas by wind blowing crawlers or mealybug-infested leaves, or by animal and insect vectors (ants, etc.).

Crawlers can survive about 24 hours without feeding, but once they find a suitable feeding site and insert their stylets, they usually remain there permanently (Williams 2004; Osborne 2006). They will anchor themselves to the plant by inserting their tubular stylets (North Carolina State University 2005) and feed by sucking plant sap. Once feeding, they secrete a waxy mealy coating that helps to protect them. Often the pest is not detected, as early mealybug instars are very small and they hide in crevices and protected spaces in the fruit. Long-range dispersal usually occurs through human transport of infested plant material from one area to another (Williams 2004). Additional information can be found in the mealybug datasheets (see Part C).

Mealybugs may damage plants in a number of ways:

- by sucking plant sap through their tubular stylets. If left unchecked, heavy infestations of mealybugs may damage or weaken plants, directly causing premature leaf drop, dieback and even plant death.
- causing indirect damage by injecting toxins or plant pathogens into host plants (such as mealybug pineapple wilt).
- by detracting from the appearance of the plant when high levels of infestation are present
- by depositing a waste product, ‘honeydew’, that may also lead to sooty mould growing on the fruit, thus reducing photosynthesis and ruining the plant's appearance.

Many mealybug species pose particularly serious problems to agriculture when introduced into new areas of the world where natural enemies are not present (Miller et al 2002; Moore 2004). Many countries importing bananas consider mealybugs to be a quarantine pest. Targeted inspections for these insects are usually required for bananas imported into the USA and New Zealand (Levy 1997, Biosecurity New Zealand MAF, Wellington, New Zealand 2006).

### **16.3 Risk scenario**

The risk scenario of concern for the species of mealybugs considered in this PRA is their presence in protected spaces on harvested mature hard green banana clusters.

Mealybugs depend on sap, which is available through living plant material, as a food source. They also hide in small crevices and dark places on a food source. On bananas, they are often found in the protected spaces between the individual banana fingers in fruit clusters, at the cushion end of the clusters or at the very tip at the flower end of a banana finger (Biosecurity New Zealand MAF, Wellington, New Zealand, 11 January 2006; D Peasley, IRA team, pers comm 24 June 2005).

### **16.4 Entry, establishment and spread**

The following analysis examines in detail the probabilities that mealybugs will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines.

These probabilities are later combined with the estimated consequences for these pests to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

Where available, pest interception data from countries already importing Philippine bananas have been used to estimate values for the probabilities of these mealybugs entering, establishing and spreading in Australia.

### 16.4.1 Entry

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the probability that a given pest will remain viable and undetected as each of the component steps is completed.

#### *Probability of importation*

The likelihood that mealybugs will arrive in Australia with the importation of mature hard green bananas from the Philippines: **High**.

The initiating step for the importation scenario for banana fruit is the sourcing of mature hard green bananas from plantations in the Philippines, whereas the end point is the release of imported mature hard green bananas from the port of entry.

Banana plantations in the Philippines are commonly infested with *D. neobrevipes* and *P. jackbeardsleyi* mealybugs and in extreme cases, high infestations of mealybugs with sooty mould are observed on the banana clusters (PCARRD 1988; BPI 2002a). The potential for viable mealybugs to be associated with bananas after harvesting, packing station processing and transport is high. Both *D. neobrevipes* and *P. jackbeardsleyi* feed on fruit up to the point of importation, when they are detected in the importing countries (Spence 2002).

Adult female mealybugs and nymphs (that is, immature male and female mealybugs) are small (1.4–3 mm), oval shaped, often inconspicuous, lack wings and have limited mobility. Adult females and nymphs have mainly white waxy cocoons that are moisture repellent and protect them against desiccation. They are often found in small crevices and in dark places. On bananas, mealybugs are found in the protected spaces between the individual banana fingers in fruit clusters, at the cushion end of the clusters or at the very tip at the flower end (see Section 16.3 above).

Once mealybugs find a suitable feeding site, they insert their stylets and suck plant sap from the fruit. This procedure anchors the mealybugs to the fruit, where they generally remain and are dislodged with difficulty (Williams 2004).

Honeydew, the waste product of the mealybug feeding process, is a growth medium for sooty mould fungi.

Routine washing procedures within the packing house may remove most mobile insects from the fruit, but not sessile insects like mealybugs (Armstrong 2001). This is particularly true of those nymphs or adult females that have found protective spaces around the cushion ends of the banana clusters and are protected by waxy cocoons.

Inspection procedures carried out at the packing station are directed towards maintaining a standard quality of fruit with regard to blemishes, premature ripening and visible splits, cracks, bruising or damage to the skin. Although all fruits are inspected, the procedures are not specifically directed towards detecting small arthropod pests in the protected spaces. Therefore, mealybugs hiding on banana clusters are unlikely to be detected during routine visual quality inspection procedures within packing stations in the Philippines. As mealybugs are unlikely to be removed by routine washing procedures within packing stations in the Philippines, fruit packed for export is therefore highly likely to contain them.

The evidence that these pests are likely to survive storage and transportation to Australia is provided by historical pest interception data, which show frequent detection of live *D. neobrevipes* and *P. jackbeardsleyi* by quarantine inspectors in New Zealand, Japan and South Korea in bananas imported from the Philippines. These insects have tolerated a prolonged period of modified atmosphere as well as cool storage for more than two weeks (Sugimoto 1994; Spence 2002; Biosecurity New Zealand MAF, Wellington, New Zealand, 29 June 2005).

Considering the information above, the likelihood of importation is assessed as **high**.

### *Probability of distribution*

The likelihood that mealybugs will be distributed to endangered areas as a result of the processing, sale or disposal of mature hard green bananas from the Philippines: **High**.

The initiating step for the distribution scenario is the release of imported mature hard green bananas 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 bananas) in a viable state to an endangered area and subsequently being transferred to a suitable host.

Bananas will be distributed throughout Australia for retail sale. The majority of banana retailers, processors and consumers are located in metropolitan and suburban areas. Nymphs and/or adults need to survive transport and processing from the port of entry, sale and disposal of the banana clusters. 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 susceptible host on which to lay their eggs or live young. Finally, environmental conditions need to be suitable for population development.

Mealybugs may be distributed into the environment in three ways:

- Feeding adult females, crawlers and nymphs can be associated with banana fruit and discarded banana skins. Long-range dispersal of these pests would require movement of adults and nymphs on banana clusters.
- Crawlers may be discarded with waste cartons and liners that previously contained fruit.
- Crawlers can be blown by wind or carried by vectors (for example, humans or ants) from banana clusters at the point of sale or after purchase by consumers.

Shorter-range dispersal would occur easily by the random movement of crawlers with wind currents and biological or mechanical vectors. Crawlers are small and less robust than adult females, but they can be dispersed onto other plants up to several hundred metres by wind (Rohrbach et al 1988).

Mealybugs can survive in the protected areas of a cluster of bananas during the distribution chain (retail) procedures and be transported to the homes of consumers (Peterson et al 2006). Waste material would be generated at various points from the border to the consumer. Waste in the form of banana skins, cartons and liners is produced by banana retailers and consumers. Once in a household, as individual bananas are pulled off the cluster, mealybugs would be exposed. Mealybugs at the flower end of the individual fruit are more likely to survive peeling and disposal of the banana skin. Infested waste may end up in landfills and compost heaps. Surviving mealybugs would have to disperse from infested waste to find another suitable host and then mate in order to establish.

Although commercial host plants would usually not be near landfill sites, wild and amenity host plants may be. These species of mealybugs are polyphagous and have between 85–150 host plants from 45–50 plant families, including commercial fruit (citrus, mango and banana), vegetable (tomato, pepper and okra) and tree crops (cocoa), non-commercial or wild plants, ornamental plants (cactus, orchid and croton) and a number of weeds. All these host plants are widely distributed within the PRA area. Therefore, wild and amenity plants are likely to be susceptible to infestation if mealybugs are able to survive landfill processing procedures. Where households dispose of their organic waste as compost,

susceptible host plants within the garden may be exposed to mealybugs from infested banana skins, if they survive and transfer from the composting site.

While the ability of mealybugs to self-disperse is limited, this is offset by the capacity of mealybugs to produce large numbers of offspring and by other means of dispersal. Juveniles are the most mobile stage and may be blown or crawl onto susceptible host plants. Adult females are slow-moving, but they may be transported by attendant ant species such as *Pheidole megacephala* and *Acropyga* sp., both of which are found in Australia (CSIRO 2004d, f; Williams 2004). Adult males are winged, fragile and short-lived and do not persist for more than several days. They detect females through pheromones and are able to fly to them in order to mate (Kessing and Mau 1992).

Considering the information above the likelihood that mealybugs would be distributed, as a result of the processing, sale or disposal of mature hard green bananas from the Philippines to susceptible plant hosts is assessed as **high**.

#### *Probability of entry (importation x distribution)*

The likelihood that mealybugs will enter the PRA area as a result of trade in bananas from the Philippines and be distributed in a viable state to the endangered area: **High**.

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 3.1.

### **16.4.2 Establishment**

The probability 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 2006). 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.

Many mealybugs are considered invasive and have been introduced into new areas, becoming established (Miller et al 2002). Mealybugs can become serious economic pests on previously minor host plants, if introduced into a new area without their natural enemies. *D. neobrevipes* and *P. jackbeardsleyi* have both shown that they have the ability to establish after being introduced into new environments. Williams (2004) reports that *D. neobrevipes* and *P. jackbeardsleyi* are introduced species into southern Asia, where they have become ‘well-known cosmopolitan pests’. Williams (2004) considers *D. neobrevipes* and *P. jackbeardsleyi* to have been introduced into the Philippines through the movement of infested plant material, while Lit and Calilung (1994) also suggest that both species may have been blown into the Philippines during typhoons.

Establishment is affected by the reproductive strategy and thus persistence of these mealybugs. Their reproductive strategy is based largely on the longevity and fecundity of the adult female, the mobility of the short-lived adult male and the ability of the crawlers to disperse by crawling, vectors or wind and locate new hosts.

These mealybug species reproduce sexually and have a high reproductive rate. Adult females cease feeding before reproduction and commonly move to a protected site to lay eggs over a period of 30–90 days. They can produce 300–1000 eggs or live crawlers. The females will die once all the young have been produced (Mau and Kessing 1993b; Kessing and Mau 1992; Williams 2004). Mealybugs can complete a lifecycle in 26–30 days (Kessing and Mau 1992, Mau and Kessing 1993b) and a population may be established from these eggs or crawlers.

The crawlers disperse to suitable feeding sites on new plants. They can travel some distance to a new plant before their mobility becomes limited in the remaining instars. Crawlers can be dispersed onto other plants for up to several hundred metres by wind (Rohrbach et al 1988), but they can survive only about a day without feeding. These mealybugs are highly polyphagous and have been recorded on 85–150 plant hosts in 45–50 plant families. Many of their host plants are grown in Australia and found in many suburban gardens (ANBG 2006).

Adult female mealybugs may be transported and protected from natural enemies by attendant ant species such as *Pheidole megacephala* and *Acropyga* sp. (CSIRO 2004c, e; Williams 2004).

*Dysmicoccus* sp., *Planococcus* sp., *Nipaecoccus* sp. and *Pseudococcus* sp. mealybugs are present in Australia (Australian faunal directory 2006; CSIRO 2004c, e) therefore mealybugs associated with the importation of mature hard green bananas from the Philippines are likely to find environmental conditions in the endangered areas suitable for their establishment.

A number of natural enemies of the endemic *Dysmicoccus* sp., *Planococcus* sp., *Nipaecoccus* sp. and *Pseudococcus* sp. mealybugs are present in Australia and have an effect on the population level of these species in Australia. They include the parasitic wasps *Gyranusoidea* sp., *Anagyrus* sp., including *A. fusciventris* (Girault 1951) and *Tetrastichus* sp., the predatory ladybird *Cryptolaemus montrouzieri* Mulsant 1853 and the fungal pathogens *Hirsutella* sp. (CSIRO-AFFA 2006).

Consequently, once exposure has taken place on a suitable host plant as defined above, there is a **high** likelihood of it leading to establishment.

### 16.4.3 Spread

The probability 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.

Once second and subsequent generations of mealybugs are established on susceptible commercial, household and wild host plants, mealybugs are likely to persist indefinitely and spread progressively over time. This spread would be assisted by wind dispersal, animal vectors and by the movement of plant material. Due to their small size (1–6 mm long), mealybugs are unlikely to be detected in infested plant material. The transportation of infested plant material would result in long distance movement of these mealybugs.

As discussed in Section 16.4.2 ‘Establishment’, tropical or subtropical areas of Australia would be suitable for the spread of these mealybugs. Potential natural enemies are also present in Australia and are likely to assist in the control of these mealybugs. However, it is very unlikely that mealybugs would be contained by pest management practices, natural enemies or regulation.

Given the availability of suitable environments over extensive areas throughout Australia, the likelihood of this pest expanding in the endangered area was considered to be **high**.

#### 16.4.4 Probability of entry, establishment and spread

The overall likelihood that mealybugs will enter Australia as a result of trade in mature hard green bananas from the Philippines, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **High**.

The probability of entry, establishment and spread was determined by combining the probabilities of entry, of establishment and of spread using the matrix of rules for combining descriptive likelihoods outlined in Table 3.1.

### 16.5 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of mealybugs by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of mealybugs was assessed on the basis of their potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: 'unlikely to be discernible', 'minor', 'significant' and 'highly significant'.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

#### 16.5.1 Direct impact

##### *Plant life or health – D*

This criterion describes production losses associated with the presence of mealybugs in commercial bananas, as well as any losses in productivity of other susceptible species. The direct effects of mealybugs have to be considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of 'indirect impacts'.

Mealybugs have two forms of direct impact on bananas and other susceptible crops. Firstly, through feeding on leaves, stems and fruit they reduce the quantity and quality of marketable product from a wide variety of tropical and subtropical crops. The severity in Australia of this form of direct impact is difficult to estimate, although the fact that these mealybugs are polyphagous is of concern. Natural enemies of these mealybugs (such as predatory ladybirds, parasitic wasps and fungal pathogens) are present in Australia and they contribute to the control of endemic *Dysmicoccus* sp., *Planococcus* sp., *Nipaecoccus* sp. and *Pseudococcus* sp. mealybugs.

The second form of direct impact on crop production results from transmission of plant diseases. *D. neobrevipes* is known to vector pineapple mealybug wilt-associated closterovirus (German et al 1992) and may also vector banana streak disease (Lockhart and Jones 2000). It is also implicated with a physiological reaction on pineapple known as green spot (Beardsley 1965; Kessing and Mau 1992).

With an extensive host range of between 85–150 plant species, it is highly likely that these mealybugs would find suitable hosts to feed on in Australia. Many tropical and subtropical native species would be susceptible, including native *Musa* species. Environmental conditions, where these plants grow would favour the establishment and spread of these mealybugs. Therefore, the direct impact of these mealybugs on the Australian environment would be significant.

Although these mealybugs would have a direct impact, bananas and other susceptible plants are already subject to infestation by a range of endemic mealybug species which have the same effects. *D. brevipes*, which is endemic to Australia, has a wider host range and is found in more countries worldwide than *D. neobrevipes*. In countries where both species exist, *D. brevipes* is considered the



more dominant species (Beardsley 1993). This may diminish the effects of the introduction of *D. neobrevipes* into Australia.

Overall, the direct impact of these mealybugs was considered to be ‘significant’ at the district level and the rating of **D** was assigned to this criterion.

#### *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 the environment – A*

This criterion addresses the possible direct impact of pests on ‘other aspects’ of the natural or built environment, such as the physical environment or micro-organisms. There are no known direct impacts of mealybugs on these aspects, and the rating assigned to this criterion was therefore **A**.

### **16.5.2 Indirect impact**

#### *Control or eradication – C*

If one of these mealybug species were to be detected in Australia, the initial response would be to consider eradication, which could be initiated under the Emergency Plant Pest Deed through PHA. However, this approach would be unlikely to be adopted because it is unlikely to succeed. The alternative would be to establish control measures to minimise the impact of mealybugs on affected crops. These would be the use of pesticide sprays and biocontrol agents that are currently used in Australia against pest mealybug species and their attendant ants.

Overall, the indirect cost of control programs for mealybugs was considered to be ‘significant’ at the local level. This gave the pest a rating of **C** for this criterion.

#### *Domestic trade – D*

Domestic trade is likely to be disrupted as a result of the entry, establishment and spread of exotic mealybugs. Furthermore, interstate trading restrictions may be introduced leading to a loss of markets for a number of commodities, which in turn would be likely to require industry adjustment. The scope and severity of restrictions are difficult to estimate, but because these pests are polyphagous they may have impacts on a broad range of industries.

The presence of any of these mealybugs on a commercial crop may result in intrastate and interstate restrictions on the sale or movement of a wide range of fruit. The horticulture industries are important to the economies of many rural localities and districts throughout Australia. Restrictions on the sale of fruit and, consequently, the viability of many producers would be damaging to each of these communities.

On this basis, the indirect impact of mealybugs on domestic trade and industry was considered to be ‘significant’ at the district level, which resulted in a rating of **D** for this criterion.

#### *International trade – D*

Australia exports negligible quantities of bananas. However, citrus exports to the United States from the Riverland–Sunraysia–Riverina areas are currently valued at \$40–60 million a year and negotiations are progressing with other export markets.

These mealybugs, should they become established and spread in Australia, may result in additional quarantine treatment for export commodities.

Therefore, the indirect impact of these mealybugs was considered likely to be ‘significant’ at the district level, giving them a rating of **D** for this criterion.

### *Environment – B*

Mealybugs introduced into a new environment will compete for resources with native species. Existing mealybug control measures, including biological control programs, may also control introduced mealybugs. Any additional insecticide usage is unlikely to affect the environment any more than the present amounts used to control other mealybugs.

The indirect consequences on the environment were considered to be ‘minor’ at the local level. Consequently, a rating of **B** was assigned to this criterion.

### *Communities – B*

These mealybugs could attack a range of commercial hosts found in Australia (for example, citrus or mango). While these plants are already host to endemic mealybugs and increased crop maintenance would not be likely to be necessary, intrastate or interstate quarantine restrictions may be required.

The indirect consequences on communities were considered to be ‘minor’ at the local level and thus a rating of **B** was assigned to this criterion.

## 16.5.3 Overall consequences

The overall consequences to the Australian community of the entry, establishment and spread of mealybugs as a result of trade in mature hard green bananas from the Philippines: **Low**.

Table 16.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of mealybugs within Australia.

Based on the decision rules described in Chapter 6 of this document, where the consequences of a pest with respect to one or more criteria are **D**, the overall consequences are considered to be **low**.

**Table 16.1** Consequence assessment for mealybugs

	Impact scores
<b>Direct impact</b>	
Plant life or health	D
Human life or health	A
Any other aspects of the environment	A
<b>Indirect impact</b>	
Control or eradication	C
Domestic trade	D
International trade	D
Environment	B
Communities	B

## 16.6 Unrestricted risk

An overall estimate of the unrestricted risk for mealybugs associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 16.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Low**.

Table 16.2 provides an estimate of the unrestricted risk of mealybugs entering Australia as a result of trade in mature hard green bananas from the Philippines.

**Table 16.2 Unrestricted risk estimation for mealybugs**

Probability of entry, establishment and spread	High
Consequences	Low
Risk	Low

As indicated in Table 16.2 above, the unrestricted risk is **low**, which exceeds Australia’s ALOP. Therefore, risk management would be required for these pests for the importation of Philippine mature hard green bananas from the Philippines into Australia.

## 16.7 Risk management

Mealybugs have been assessed as having an unrestricted risk estimate of **low** (Table 16.2) and therefore they require risk management measures.

The following risk management measures and procedures are proposed to take account of the risk identified in this PRA and reduce the risk to achieve Australia’s ALOP. For the initial trade pre-clearance will be used. However, if this requirement changes in the future AQIS would perform ‘on-arrival’ visual inspections and corrective action. It is part of the proposed draft import conditions for mature hard green bananas from the Philippines that are described more fully in Chapter 20, Risk Management and Draft Operational Framework.

### 16.7.1 Pre-clearance inspection and corrective action

All bananas for export to Australia will be subjected to inspection for mealybugs by BPI staff or their accredited agency staff.

