Citrus industry biosecurity and incursion management (follows CT07026)

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Citrus Australia Limited

Project Number: CT10025

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Citrus Australia Ltd

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Statement of Purpose: The purpose of this report is to provide an overview of key activities and outcomes relating to methods to maintain and improve the health status of the Australian citrus industry through industry biosecurity and incursion management planning; awareness and response strategies; provision and use of high health status planting material; and, a commitment to industry sustainability and risk minimisation.

Funding Sources: This project was fully funded by citrus R&D levies through Horticulture Australia Ltd (HAL). The successful outcomes of the project were a result of collaboration between Citrus Australia, HAL and industry

Date of Report: 30 May 2013

Contents

Summary

The aim of this project is to ensure the citrus industry's high health / low pest and disease status is maintained by the maintenance and further development of the citrus industry biosecurity plan and incursion contingency plans; and maintaining biosecurity awareness by providing a national framework for citrus health by ensuring:

- The relevance of the PHA Plant Plan and Citrus Biosecurity Plan;
- The development of contingency plans for major exotic pests and diseases, with coordinated awareness, preparedness response and management strategies;
- The availability of high health status planting material and the development of an accreditation scheme for the use of high health status propagating material;
- Inputs into Import Risk Analyses;
- Inputs into endemic pest control e.g. fruit fly freedom, orange stem pitting; and,
- Strategic alliances with Plant Health Australia (PHA), DAFF, AQIS, state Departments of Primary Industries and other research bodies as required.

It is critical to the sustainability of the citrus industry that the Australian citrus industry's high health / low pest and disease status is maintained. This project continued to provide methods to maintain and improve the health status of the Australian citrus industry through industry biosecurity and incursion management planning; awareness and response to strategies; provision and use of high health status planting material; and, a commitment to industry sustainability and risk minimisation.

Through the project, Citrus Australia Ltd employed a part-time Technical Advisor, Pat Barkley (until September 2012) who assisted in the implementation of required strategies to achieve the desired outcomes of the project.

Activities included within this project, but not limited to, are:

- Continued involvement in citrus canker related activities
- Provide input into Auscitrus strategies and operations
- Market access technical meetings with Biosecurity Australia and AQIS
- Continued involvement in review of citrus industry Biosecurity Plan and Incursion Plans
- Biosecurity Australia meetings

- Plant Health Australia meetings
- Continued development of succession plan for citrus pathology
- National Fruit Fly Strategies
- Attend international workshop annually
- Communication through various mediums

In order to maintain these priorities, an ongoing commitment by the industry must be made to ensure that it has the ability and resources available to develop sound and effective management planning and implementation strategies.

Citrus Australia has worked in collaboration with Plant Health Australia (PHA) in developing a new project to ensure the ongoing implementation of these strategies. The project will be managed by PHA who will continue to work with industry on this high priority area.

Introduction

Citrus Australia Ltd is the peak industry body (PIB) representing Australian citrus growers.

Citrus is one of the largest horticultural industries and exporters in Australia with an estimated $540 million gross value of production and is one of the largest exporters of Australian fresh fruit with exports valued at approximately $190 million annually.

The key purpose of this project was to continue to provide methods to maintain and improve the health status of the Australian citrus industry through industry biosecurity and incursion management planning; awareness and response to strategies; provision and use of high health status planting material; and, a commitment to industry sustainability and risk minimisation.