Visual inspection of each lot will be undertaken using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of mealybugs are known to contaminate packaging materials.

The inspected sample must be free from mealybugs.

Where any live mealybugs are found the lot must be subjected to an appropriate corrective action or rejected for export to Australia.

Only lots that pass the BPI/agency phytosanitary inspection may be presented for AQIS pre-clearance inspection.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of mealybugs are known to contaminate packaging materials.

Under pre-clearance arrangements AQIS would be involved in the supervision of all procedures.

AQIS will undertake a documentation compliance examination for consignments pre-cleared in the Philippines prior to their release from quarantine in Australia.

Under pre-clearance arrangements, 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.

### **16.7.2 On-arrival inspection and corrective action**

If requirements change in the future AQIS would perform 'on-arrival' visual inspection and corrective action. This section sets out the provisions that would apply to shipments that do not undergo pre-clearance.

Visual inspection by AQIS officers will be conducted upon arrival at the first port of call in Australia.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of mealybugs are known to contaminate packaging materials.

Corrective action when mealybugs are present is proposed as an appropriate risk management measure for this pest, given that trained inspectors can readily detect mealybugs.

Consignments inspected and found to be free of live mealybugs will not require further risk management measures to be applied.

When a consignment is found to be infested with live mealybugs at on-arrival inspection in Australia, one of the following risk management options must be applied:

- re-export of the consignment from Australia
- destruction of the consignment
- treatment of the consignment to ensure that the pest is no longer viable.

### **16.7.3 Risk management conclusion**

The objective of these measures is to ensure that consignments of mature hard green banana fruit from the Philippines infested with live mealybugs can be readily identified and subjected to appropriate corrective action. It is considered that these measures will reduce the risk associated with mealybugs to achieve Australia's ALOP.

It was considered that these measures would reduce the probability of entry from **high** to **low** and the probability of entry, establishment and spread from **high** to **low**. When the adjusted value of PEES is combined with an overall consequence of **low**, the risk associated with mealybugs was considered to achieve Australia's ALOP.

## 17. Spider mites

### 17.1 Introduction

This unrestricted risk assessment relates to four species of spider mites identified as being not present in Australia, but present on the pathway and one species not present in Western Australia but present on the pathway.

This unrestricted risk assessment includes the following species which are of quarantine significance to the whole of Australia:

- *Oligonychus orthius* Rimando 1962
- *Oligonychus velascoi* Rimando 1962
- *Raoiella indica* Hirst 1924
- *Tetranychus piercei* McGregor 1950

The assessment also includes the following species that is of quarantine significance to Western Australia:

- *Tetranychus marianae* McGregor 1950

The biology of these species was considered sufficiently similar to justify addressing these species under a single assessment.

The biology of most spider mite species is similar, with the main differences being in host preferences, reproductive behaviour and some aspects of life history – such as temperature preferences and intrinsic rate of growth (Helle and Sabelis 1985). Consequently, this assessment takes into account existing policy with appropriate modifications reflecting differences in biology.

### 17.2 Biology

Spider mites are generally less than half a millimetre in length. Although the common name for the family is Red spider mite, body colour can vary from green or white through to yellow, orange and red. For instance, summer individuals may be greenish while diapausing individuals may be white, yellow, orange or red, and non-diapausing large males may be white (Helle and Sabelis 1985).

Spider mites puncture plant tissues in order to feed on fluids, so they can be important pests causing damage and loss to agricultural crops, ornamentals and forest plants (McGregor 1950; Helle and Sabelis 1985). They are usually found on the underside of leaves, but some species feed on the dorsal (upper) leaf surface. As the colony grows, the mites may move up the plant, colonising stems and fruit as well as leaves. Their feeding results in stippling, bleaching and eventual death of the leaves, with fruit becoming discoloured and stunted. Mites tend to seek out protected spaces, such as the cavities between the fingers of banana fruit when still in bunches.

Spider mites pass through four stages of development: eggs, larvae, nymphs and adults. Eggs are laid singly on the surface of the food plant. They hatch in a few days, giving rise to larvae (Helle and Sabelis 1985). Fertilised females can each produce around 155 eggs during their lifespan of about 27 days. Unfertilised females can also lay eggs, but they only give rise to male offspring and around 83 eggs over 27 days (Gutierrez et al 1979). This means that both fertilised and unfertilised females are capable of establishing a new colony, because unfertilised females, if they live long enough, can mate with their own male offspring. This strategy increases the likelihood of establishment when the number of female mites is low.

The time required to complete a lifecycle from egg to adult ranges from 7–14 days at optimum temperatures but varies with temperature, host plant and species, being faster at high temperatures

(Zhang et al 2001). Even at 15 °C development can continue slowly; adult female *Tetranychus urticae* Koch 1836, for instance, survived 22 days at that temperature (Bounfour and Tanigoshi 2001).

In the tropics, spider mites continue to be active in all seasons and there can be as many as 26 generations a year. In colder conditions, eggs and adult females survive the winter in an inactive state (diapause). Diapause is initiated by decreasing day length and temperatures, and is often accompanied by an increasingly unfavourable food supply. In unfavourable conditions, adults (mainly females) enter diapause and often retreat to cracks and crevices on the host, such as under bark, or in leaf litter under the hosts where they lay eggs, often in large numbers. Diapausing eggs may also remain on the host plant (Jeppson et al 1975).

*Tetranychus* and other genera spin hydrophobic (water repellent) webbing on or between leaves and banana fruit. This webbing has several functions. It forms a retreat under which the mites live, feed, mate and lay eggs. It also secures and protects the eggs by maintaining uniform humidity; plays a role in mating behaviour; acts as a 'lifeline' if an individual is dislodged from the host; protects the mite from predators, strong winds and rain, as well as from acaricide sprays and dusts (Gerson 1985).

Although spider mites are small at only half a millimetre in length at most, with walking speeds that average between 5–6 cm/hr, they have well-developed dispersal mechanisms which allow them to spread rapidly and travel long distances, as they are readily blown by air currents. They can also be dispersed by floating on water.

Bell et al (2005) have reviewed ballooning in mites as described below. Under conditions of high density and plant damage when food is of low quality, the mites undergo a change in behaviour from a feeding or reproductive phase to a dispersal phase and move to the periphery of the plant. From here, in still air conditions they may spin down or adopt a dispersal rearing posture in response to air currents and enter the aerial plankton. In order to catch air currents, females and sometimes nymphs of *Tetranychus* cluster at the tips of plants and respond to wind by facing away from the source of light, raising their first pair of legs and 'body surfing' on the air current (Kennedy and Smitley 1985). Norambuena et al (2000) documented distances of from 6–1000 m travelled by *Tetranychus lintearius* Dufour 1832, from gorse in Hawaii and Chile, with a mean distance of 157 m.

Other factors can induce a change to a dispersal phase in the mites, such as the application of an acaricide if it has an anti-feeding effect, causing the mites to become desiccated and disperse by ballooning. Other causes of desiccation can also induce migration. The majority of ballooning individuals are recently emerged mated or virgin females, but a proportion of the newly fertilised adult females will emigrate regardless of the population density of the natal leaf (Walter and Proctor 1999). New colonies of spider mites are known to start primarily with the arrival of dispersing pre-reproductive females onto new substrates, followed by egg laying (Kennedy and Smitley 1985).

Establishment commonly takes place first along the direction of prevailing winds, with the mites' mobility allowing rapid spread after establishment. Wind is frequent within plantations on Mindanao, as the island is in an area subject to typhoons and severe weather of this type seems to occur every five years (Alojado and Padua 2000). Landscape features that interrupt the flow of air seem to allow spider mite populations to establish more easily.

All five spider mite species included in this assessment are polyphagous. A large proportion of *Oligonychus* species predominantly feed on grass. In addition to banana, *O. orthius* feeds on sugarcane and *O. velascoi* has been found on coconut. The known host range of *R. indica* covers more than 25 plant species, including commercial palms and plants within the Musaceae and Zingiberaceae families, while *T. marianae* and *T. piercei* have a known host range comprising more than 30 plant species and includes tropical and temperate commercial crops and other plants (Cayme and Gapasin 1987; Corpuz-Raros 1989; Bolland et al 1998; Pena et al 2006).

Other information on the biology of the five species of spider mites on the pathway is available in the datasheets on spider mites.

### 17.3 Risk scenario

The risk scenario of concern for spider mites in this report is the presence of eggs, nymphs and adults in protected spaces on harvested mature hard green banana fruit from the Philippines.

The presence of spider mites in trash materials such as dead leaf and floral tissue would not pose a risk because it is unlikely spider mites would survive harvesting, packing station processing and transport to Australia, due to lack of food.

### 17.4 Entry, establishment and spread

The following analysis examines in detail the probabilities that spider mites will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines. These probabilities are later combined with the estimated consequences for these pests to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

#### 17.4.1 Entry

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.

##### *Probability of importation*

The likelihood that spider mites will arrive in Australia with the importation of banana fruit from the Philippines: **High**.

The initiating step for the importation scenario is the sourcing of bananas from plantations in the Philippines, while the end-point is the release of imported bananas from the port of entry. Supporting evidence for a high probability of importation of spider mites is provided in the text below.

No quantitative pest prevalence data for mites is available for Philippine banana plantations, but spider mites are known to be common and abundant there. Trials to test the effectiveness of the fumigant Vapormate™ in controlling infestations of common invertebrates on fruit for export carried out in the Philippines used species that were common, abundant and easily collected. They included spider mites, some belonging to the genus *Tetranychus* (Krishna et al 2005; J Beard, Post doctoral fellow, University of Queensland, pers comm 2 September 2005; F Beaulieu, Research Scientist, Agriculture and Agri-Food Canada, pers comm 20 June 2006).

Spider mites tend to colonise lower stems and leaves first, moving upwards through the plant away from the damaged plant material and towards the fruit as populations increase. As a result, fruit can be infested when populations are high.

Infestation during transport to the packing station is possible but unlikely, as the bunches remain within their plastic covers. The chance of infestation during transport may increase if mobile packing stations operating within plantations are used, instead of fixed packing stations that operate adjacent to plantations. Currently around 10% of Philippines plantations use mobile facilities, although this figure may increase in future years.

When bunches arrive at the permanent packing station by cableway, covers are removed, bunches are inspected and washed with a high pressure jet of water, divided into clusters and placed in a flotation tank. These processes are likely to remove most spider mites moving over the open surface of the fruit, but not those under webbing or protected in spaces between fingers.

Mites that are lodged under webbing or between fruit fingers, and thus are protected from washing, would probably remain protected through the flotation process. The silk webbing spun by *T. piercei* is

particularly profuse and is hydrophobic like all mite webbing, so it will protect the mites from being removed during washing (Gerson 1985).

The temperatures of between 13–14 °C during transport to Australia are above the lower threshold for development of all stages of *T. piercei*, so all stages would be capable of surviving transport to Australia. Moreover, adults can live longer at lower temperatures (32 days at 16 °C) so spider mites would easily survive 14 days of transportation at this temperature (Fu et al 2002).

There is likely to be some natural mortality during transport related to age or disease. Mortality of *T. piercei* at 16 °C was found to be 64%, so at 14 °C it would be expected to be slightly lower, probably around 50% (Fu et al 2002). This does not take into account any reproduction during transport to Australia.

There are no records of interceptions of spider mites on mature hard green banana fruit from the Philippines by border inspections either in New Zealand or Japan, but these species have been detected live by quarantine inspectors at borders in both Japan and Malaysia on other hosts. Also, *T. piercei* has been intercepted live entering both Thailand and the USA on *Pandanus* and *Dracaena* sp. respectively (Masaki 2001; Florida Department of Agriculture and Consumer Services 2005). However, data show a considerable number of interceptions of unidentified mites and viable eggs that may include spider mites on mature hard green banana fruit from the Philippines.

Unidentified mites have been frequently detected concealed at the fruit end of the banana fruit and at the stalk end (Biosecurity New Zealand MAF, Wellington, New Zealand, 29 June 2005). Over 13% of consignments of bananas from the Philippines entering New Zealand recorded unidentified mites. Other mites have been intercepted, notably stored product mites such as *Tarsonemus confusus* and others belonging to the order Astigmata Ewing, 1939 (Tarsonemidae: Prostigmata). Considering mites were recorded entering New Zealand, including various species of Astigmata or Oribatida, in all examined consignments, live mites and their propagules could survive handling and transport to Australia.

Taking into consideration the high interception rate of unidentified mites at the border and the possibility of misidentification, the likelihood that spider mites will arrive in Australia with the importation of banana fruit from the Philippines was assessed as **high**.

### *Probability of distribution*

The likelihood that spider mites will be distributed to the endangered area as a result of the processing, sale or disposal of banana fruit from the Philippines: **High**.

The initiating step for the distribution scenario is the release of imported mature hard green bananas 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 bananas) in a viable state to an endangered area and subsequently being transferred to a suitable host.

After the bananas are released at the border, the main pathway followed is transportation from the port of entry to the ripening facility, ripening at a temperature of 14.5–21 °C, transportation to wholesaler, sale to retailer, transportation to retail store, time in store, sale to consumer, storage in household and disposal of the banana waste.

All life stages are associated with the banana fruit: eggs, immature stages and adults. The combination of cool storage at about 14.5–21 °C and 95% relative humidity for ripening, which takes 3–7 days, would permit survival of spider mites. Adult and immature spider mites are likely to survive ripening and transportation, as they are protected by webbing located in protected spaces around the stalk or at the flower end of the fruit. The higher temperatures and increase in light intensity will allow survival and continued development, although there will be some natural mortality.



During this step, immature mites can continue developing into adults that can mate and lay eggs on fruit. Egg laying and hatching could occur at unpacking and repacking facilities or retailers, and during transportation of purchased bananas from retailers to households.

Adults and immature mites may disperse from banana fruit before or at the point of sale, or after purchase by consumers. The only means by which spider mites can leave fruit and enter the environment of exposure groups is by walking or wind-assisted dispersal. The scenario of highest risk for immature mites entering the environment from fresh banana fruit is probably in the supermarket before sale, or in the household before consumption. Both these environments are likely to have susceptible host plants close by.

These spider mites are unlikely to survive on managed waste disposal sites or in domestic compost heaps because the waste is likely to be covered. However, banana waste that is discarded as litter could lie in the general environment or within a household garden. The scenario of highest risk, therefore, is of fresh waste banana skins being deposited on the surface of the ground immediately after consumption, but this is a negligible proportion of the total waste (see Chapter 7).

The next risk step in distribution relates to the proximity of susceptible hosts in a supermarket, home or at a waste point. If hosts are close to waste skin, then live spider mites may be able to reach them. The spider mites of interest in this assessment are polyphagous with host ranges that include many tropical and subtropical fruiting plants, some of which are commercially cultivated or grown as ornamentals or utility plants.

Many *Oligonychus* species are predominately grass-feeding, but others are associated with a range of non-grass hosts, including bananas and corn (Corpuz-Raros 1989; Bolland et al 1998). *O. orthius* has also been associated with sugarcane (Corpuz-Raros 1989; Bolland et al 1998), while *O. velascoi* has been found on coconut (Cayme and Gapasin 1987; Corpuz-Raros 1989; Bolland et al 1998). The known host range of *R. indica* comprises more than 25 plant species, including commercial palms and plants within the Musaceae and Zingiberaceae families (Pena et al 2006). Both *T. marianae* and *T. piercei* have a known host range covering more than 30 plant species and includes bananas, papayas and sweet potatoes (Corpuz-Raros 1989; Bolland et al 1998). Most of these hosts are widespread and common in gardens in the tropical or subtropical population centres of Queensland. Although often less successful, some of these hosts are also common garden plants in temperate or semi-arid parts of Australia.

Susceptible wild, native or naturalised plants include palms that are often found as amenity plants in urban public gardens, as well as those that occur naturally in parks and reserves, by urban or rural roadsides, on farms or grazing land. In the Philippines, shelter trees can be an important host from which spider mites disperse into plantations. Although susceptible host plants will be more common in tropical and subtropical parts of Australia, the host list is sufficiently broad to expect that at least one species would be present in most parts of the country where banana waste is likely to be deposited. It is considered very likely that either fresh fruit or waste from bananas from the Philippines would be present or deposited close to susceptible host plants.

Part of the distribution pathway relates to biological and epidemiological factors that are likely to contribute to the ability of spider mites to move from banana fruit or discarded waste to a suitable entry site on a susceptible host. Having left the fruit or skin, spider mites would need to find a susceptible host in a short time or succumb to desiccation, starvation or other factors. While dispersing, mites may encounter predators, parasites, adverse weather, pesticides and other factors that could prevent successful transfer. For instance, pesticides are regularly applied to commercial orchards and other crops, as well as plants in home gardens and on some roadsides.

Considering the polyphagous nature of the five spider mites and their well developed dispersal ability, the overall probability of distribution was assessed as **high**.

### *Probability of entry (importation × distribution)*

The likelihood that spider mites will enter the PRA area as a result of trade in bananas from the Philippines and be distributed in a viable state to the endangered area is assessed as: **High**.

The overall probability of entry is determined by combining the likelihoods of importation and distribution using the matrix of rules for combining descriptive likelihoods.

### **17.4.2 Establishment**

The probability that spider mites 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 2006). In this assessment the initiating point for establishment of the pest begins with adults or immature mites arriving on the host. The end point is the persistence of a breeding population of the pest in the PRA area derived from the founder population, with concomitant development to maturity where necessary, mating and the laying of viable eggs.

Under IPPC guidelines (FAO 2004) some factors to consider at this step are:

- availability, quantity and distribution of hosts in the PRA area
- environmental suitability of the PRA area
- potential for adaptation of the pest
- reproductive strategy of the pest
- method of pest survival
- cultural practices and control measures.

There are no restrictions to establishment as far as environmental suitability and availability of host plants in the endangered area, due to climatic similarities and the large number of plant hosts present.

Mated and unmated adult females can lay eggs, although unmated females produce only male progeny. This means that it is not necessary to have both males and females present in the founder population, as long as a single female can live long enough to mate with her male offspring. Consequently, the establishment of a breeding colony could result either from a single fertilised female, the presence of both a female and a male, or the presence of several females of varying age and fertility. As these spider mites can disperse both as mated and unmated females, the minimum number of mites required to establish a population could be as few as one.

Other factors favouring establishment are that the fecundity of the adult female is high in warm climates, with development continuing all year round, resulting in up to 26 generations a year. Moreover the lifecycle is very short (only seven days egg-to-egg at optimum temperatures). A mated female produces on average 155 eggs and an unmated female produces on average 82 eggs during her lifetime. These reproductive strategies all increase the likelihood of successful establishment. So, the high fecundity of adult females means that colonies are able to develop from a single female or a small group of females within a few days.

Barriers to establishment would include the natural defences of the plant, predation or parasitism after settling, pesticides, disease, mortality due to adverse weather, damage to host plant and other environmental factors, as well as the settled site not being suitable for continued survival.

Considering all the factors above, it is considered there is a **high** likelihood of establishment being successful.

### 17.4.3 Spread

The probability that spider mites 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 2006). 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 IPPC describes several key factors that may be relevant to the ability of a pest to spread from a point of establishment in an exposed plant or group of plants. These are:

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

Other relevant factors include the intrinsic rate of growth of the pest (that is, the number of immature mites likely to be produced during the lifetime of the female at given temperatures), the pesticides applied to the PRA area, the density of susceptible hosts and movement of infested plant material. Some of the same factors will influence spread as well as the likelihoods of distribution and establishment. In more specific terms, the likelihood will be lower if the mites undergo a long period of development, there is limited access to males, their phenology is specialised and if there are high levels of competition, predators or parasites. Alternatively, the likelihood of spread will be higher if there is resistance to insecticide, tolerance of a wide range of conditions and movement of plant material by wind or other agents.

The presence of a commercial banana, citrus or papaya plantation, or any other susceptible economic crop in a tropical or subtropical environment in the vicinity of a waste disposal sites or home garden where waste is deposited, would favour spread. However, natural predators will be abundant in all areas where waste is deposited, except those to which insecticide is regularly applied, such as commercial crops. Mites established on host plants from a supermarket or in a household are more likely to spread than those in other situations, because of the absence or very low density of predators, parasitoids and similar controlling factors.