Background

The project is underpinned by previous outcomes resulting from *CT01034 "Preparing for and managing incursions of citrus pests and disease"* and, *CT05022 and CT07026 "Citrus industry biosecurity and incursion management",* the outcomes of which included the development of:

- PHA Plant Plan
- PHA Citrus Biosecurity Plan
- Citrus Canker Contingency Plan prepared by DAFF
- Huanglongbing (HLB) Incursion Management Plan
- PHA Government and Plant Industry Cost Sharing Deed in respect of Emergency Plant Pest Responses
- Asian citrus psyllid bookmarks
- Citrus Canker / HLB Identification Guide
- Orchard Biosecurity Manual for the Citrus Industry: Reducing the risks of new pests entering and becoming established in your orchard – a manual for citrus growers (Version 1.0)

Methodology

The aim of this project is to ensure the citrus industry's high health / low pest and disease status is maintained by the maintenance and further development of the citrus industry biosecurity plan and incursion contingency plans; and maintaining biosecurity awareness by providing a national framework for citrus health by ensuring:

- The relevance of the PHA Plant Plan and Citrus Biosecurity Plan;

- The development of contingency plans for major exotic pests and diseases, with coordinated awareness, preparedness response and management strategies;
- The availability of high health status planting material and the development of an accreditation scheme for the use of high health status propagating material;
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It is critical to the sustainability of the citrus industry that the Australian citrus industry's high health / low pest and disease status is maintained. This project continued to provide methods to maintain and improve the health status of the Australian citrus industry through industry biosecurity and incursion management planning; awareness and response to strategies; provision and use of high health status planting material; and, a commitment to industry sustainability and risk minimisation.

Through the project, Citrus Australia Ltd employed a part-time Technical Advisor, Pat Barkley (until September 2012) who assisted in the implementation of required strategies to achieve the desired outcomes of the project.

Pat Barkley formally retired and resigned from this position on 11 September 2012 although continues in a volunteer capacity on the Horticulture Advisory Committee for the CRC Plant Biosecurity.

As this project was to be finalised in May 2013 a replacement resource was not sought however Citrus Australia worked closely with Plant Health Australia who have developed and submitted a new project proposal to continue the important work of this major priority for the citrus industry.

Activities included within this project, but not limited to, are:

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- Provide input into Auscitrus strategies and operations
- Market access technical meetings with Biosecurity Australia and AQIS
- Continued involvement in review of citrus industry Biosecurity Plan and Incursion Plans
- Biosecurity Australia meetings
- Plant Health Australia meetings
- Continued development of succession plan for citrus pathology

- National Fruit Fly Strategies
- Attend international workshop annually
- Communication through various mediums

Results

Key outcomes from the project are the continued development of effective management and implementation strategies that include:

- Prevention through effective quarantine measures
- Overseas intelligence to alert to new or unreported incursions and to newly identified pests
- Maintain grower and public awareness of exotic and endemic (e.g. fruit fly) pests and biosecurity measures to exclude them
- Sound scientific assessment of import risks
- Prevention through education of growers, nurserymen and general public
- Preparedness by sound contingency planning
- Active surveillance and early detection
- Early containment of initial outbreak(s)
- A rapid and easily implemented, adequately funded, eradication program
- Provision of high health status planting material through Auscitrus

Key Outcomes and Activities

The following provides an overview of the main project related activities that have contributed to the key outcomes during the course of the project.

Continued and ongoing activities

- Continued involvement in citrus canker related activities including review of canker contingency plan
- Continued review and update of HLB Incursion Management Plan
- Input into new biosecurity legislation
- Participation in teleconferences as required

- Provision of input into National Citrus Pathology Program
- Participation as an ex-officio member of the Citrus Industry Advisory Committee
- Participation as a member of the Variety Committee
- Participation in Citrus Industry R&D Plan review and development
- Preparation of articles for Australian Citrus News; papers and reports; and assisting with general enquiries as required
- Provision of technical advice on HLB, canker and susceptible varieties to researchers, government and industry

Major monthly activities

July 2010:	Visit by Technical Advisor, Pat Barkley to New Zealand including attendance and participation at various meetings and field trips and invited presenter on "Biosecurity in Citrus" at Global Citrus Conference, Cape Town, South Africa.
July & September 2010:	Attendance and participation of Technical Advisor, Pat Barkley at Plant Entry Quarantine meetings.
29 Nov to 1 Dec 2010:	Attendance and participation of Technical Advisor, Pat Barkley at National Citrus Pathology meeting in Mildura.
March 2011:	Attendance and participation of Technical Advisor, Pat Barkley at Plant Entry Quarantine meetings.
April 2011:	Attendance and participation of Technical Advisor, Pat Barkley at PHA EPPRD Pest Categorisation Meeting in Melbourne.
June 2011:	Attendance and participation of Technical Advisor, Pat Barkley at HAL Gene Technology Workshop in Sydney.
October 2011:	Attendance and participation of Technical Advisor, Pat Barkley at Fruit Fly Symposium in Sydney.
	Attendance and participation of Technical Advisor, Pat Barkley at PEPICC Meeting in Canberra.
February 2012:	Attendance and participation of Technical Advisor, Pat Barkley at Plant Biosecurity CRC meeting in Melbourne.

April 2012:	Attendance and participation of Technical Advisor, Pat Barkley at Auscitrus Risk Analysis meeting at EMAI in Sydney.
16 May 2012:	Attendance and participation of Technical Advisor, Pat Barkley in HAP Plant Biosecurity CRC meeting in Canberra.
July 2012:	Attendance and participation of Technical Advisor, Pat Barkley at HAP Plant Biosecurity CRC meeting in Melbourne.
	Attendance of Technical Advisor, Pat Barkley at DAFF meeting re new biosecurity legislation in Sydney.
	Attendance and participation of Technical Advisor, Pat Barkley and General Manager Market Development, Andrew Harty in Postharvest Disinfestation meeting in Melbourne.
September 2012:	Attendance and participation of Technical Advisor, Pat Barkley and General Manager Market Development, Andrew Harty at Citrus Pathology Workshop in Brisbane.
October 2012:	Attendance and participation of General Manager Market Development, Andrew Harty at HLB Workshop in Sydney (also attended by Pat Barkley).
	Development of biosecurity focus at Citrus Australia National Conference including organising HLB presentations by Florida's Mike Irey and UWS' Andrew Beattie.

Technology Transfer

Project results have been communicated through the following key mediums:

- Media Releases
- Industry bimonthly magazine, *Australian Citrus News*
- Industry website
- Printed materials including reports and fact sheets

Increasing Awareness

With the threat of exotic pests and diseases, biosecurity awareness has been a major priority for the industry.

The following is an example of some of the awareness material developed as part of the awareness program.

National Conference

The Citrus Australia National Conference held in Leeton, New South Wales in October 2012 included a biosecurity session titled *"Biosecurity – dealing with major threats to our industry"* that featured keynote speaker Mike Irey, United States Sugar Corporation and Southern Gardens Citrus, an expert of Florida's citrus crisis with Huanglongbing (HLB) and Professor Andrew Beattie, University of Western Sydney.

Mike Irey 'pulled no punches' when speaking on Florida's experience in dealing with HLB warning that if HLB did arrive in Australia it would be difficult to detect and would have already spread and stressed the importance of watching for the carrier of the disease, the Asian Citrus Psyllid to prevent HLB taking hold.

Andrew Beattie spoke on Australia's preparedness to deal with this major threat stressing that, despite our climate, we are still at risk.

Both presentations are available to download from the Citrus Australia website *(presentations from the 2012 National Conference)*.

Andrew Beattie & Mike Irey answer questions from delegates on HLB

Articles

The bimonthly industry publication *Australian Citrus News* is a key mechanism for promoting awareness and response strategies.