The intrinsic rate of growth is high in spider mites, with a minimum generation time of seven days and continuous reproduction throughout the year in warm climates, all of which would favour spread. Also, if the founder population is large, mites are likely to be moved within and between plantations with the movement of equipment and personnel, and they may also be dispersed by wind. However, it is more likely that founder populations will initially be small, so the likelihood of involuntary spread would be negligible, but will increase later if the founder population increases in size. They have well-developed dispersal mechanisms which allow them to spread rapidly and travel long distances, as they are readily blown by air currents.

Considering the polyphagous feeding habits of these mites and their rapid rate of increase, once established the likelihood of spread was considered to be **high**.

### 17.4.4 Probability of entry, establishment and spread

The overall likelihood that spider mites will enter Australia as a result of trade in mature hard green bananas from the Philippines, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **High**.

The probability of entry, establishment and spread was determined by combining the probabilities of entry, of establishment and of spread using the matrix of rules for combining descriptive likelihoods outlined in Table 3.1.

## 17.5 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of spider mites by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of spider mites was assessed on the basis of their potential effect on the entire local, district, regional and national community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

### 17.5.1 Direct impact

#### *Plant life or health – D*

The direct effects of spider mites have to be considered in the context of existing horticultural practices for control of pests and diseases.

*T. piercei* is considered to be a serious polyphagous pest that has been recorded as causing severe damage to bananas and papaya in southern China (Liu and Liu 1986; Fu et al 2002). Spider mites in large numbers may deplete nutrients from the host plant to such an extent as to cause severe damage, resulting in very heavy production losses and even death of the plant (Rabbinge 1985).

The hosts of *T. piercei* include the genera *Cassia* and *Pandanus*, as well as the family *Palmae*, all taxa with native and endemic Australian species. Its effect on the native vegetation is likely to be significant. The hosts for the *Oligonychus* and *Raoiella* species include amenity trees such as *Cocos nucifera*.

Spider mites have highly evolved means of dispersal and once a population is established, they can spread rapidly within a crop.

Considering all the above factors, the direct impact of spider mites on plant health was considered ‘significant’ at the district level, giving an overall rating of **D**.

#### *Human life or health – A*

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

#### *Any other aspects of the environment – D*

This criterion addresses the possible direct impact of pests on ‘other aspects’ of the natural or built environment such as the physical environment, micro-organisms and other fauna. These mites may compete with the current Australian fauna of spider mites, which comprises 15 genera and 55 species, although they may not all be native. They may also affect populations of native predators and parasitoids. The effect of spider mites is likely to be ‘significant’ at the district level, so the rating assigned to this criterion was **D**.

## 17.5.2 Indirect impact

### *Control or eradication – D*

The initial response to the detection of one of the quarantinable spider mite species in Australia would be to consider eradication, which could be initiated under an Emergency Plant Pest Deed. This approach is unlikely to be adopted because of the low probability of success. The alternative would be to establish measures to minimise the impact of spider mites on affected fruit and other crops. Such measures would be based on the use of additional pesticide or acaricide sprays, or the use of predatory mites in an integrated pest management program. Pesticide sprays are costly and additional applications may alter the economic viability of some crops. Experience overseas has shown that acaricides applied several times a year may result in increased mite abundance, as natural enemies are also killed. It will then take longer to rebuild predator populations than the spider mite populations, so that the problems posed by them are exacerbated. This would result in a further decrease in productivity associated with spider mites.

The cost of pest control programs was considered to be ‘significant’ at the district level, so the rating assigned to this criterion was **D**.

### *Domestic trade – C*

The entry, establishment and spread of these spider mites is likely to cause a change in interstate trading movements. Intrastate and interstate trading restrictions on plant materials and fruit, if adopted, would affect all domestic trade associated with the introduction and spread of spider mites. Restrictions on the movement of plant materials would be similar to those already in place to prevent spread of other pests and diseases.

Restrictions on fruit may disrupt national marketing arrangements for a short time after the initial discovery of pest infestation and lead to longer-term changes in the requirements of quarantine sensitive markets in production areas. Although pest species of spider mites already occur in Australia, the addition of another species such as *T. piercei* may have more serious effects, as it is considered to be a damaging pest of several crops.

Interstate trading restrictions may lead to a loss of markets, which in turn would be likely to require industry adjustment. The scope and severity of restrictions are difficult to estimate, but the polyphagous nature of these pests would suggest that impacts would not be felt in the banana industry alone. The indirect impact on domestic trade was considered to be ‘significant’ at the local level, and a rating of **C** was assigned to this criterion.

### *International trade – C*

Australia exports only insignificant quantities of bananas to specialty markets, so the presence of spider mites is unlikely to disrupt bilateral trade arrangements in this commodity. However, these spider mites are also pests of commercial crops such as coconut, papaya, sweet potato, peach, beans, eggplant, sugarcane, maize and some ornamental palms. These crops are grown in tropical, subtropical and Mediterranean climate areas of Australia and some are exported.

Their presence in Australian tropical fruit orchards and in some other crops might impact on current trade arrangements. Overall, the indirect impact of the spider mites on international trade was considered to be ‘minor’ at the district level. A rating of **C** was therefore assigned to this criterion.

### *Environment – B*

Although additional pre-harvest pesticide application may be required to control spider mites on susceptible fruit crops, this is unlikely to impact on the environment to any greater extent than already

occurs from run-off into waterways and marine ecosystems from commercial crops. As this is likely to be ‘minor’ only at the local level, a rating of **B** was assigned to this criterion.

### *Communities – B*

Incursions and establishment of these spider mite species are unlikely to cause any losses to farm workers or local communities, but may entail extra surveillance and pest control work. The indirect effects on communities are likely to be only ‘minor’ at the local level and a rating of **B** was therefore assigned to this criterion.

## 17.5.3 Overall consequences

The overall consequences to the Australian community of the entry, establishment and spread of spider mites as a result of trade in mature hard green bananas from the Philippines: **Low**.

Table 17.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of spider mites within Australia.

Based on the decision rules described in Chapter 6 of this document, where the consequences of a pest with respect to one or more criteria are **D**, the overall consequences are considered to be **low**.

**Table 17.1 Consequence assessment for spider mites**

	Impact scores
<b>Direct impact</b>	
Plant life or health	D
Human life or health	A
Any other aspects of the environment	D
<b>Indirect impact</b>	
Control or eradication	D
Domestic trade	C
International trade	C
Environment	B
Communities	B

## 17.6 Unrestricted risk

An overall estimate of the unrestricted risk for spider mites associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 17.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Low**.

Table 17.2 provides an estimate of the unrestricted annual risk of spider mites entering Australia as a result of trade in mature hard green bananas from the Philippines.

**Table 17.2 Unrestricted risk estimation for spider mites**

Probability of entry, establishment and spread	High
Consequences	Low
Risk	Low

As indicated in Table 17.2 above, the unrestricted risk is **low**, which exceeds Australia's ALOP. Therefore, risk management would be required for these pests for the importation of mature hard green bananas from the Philippines into Australia.

## 17.7 Risk management

Spider mites have been assessed as having an unrestricted risk estimate of **low** (see Table 17.2) and therefore they require risk management measures.

The following risk management measures and procedures are proposed to take account of the risk identified in this PRA and reduce the risk to achieve Australia's ALOP. For the initial trade pre-clearance will be used. However, if this requirement changes in the future AQIS would perform 'on-arrival' visual inspections and corrective action. It is part of the proposed final import conditions for mature hard green bananas from the Philippines that are described more fully in Chapter 20, Risk Management and Draft Operational Framework.

### 17.7.1 Pre-clearance inspection and corrective action

All bananas for export to Australia will be subjected to inspection for spider mites by BPI staff or their accredited agency staff.

Visual inspection of each lot will be undertaken using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of spider mites are known to contaminate packaging materials.

The inspected sample must be free from spider mites.

Where any live spider mites are found the lot must be subjected to an appropriate corrective action or rejected for export to Australia.

Only lots that pass the Bureau of Plant Industry/agency phytosanitary inspection may be presented for AQIS pre-clearance inspection.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of spider mites are known to contaminate packaging materials.

Under pre-clearance arrangements AQIS would be involved in the supervision of all procedures.

AQIS will undertake a documentation compliance examination for consignments pre-cleared in the Philippines prior to their release from quarantine in Australia.

Under pre-clearance arrangements, 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.

### 17.7.2 On-arrival inspection and corrective action

If requirements change in the future AQIS would perform ‘on-arrival’ visual inspection and corrective action. This section sets out the provisions that would apply to shipments that do not undergo pre-clearance.

Visual inspection by AQIS officers will be conducted upon arrival at the first port of call in Australia.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of spider mites are known to contaminate packaging materials.

Corrective action when spider mites are present is proposed as an appropriate risk management measure for this pest, given that trained inspectors can readily detect spider mites.

Consignments inspected and found to be free of live spider mites will not require further risk management measures to be applied.

When a consignment is found to be infested with live spider mites at on-arrival inspection in Australia, one of the following risk management options must be applied:

- re-export of the consignment from Australia
- destruction of the consignment
- treatment of the consignment to ensure that the pest is no longer viable.

### 17.7.3 Risk management conclusion

The objective of these measures is to ensure that consignments of mature hard green banana fruit from the Philippines infested with live spider mites can be readily identified and subjected to appropriate corrective action. It is considered that these measures will reduce the risk associated with spider mites to achieve Australia’s ALOP.

It was considered that these measures would reduce the probability of entry from **high** to **low** and the probability of entry, establishment and spread from **high** to **low**. When the adjusted value of PEES is combined with an overall consequence of **low**, the risk associated with spider mites was considered to achieve Australia’s ALOP.



## 18. Weevils

### 18.1 Introduction

This unrestricted risk assessment relates to five species of weevils identified as being not present in Australia, but present on the pathway. The weevils examined in this PRA are:

- *Philicoptus demissus* Heller 1929
- *Philicoptus iliganus* Heller 1929
- *Philicoptus* sp.1 CN3 in Stephens 1984
- *Philicoptus* sp.2 CN9 and CN10 in Stephens 1984
- *Philicoptus strigifrons* Heller 1929.

Several weevil species of the genus *Philicoptus*, subfamily Entiminae, commonly called peel-scarring weevils, are found in banana plantations in the Philippines (BPI 2001). The five weevil species listed are recognised as pests of bananas in the Philippines. Because *P. iliganus* is regarded as the most important of the five weevils examined and information for *Philicoptus* sp.1 is available (Stephens 1984), these two species were used as the basis for this risk assessment.

The biology of these species was considered sufficiently similar to justify combining these species into a single assessment.

### 18.2 Biology

Weevils are beetles belonging to the family *Curculionidae* and they have four life stages: adult, egg, larva and pupa. They vary in size from small seed weevils less than 2 mm long to the large pine weevils, which are 20–25 mm long. Adults are characterised by an elongated downwards-curving snout, while larval stages are relatively featureless white or yellowish grubs, usually without legs, but with well-developed heads and jaws. Larvae and adults of all species in the family feed on either living or dead plant tissues and, as a result, many species are serious pests of crops, seeds and plants. The larvae of many species feed inside the roots, stems or seeds of agricultural crops, garden plants and stored food products (Lawrence and Britton 1991).

Adults of the genus *Philicoptus* are relatively large (5–8 mm in length), flightless, slow-moving and brightly coloured (Heller 1929; Stephens 1984). Adult females lay eggs singly or in a mass in the soil, with eggs being creamy white, oval and about 0.9 mm long and 0.31 mm wide. They hatch in 10 days (BPI 2001). The complete larval period takes from 102 to 174 days on banana suckers (BPI 2001). Larvae pupate in a chamber in the soil and this pupal period lasts from 10 to 23 days (BPI 2001). The lifecycle from egg to adult takes from 111 to 176 days (BPI 2001).

Adults of the genus *Philicoptus* feed on leaf veins near the base of the youngest leaf of non-fruiting banana plants and on lower bracts before the young banana fingers are exposed. When the bracts open, the adult weevils enter the flower bud and scar young fingers. Feeding on fruit continues up to the point of harvest, even on the ridges of ripening fruit. Continuous feeding creates deep scars that remain visible on the fruit peel (Stephens 1984). *P. strigifrons* is reported on banana flowers and young fruit, and is suspected of feeding on hard green fruit, although this has not been observed in the field (Stephens 1984).

Adults of the genus *Philicoptus* do not have an effective means of dispersal since they have no hind wings and the elytra (first pair of wings) are firmly united at the suture. As a consequence, they are unable to move any distance (BPI 2001). When disturbed, peel-scarring weevils fall to the ground and feign death, thus minimising opportunities to be transported inadvertently with fruit or leaf material. In

the Philippines, weevils tend to be found in discrete isolated populations that remain in the same place for some years (Stephens 1984).

### 18.3 Risk scenario

The risk scenario of concern for peel-scarring weevils in this document is the presence of adult peel-scarring weevils in protected spaces between fingers of harvested banana fruit.

### 18.4 Entry, establishment and spread

The following analysis examines in detail the probabilities that weevils will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines. These probabilities are later combined with the estimated consequences for these pests to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

#### 18.4.1 Entry

The probability of entry is obtained by considering the 'importation' and 'distribution' pathways for the commodity and the probability that a given pest will remain viable and undetected as each of the component steps is completed.

##### *Probability of importation*

The likelihood that weevils will arrive in Australia with the importation of bananas from the Philippines: **Extremely low**.

The initiating step for the importation scenario for bananas is the sourcing of bananas from plantations in the Philippines, while the end point is the release of imported bananas from the port of entry.

While detailed information on the precise distribution of peel-scarring weevils within source plantations in the Philippines is not available, they are generally found in discrete populations because, unlike many other arthropod pests, they have no effective means of dispersal.

Distribution information for individual species is as follows:

- *Philicoptus demissus* is found in the arid General Santos banana zone of Mindanao (Stephens 1984).
- *P. iliganus* is distributed west of the Davao River Valley (south banana zone) and is the most economically important banana peel-scarring pest in Mindanao (Stephens 1984).
- High populations of *P. iliganus* are found at sea level near Davao City, and also at a location about 700 m above sea level near Guianga on the cool slopes of Mount Talomo (Stephens 1984).
- An unidentified pest *Philicoptus* species is restricted to the north banana zone, north and east of the Lasang River (Stephens 1984).

Only adult peel-scarring weevils are present on the leaves and fruit of bananas. When disturbed, adult weevils fall to the ground and feign death (Stephens 1984). Adult weevils enter the flower bud and scar young fingers. Feeding occurs mostly in young fruit. Adults move out of the bunch when the fruit gets older (BPI 2001).

The known feeding habits for individual species are:

- Adult *P. demissus* feed near the base of the youngest leaf, on leaf petioles, ridges of leaf veins, the flower bracts and along the fruit ridges (BPI 2001). Larval *P. demissus* are usually root feeders, but also feed on corms and suckers (BPI 2001).
- Adult *P. iliganus* feed on the peel of banana fruit, leaving ugly scars on the surface (BPI 2001).

During harvest the majority of bananas will be transported by cableway to permanent packing stations, and so will not come into physical contact with the ground or transport equipment. Mobile facilities are currently used in about 10% of Philippine plantations. In this case, covers are removed from banana bunches, they are de-handled in the field and carried to the packing station on padded stretchers. It is possible that some weevils will be dislodged from the bananas and lodge on the stretchers, where they could contaminate other banana hands. When disturbed, adult weevils fall to the ground and feign death (Stephens 1984). As a result of this drop-down and feigning-death behaviour, it would be highly unlikely that adult weevils would move onto clean harvested fruit.

During the processing of fruit in the packing station, it is highly likely that the majority of adult peel-scarring weevils would be removed as a result of standard grading, washing and packing procedures. As the adults only feed on the surface of the fruit it is likely that they will be washed off the fruit during high pressure washing or subsequently in the water bath. Also, damaged fruit with obvious deep scars on the peel that crack with age (Stephens 1984) would be discarded before packing, which further reduces the likelihood of weevils remaining with the fruit.

While it is possible that adults of these weevil species could conceal themselves within bunches of bananas, it is significant that they have never been intercepted on bananas imported from the Philippines at the New Zealand border (Spence 2002; Biosecurity New Zealand MAF, Wellington, New Zealand, 11 January 2006.). Similarly, there are no records of interceptions of peel-scarring weevils on exported Philippine bananas at border inspections in Japan (Sugimoto 1994).

Despite the relatively large size of these weevils (adults of *P. demissus* are 6–7 mm in length) and their conspicuously bright colour, there have been no interceptions recorded in either New Zealand or Japan for bananas from the Philippines.

Considering the information above the likelihood of importation is assessed as **extremely low**.

#### *Probability of distribution*

The likelihood that peel-scarring weevils will be distributed to susceptible areas as a result of the processing, sale or disposal of mature hard green bananas from the Philippines: **Extremely low**.

The initiating step for the distribution scenario is the release of imported bananas 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 bananas) in a viable state to an endangered area and subsequently being transferred to a suitable host.

The insect stage associated with the banana fruit is the adult, present in protected spaces between fingers of harvested bananas.

Bananas will be distributed throughout Australia for retail sale, as the intended use of the commodity is human consumption. Waste material would be generated at various points along the pathway from border to consumer.

Factors affecting distribution are:

- The larvae of banana peel-scarring weevils are soil dwellers and feed on the roots and corms of banana plants (Stephens 1984; BPI 2001). The larval stage lasts 102–174 days, while the adult stage lasts 33–128 days and the total lifecycle from egg to adult lasts 111–176 days (Stephens 1984).
- Adults are flightless (Stephens 1984); therefore, the movement of peel-scarring weevils from banana clusters would be limited.
- During the day, adults experience periods of inactivity, although these are interspersed with periods of active crawling.
- Adults move out of the bunch when the fruit ages (BPI 2001).

As a result of the inability of banana peel-scarring weevils to fly, the general inactivity of adults, and the soil habitats of the larvae, the likelihood of distribution of these weevils in Australia was assessed as **extremely low**.

#### *Probability of entry (importation x distribution)*

There is a **negligible** probability that peel-scarring weevils will enter Australia as a result of trade in bananas from the Philippines and be distributed in a viable state to the endangered area.

The overall probability of entry is determined by combining the probabilities of importation and of distribution using the matrix for combining likelihoods (Table 3.1).

#### **18.4.2 Establishment**

The probability that weevils 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: **Moderate**.

The initiating step for the establishment scenario is a sufficient number of individuals to allow for a reproducing population to establish on a host, and the final stage is the production of eggs and larvae from this founder population.

Characteristics of the biology of these weevil species relevant to the assessment of establishment are as follows:

- Banana peel-scarring weevils have a wide host range including a number of commonly grown tropical fruits - avocado, cacao, coffee, durian, jackfruit, mangosteen, rambutan as well as citrus, mungbean and young crop plants of pechay/bokchoy (*Brassica rapa* ssp. *chinensis*), and two weed species *Ageratum conyzoides* (chickweed and goatweed) and *Crassocephalum crepidioides* (thickhead) (Szinicz 2005).
- Several of the tropical fruit hosts are grown commercially in northern Queensland.
- Banana peel-scarring weevils of the genus *Philicoptus* are found in tropical lowland regions of the Philippines. Similar environments occur in the tropical/subtropical regions of Australia.
- Banana peel-scarring weevils reproduce sexually.
- Adult females lay eggs singly or in mass in the soil near banana plants, with eggs hatching in 10 days (BPI 2001).
- Larvae are soil-living and feed on the corm and roots of banana plants (Stephens 1984). The larval stage lasts 102–174 days (Stephens 1984).
- Larvae pupate in the soil in an underground chamber. The pupal period lasts 10–23 days.
- A generation (egg to adult) can be completed in 111–176 days (BPI 2001).
- Weevils are subject to attack by an array of predators and parasitoids. Various Hymenoptera (that is, *Mymaridae* and *Pteromalidae*) attack eggs, and weevils and wasps prey upon larvae (Lawrence and Britton 1991). However, no predators or parasitoids have been reported attacking the eggs or

larvae of peel-scarring weevils in the Philippines. The relevance of natural enemies in Australia is not known.

- Existing control programs may be effective for some hosts (for example, broad spectrum pesticide applications) but not for all.

As a result of these species' long life history, habitat requirements and susceptibility to predators and pesticides, the likelihood of the *Philicoptus* species establishing in Australia was assessed as **moderate**.

### 18.4.3 Spread

The probability that weevils 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**.

The initiating step for the spread scenario is the production of larvae and adults from the founder population and the final step is the successful spread of adults and larvae to new areas, with the result that new populations establish.

Characteristics of the biology of these weevil species that contribute to the assessment are:

- Many of the fruit crop hosts of banana peel-scarring weevils are located across the northern regions of Australia. Natural barriers such as arid areas, climatic differentials and long distances exist between these areas.
- These pests may be spread as adults via infested host commodities or as larvae in soil, or on products/machinery that are contaminated with soil.
- Weevils are subject to attack by an array of predators and parasitoids. Various Hymenoptera (that is, Mymaridae and Pteromalidae) attack eggs, and weevils and wasps prey upon larvae (Lawrence and Britton 1991). However no predators or parasitoids have been reported attacking the eggs or larvae of peel-scarring weevils in the Philippines. The relevance of natural enemies in Australia is not known.
- Similar environments, as far as climate and vegetation type are concerned, occur both in the Philippines and Australia.
- The reproductive strategy, described above, is also relevant to spread of the species.

As a result of the host specificity of these weevils, their means for natural spread and dispersal and their natural enemies and effects of pesticides, the likelihood of *Philicoptus* weevils spreading in Australia was assessed as **moderate**.

### 18.4.4 Probability of entry, establishment and spread

The overall likelihood that weevils will enter the PRA area as a result of trade in bananas from the Philippines, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **Negligible**.

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 (Table 3.1).

## 18.5 Consequences

The following analysis examines the consequences to the Australian community of the entry, establishment and spread of weevils by considering, on a range of direct and indirect criteria, their potential impact at the local, district, regional and national level. At each level, the impact of weevils was assessed on the basis of their potential effect on the entire local, district, regional and national

community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6. Consideration of the direct and indirect impacts is provided in the following text.

### **18.5.1 Direct impact**

#### *Plant life or health – D*

This criterion describes the possible production losses associated with the presence of peel-scarring weevils in commercial bananas, as well as any losses in productivity of other susceptible species.

The direct effects of weevils are considered in the context of existing horticultural practices for control of pests and diseases. Costs associated with control measures or trade restrictions are considered within the discussion of ‘indirect impacts’. In banana plantations, adult peel-scarring weevils feed on leaf veins near the bases of the youngest leaves, and on lower bracts before the young banana fingers are exposed. When the bracts open, the weevils enter the flower bud and scar young fingers. Scarring occurs over the period up to harvest time. Adults also feed on the ridge of ripening fruit, leaving deep scars that remain visible on the fruit peel. The larvae live in the soil and feed on the corm or roots of banana plants (Stephens 1984).

Damage to fruit reduces the marketability or value of a crop. *P. iliganus* was considered the most economically important banana peel-scarring pest in Mindanao and high population densities were observed near sea level in Lapanday Farm near Davao City. They were also observed about 700 m above sea level in the Davao Fruit Company’s Plantation One near Guianga on the cool slopes of Mount Talomo (Stephens 1984). *Philicoptus* sp.1 is second in importance as a peel-scarring pest in the Davao banana zone (Stephens 1984). The weevils also feed on many other tropical and subtropical plants such as cacao, coffee, durian, jackfruit, mangosteens and rambutan. The impact of weevils on other fruit species will vary, although it is unlikely to be deleterious to the health of the host plant.

Considering the above factors, the direct impact of peel-scarring weevils was considered to be ‘significant’ at the district level, so the rating assigned to this criterion was **D**.

#### *Human life or health – A*

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

#### *Any other aspects of the environment – C*

This criterion addresses the possible direct impact of pests on other parts of the natural or built environment. There are no known direct consequences of these pests on the natural environment. However, their introduction into a new environment is likely to lead to competition for resources with native species and changes in densities of predators such as birds, because these weevils have a wide host range and are natural forest inhabitants (Stephens 1984).

The impact of peel-scarring weevils is considered to be ‘significant’ at the local level and a rating of **C** was assigned to this criterion.

### **18.5.2 Indirect impact**

#### *Control or eradication – D*

Two pest species of weevil, *Cosmopolites sordidus* (Germer 1824), the banana weevil borer, and *Araecerus coffeae* (Fabricius 1801), Coffee bean weevil are already present in Australian banana

plantations. Regular monitoring of pest levels is carried out. If populations reach a certain threshold value, spraying is initiated. However, control measures for these weevils are sporadic and targeted, and are unlikely to be effective for peel-scarring weevils.

The initial response to the detection of peel-scarring weevils would be to attempt eradication, but this is unlikely to be adopted because of the low likelihood of success. A more probable response would be measures to control the incursion using pesticide sprays or pesticide-impregnated bunch covers. Indirect consequences of the eradication or control as a result of the introduction of a banana peel-scarring weevil species are likely to be:

- a considerable increase in the cost of pesticide applications to producers because of initial difficulties in estimating the optimum time for insecticide application
- a control program in infested plantations to reduce fruit damage and yield loss, thereby increasing production costs
- damage to leaves would permit entry of plant pathogens, requiring further costly control measures
- increased costs of crop monitoring and consultant's advice to the producer
- widespread and long term increases in control measures, depending on the extent of the incursion.

The impact of peel-scarring weevils is likely to be 'significant' at the district level and a rating of **D** was assigned to this criterion.

#### *Domestic trade – B*

The domestic trade effects associated with the introduction and spread of banana peel-scarring weevils are likely to be minimal. The evasive behaviour of adult weevils and the disturbance provided by the general handling of fruit during harvesting and packing mean that weevils are unlikely to contaminate bananas packed in cartons for transport to market, or other fruit such as avocado or citrus. The fact that adult weevils are relatively large (6–7 mm in length) and brightly coloured also means that they are highly likely to be noticed by packing station staff and removed. However, some effects at the local level will occur because of the increased surveillance necessary at packing stations.

The impact of peel-scarring weevils is likely to be 'minor' at the local level and a rating of **B** was assigned to this criterion.

#### *International trade – B*

Australia exports only very small quantities of bananas to specialty markets. Although some other susceptible crops such as avocado are exported, the presence of peel-scarring weevils is unlikely to disrupt bilateral trade arrangements for the reasons discussed above. It should be noted that the presence of peel-scarring weevils in the commercial production areas of commodities such as avocado or banana may limit access to overseas markets.

The impact of peel-scarring weevils is likely to be 'minor' at the local level and a rating of **B** was assigned to this criterion.

#### *Environment – B*

Host plants of these peel-scarring weevils include commercial crop species such as avocado, banana, cacao, citrus, coffee, durian, jackfruit, mangosteen, rambutan and pechay/bokchoy. Commercial crops of these hosts are grown under intensive cultivation. So there would be little effect on designated environmentally sensitive or protected areas, because few such host plant species are able or allowed to continue to grow in those areas. However, pesticide residues in runoff after heavy rainfall will affect areas outside grower areas and may also enter sensitive marine environments. The increased pesticide use on susceptible fruit crops could cause undesired effects on the environment at the local and possibly district level through runoff into non-production areas.

Furthermore, new biological control agents introduced in an attempt to control banana peel-scarring weevils could affect existing biological control programs at the local and possibly also district levels. The impact of peel-scarring weevils is likely to be ‘minor’ at the local level and a rating of **B** was assigned to this criterion.

### *Communities – B*

Incursions and the establishment of these weevil species are unlikely to cause any losses to farm workers or local communities. Consequently, the impact of peel-scarring weevils is considered to be ‘minor’ at the local level and a rating of **B** was assigned to this criterion.

## 18.5.3 Overall consequences

The overall consequences to the Australian community of the entry, establishment and spread of peel-scarring weevils as a result of trade in mature hard green bananas from the Philippines: **Low**

Table 18.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of weevils within Australia.

Based on the decision rules described in Chapter 6 of this document, where the consequences of a pest with respect to one or more criteria are **D**, the overall consequences are considered to be **low**.

**Table 18.1** Consequence assessment for weevils

	Impact scores
<b>Direct impact</b>	
Plant life or health	D
Human life or health	A
Any other aspects of the environment	C
<b>Indirect impact</b>	
Control or eradication	D
Domestic trade	B
International trade	B
Environment	B
Communities	B

## 18.6 Unrestricted risk

An overall estimate of the unrestricted risk for weevils associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 18.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Negligible**.

Table 18.2 provides an estimate of the unrestricted risk of peel-scarring weevils entering Australia as a result of trade in mature hard green bananas from the Philippines.



**Table 18.2 Unrestricted risk estimation for peel-scarring weevils**

Probability of entry, establishment and spread	Negligible
Consequences	Low
Risk	Negligible

As indicated in Table 18.2 above, the unrestricted risk is ‘negligible’, which achieves Australia’s ALOP. Therefore, risk management would not be required for these pests for the importation of Philippine mature hard green bananas into Australia.



## 19. Thrips

### 19.1 Introduction

This unrestricted risk assessment relates to two species of thrips identified as being not present in Western Australia, but determined to be a pest of regional quarantine concern for that State. These two species of thrips occur, and have established self-sustaining populations, in eastern Australia. These pests are considered to be present on the pathway. The species are:

- *Chaetanaphothrips signipennis* Bagnall 1913.
- *Elixothrips brevisetis* (Bagnall 1919).

Biosecurity Australia has previously assessed other thrips species with similar biology. The method used in those IRAs will be followed here, with appropriate modifications for differences between species and the commodity. There was no specific published information on the biology of the species *E. brevisetis* and the IRA team considered that the biology of these species was sufficiently similar to justify combining these species into a single assessment.

### 19.2 Biology

Given the lack of published information and the biological similarity of *E. brevisetis* to *C. signipennis* it was considered that the assessment of *C. signipennis* would apply equally to *E. brevisetis*.

The adults of banana rust thrips, (Bagnall), are creamy yellow to golden brown and 1–1.6 mm long (Hara et al 2002). The wings are fringed with eye-like dark spots at the base; when the wings are folded, the adult appears to have a black line down its back (see fig. 4.14 of Pinese and Piper 1994).

Banana rust thrips reproduce sexually. After mating, females lay kidney-shaped eggs in the plant tissue, just below the surface of the fruit or under leaf sheaths (Pinese and Piper 1994; Hara et al 2002; Trevorrow 2002). These eggs hatch after about a week. The newly hatched larvae are white to cream and, when fully developed after about another week, are about the same size and shape as the adults, but have no wings (Trevorrow 2002). The mature larvae enter the soil and develop into prepupae and then form white pupae. Adult thrips emerge from the pupae 7–10 days later.

The lifecycle (from egg to adult) is completed in approximately 28 days, but it may take up to three months during cooler seasons (Hara et al 2002).

The larvae and adults congregate in colonies on the pseudostems behind the bases of leaf sheaths, and their feeding results in the plant tissue becoming blood red in colour. They congregate on fruit, mainly where the fruits touch each other (Braithwaite 1963).

Both adults and larvae feed by puncturing plant surface cells, including the skin of young fruit and suck up the sap (Braithwaite 1963). Damage on fruit is caused throughout the year but in Australia the period of greatest pest activity is November to April (Pinese and Piper 1994; Trevorrow 2002).

Although adult thrips can fly, major spread is far more likely by movement of infested planting material to new areas (Trevorrow 2002).

Banana rust thrips may infest bunches at any time during their growth, but infestations that develop when bunches emerge result in the most severe damage (Trevorrow 2002). Injured areas on young fruit first look water-soaked, then discoloured and grey and later become rust coloured. With further growth of the fruit cracks may develop in the scarred areas. Injury to fruit is usually on the sides of fruit that are touching or are close together, but in severe infestations the whole fruit may be blemished. Sometimes fruit split.

The host plants of *C. signipennis* include *Anthurium* sp., *Cordyline fruticosa* (ti, good-luck-plant), *Dracaena* sp., *Musa* sp. (banana), *Musa x paradisiaca* (plantain), *Maranta leuconeura* (banded arrowroot), *Strelitzia reginae* (Queens bird-of-paradise) (Denmark and Osborne 1985). The species also infested the immature fruits of *Citrus sinensis* (orange), *Citrus reticulata* (tangerine-mandarin), *Lycopersicon esculentum* (tomatoes) and *Phaseolus vulgaris* (green beans) (Hara et al 2002).

Other information on the biology of thrips is available in the datasheet (Appendix 15 of Part C).

### 19.3 Risk scenario

The risk scenario of concern for these thrips in this report is the presence of eggs just below the surface of the fruit, and nymphs and adults on fruit, mainly where fruit touch each other on harvested mature hard green banana clusters.

### 19.4 Entry, establishment and spread

The following analysis examines in detail the probabilities that thrips will enter, establish and spread in Australia as a result of the importation of mature hard green bananas from the Philippines. These probabilities are later combined with the estimated consequences for this pest to give an overall estimate of the unrestricted risk with respect to Australia's ALOP.

Where available pest interception data for bananas from eastern Australian states to Western Australia have been used to estimate qualitative values for thrips entering, establishing and spreading in the PRA area (Western Australia).

#### 19.4.1 Entry

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.

##### *Probability of importation*

The likelihood that thrips will arrive in Western Australia with the importation of banana fruit from the Philippines: **High**.

The initiating step for the importation scenario is the sourcing of bananas from plantations in the Philippines, while the end point is the release of imported bananas from the international port of entry.

No quantitative pest prevalence data for banana rust thrips is available for Philippine banana plantations, but banana rust thrips are known to be a banana pest in the Philippines (PCARRD 1988) and banana rust thrips have been intercepted on banana fruit moving from eastern Australian states into Western Australia (Carnarvon Banana Industry Protection Committee 2004).

Banana rust thrips feed on the pseudostem and on banana fruit (Hara et al 2002). Feeding damage to the fruit occurs on fingers soon after the flower petals dry, initially typified by a water-soaked appearance. On mature fruit, oval-shaped, reddish stains may be seen where the fingers touch. Extensive damage may cover more of the fruit surface with reddish-brown or black discoloration and superficial cracks (see figures 4.10, 4.11 and 4.12 of Pinese and Piper 1994; figure 2 of Hara et al 2002).

Infestation during transportation to the packing station is possible because the adults can fly. However, this is considered unlikely, as bunches remain within their plastic covers. The chance of infestation during transportation may increase if mobile packing stations operating within plantations are used,

instead of fixed packing stations that operate adjacent to plantations. Currently around 10% of Philippine plantations use mobile facilities, although this figure may increase in future years.

When bunches arrive at the permanent packing station by cableway, covers are removed, bunches are inspected and washed with a high pressure jet of water, divided into clusters and placed in a flotation tank. These processes are likely to remove most larvae and adults of thrips moving over the open surface of the fruit, but not eggs below the surface of the fruit or thrips protected in the space between fingers.

The temperatures during transportation of bananas from the Philippines to Australia would be between 13–14 °C. There are apparently no specific data to indicate how long thrips would survive under these conditions. However, different stages of the thrips would live longer at such temperatures and be able to survive 14 days of transportation.

There is likely to be some natural mortality during transport related to age or disease. But it is likely that there would be some reproduction during transport to Australia that may increase the number of thrips.

Live banana rust thrips have been detected on bananas from Queensland to Western Australia. These data indicate that live banana rust thrips could survive on bananas during handling and transportation.

Taking into consideration the evidence that the eggs of thrips which are under the skin of the fruit survive harvesting, pack station processes and transportation; that larvae and the adults feed on fruits; and that banana rust thrips have been intercepted on bananas from Queensland to Western Australia, the likelihood that thrips will arrive in Western Australia with the importation of banana fruit from the Philippines was assessed as **high**.

#### *Probability of distribution*

The likelihood that thrips will be distributed to the PRA area as a result of the processing, sale or disposal of banana fruit from the Philippines: **High**.

The initiating step for the distribution scenario is the release of imported bananas from the international port of entry, while the final step is that a minimum number of one live individual (mated female), or a male and a female of the pest, are transferred from banana fruit or waste to a susceptible host. Distribution involves the release of imported bananas from the port of entry and transportation to a location where susceptible hosts are present.

After the bananas are released at the international port of entry, the main pathway followed is transportation to the ripening facility, ripening at a temperature of 18 °C, transportation to wholesaler, sale to retailer, transportation to retail store, time in store, sale to consumer, storage in household and consumption. Distribution is likely to take on average a minimum of two to three weeks, with the end point being consumption and waste production. The final step will be prolonged if the waste is retained for a number of days before being discarded into the environment.

All life stages are associated with banana fruit: eggs, larvae and adults. The combination of cool storage and ripening (which takes 3–7 days) at about 14.5–21 °C and 95% relative humidity would permit survival of thrips. Adult and larvae of thrips are likely to survive ripening and transportation, as they are protected in spaces between fingers. The higher temperatures and increase in light intensity will allow survival and continued development, although there will be some natural mortality.

During this step, larvae of thrips can continue developing into mature larvae that would become adults, ready to mate. This could occur at unpacking facilities, or at retailers, and during transportation of purchased bananas from retailers to households. In the field situation, mature larvae of banana rust thrips migrate from the host plant into the soil or debris beneath and moult into prepupae first and then become pupae (Hara et al 2002). The environment at the utility points is very different from the field situation and there would be no soil or debris as sites for the pupation. It is not known how this

process would occur at such points. However, it is expected that there would be some mortality before the adults emerge from the pupae. The adults of thrips that are already on the fruit will not go through this process and thus more would survive.

Adults and larvae of thrips may disperse from banana fruit before or at the point of sale, or after purchase by consumers. The only means by which thrips can leave fruit and enter the environment of exposure groups is by adults flying or larvae walking. The scenario of highest risk for thrips entering the environment from fresh banana fruit is probably in the supermarket before sale, or in the household before consumption. Both these environments are likely to have susceptible host plants close by.

The next risk step in distribution relates to the proximity of susceptible hosts in a supermarket, home or at a waste disposal site. If hosts are close by, then live thrips may be able to find them. The hosts of thrips include many tropical and subtropical plants, some of which are commercially cultivated or grown as ornamentals or as utility plants.

The reported host plants of banana rust thrips are *Anthurium* sp., *Cordyline fruticosa*, *Dracaena* sp., *Musa* sp. (banana), *Musa x paradisiaca*, *Maranta leuconeura*, *Strelitzia reginae* (Denmark and Osborne 1985). The species also infest the immature fruits of *Citrus sinensis* (orange), *Citrus reticulata* (tangerine-mandarin), *Lycopersicon esculentum* (tomatoes) and *Phaseolus vulgaris* (green beans) (Hara et al 2002). Some of these hosts are widespread and may be common in gardens in tropical or subtropical Western Australia.

Although susceptible host plants will be more common in tropical and subtropical parts of Western Australia, at least some would be present in most parts of the state where banana waste is likely to be deposited. It is considered very likely that either fresh fruit or waste from bananas from the Philippines would be present or deposited close to susceptible host plants.

Considering the above evidence, the overall probability of distribution was assessed as **high**.

#### *Probability of entry (importation × distribution)*

The likelihood that thrips will enter the PRA area as a result of trade in bananas from the Philippines and be distributed in a viable state to the endangered area is assessed as: **High**.

The overall probability of entry is determined by combining the likelihoods of importation and distribution using the matrix of rules for combining descriptive likelihoods outlined in Table 3.1.

### **19.4.2 Establishment**

The probability that thrips 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**.

In this assessment the initiating point for establishment of the pest begins with adults or immature thrips arriving on the host. The end point is the persistence of a breeding population of the pest in the PRA area.

At a minimum only one mated female or a single mated pair would be required to establish a population.

The lifecycle of thrips is approximately 28 days but it may take up to three months during cooler seasons (Hara et al 2002). The development period is 6–9 days for eggs, 8–10 days for larvae, 2–5 days for pre-pupae and 6–10 days for pupae before becoming adults (Hara et al 2002). There are many generations per year but the greatest numbers of thrips occur from November to March (Trevorrow 2002). This would increase the likelihood of successful establishment.

Thrips occur, and have established self-sustaining populations, in eastern Australia. Similar environments and hosts occur in Western Australia and it is expected that the thrips would also establish in suitable areas in Western Australia.

Barriers to establishment may include the natural defences of the plant, predation or parasitism after settling, pesticides, disease and mortality due to adverse weather, damage to host plant and other environmental factors, as well as the settled site not being suitable for continued survival.

Considering the overall factors above, especially the suitability of the environment, the availability of the hosts and its continuous activity throughout the year, it is considered there is a **high** likelihood of establishment being successful.

### 19.4.3 Spread

The probability that thrips 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**.

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 Western Australia.

Relevant factors include the intrinsic rate of growth of the pest population, the pesticides applied in the PRA area, the density of susceptible hosts and movement of infested plant material. In more specific terms, the likelihood of spread will be lower if the thrips undergoes a long period of development, there is limited access to males, their phenology is specialised and if there are high levels of competition, predators or parasites. Alternatively, the likelihood of spread will be higher if there is resistance to insecticide, tolerance of a wide range of conditions, movement of plant material by wind or other agents.

Thrips have highly evolved means of dispersal and once a population is established, they can spread rapidly within a crop. Thrips established on host plants from a supermarket or in a household are more likely to spread than those in other situations, because of the absence or very low density of predators, parasitoids and similar controlling factors. The generation time for banana rust thrips is 28 days. They can continue reproduction throughout the year in warm climates. The adults have wings and can fly. All of these would favour the spread of thrips. Also, if the founder population is large, it is possible that thrips could be moved within and between plantations with the movement of equipment and personnel. However, it is more likely that founder populations will initially be small, so the likelihood of involuntary spread would be negligible, but will increase later if the founder population increases in size.

Considering the ability of thrips to fly and other favourable factors, once established the likelihood of spread was considered to be **high**.

### 19.4.4 Probability of entry, establishment and spread

The overall likelihood that thrips will enter Western Australia as a result of trade in mature hard green bananas from the Philippines, be distributed in a viable state to suitable hosts, establish in that area and subsequently spread within Australia: **High**.

The probability of entry, establishment and spread was determined by combining the probabilities of entry, of establishment and of spread using the matrix of rules for combining descriptive likelihoods described in Table 3.1.

## 19.5 Consequences

Thrips are a pest of regional concern for Western Australia. The following assessment of consequences applies only to the regional level (Western Australia) and not at the national level.

The analysis examines the consequences to the Western Australian community of the entry, establishment and spread of thrips by considering, on a range of direct and indirect criteria, their potential impact at the local, district and regional level. At each level, the impact of thrips was assessed on the basis of their potential effect on the entire local, district and regional community. These assessments were expressed in qualitative terms as being: ‘unlikely to be discernible’, ‘minor’, ‘significant’ and ‘highly significant’.

An overall assessment of consequences was based on the decision rules discussed in Chapter 6.

Consideration of the direct and indirect impacts is provided in the following text.

### 19.5.1 Direct impact

#### *Plant life or health – D*

The direct effects of thrips have to be considered in the context of existing horticultural practices for control of pests and diseases.

Thrips are a pest in the Philippines (PCARRD 1988). They are also a pest in Honduras, Panama, Brazil, Florida, Hawaii, Fiji, Sri Lanka and India (Denmark and Osborne 1985; Hara et al 2002) as well as the north coast region of New South Wales and in Queensland (Trevorrow 2002).

Banana rust thrips damage ornamental plants such as anthurium, as well as banana (Pinese and Piper 1994; Hara et al 2002).

Thrips have highly evolved means of dispersal and once a population is established, they can spread rapidly within a crop. If thrips enter, establish and spread in Western Australia they are likely to result in a decrease in banana production and adversely affect a range of other crops and ornamental plants.

Considering all the above factors, the direct impact of thrips on plant health was considered ‘significant’ at the district level, giving an overall rating of **D**.

#### *Human life or health – A*

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

#### *Any other aspects of the environment – B*

This criterion addresses the possible direct impact of pests on ‘other aspects’ of the natural or built environment such as the physical environment, micro-organisms and other fauna. The thrips may compete with the current Australian fauna of thrips. They may also affect populations of native predators and parasitoids. The effect of thrips is likely to be ‘minor’ at the local level, so the rating assigned to this criterion was **B**.

### 19.5.2 Indirect impact

#### *Control or eradication – D*

The initial response to the detection of the thrips in Western Australia would be to consider eradication. This approach is unlikely to be adopted if the population was well established and widely distributed, as there would be a low probability of success. The alternative would be to establish



measures to minimise the impact of thrips on affected crops and ornamental plants. Such measures would be based on the use of additional pesticide sprays, or the use of predators in an integrated pest management program. Pesticide sprays are costly and additional applications may alter the economic viability of some crops. Experience overseas has shown that pesticides applied several times a year may result in increased thrips abundance, as natural enemies are also killed. It will then take longer to rebuild predator populations than the thrip populations, so that the problems posed by them are exacerbated.

The indirect impact of control and eradication programs was considered to be ‘significant’ at the district level, so the rating assigned to this criterion was **D**.

#### *Domestic trade – B*

The entry, establishment and spread of the thrips is unlikely to cause a change in interstate trading movements as the species is already present in New South Wales and Queensland. However, if an incursion of thrips occurs in one local area, intrastate trading restrictions to prevent further spread of thrips may impact on local areas.

Restrictions on fruit could disrupt Western Australia marketing arrangements for a short time after the initial discovery of a pest infestation and lead to longer-term changes in the requirements of quarantine sensitive markets in production areas.

The indirect impact on domestic trade was considered to be ‘minor’ at the local level, and a rating of **B** was assigned to this criterion.

#### *International trade – B*

Export of bananas from Western Australia is not significant, so the presence of thrips is unlikely to disrupt bilateral trade arrangements in this commodity.

Similarly other hosts of thrips, such as anthurium, have little export potential for Western Australia.

Overall, the indirect impact of the thrips on international trade was considered to be ‘minor’ at a local level. A rating of **B** was therefore assigned to this criterion.

#### *Environment – B*

Although additional pre-harvest pesticide application may be required to control thrips on susceptible fruit crops, this is unlikely to impact on the environment to any greater extent than already occurs from run-off into waterways and marine ecosystems from commercial crops. As this is likely to be ‘minor’ at the local level, a rating of **B** was assigned to this criterion.

#### *Communities – B*

Entry, establishment and spread of thrips is unlikely to cause any losses to farm workers or local communities, but may entail extra surveillance and pest control work. The indirect effects on communities are likely to be only ‘minor’ at the local level and a rating of **B** was therefore assigned to this criterion.

### **19.5.3 Overall consequences**

The overall consequences to the Western Australian community of the entry, establishment and spread of thrips as a result of trade in mature hard green bananas from the Philippines: **Low**.

Table 19.1 shows the impact scores assigned to the direct and indirect consequences that would result from the entry, establishment and spread of thrips within Western Australia.

Based on the decision rules described in Chapter 6 of this document, where the consequences of a pest with respect to one or more criteria are **D**, the overall consequences are considered to be **low**.

**Table 19.1 Consequence assessment for thrips**

	Impact scores
<b>Direct Impact</b>	
Plant life or health	D
Human life or health	A
Any other aspects of the environment	B
<b>Indirect impact</b>	
Control or eradication	D
Domestic trade	B
International trade	B
Environment	B
Communities	B

## 19.6 Unrestricted risk

An overall estimate of the unrestricted risk for thrips associated with the importation of mature hard green bananas from the Philippines was obtained using the decision rules in the risk estimation matrix described in Chapter 3 to combine the probability of entry, establishment and spread with the assessment of consequences.

### 19.6.1 Unrestricted risk estimate

The unrestricted risk estimate determined by combining the overall ‘probability of entry, establishment and spread’ with the ‘consequences’ using the risk estimation matrix described in Chapter 3: **Low**.

Table 19.2 provides an estimate of the unrestricted risk of thrips entering Western Australia as a result of trade in mature hard green bananas from the Philippines.

**Table 19.2 Unrestricted risk estimation for thrips**

Probability of entry, establishment and spread	High
Consequences	Low
Risk	Low

As indicated in Table 19.2 above, the unrestricted risk is **low**, which exceeds Australia’s ALOP. Therefore, risk management would be required for this pest for the importation of Philippine mature hard green bananas from the Philippines into Western Australia.

## 19.7 Risk management

Thrips have been assessed as having an unrestricted risk estimate of **low** (see Table 19.2) and therefore they require risk management measures.

The following risk management measures and procedures are proposed to take account of the risk identified in this PRA and reduce the risk to achieve Australia’s ALOP. For the initial trade pre-clearance will be used. However, if this requirement changes in the future AQIS would perform ‘on-

arrival' visual inspections and corrective action. It is part of the proposed final import conditions for mature hard green bananas from the Philippines that are described more fully in Chapter 20, Risk Management and Draft Operational Framework.

### **19.7.1 Pre-clearance inspection and corrective action**

All bananas for export directly to Western Australia will be subjected to inspection for these thrips by the Philippines Bureau of Plant Industry (BPI) staff or their accredited agency staff.

Visual inspection of each lot will be undertaken using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of thrips are known to contaminate packaging materials.

The inspected sample must be free from these thrips.

Where any live thrips are found the lot must be subjected to an appropriate corrective action or rejected for export to Australia.

Only lots that pass the BPI/agency phytosanitary inspection may be presented for AQIS pre-clearance inspection.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of thrips are known to contaminate packaging materials.

Under pre-clearance arrangements AQIS would be involved in the supervision of all procedures.

AQIS will undertake a documentation compliance examination for consignments pre-cleared in the Philippines prior to their release from quarantine in Western Australia.

Under pre-clearance arrangements, 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.

### **19.7.2 On-arrival inspection and corrective action**

If requirements change in the future AQIS would perform 'on-arrival' visual inspection and corrective action. This section sets out the provisions that would apply to shipments that do not undergo pre-clearance.

Visual inspection by AQIS officers will be conducted upon arrival at the first international port of call in Western Australia.

AQIS will inspect each lot using standard 600-unit AQIS sampling procedures (to provide 95% confidence that there is not more than 0.5% infestation in the consignment). The sample size for inspection of bananas is 600 clusters selected randomly. Particular care will be taken with inspection of packaging, as some stages of thrips are known to contaminate packaging materials.

Corrective action when thrips are present is proposed as an appropriate risk management measure for this pest, given that trained inspectors can readily detect thrips.

Consignments inspected and found to be free of live thrips will not require further risk management measures to be applied.

When a consignment is found to be infested with live thrips at on-arrival inspection in Western Australia, one of the following risk management options must be applied:

- re-export of the consignment from Western Australia
- destruction of the consignment
- treatment of the consignment to ensure that the pest is no longer viable.

### **19.7.3 Risk management conclusion**

The objective of these measures is to ensure that consignments of mature hard green banana fruit from the Philippines infested with live thrips can be readily identified and subjected to appropriate corrective action. It is considered that these measures will reduce the risk associated with thrips to achieve Australia's ALOP

It was considered that these measures would reduce the probability of entry from **high** to **low** and the probability of entry, establishment and spread from **high** to **low**. When the adjusted value of PEES is combined with an overall consequence of **low**, the risk associated with thrips was considered to achieve Australia's ALOP.v

## 20. Risk management and draft operational framework

This chapter broadly addresses the export pathway sequence for mature hard green banana fruit from the plantation to packing arrangements, their transport, treatment, inspection and arrival in Australia including specific pest or disease procedures, as required. Individual pest risk analyses chapters in this report contain, where appropriate, examples of potential phytosanitary risk management measures presented as system approaches or phytosanitary risk management measures that would be implemented in line with existing policy. Some general administrative requirements upon which these phytosanitary risk management measures rely are also presented.

### 20.1 Introduction

Risk management measures were discussed in earlier chapters on each of the following pests that have an unrestricted risk exceeding Australia's ALOP:

- Moko
- black Sigatoka
- freckle
- armoured scales
- mealybugs
- spider mites
- thrips.

This chapter provides an overview of the proposed risk management measures and procedures to be implemented in the Philippines and Australia to reduce the quarantine risks associated with the importation of Philippine bananas to achieve Australia's ALOP. The systems that Australia would require the Philippine Bureau of Plant Industry (BPI) to implement include:

- registration of all plantations/blocks and packing stations wishing to export to Australia (including criteria for initial registration and for reinstatement following suspension)
- disease inspection and record keeping for each registered plantation/block
- maintaining standard horticultural and processing practices (including spraying, trash minimisation, and treatments for quarantine pests and diseases)
- inspections and audits at various points along the export pathway including cooperation with AQIS officers initially stationed in the Philippines to undertake audits and pre-clearance inspections
- phytosanitary documentation for consignments arriving in Australia.

This report recognises that critical failures may occur and immediate actions would be required to address these failures to meet Australia's requirements. The immediate actions to address the risks posed by critical failures will include one or more of the following, as appropriate for the identified risk situation:

1. exclusion of identified bananas from a bunch, plantation/block, lot or packing station from export to Australia
2. suspension of registration of identified plantation/block or packing station for export to Australia
3. suspension of all trade in Philippine bananas to Australia
4. immediate notification of the competent Australian quarantine authority (AQIS) by BPI that one or more of the actions 1–3 has been taken.

Prior to the implementation of any risk management measures identified, BPI would need to provide data, gathered through laboratory and/or field trials and under commercial conditions, on the efficacy

of proposed systems and processes for evaluation by AQIS and Biosecurity Australia. This particularly applies to the elements of the proposed systems approaches to mitigate the risks of introduction of Moko, black Sigatoka and freckle pathogens. It would also apply to disinfection and other corrective treatments.

## **20.2 General administration**

This section addresses the general administrative requirements for entry of Philippine mature hard green bananas to Australia including competent authority, registration, operations manual, work plan and audit.

### **20.2.1 Recognition of the competent authority and agency arrangements**

Under the IPPC, the BPI in the Philippines Department of Agriculture is the designated National Plant Protection Organization (NPPO) for the Philippines. BPI's responsibilities include inspection of plants and plant products moving in international trade, and the issuing of phytosanitary certificates relating to phytosanitary condition and origin of consignments of plants and plant products.

BPI must ensure that all service and certification standards and work plan procedures are met by all Philippine organisations and individuals registered to participate in this program.

BPI must also ensure the registration of all of its agents working on plantations and in packing stations with responsibility for providing appropriate assurance that BPI/AQIS requirements are met. It includes BPI ensuring that the agents are suitably trained and skilled, and have their work audited on a regular basis.

As part of its responsibilities BPI must ensure that administrative processes are established to provide assurance that the requirements of the program are being met.

For Australia, AQIS is the designated authority for quarantine operational matters and is responsible for pre-clearance and the clearance of imported consignments of plant products.

### **20.2.2 Operating manual, work plan and certification system**

It is a requirement that BPI, or the registered agency, prepares a documented standard operating procedure 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 achieving these requirements. The manual, work plan and certification system must all be approved by AQIS before exports can commence.

Operational components and the development of risk management procedures may be delegated by BPI to an accredited agent under an agency arrangement as appropriate (for example, through an accredited independent verification agency). This delegation must be approved by AQIS and will be subject to the requirements of the pre-clearance system. BPI will be responsible for auditing all delegated risk management procedures and making information available for AQIS audit, as required. All such work will also be subject to ongoing audit by AQIS.

AQIS will develop procedures for pre-clearance arrangements, inspection and audits.

Both the operating manual and work plan will be developed between AQIS and BPI following the finalisation of this IRA.

### **20.2.3 Registration of plantations/blocks and packing stations**

All plantations or blocks within plantations supplying bananas for export to Australia must be registered with BPI for the purpose of providing traceback and monitoring of field controls. Similarly,

all packing stations processing bananas for export to Australia need to be registered by BPI. Each export plantation/block and each packing station must be allocated a unique identification number by BPI. These unique identification numbers must enable traceback of consignments.

Exporters must notify BPI of their intention to register a plantation/block or a packing station, and provide sufficient detail to clearly identify the plantation/block boundaries and packing station location. For identification purposes a plantation/block or a packing station may be identified by maps or physical landmarks that can be used to define boundaries and location. Growers must retain copies of plantation/block or packing station descriptions/maps for audit purposes.

Export plantations/blocks must be registered before the start of export to Australia in time to allow the initial inspection to take place for the prevalence of Moko, black Sigatoka and freckle, and implementation of measures for trash minimisation.

Copies of plantation registration records must be made available to AQIS on request.

Growers/packing stations must have approved documented systems (including appropriate records) in place ensuring that bananas destined for Australia are harvested only from plantations/blocks that are registered for Australia.

Bananas for export to Australia must be clearly identified at all times post-harvest, including reference to the plantation/block registration number to allow traceback. Growers must ensure that bananas from registered plantations/blocks and destined for Australia are kept segregated from bananas from non-registered plantations/blocks at all times during the harvest, processing, packing and transport operations.

Growers must provide access to registered plantations/blocks for the purpose of monitoring/surveillance for compliance with the proposed export requirements. Similar arrangements are required for registered packing stations.

#### **20.2.4 Audit**

The Philippine operating manual and work plan on their production, processing and certification system will be 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 plantation registration, block identification, disease management/monitoring, records management and the administration of the areas of low pest prevalence and accreditation requirements.

Audits will be conducted to measure compliance, such as trash minimisation in registered plantations/blocks, packing station responsibilities, traceability, labelling, segregation and product security, BPI/agency inspection and certification processes and other procedures relevant to the identified quarantine pests.

Participants in BPI certification arrangements will be audited by AQIS to verify that requirements including the following continue to be met:

- There is an effective approved documented system in operation, including product identification and labelling at each facility to ensure that product inspected by BPI is kept separate from not-inspected products.
- The transport systems used must maintain the integrity of the inspected product if, at any time, the inspected product is moved,
- Appropriate records are maintained for all checked product in storage.

## 20.3 Plantation requirements

This section lists the requirements for plantations/blocks registered for export to Australia including, specification of commercial practices, conditions for areas of low pest prevalence, inspection of the plantation, fungicide treatments, bunch, pseudostem and peduncle inspections, trash minimisation and general requirements.

The general maintenance, including pest and disease monitoring and management, of banana export plantations in the Philippines with regard to pest and disease management is outlined in Section 7.2.2. Similar standard practice procedures are outlined for packing station operations in Section 7.2.4.

### 20.3.1 Standard commercial practice

This risk analysis and the proposed risk management measures are based on bananas produced under the nominated standard commercial production practices. Information provided by BPI on plantation and packing station practices and procedures, levels of pest infestation/infection in plantations and on banana fruit is largely based on data derived from commercial banana production systems used in the Philippines. Examples of relevant commercial production practices include the production and packing for export of bananas in mature hard green condition free of blemishes, and the maintenance of disease control programs for quarantine pests, including Moko, black Sigatoka and freckle. Where relevant, commercial production practices are discussed under specific pests.

BPI will ensure that all plantations registered for export to Australia are operating under standard commercial practices. Growers are responsible for maintaining adequate records relating to pest control and plantation monitoring, and spray diaries that confirm that the nominated standard commercial practices were used. These records are subject to AQIS audit.

### 20.3.2 Areas of low pest prevalence

The generic requirements for establishing that registered export plantations/blocks are areas of low pest prevalence are given below and these are followed by specific requirements for Moko, black Sigatoka and freckle:

- Registered plantations/blocks must have boundaries identified by precise grid or GPS references.
- Plantations/blocks must be inspected at a frequency to be determined by Australia and based on efficacy data derived by the Philippines from laboratory and/or field trials and under commercial conditions (for example, weekly) for symptoms of Moko, black Sigatoka and freckle.
- Growers are responsible for maintaining adequate records relating to regular disease control and plantation monitoring, and spray diaries that confirm that the nominated standard commercial practices were used. These records will be subject to AQIS audit.
- The low level of pest prevalence for Moko, black Sigatoka and freckle would be demonstrated at a frequency to be determined by Australia and based on efficacy data derived by the Philippines from laboratory and/or field trials and under commercial conditions (for example, weekly) by survey data over a minimum predetermined period for Moko, for black Sigatoka and for freckle for initial registration as well as re-registration of an export plantation/block.
- Pseudostems from which bunches are harvested must have a minimum of eight sound green leaves on the day of harvest. A sound green leaf is defined as one on which there is no yellow or dead tissue and its surface area has not been reduced by more than 10% as a result of pruning for leaf disease management. This measure provides for maintenance of disease control standards throughout the production cycle and therefore the minimisation of black Sigatoka infection in leaf trash.
- All bunches intended for export to Australia should be covered with non-perforated bunch covers. Bunch covers must be inspected weekly for damage and immediately replaced when damaged. Plantations must also record the replacement of damaged bunch covers with the system subject to



audit by AQIS.

- BPI must provide details of the proposed inspection methodology including an analysis showing that the proposed methodology will achieve the required efficacy in advance of commencement of exports. This analysis must address practical issues such as visibility of symptoms, the inspection time needed to meet the efficacy level and training and certification of inspectors. The proposed system will need to be approved and audited by AQIS before the commencement of trade.
- Plantation inspections must be undertaken by BPI or persons accredited by BPI. Accredited persons must be assessed and audited as being competent in the recognition of disease symptoms of concern in the field and may include BPI officers, agency staff, plant pathologists or other accredited persons. The accrediting authority must provide BPI with the documented criteria upon which accreditation is based and this must be available for audit by BPI and AQIS.
- BPI would regularly audit and verify the pest survey records and make this information available to AQIS on request.
- In the event that the pest prevalence exceeds the accepted level of low pest prevalence, the affected plantation/block will be suspended immediately from export to Australia.
- Reinstatement would require confirmation that the level of pest prevalence has been re-established following the application of risk management measures (for example, removal of infected mats for Moko, and leaf pruning and fungicide sprays for black Sigatoka and freckle), which is to be confirmed by inspection and test results over a predetermined period for Moko, for black Sigatoka, and for freckle.

### *Moko*

The areas of low pest prevalence for Moko must, in combination with visual inspection for discolouration of pseudostem and peduncle followed by corrective action, achieve Australia's ALOP ensuring that there are no more than 2.5 infected clusters per million imported clusters. The Philippines Government will be required to demonstrate, to Australia's satisfaction, that any proposed phytosanitary risk management measure, or a combination of measures, will effectively reduce the risk to a level acceptable to Australia. The efficacy of any proposed measures will need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

### *Black Sigatoka*

The areas of low pest prevalence for black Sigatoka must, in combination with trash minimisation and post harvest fungicide treatment, achieve the levels highlighted in Figure 10.2 (Section 10.19) to achieve Australia's ALOP. The Philippines Government will be required to demonstrate, to Australia's satisfaction, that any proposed phytosanitary risk management measures, or a combination of measures, will effectively reduce the risk to a level acceptable to Australia. The efficacy of any proposed measures will need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

### *Freckle*

The areas of low pest prevalence for freckle must, in combination with fungicide bunch spray, achieve Australia's ALOP ensuring no more than 7.5 infected clusters per one thousand clusters after fruit has been processed in the pack house. The Philippines Government will be required to demonstrate, to Australia's satisfaction, that any proposed phytosanitary risk management measures, or a combination of measures, will effectively reduce the risk to a level acceptable to Australia. The efficacy of any proposed measures will need to be demonstrated by laboratory and/or field trials and also under commercial conditions.

### **20.3.3 Visual inspection and corrective action for Moko in the plantation**

The requirements for visual inspection for discolouration of the pseudostem and peduncle in the plantation include that:

- All freshly cut pseudostems and peduncles must be examined by trained operators for signs of vascular discolouration at the time of harvest.
- The inspection regime will be done by inspectors who have the ability to detect visible symptoms of vascular discolouration with an effectiveness of 95% of all cases.
- Inspection of freshly cut cross-sections of pseudostems and peduncles at harvest and further inspection of fresh cuts to the peduncles at packing stations will be required to detect any vascular discolouration that could be symptomatic of Moko infection.
- All bunches showing vascular discolouration be removed from the export pathway in the field and in the packing station before de-handing commences.
- Records be maintained of all inspections of the pseudostems and the peduncle, including details of the numbers of bunches per registered plantation/block removed from the export pathway due to vascular discolouration. Records are regularly audited by BPI and made available to AQIS as required.

However, before exports can begin, BPI must provide details of the proposed inspection methodology including an analysis of the proposed inspection methodology showing that it will achieve the required efficacy. This analysis must address practical issues such as visibility of symptoms, 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.

### **20.3.4 Fungicide bunch sprays for freckle**

Fungicide bunch sprays must be applied in plantations/blocks at the time when bunch covers are fitted and at regular intervals thereafter consistent with the efficacy of any approved fungicide. This measure is intended to prevent late infections of fruit that could support the development of fungal fruiting bodies after passing quarantine inspection.

Before exports can begin, BPI must nominate a spray schedule and provide data on its efficacy in reducing the level of freckle infection on banana bunches. The effectiveness of the proposed systems approach must be demonstrated, to Australia's satisfaction, by laboratory and/or field trials and also under commercial conditions before commencement of exports. Trials would include inspection of fruit samples for freckle disease following incubation at optimal conditions for symptom expression.

Plantations must have a documented system approved by BPI for measuring and recording the application of the approved fungicides.

### **20.3.5 Trash minimisation for black Sigatoka**

Trash minimisation procedures are required in each registered plantation/block and packing station (see also 20.4.3) to eliminate primary sources of leaf and floral fragments associated with bunches of fruit during maturation and prior to harvest. Fruit presented for export must be free of trash by using the following:

- female flower remnants must be removed after fruit set
- the flag leaf must not be placed within bunch covers
- bunches must be covered and any damaged bunch covers must be immediately replaced
- bunches with visible trash or that fall to the ground during harvest must be rejected
- regular audits of trash minimisation procedures must be conducted by BPI and the results of these audits made available to AQIS as required.

### **20.3.6 General requirements for plantations**

All suspected symptoms of quarantinable diseases are to be reported by BPI to AQIS immediately. Suspected symptoms are to be verified by a BPI accredited plant pathologist for confirmation. All exports from a suspect plantation/block will be suspended until the symptoms are formally identified and appropriate corrective action has been taken.

BPI must immediately suspend exports from plantations/blocks found to be non-compliant and notify AQIS of the suspension. Suspended plantations/blocks may only be reinstated for processing of bananas for export to Australia when BPI and AQIS are satisfied that non-compliance issues have been adequately addressed.

## **20.4 Packing station requirements**

Philippine bananas harvested for export to Australia would require post-harvest management of pest and disease risks, the registered packing stations (both fixed and mobile) through which they pass must also comply with AQIS processing requirements. This section outlines the requirements for packing stations and subsequent storage and transport, including inspection, disinfection, prevention of contamination, labelling of lots, freedom from trash and further contamination during transport.

### **20.4.1 General requirements for packing stations**

All bananas for export to Australia must be processed at registered packing stations. Packing stations registered for export of bananas must source fruit only from plantations/blocks with current registration to export to Australia.

Each packing station must have an approved documented system for traceability, including record keeping of receipt receipts, plantation/block identification numbers, and storage, packing and load-out records.

The manager of the packing station will ensure that equipment and storage areas used for handling export bananas are clean and are free from quarantine pests, leaf or floral remnants or other regulated articles before being used to process export fruit.

Packing stations, including mobile packing stations, must provide details of the layout of the premises including storage areas and procedures for product segregation. Packing stations must also provide details of the equipment that will be used to comply with the fungicide or approved alternative dip requirements and for any disinfection treatments.

The packing station must maintain hygiene standards and weed control to reduce the potential contamination of harvested fruit. The bananas will be packed in clean new packaging. Fruit will be packed into polyethylene bags which are then placed into vented cartons. Cartons will be assembled immediately before packing.

BPI will inspect packing stations during the packing and storage of export bananas to monitor and verify that the necessary requirements are met, including measures to prevent contamination of fruit and packing materials with quarantine pests and other regulated articles.

BPI will conduct audit checks on approved packing stations to monitor the measures taken to prevent mixing or substitution of bananas not produced under Australian export conditions with bananas destined for export to Australia.

BPI must immediately suspend exports from packing stations found to be non-compliant and notify AQIS of the suspension. Suspended packing stations may only be reinstated for processing of bananas for export to Australia when BPI and AQIS are satisfied that non-compliance issues have been adequately addressed.

BPI must make available to AQIS, on request, information on its supervisory activities in relation to packing stations.

Bananas for other markets may be packed in conjunction with bananas for Australia provided that all bananas have been sourced from plantations/blocks which satisfy AQIS requirements. Bananas for Australia must remain separated from bananas from non-registered plantations/blocks at all times.

#### **20.4.2 Visual inspection and corrective action for Moko in the packing station**

The requirements for visual inspection for discolouration of the peduncle in the packing station are:

- All peduncles must be freshly cut and examined by trained operators for signs of vascular discolouration before de-handing.
- The inspection regime will be undertaken by inspectors who have the ability to detect visible symptoms of vascular discolouration with an effectiveness of 95% of all cases.
- All bunches of bananas from pseudostems that show signs of vascular discolouration, and/or show signs of vascular discolouration of the freshly cut peduncle, must be immediately removed from the export pathway in the packing station before de-handing commences.

#### **20.4.3 Trash minimisation for black Sigatoka**

Trash minimisation procedures are required in the plantation and in the packing station. The following trash minimisation practices must be followed in packing stations registered for export to Australia:

- All bunches of bananas must be washed with high pressure hose to remove extraneous plant material as far as practical.
- Every bunch of bananas must be inspected at the packing station for freedom from plant material, including rodent and bird nests and leaf and floral remnants. All affected bunches must be rejected or cleaned.

The efficacy of trash minimisation measures must be verified by inspection of at least 3000 processed clusters for extraneous leaf or floral material, prior to presentation to AQIS for pre-clearance inspection. If inspected after packing, all cartons in the inspection sample must be emptied and inspected for freedom from leaf and floral material.

#### **20.4.4 Post-harvest disinfection treatments for Moko and black Sigatoka**

The operational procedures below are applicable for any mandatory procedures such as a fungicidal dip for black Sigatoka. BPI will be required to nominate a post-harvest disinfection treatment for approval by AQIS and provide data on its efficacy in reducing the level of contamination of banana clusters with conidia and ascospores of the black Sigatoka fungus. BPI would need to demonstrate, to Australia's satisfaction, by laboratory and/or field trials and also under commercial conditions that the proposed measures achieve Australia's ALOP.

Packing stations must have a documented system approved by BPI for monitoring the application of any approved fungicide treatment. As part of this system, packing stations must have controls in place to limit the build-up in the treatment tank of extraneous organic matter, including plant matter, weeds, soil or any other material that would interfere with the treatment.

Packing stations must also have a documented system approved by BPI for the application of any approved disinfection agent. The treatments must be compatible, monitored for chemical stripping and top-up procedures must be specified and the operations audited by both BPI and AQIS.

#### **20.4.5 Prevention of contamination**

Procedures must be in place to prevent the contamination of the bananas after post harvest disinfection treatment.

Packing stations must ensure that all grading and packing equipment that comes in direct contact with bananas is cleaned and disinfected using an approved disinfectant immediately before each packing run for Australia. Maintenance of good hygiene on the packing line in the Philippines must be documented and subject to audit by BPI and AQIS.

#### **20.4.6 BPI supervised inspection**

All consignments of bananas for export to Australia will be inspected by BPI/agency prior to presentation to AQIS for pre-clearance.

##### *Sampling procedure*

Each consignment will be visually inspected at an inspection rate of 3000 clusters for the confirmation of compliance with Australia's requirements, including infestation and infection. A sample of 3000 clusters will be selected at random across the cartons comprising the whole consignment. All clusters of bananas will be inspected in each selected carton. Where the consignment comprises bananas from more than one lot, the inspection sample should be selected proportionally across all lots. A lot is one day's packing of bananas for despatch to Australia for each packing station. Where the lot comprises bananas from more than one registered plantation/block then the inspection sample should also be selected proportionally across all plantations/blocks.

The full inspection of all sampled clusters must be completed, regardless of the lot/consignment passing or failing.

BPI may choose to inspect samples of export bananas in the packing station or at the wharf, and may use a composite of samples drawn and inspected by its own officers, and by registered agents in the packing station to meet the total required sample size of inspecting 3000 clusters. This includes any BPI sample drawn to meet its phytosanitary certification requirements.

In the event that a composite sample is drawn, BPI must approve and regularly audit a formal written agreement with each packing station on how the composite sampling procedure will be implemented. AQIS will also be involved in the approval, supervision and audit of these arrangements.

##### *Inspection requirements*

The inspected fruit sample must be in mature hard green condition free from all symptoms of quarantinable diseases, arthropods and contaminants, trash including leaf and floral material, weed seeds, soil and other foreign matter.

Inspections must be conducted under adequate lighting (daylight or 600 lux at the point of examination) conditions. Particular attention must be given to the spaces between banana fingers. Each individual banana finger in the inspection sample cluster is to be examined. During inspection of packed fruit, all bananas are to be removed from the box and the empty box and packaging material examined for dislodged insects, trash including leaf and floral material, and contaminants.

Only lots/consignments that pass the BPI/agency inspection may be presented for AQIS pre-clearance inspection.

##### *Detection of pests and diseases*

The detection of bananas showing evidence of any quarantinable pest or disease within the inspection sample will result in the rejection of the entire lot/consignment for the Australian market. If the

lot/consignment is rejected because of the presence of symptoms of the quarantinable diseases Moko, black Sigatoka or freckle, all remaining bananas from the supplying plantation/block must be removed immediately from the export pathway to Australia and AQIS notified. The registration of the non-compliant plantation/block will also be suspended immediately from the Australian program.

Where inspection reveals the consignment of bananas is infested with a contaminant pest (refer to Chapter 8 of Part B) an appropriate AQIS approved corrective action must be applied.

Where bananas are infested with any live quarantinable arthropods the entire lot/consignment must be rejected. The rejected lot/consignment may be subjected to an appropriate, AQIS approved treatment and re-presented for inspection. Alternatively, when fruit from multiple plantations/blocks are present in one lot/consignment and only one registered plantation/block is found to be non-compliant then the lot/consignment can be reconfigured to remove fruit from the non-compliant plantation/block.

However, the entire newly configured lot/consignment must be re-inspected (that is, a new lot will be inspected at the appropriate inspection intensity) and found free from any live quarantinable arthropod including contaminant pests using a new sample of the same size as originally drawn.

If an organism is detected that has not been categorised previously, the movement of that consignment and any others from the same plantation/block will be suspended, and the registration of the plantation/block will also be suspended. BPI will identify the organism and consult AQIS to determine its quarantine status and if phytosanitary action is required.

The detection of any significant pest that has not previously been assessed or categorised in respect to their quarantine status for Australia, will result in the suspension of trade while a review is conducted to ensure that measures are implemented that continue to achieve Australia's ALOP.

#### *Identification and security*

Each consignment must be appropriately identified (for example, by pallet card numbers) on the accompanying phytosanitary certificate or Declaration of Intent (DOI).

Consignments that pass BPI/agency inspection must then be kept segregated from yet to be inspected product and product destined for other markets.

Failed lots must be identified with an appropriate label or sticker and kept separate from other passed product or product awaiting inspection. The inspection location must maintain records regarding the storage and movement/disposal of bananas rejected for the Australian market.

#### **20.4.7 Requirement for pre-clearance by AQIS**

It is proposed, at least for the initial trade, that the quarantine measures will be undertaken through a standard pre-clearance arrangement with AQIS officers in the Philippines being directly involved. The need for pre-clearance would be reassessed after experience had been gained following significant trade.

Under pre-clearance arrangements, AQIS officers would be involved in plantation inspections for Moko, black Sigatoka, freckle and other quarantine pests in direct verification of packing station procedures, and in fruit inspection. The fruit inspection would comprise checking 600 clusters of bananas from boxes chosen at random from each consignment. Inspection would cover the full range of measures to be applied to all export fruit bound for Australia.

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, quarantine procedures on arrival in Australia would provide verification that the consignment received was the consignment pre-cleared by AQIS and that the

integrity of the consignment had been maintained. This includes checking for any external and internal contamination of containers and their packaging.

#### **20.4.8 Adequate labelling of lots**

Identification of origin of fruit will be displayed on each carton – including plantation/block identification number (as per register), packing station 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 plantations/blocks and packing stations.

All pre-cleared product must be identified by pallet card number.

#### **20.4.9 Prevention of contamination in storage, transport and handling**

After inspection, packed fruit should be stored in approved premises free from quarantine pests or regulated articles, or be immediately loaded into shipping containers or onto vehicles and transported to the wharf.

All packed bananas that are not immediately transported to the wharf must be stored in BPI approved premises free from quarantine pests of concern to Australia.

Packed product and packaging is to be protected from pest contamination during and after packing, and during movement between locations (for example, by use of bulkheads, tarpaulins or shrink-wrap).

Banana fruit inspected and certified by BPI for export to Australia and pre-cleared by AQIS must be securely stored and segregated from fruit for other destinations or fruit not meeting AQIS requirements, to prevent cross-contamination.

Security of the consignment must be maintained until its release from quarantine in Australia.

Fruit must be transported in an enclosed unit or in covered packages to prevent contamination with quarantine pests.

If fruit is not containerised, palletised fruit at the wharf must 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, or while in another country, en route to Australia.

### **20.5 Auditing and compliance**

Where conditions for the importation of plants or plant products are developed as a result of an import risk analysis, it will generally be appropriate to specify as part of the conditions that permits will only be issued for importations from countries that have been specifically approved by the relevant Australia authorities.

This section of the report outlines the broad procedures by which Australian authorities would approve the Philippines' systems and procedures for the purposes of export bananas to Australia. Biosecurity Australia and AQIS will perform the initial systems review of the country's plant quarantine services. AQIS would undertake the plantation and pack house inspections and pre-clearance inspections as described below and would undertake subsequent audits of the Philippine plant quarantine service.

As bananas have not previously been exported to Australia, the Philippines banana production procedures and certification systems would be subject to a review by both AQIS and Biosecurity

Australia to ensure that the Philippines would meet Australia's requirements. This could include an on-ground assessment and an assessment of Philippines plant quarantine services.

The "systems review" process involves assessment of the Philippines banana production and certification systems to ensure that they are reliable and can deliver the risk management measures to the standard required by Australia under commercial conditions.

In addition to this "systems review" of the Philippines there is a requirement for assessment of particular export facilities (for example, pack houses and storage facilities). As stated above, these assessments would normally be undertaken by AQIS. Assessment of such facilities involves demonstration that the plantations and/or pack house has systems in place such as:

- suitable separation of product for export to Australia
- reliable compliance with minimum standard commercial practises for bananas in the Philippines
- auditable records of information required by AQIS, for example on the source of bananas, pack house records, and surveillance of plantations for pests and diseases by BPI inspectors
- controls to prevent post-packing contamination; and
- standards of hygienic construction and operation that provide equivalent quarantine safeguards to those provided by relevant Australian standards.

If approval is given for the Philippines to export bananas to Australia, AQIS will monitor the performance of the exporting country in relation to certification and compliance with import conditions through on ground audits and compliance checking and pre-clearance inspections. Detection of non-compliance would trigger suspension of trade and follow-up audit by appropriate Australian authorities. A suspension would be reviewed following a joint investigation by Biosecurity Australia, AQIS and BPI.

## **20.6 Requirements on arrival in Australia**

Each consignment of bananas arriving in Australia is subject to quarantine arrangements. This section lists these on arrival arrangements including phytosanitary certification, notification of non-compliance, import permit, quarantine entry, use of accredited personnel, document verification to assure that the integrity of the consignment has been maintained. It also includes the checking for any external and internal contamination of containers, their packaging and the treatment for pests, if required.

### **20.6.1 Inspection in Australia for regional freedom**

All consignments entering Australia will require evidence of pre-clearance for all pests of quarantine concern for the region where the port is located. Consignments released from quarantine at the port of entry and subsequently moved between regions will be subject to further inspection if they enter a region that has concerns about quarantine pests specific to that region.

Due to Western Australia's different pest and disease status, this will be the case for consignments moved to that state after entering Australia through ports not located in it. Such consignments will be subject to additional inspection in accordance with regional requirements and under the supervision of regional agency staff.



### **20.6.2 Phytosanitary certification**

BPI is to issue a phytosanitary certificate for each consignment after completion of its 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 station numbers, and registered plantation/block numbers
- additional declaration:

‘The bananas in this consignment have been produced in the Philippines in accordance with the conditions governing the entry of mature hard green banana fruit from the Philippines to Australia.’

### **20.6.3 Import permit**

A valid ‘Permit to import quarantine material’ is required which can be obtained from AQIS before importation. An importer or their agent must submit an ‘Application to Import Plant Materials – Horticultural Products’ to AQIS to obtain an import permit.

### **20.6.4 Quarantine entry**

A Quarantine entry application must be lodged with AQIS for import of consignments of mature hard green banana fruit from the Philippines. An importer or their agent or broker may lodge the Quarantine entry application.

### **20.6.5 Verification of documents, and inspection on arrival without AQIS pre-clearance in the Philippines**

It is proposed that, at least for initial trade, pre-clearance by AQIS be used (see above). However, this requirement may change in the future. This section sets out the provisions that would apply to shipments that do not undergo pre-clearance by AQIS. Their similarity to arrangements for pre-clearance is deliberate and reflects similar requirements to reduce quarantine risks for Australia from the import of Philippine bananas.

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 plantations/blocks and registered packing stations 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 options of re-export or destruction. AQIS would notify BPI 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 a registered plantation/block has been certified as meeting a level of pest prevalence (Moko, black Sigatoka and freckle) will result in the rejection of the consignment and the suspension of the plantation/block from supplying bananas for export to Australia. The consignment must be re-exported or destroyed. AQIS will notify BPI/agency of the rejection to facilitate suspension of the registered plantation/block.

Any trash detected will result in the consignment being rejected. Trash includes twigs, sticks, whole or parts of leaves and floral material (whether loose or attached to fruit), organic matter, grass, weeds, seeds and soil.

The detection in Australia of live quarantinable arthropods including contaminant pests (refer to Chapter 8) will require the consignment either to be treated, re-exported or destroyed.

Any banana fruit that is found not to be in mature hard green condition at the time of on-arrival inspection will result in the consignment being rejected.

If any pests are detected that have not previously been assessed or categorised in respect to their quarantine status for Australia, the consignment will be held. AQIS, in consultation with Biosecurity Australia, will determine the quarantine status of the pest and the appropriate action to be taken.

## **20.7 Review of import conditions**

AQIS may review operational procedures at any time and may, in consultation with BPI, suspend the importation of bananas, if deemed necessary because of phytosanitary considerations. A suspension would be reviewed following a joint AQIS, Biosecurity Australia and BPI investigation.

It is proposed that Biosecurity Australia and AQIS may consult with BPI, and may review the import requirements after the first year of trade. Further reviews will occur if circumstances or information warrant such action.

## 21. BRS Involvement

### **Summary of BRS audit and verification of the Philippines banana import risk analysis model — July-September 2008**

#### **Introduction**

Biosecurity Australia (BA) asked the Bureau of Rural Sciences (BRS) to audit the series of Microsoft Excel spreadsheets comprising the quantitative component of the Import Risk Analysis (IRA) for the importation of bananas from the Philippines. The IRA also includes a qualitative component to assess the likely consequences of any pest (including any disease) becoming established in Australia. BRS was not asked to consider the qualitative components (consequences) of the IRA as this was the responsibility of the IRA Team.

The quantitative component of the IRA estimates the probability of entry, establishment and spread (PEES) of a pest associated with imported bananas. It is implemented as a series of spreadsheet models—one for each pest and scenario—and is described in detail in the final IRA (*Final Import Risk Analysis Report for the Importation of Cavendish Bananas from the Philippines*).

#### ***Audit details***

The audit comprised two phases:

- Phase I: the spreadsheet models and the draft final IRA were checked in detail and the results reported to BA.
- Phase II: a revised set of workbooks and final IRA provided by BA were checked to verify that the recommended changes had been correctly implemented.

The first phase comprised three major components:

- *Review of the 'Factors' workbooks.* These workbooks contain several worksheets necessary for implementing preliminary calculations in the model(s).
- *Review of the 'Model' workbooks.* These workbooks simulate the model for each pest/scenario combination.
- *Review of the simulation results.* Independent simulation of the Model workbooks to confirm the accuracy of the workbooks.

The review of the Factors and Model workbooks consisted of checking the input values and calculations performed in those files against the values and logic laid out in the IRA.

Simulation results from the Model workbooks were independently replicated using a function to automate calculation of the model.

#### ***Audit results***

During Phase I of this audit BRS:

1. Concluded that the draft final IRA workbooks, with minor modifications, accurately reflected the values documented in the IRA.
2. Concluded that the simulation algorithms used by BA in the draft final IRA were sound. BRS independently replicated the algorithms and all results from the replication using the base version of the model converged to those contained in the BA Model worksheets.

3. Recommended modifications to the Factors workbooks and the inputs to one of the Model worksheets used in the draft final IRA. The modifications affected the estimate of the probability of entry, establishment and spread (PEES) for some Pest Risk Assessments.

Based on this recommendation (3) and the conclusions (1 and 2) concerning the draft final IRA, BA developed a revised set of workbooks and a final IRA report. BRS checked the revised workbooks and final IRA during a second phase.

Conclusions from Phase II were:

1. All required modifications were implemented in the workbooks.
2. The changes in outcomes recommended in Phase 1 were accurately reflected in the final IRA.
3. The final PEES values were verified by independent simulation.

#### *Assumptions and specific exclusions*

BRS did not check that all values calculated in the Factors workbook were correctly transcribed into the IRA. However, in all cases the final results in each worksheet of the Factors workbook were checked to ensure they are accurately recorded in the IRA and correctly entered into the PEES simulation worksheets.

Model components described in the IRA that affected calculation of the PEES were checked. Because much of the audit required hand-checking of the text of the IRA against worksheet cells, it is not possible to guarantee that all typographical discrepancies have been found.

Many of the values presented in the IRA reflect expert opinion. The BRS audit was not required to check the accuracy or validity of particular values chosen or specified as inputs to the model.

The model itself is the result of deliberations and research undertaken by the expert IRA Team. The BRS was not asked to check any aspects of the model itself for accuracy or validity; only that calculations in the workbooks used by the IRA Team accurately reflect the model as described in the IRA.

Bureau of Rural Sciences  
Canberra

November 2008

## **22. Further steps in the import risk analysis (IRA) process**

The administrative process adopted requires that the following steps be undertaken:

- consideration of appeals, if any
- if there are no appeals or the appeals are rejected, the recommended policy will be submitted to the Director of Animal and Plant Quarantine for a policy determination
- if an appeal is allowed the IRA Appeal Panel may advise the Chief Executive of Biosecurity Australia on how to overcome the identified deficiencies. When this process is completed the recommended policy will be submitted to the Director of Animal and Plant Quarantine for a policy determination
- notification of the proponent/applicant, registered stakeholders, and the WTO of the policy determination.

Stakeholders will be advised of any significant variations to this process.



## 23. Abbreviations and acronyms

<b>AABW</b>	Association of Australian Banana Wholesalers
<b>ABARE</b>	Australian Bureau of Agricultural and Research Economics
<b>ABGC</b>	Australian Banana Growers' Council
<b>ABS</b>	Australian Bureau of Statistics
<b>ABTV</b>	Abacá Bunchy Top Virus
<b>ACIAR</b>	Australian Centre for International Agricultural Research
<b>AFFA</b>	Agriculture, Fisheries and Forestry – Australia, now the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF)
<b>ALOP</b>	Appropriate Level of Protection
<b>ALPP</b>	Area of low pest prevalence
<b>ANBG</b>	Australian National Botanic Gardens
<b>APPD</b>	Australian Plant Pest Database (Plant Health Australia)
<b>APHIS</b>	United States Department of Agriculture's Animal and Plant Health Inspection Service
<b>AQIS</b>	Australian Quarantine and Inspection Service, an operating group within DAFF
<b>BA</b>	Biosecurity Australia, an operating group within the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF)
<b>BBrMV</b>	<i>Banana Bract Mosaic Virus</i>
<b>BBTV</b>	<i>Banana Bunchy Top Virus</i>
<b>BDB</b>	Blood Disease Bacterium
<b>BPI</b>	Bureau of Plant Industry (Philippines)
<b>BRS</b>	Bureau of Rural Sciences, an operating group within the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF)
<b>CABI</b>	CAB International, Wallingford, UK
<b>CEPM</b>	The Centre for Economic Policy Modelling
<b>CIE</b>	Commonwealth Institute of Entomology
<b>CMI</b>	Commonwealth Mycological Institute
<b>CMV</b>	<i>Cucumber Mosaic Virus</i>
<b>CSIRO</b>	Commonwealth Scientific and Industrial Research Organisation
<b>cv.</b>	cultivar
<b>DAFF</b>	Department of Agriculture, Fisheries and Forestry, formerly Agriculture, Fisheries and Forestry Australia (AFFA)
<b>DMAQ</b>	Domestic Market Access Quarantine Committee
<b>DNA</b>	Deoxyribonucleic acid; the molecule responsible for the transference of genetic characteristics

<b>E (1.00E–06)</b>	1x10 <sup>-6</sup> ; the E stands for exponent, used in specifying small numbers
<b>ELISA</b>	Enzyme-Linked Immunosorbent Assay
<b>EPPO</b>	European and Mediterranean Plant Protection Organization (see also OEPP)
<b>FAO</b>	Food and Agriculture Organization of the United Nations
<b>FSANZ</b>	Food Standards Australia New Zealand
<b>f. sp.</b>	<i>forma specialis</i> (plural: <i>formae speciales</i> )
<b>IAPSC</b>	InterAfrican Phytosanitary Council
<b>ICA</b>	Interstate Certification Arrangement
<b>IAEA</b>	International Atomic Energy Agency
<b>IJSB</b>	International Journal of Systematic Bacteriology
<b>IPGRI</b>	International Plant Genetic Resources Institute
<b>IPN</b>	Interstate Produce Number
<b>IPPC</b>	International Plant Protection Convention, as deposited in 1951 with FAO in Rome
<b>IRA</b>	Import Risk Analysis
<b>ISEM</b>	Immunosorbent Electron Microscopy
<b>ISPM</b>	International Standard for Phytosanitary Measures
<b>ITFNet</b>	International Tropical Fruits Network
<b>LGA</b>	Local Government Area
<b>MAF</b>	Ministry of Agriculture and Forestry, New Zealand
<b>MAFF</b>	Ministry of Agriculture Forestry and Fisheries, Japan
<b>MLG</b>	Multi Locus Genotype
<b>MOU</b>	Memorandum of Understanding
<b>µm</b>	micrometre/micron
<b>OEPP</b>	European and Mediterranean Plant Protection Organisation (also EPPO)
<b>OGS</b>	Office of the Government Statistician Queensland Government
<b>PBPM</b>	Plant Biosecurity Policy Memorandum
<b>PBGEA</b>	Pilipino Banana Growers and Exporters Association
<b>PCARRD</b>	Philippine Council for Agriculture, Forestry and Natural Resources, Research and Development
<b>PCR</b>	Polymerase Chain Reaction
<b>PEES</b>	Probability of Entry, Establishment and Spread
<b>PFA</b>	Pest Free Area
<b>PHA</b>	Plant Health Australia
<b>PIMC</b>	Primary Industries Ministerial Council
<b>PRA</b>	Pest Risk Analysis



<b>QAP</b>	quarantine approved premises
<b>QBAN</b>	Quality Banana Approved Nursery (QDPIF scheme)
<b>QDPI</b>	Queensland Department of Primary Industries, now Queensland Department of Primary Industries and Fisheries (QDPIF)
<b>RAP</b>	Risk Analysis Panel
<b>RDIRA</b>	Revised Draft Import Risk Analysis
<b>RFLP</b>	Restriction Fragment Length Polymorphism
<b>RMBG</b>	Royal Melbourne Botanic Gardens
<b>sp.</b>	species
<b>SPC</b>	Secretariat of the Pacific Community
<b>subsp.</b>	subspecies
<b>t</b>	tonne
<b>TWG</b>	Technical Working Group
<b>UNCTAD</b>	United Nations Conference on Trade Development
<b>USDA</b>	United States Department of Agriculture



## 24. List of terms

**abacá** – a species of banana (*Musa textilis*) that is grown almost exclusively in the Philippines; the fibre of which is processed to become manila rope. The abáca is also grown to some extent in Central America and Indonesia.

**abiotic** – relating to non-living objects, substances and processes (for example, geological, geographical and climatic factors).

**abscission** – the normal shedding from a plant of an organ that is mature or aged; for example, a ripe fruit, or an old leaf.

**acaricide** – an agent, usually chemical, used to kill mites.

**aedeagus** – a reproductive organ of male insects through which they secrete sperm from the testes during copulation with a female insect.

**aerial plankton** – the collective term for tiny organisms that are carried by wind currents. Examples of aerial plankton include spores, pollen, seeds, small insects and spiders.

**aestivate (also estivate)** – to pass the summer in a dormant or stagnant state.

**agrochemical** – a generic term for the various chemical products used in agriculture.

**alate** – winged form of an insect.

**allele** – in genetics, any one of a number of viable DNA codings occupying a given locus (position) on a chromosome. Usually alleles are DNA sequences that code for a gene.

**allopatric** – having separate and mutually exclusive areas of geographical distribution.

**amenity plant** – any plant located in a public place.

**amyloid** – insoluble fibrous protein aggregations sharing specific structural traits; usually part of a larger protein.

**anamorph** – the asexual form (also called the imperfect state) in the lifecycle of a fungus, when asexual conidia or spores are produced.

**andromorph** – female form which is similar to the male of the species.

**apoplast** – the intercellular spaces and cell walls of a plant; all the volume of a plant that is not occupied by protoplasm (the symplast).

**appressorium (plural: appressoria)** – a bulbous formation produced by fungi as a site of nutrient uptake from their hosts.

**apterous** – wingless.

**area** – an officially defined country, part of a country or all or parts of several countries (ISPM 5 (FAO 2006)).

**area of low pest prevalence (ALPP)** – an area, whether all of a country, part of a country, or all or parts of several countries, as identified by the competent authorities, in which a specific pest occurs at low levels and which is subject to effective surveillance, control or eradication measures (ISPM 5 (FAO 2006)).

**aroid** – the common name for members of the Araceae family of plants, sometimes known as the *Philodendron* or *Arum* family.

**arthropod** – the largest phylum of animals, including the insects, arachnids and crustaceans.

**ascoma** – an ascus-producing structure, ascocarp; a fruit-body containing asci.

**ascomycete** – any fungi that is a member of the Division Ascomycota (that is, fungi that produce spores in a distinctive type of microscopic sporangium called an ascus).

**ascospore** – a sexual spore produced in an ascus.

**ascus (plural: asci)** – the sac-like cell of the sexual state of a member of the Ascomycota in which the ascospores are produced.

**asymptomatic carrier host** – a host in which a root system is colonised by *R. solanacearum* without evidence of wilt (asymptomatic carrier host and tolerant host are equivalent).

**authority** – the National Plant Protection Organisation, or other entity or person officially designated by the government to deal with matters arising from the responsibilities set forth in the (ISPM 5 (FAO 2006)).

**axenic** – not contaminated by or associated with any other living organisms. Usually used in reference to pure cultures of microorganisms that are completely free of the presence of other organisms.

**axil** – the angle or point of divergence between the upper side of a branch, leaf or petiole, and the stem or branch from which it springs.

**bacterial ooze** – ooze refers to the opalescent to opaque mass of bacteria exuding from infected fruit, stems, petioles, peduncles or fruit stalks and other plant parts through natural openings such as stomata, hydathodes, lenticels or through wounds, in later stages of infection.

**Banana bract mosaic virus (BBrMV)** – a virus belonging to the family Potyviridae known to infect plants of the genus *Musa*.

**Banana bunchy top virus (BBTV)** – a virus belonging to the family Nanoviridae known to infect plants of the genus *Musa*.

**biocide** – any chemical substance capable of killing different forms of living organisms.

**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.

**biovar** – a group of related strains based on biochemical properties.

**biseriate** – arranged in two rows.

**bitunicate** – an ascus with a clearly differentiated inner and outer wall.

**black Sigatoka** – a leaf spot disease of bananas and plantains caused by the ascomycete fungus *Mycosphaerella fijiensis*.

**bract** – a modified or specialised leaf, from which the axil of a flower or flower stalk arises; or any leaf associated with an inflorescence.

**buffer zone** – an area in which a specific pest does not occur or occurs at a low level and is officially controlled, that either encloses or is adjacent to an infested area, an infested place of production, an area of low pest prevalence, a pest free area, a pest free place of production or a pest free production site, and in which phytosanitary measures are taken to prevent spread of the pest (ISPM 22 (FAO 2005a)).

**Bugtok** – local Philippine name for Moko disease on the cooking banana cultivars Saba (ABB) and Cardaba (BBB).

**bunch** – the total collection of fruit contained in an inflorescence, consisting of several banana hands.

**Cavendish** – the most commonly commercially traded dessert banana cultivar type.

**cfu (Colony-forming unit)** – a measure of viable bacterial or fungal numbers. Unlike in direct microscopic counts where all cells, dead and living, are counted, cfu measures viable cells per millilitre. Some bacteria do not separate completely during sample preparation and the results of the count will be below the number of individual cells using direct methods.

**chemical stripping** – the loss of an active constituent from a solution by which the solution becomes ineffective as a treatment.

**chloroplast** – organelle found in plant cells and eukaryotic algae that conducts photosynthesis.

**chlorotic** – producing insufficient chlorophyll (in regard to leaves/foilage).

**clade** – a group of organisms consisting of a single common ancestor and all the descendants of that ancestor.

**cluster** – a cut section of a harvested banana hand (of about 5–7 individual banana fruit) weighing about 1 kg.

**commodity** – a type of plant, plant product or other article being moved for trade or other purpose.

**conidiophore** – a simple or branched hypha bearing conidiogenous cells from which conidia are produced.

**conidiogenous** – relating to the physical structure of the conidiophores.

**conidium** – (plural: conidia) an asexual spore.

**contaminating pest** – a pest that is carried by a commodity and, in the case of plants and plant products, does not infest those plants or plant products (ISPM 5 (FAO 2006)).

**control (of a pest)** – suppression, containment or eradication of a pest population (ISPM 5 (FAO 2006)).

**controlled area** – a regulated area which an NPPO has determined to be the minimum necessary to prevent spread of a pest from a quarantine area (IPSM 5 (FAO 2006)).

**controlled waste** – waste disposed of in a controlled manner, using municipal garbage collection, to a municipal tip; this can also include package and commercial waste recycling.

**corm** – a short, vertical, swollen underground stem of a plant (usually in monocots) that serves as a storage organ enabling the plant to survive adverse conditions.

**cortex** – the outer portion of the stem or root of a plant.

**cosmopolitan pest** – any pest known to feed on a wide range of different hosts.

**crawler** – intermediate mobile nymph stage of certain arthropods.

**crenate** – scalloped or notched, specifically in regard to the appearance of cells that have contracted as a result of loss of water through osmosis.

**crozier** – the hook of an ascogenous hypha before ascus development.

**cryptic animal** – any animal that is able to avoid detection using camouflage, transparency or mimicry.

**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.

**day-degree** – the rate of development that occurs in 24 hours when the temperature is one degree above the development threshold.

**dehiscence** – the spontaneous opening at maturity of a plant structure, such as a fruit, to release its contents.

**detritivore** – are animals and plants that consume detritus (decomposing organic material), and in doing so contribute to decomposition and the recycling of nutrients.

**deutonymph** – the second of up to three nymphal stages in mites. In most cases the deutonymph molts to the adult stage.

**diapause** – period of suspended development/growth occurring in some insects, in which metabolism is decreased.

**Diaspidid** – belonging to the family Diaspididae (armoured scale insects).

**diploid** – the state of having each chromosome in two copies per nucleus or cell. A cell having two chromosome sets, or an individual having two chromosome sets in each of its cells.

**eclosion** – the emergence of an adult insect from its pupal case, or the hatching of an insect larva from an egg.

**ecosystem** – a dynamic complex of plant, animal and microorganism communities and their abiotic environment interacting as a functional unit (ISPM 5 (FAO 2006)).

**ecotype** – a group of organisms within a species adapted genetically to a particular habitat but able to cross freely with other organisms of the same species.

**efficacy (treatment)** – a defined, measurable and reproducible effect by a prescribed treatment (ISPM 5 (FAO 2006)).

**elytron** – (plural: elytra) a modified, hardened forewing of certain insect orders, notably beetles (Coleoptera) and true bugs (Hemiptera), that serves as protection for the hind wings underneath.

**endangered area** – an area where ecological factors favour the establishment of a pest whose presence in the area will result in economically important losses (ISPM 5 (FAO 2006)).

**endemic** – belonging to, native to, or prevalent in a particular geography, area or environment.

**endophytic (of a pest)** – describes internal colonisation (infection) of a plant including the fruit itself.

**enset** – one of three genera of plants in the Musaceae family, native to tropical regions of Africa and Asia.

**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 (FAO 2006)).

**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 colonisation (infestation) of the surface of a plant, including the fruit.

**eradication** – application of phytosanitary measures to eliminate a pest from an area (ISPM 5 (FAO 2006)).

**establishment (of a pest)** – the perpetuation, for the foreseeable future, of a pest within an area after entry (ISPM 5 (FAO 2006)).

**establishment potential** – likelihood of the establishment of a pest (ISPM 5 (FAO 2006)).

**exopolysaccharide** – a high molecular weight polymer that is composed of sugar residues and is secreted by a microorganism into the surrounding environment.

**exposure group** – a grouping of susceptible plants for which the likelihood of exposure and the impact of a pest are likely to be meaningfully different to that of other groupings. Exposure groups in this analysis are *commercial crops* (bananas and other susceptible crops), *home gardens* (that have susceptible plants), and *other plant communities* such as native, feral, abandoned or amenity plants growing on parkland, roadsides, farmland or bushland.

**exudation** – active secretion of fluid from cells as a result of disease or injury.

**exuviae** – the remains of an exoskeleton that is left after an arthropod has moulted.

**fascicle** – a dense cluster or bundle.

**fecundity** – the fertility of an organism.

**feral plant** – any plant that has escaped from domestication and returned, partly or wholly, to its wild state.

**finger** – an individual banana fruit.

**flagellum** – (plural: flagella) a thin whip-like filamentous appendage on cells, such as bacteria and protists that is responsible for locomotion.

**forma speciales** – a taxonomic grouping applied within a pathogenic species which defines variants in terms of host range.

**freckle** – a leaf and fruit spotting disease of bananas and plantains caused by the ascomycete fungus *Guignardia musae*.

**free from (of a consignment, field or place of production)** – without pests (or a specific pest) in numbers or quantities that can be detected by the application of phytosanitary procedures (ISPM 5 (FAO 2006)).

**fumigation** – application of a fumigant to a fumigation enclosure to eradicate pests (ISPM 5 (FAO 2006)).

**gamete** – the specialised germ cells that come together during fertilisation in organisms that reproduce sexually.

**geniculate** – bending abruptly on an obtuse angle.

**genotype** – the specific genetic makeup (or genome) of an individual organism.

**genus** – (plural: genera) 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, followed by a Latin adjective or epithet, to form the name of a species.

**germplasm** – plants intended for use in breeding or conservation programmes (ISPM 5 (FAO 2006)).

**globose** – globular or spherically-shaped.

**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.

**gravid** – carrying developing young or eggs.

**habitat** – part of an ecosystem with conditions in which an organism naturally occurs or can establish (ISPM 5 (FAO 2006)).

**haploid** – a cell having one set of chromosomes, which is the same as a gamete (pollen or egg cell).

**herbivore** – any organism that exclusively feeds on plant material.

**heterothallic** – a species having sexes that reside in different individuals.

**holomorph** – any fungus considered in its entirety, including all its morphs and phases.

**homothallic** – a botanical term used for groups whose individuals stem from sexual reproduction without the interaction of two differing thalli (or sexes).

**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 as a parasite (ISPM 5 (FAO 2006)).

**hyaline** – resembling glass, as in translucence or transparency; glassy.

**hydrophobic** – water repellent.

**hypergeometric distribution** – in probability theory and statistics, a discrete probability distribution that describes the number of successes in a sequence of n draws from a finite population without replacement.

**hyperplasia** – general term for an increase in the number of cells of an organ or tissue, causing it to increase in size.

**hypha** – (plural: hyphae) a long, branching filament that, along with other hyphae, forms the feeding thallus of a fungus, termed the mycelium.

**inamyloid** – not reacting in iodine-containing solutions such as Melzer's Reagent and therefore appearing yellow or hyaline.

**incursion** – an isolated population of a pest recently detected in an area, not known to be established, but expected to survive for the immediate future (ISPM 5 (FAO 2006)).

**indehiscent** – fruits which do not open spontaneously upon maturity and drying.

**infection** – the internal (endophytic) colonisation of a plant or plant organ, generally associated with the development of disease symptoms as the integrity of cells and/or biological processes are disrupted.

**infection court** – a suitable site in or on a host plant where infection can occur.

**infestation** – the 'epiphytic' colonisation of the surface of a plant, or plant organ, and is characterised by the absence of disease symptoms.

**infestation (of a commodity)** – presence in a commodity of a living pest of the plant or plant product concerned. Infestation includes infection (ISPM 5 (FAO 2006)).

**inflorescence** – a general term for a cluster of flowers on one plant. An inflorescence can be very loosely arranged, tightly bunched, or anything in between.

**inoculum** – pathogen or its parts, capable of causing infection when transferred to a favourable location.



**inspection** – official visual examination of plants, plant products or other regulated articles to determine if pests are present and/or determine compliance with phytosanitary regulations (ISPM 5 (FAO 2006)).

**instar** – a stage of insect larval development which is between two moults.

**Integrated Pest Management (IPM)** – integration of chemical means of pest control with other methods, notably biological control.

**interception (of a consignment)** – the refusal or controlled entry of an imported consignment due to failure to comply with phytosanitary regulations (ISPM 5 (FAO 2006)).

**interception (of a pest)** – the detection of a pest during inspection or testing of an imported consignment (ISPM 5 (FAO 2006)).

**International Plant Protection Convention (IPPC)** – International Plant Protection Convention, as deposited with FAO in Rome in 1951 and as subsequently amended.

**International Standard for Phytosanitary Measures (ISPM)** – an international standard adopted by the conference of FAO, the Interim Commission on phytosanitary measures or the Commission on phytosanitary measures, established under the IPPC.

**intrinsic** – anatomy (of certain muscles, nerves, etc) belonging to or lying within a given part.

**introduction (of a pest)** – the entry of a pest, resulting in its establishment (ISPM 5 (FAO 2006)).

**karyotype** – the complete set of all chromosomes of a cell of a living organism.

**keystone species** – any species that exerts great influence on an ecosystem, relative to its abundance.

**lag phase** – a state of apparent inactivity in a fungus preceding a response and following inoculation; also known as a latent phase.

**lamina** – the blade or expanded portion of a leaf.

**land-bridging** – the process by which containers are transported between major metropolitan cities by rail and road.

**larva** – (plural: larvae) a juvenile form of an animal undergoing metamorphosis (for example, insects or amphibians).

**latex** – a milky liquid in certain plants that coagulates on exposure to the air.

**latificer** – is a cell that has been specially modified to contain latex.

**lux** – a unit of illumination equal to one lumen per square metre; 0.0929 foot candle.

**mat** – the banana plant, including several suckers arising from a single rhizome.

**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.

**melanised** – darkened in colour (usually through the presence of pigmentation).

**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 (for example roots and shoots).

**mesophyll** – tissue located between the upper and lower layers of epidermis making up much of the interior of the leaf.

**metabolic sink** – any site of the plant that receives nutrients produced by the plant, thereby diverting the resource from the plant’s normal use.

**microorganism** – a protozoan, fungus, bacterium, virus or other microscopic self-replicating biotic entity (ISPM 5 (FAO 2006)).

**Moko** – a vascular wilt disease caused by the bacterium *Ralstonia solanacearum* race 2.

**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).

**monoecious** – a plant which bears both male and female flowers.

**monomorphic** – when genes or proteins in different individuals of a species are invariant.

**morbidity** – the prevalence and/or incidence of a particular disease.

**moribund** – approaching death, about to die.

**mortality** – the total number of organisms killed by a particular disease.

**mycelium** – (plural: mycelia) the vegetative body of a fungus, consisting of hyphae.

**Nearctic** – one of the eight terrestrial ecozones dividing the Earth's land surface. The Nearctic ecozone covers most of North America, including Greenland and the highlands of Mexico.

**necrotic** – denotes a dead cell or group of cells in contact with living cells.

**nematicide** – a type of chemical pesticide used to kill nematodes (phylum of worms).

**neotropic** – a terrestrial ecoregion which includes South America, Central America, and the Caribbean. It has distinct fauna and flora from the Nearctic because of its long separation from the northern continent.

**non-persistent transmission** – a type of transmission in which the pathogen is acquired by the vector after very short acquisition feeding times, and is transmitted during very short inoculation feeding periods. The vector remains viruliferous for only a short period unless it feeds again on an infected plant.

**nymph** – the immature form of some species that undergo incomplete metamorphosis. Its overall form is already that of an adult.

**obligate parasite** – an organism that can grow or reproduce only on or in a living host.

**official** – established, authorised or performed by a National Plant Protection Organisation (ISPM 5 (FAO 2006)).

**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 (FAO 2006)).

**omnivore** – an organism that consumes both plant and animal material.

**ostiole** – a small opening.

**oviposition** – the process of laying eggs by oviparous animals.

**ovoid** – oval; egg-shaped, with rounded base and apex.

**ovisac** – membranous capsule containing eggs.

**oviparous** – having offspring that develop within eggs, with little or no development within the mother.

**ovoviviparous** – having offspring that develop within eggs, that remain within the mother up until they hatch.

**Palaearctic** – one of the eight ecozones dividing the Earth surface. Physically, the Palaearctic is the largest ecozone. It includes the terrestrial ecoregions of Europe, Asia north of the Himalayan foothills, northern Africa, and the northern and central parts of the Arabian Peninsula.

**Panama disease** – a plant disease caused by the fungus *Fusarium oxysporum* f. sp. *cubense*.

**papillate** – bearing minute, rounded, nipple-like projections.

**parasitoid** – an insect that is parasitic only in its immature stages, killing its host in the process of its development, and free living as an adult (ISPM 5 (FAO 2006)).

**parenchyma** – thin-walled cells that make up the bulk of most non-woody structures, although sometimes their cell walls can be lignified.

**parthenogenesis** – the growth and development of an embryo or seed without fertilisation by a male gamete.

**parthenogenetic** – occurring or reproducing without the union of male and female cells.

**pathogen** – micro-organism causing disease (ISPM 5 (FAO 2006)).

**pathogenesis** – production and development of disease.

**pathotype** – a subspecific classification of a pathogen distinguished from others of the species by its pathogenicity on a specific host(s).

**pathway** – any means that allows the entry or spread of a pest (ISPM 5 (FAO 2006)).

**pedicel** – the stalk of a flower.

**peduncle** – a flower stalk, or stem.

**perithecium** – (plural: perithecia) a flask or jug-shaped fungal fruiting body that is slightly open at one end.

**persistent transmission** – describes situations in which a vector remains viruliferous and can continue to transmit an infection over many days, and in some cases, for weeks or months.

**pest** – any species, strain or biotype of plant, animal or pathogenic agent injurious to plants or plant products (ISPM 5 (FAO 2006)).

**pest categorisation** – the process for determining whether or not a pest has the characteristics of a quarantine pest or those of a regulated non-quarantine pest (ISPM 5 (FAO 2006)).

**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 (FAO 2006)).

**Pest Risk Analysis (PRA)** – 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.

**petiole** – the stalk of a leaf, attaching the blade to the stem.

**phenology** – the study of the times of recurring natural phenomena (for example, the date of emergence of leaves and flowers).

**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.

**phloem** – in vascular plants, the tissue that carries organic nutrients to all parts of the plant where needed.

**phototropism** – the tendency of plants to move or grow in the direction of most intense light.

**phylogenetic** – pertaining to the evolutionary history of a group or lineage, or the evolutionary relationships within and between taxonomic levels; the relationships of groups of organisms as reflected by their evolutionary history.

**phytophagous** – primarily feeding upon plants.

**phytosanitary measure** – any legislation, regulation or official procedure having the purpose of preventing the introduction and/or spread of quarantine pests, or to limit the economic impact of regulated non-quarantine pests (ISPM 5 (FAO 2006)).

**pili** – thread-like structures present on some bacteria; pili are shorter than flagella, and are used to hold bacteria to one another during mating and to adhere to cells.

**pistil** – the female reproductive organ of a flower, consisting of an ovary, style, and stigma.

**plantain** – starchy bananas used for cooking, as contrasted with dessert varieties eaten as fresh produce.

**plantation** – an area of bananas generally managed in a consistent manner by one owner or management unit. It may include several blocks planted at different times and have pests at different stages in their lifecycles.

**plantlet** – a young plant.

**polymerase** – an enzyme whose central function is associated with polymers of nucleic acids such as RNA and DNA.

**Polymerase Chain Reaction (PCR)** – a molecular biology technique for enzymatically replicating DNA without using a living organism such as *Escherichia coli* or yeast. This technique allows a small amount of the DNA molecule to be amplified many times, thus making DNA more available and analysis possible.

**polymorphic** – having more than two distinct morphological variants.

**polyphagous** – feeding on a relatively large number of host plants from different plant families.

**polyploid** – cells or organisms that contain more than two copies of each of their chromosomes.

**PRA area** – area in relation to which a pest risk analysis is conducted (ISPM 5 (FAO 2006)).

**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 (FAO 2006)).

**propagule** – a reproductive structure, eg a seed, a spore, or part of the vegetative body capable of independent growth if detached from the parent.

**prosoma** – the forward part of the body of some invertebrates, including molluscs, mites, and harvestmen, characterised by only rudimentary segmentation.

**protonymph** – the first of up to three nymphal stages found in mites. Normally the protonymph represents a free-living active stage; it is usually found on the same (or similar) substrate as the subsequent stage, but non-feeding protonymphs also occur.

**pseudostem** – the erect stem of the banana plant, composed of tightly packed leaf sheaths.

**pseudothecium** – (plural: pseudothecia) perithecium-like fruiting body containing asci and ascospores dispersed rather than in an organised hymenium.

**pupa** – (plural: pupae) 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).

**pycnidium** – (plural: pycnidia) asexual, globose or flask-shaped fruiting body of fungi producing conidia.

**quarantine** – official confinement of regulated articles for observation and research or for further inspection, testing and/or treatment (ISPM 5 (FAO 2006)).

**quarantine area** – an area within which a quarantine pest is present and being officially controlled (ISPM 5 (FAO 2006)).

**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 (FAO 2006)).

**quiescent** – inactive, latent or dormant.

**race** – (see also ecotype, pathotype) the ‘race’ classification conventionally refers to physiological races of a pathogen, particularly fungi, and characterises a specialised pathogen-host relationship to different cultivars within the same series of host plant.

**ratoon** – subsequent banana crops that follow after the harvest of the first crop of bananas.

**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 (FAO 2006)).

**Restriction Fragment Length Polymorphism (RFLP)** – a laboratory technique that uses differing nucleotide sequences of DNA molecules to compare them. The distance between the restriction sites varies between individuals; so the lengths of fragments vary, and thus the position of gel bands between individuals. This can be used to genetically distinguish between individuals.

**rhizome** – an underground horizontal stem of a plant that sends out roots and shoots from its nodes.

**rhizosphere** – the soil region in the immediate vicinity of plant roots.

**saprotroph** – an organism deriving its nourishment from dead organic matter.

**satellite virus** – a strain of virus unable to replicate except in the presence of a helper virus; considered to be deficient in coding for capsid formation.

**senescent** – having undergone ageing.

**sequevar** – a group of strains with a highly-conserved endoglucanase gene sequence.

**sessile** – botanical; without a stalk, as in flowers or leaves that grow directly from the stem, zoological; those organisms which are not able to move about.

**seta** – (plural: setae) (in plants and animals) a stiff hair or bristle-like part.

**solanaceous** – belonging to the flowering plant family Solanaceae, known informally as the nightshade or potato family.

**sound green leaf** – a leaf with a green petiole and at least 30% of the lamina still healthy (Allen et al 1992).

**spermagonium** – (plural: spermagonia) a cup-shaped cavity or receptacle in which the spermatia of certain lichens and fungi are produced; ie a pseudothecium.

**sporodochium** – (plural; sporodochia) a cushion-shaped spore-producing body of a fungus.

**sporulation** – the developmental process by which a fungal cell, amoeba, bacteria or protozoan becomes a spore. It is sometimes taken to include the release of spores into the environment.

**spread (of a pest)** – expansion of the geographical distribution of a pest within an area (ISPM 5 (FAO 2006)).

**spread potential (of a pest)** – likelihood of the spread of a pest.

**stages of symptom development (for black Sigatoka)** – Stage 1a (minute depigmentation on lower surface of leaf about 14-20 days after infection; Stage 1b (initial speck phase); stage 2 (first streak stage: conidiophores and spermogonia are produced from this stage onwards); Stage 3 (second streak stage); Stage 4 (first spot stage); Stage 5 (second spot stage); Stage 6 (third or mature spot stage) (after Fouré 1987).

**stakeholder** – 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.

**stele** – in a vascular plant, the central part of the root or stem containing the vascular tissue and occasionally a pith.

**stoma** – (also ‘stomate’) a tiny opening or pore, found mostly on the undersurface of a plant leaf, and used for gaseous exchange.

**stomatopodia** – a hyphal branch (an appressorium; cf hyphopodium) or ‘plug’ above or in a stoma.

**strain** – a group of organisms of the same species, having distinctive characteristics but not usually considered a separate breed or variety (for example; a superior strain of barley, a smooth strain of bacteria).

**stromatic** – relating to the connective supportive framework of a biological cell, tissue or organ.

**stylet** – a needle-like structure; a piercing mouthpart of sap sucking insects.

**subspecies** – (abbrev. ‘subsp’) a population of a species occupying a particular geographic area, or less commonly, a species of distinct habitat, capable of interbreeding with other populations of the same species.

**sucker** – a basal shoot of a plant that competes with the main stem.

**sympatric** – describing different species or populations that live in the same geographical area.

**symptomless** – without any visible indication of disease by reaction of the host, for example, canker, leaf spot, wilt.

**teleomorph** – the sexual stage in the lifecycle of a fungus; considered the perfect stage.

**thallus** – an undifferentiated vegetative tissue of some non-mobile organisms, including fungi.

**transgenic** – an experimentally produced organism in which DNA has been artificially introduced and incorporated into the organism’s germ line, usually by injecting the foreign DNA into the nucleus of a fertilized embryo.

**tolerant host** – a tolerant host is one in which the xylem vessels at the root level are colonised to high density but not the xylem vessels in the middle part of the stem. Wilting symptoms are usually absent (Asymptomatic carrier host and tolerant host are equivalent).

**trehalose** – a 1-alpha (disaccharide) sugar found extensively but not abundantly in nature. It is thought to be implicated in anhydrobiosis - the ability of plants and animals to withstand prolonged periods of desiccation.

**Triangular distribution** – a probability distribution which a triangular shape; the notation used is  $T(0.1, 0.2, 0.5)$  which denotes a triangular distribution with a lower limit of 0.1, an upper limit of 0.5 and a most likely value of 0.2.

**uncontrolled waste** – waste originating from consumers, wholesalers, retailers, food services and food processors that is not disposed of in a controlled manner (that is, in compost bins or heaps, rather than municipal waste facilities).

**Uniform distribution** – a probability distribution which is a uniformly spread over a specified range; the notation  $U(0.1, 0.2)$  is used for a uniform distribution with a lower limit of 0.1 and an upper limit of 0.2.

**utility point** – a key point at which bananas are distributed or utilised and at which banana waste will be generated; the five utility points in this analysis are wholesalers/ripeners; retailers; food processors/manufacturers; 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.

**viruliferous** – A term used to describe a vector that has acquired and carries a virus, and can transmit the virus to a healthy plant or other host.

**viviparous** – giving birth to live young.

**volunteer plant** – a plant that grows on its own, rather than as a result of being deliberately planted. Unlike weeds, which are unwanted plants, a volunteer plant may be encouraged to grow once it appears.

**weevil** – a beetle belonging to the family Curculionidae, with adults characterised by having an elongated, downwards curving snout.

**xylem** – the water conducting vessels that run from the roots to other parts of the plant.

**Zingiberales** – an Order of monocots, including bananas and ginger, also known as Cannales.





## 25. Reference list

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