The following is an index of project related articles published in the industry publication *Australian Citrus News.*

EDITION	ARTICLE
Oct/Nov 2010	"Kimberly citrus grower recognised in national award" **Synopsis:** A passion for biosecurity was part of the driving force behind WA citrus and mango grower, Lachlan Dobson being awarded the Biosecurity Farmer of the Year in the plant category. Mr Dobson has long championed the cause for biosecurity in WA, and believes biosecurity is a whole of community issue. He helped develop the WA Banana Industry Biosecurity Plan and the OrdGuard Regional Biosecurity Plan of which he is now Chairman. He also supports research in the region as a PhD supervisor for two projects through Charles Sturt University in partnership with the Cooperative Research Centre for National Plant Biosecurity (CRC). He is a strong advocate of the work of the CRC. Plant Health Australia's Chief Executive Officer, Greg Fraser said one of Mr Dobson's contributions has been his approach to biosecurity as a whole of community issue.

Feb/Mar 2011	"New national committee tackles key variety improvement issues" **Synopsis:** A team of industry experts recently met at Dareton NSW, under the banner of Citrus Australia's newly formed Variety Committee. The Committee's first task was to define its operating objectives, under the over-arching goal of ensuring that the Australian industry has, at its disposal, world-class citrus germplasm. Two broad aims were immediately agreed upon: 1. Improved varieties and rootstocks will determine Australia's global competitiveness and the future prosperity of the industry. 2. The production base of the industry must be safeguarded from biosecurity threats which can occur during budwood importation and tree propagation.
June/July 2011	"Field trip seeks out latest information on post-entry quarantine and budwood indexing facilities" **Synopsis:** Sourcing critical funding to support the citrus industry's screenhouse repositories, which hold high health status citrus varieties, the need for mandatory certification to ensure the use of healthy budwood and seed and registration of citrus nurseries, were three issues discussed at a recent Variety Committee field trip. The Committee members met with Ausctirus and NSW DPI officers to seek out more information from AQIS on citrus imports.
	"Survey finds biosecurity is on the minds of citrus growers" **Synopsis:** A 2010 Farm Biosecurity Survey has found that Australia's citrus growers have a good comprehension of biosecurity and practices on their property. The survey, undertaken for the Farm Biosecurity Program – a campaign run by Animal Health Australiana and Plant Health Australia (PHA), aimed to improve awareness of the importance of early detection and reporting of pests, weeds and diseases, and practical information and tools to help growers boost on farm biosecurity standards.
Aug/Sep 2011	"QLD fruit fly could bring disaster" **Synopsis:** The tally of Queensland fruit fly (QFF) outbreaks across key citrus growing regions is escalating with industry experts labelling 2011 one of the "worst seasons on record". The Department of Primary Industries has been actively managing QFF outbreaks over winter and is stepping up the development of pest eradication strategies in preparation for the onset of warmer weather.

June/July 2012

"The war against Qfly"

Synopsis:
As the New South Wales and Victorian citrus regions brace themselves for more Queensland fruit fly outbreaks this spring, a newly formed committee in the Riverina is stepping up the fight to manage this serious pest.
Now for the first time, a new group known as the Riverina Biosecurity Committee, has brought together key horticulture stakeholders (including) citrus) to collectively take charge and construct a campaign that offers industry and growers a means of controlling the fly.

Aug/Sep 2012

"Riverina growers embrace fruit fly workshops"

Synopsis:
It was a triumphant turnout of more than 200 grower and industry representatives to the Riverina Biosecurity Committee's first lot of Queensland fruit fly (Qfly) workshops.
Nine meetings were held across the region showcasing the latest in fruit fly management.
The Committee distributed clear and concise brochures and posters which, were well received and, formed a useful summary of the Qfly campaign's key points.

"Arming Australia with the tools to fight citrus greening"

Synopsis:
The Asian citrus psyllid, *Diaphorina citri*, is wreaking havoc in Florida's citrus orchards. The insect also poses a real threat to the rest of the United States citrus industry, as it is a carrier of the devastating bacterial disease, huanglongbing (HLB) – commonly known as citrus greening.
In Australia, there is a real fear that the Asian citrus psyllid and HLB could also pose a threat to our industry. So what can we do to be prepared?
An expert on Florida's citrus crisis is Mike Irey, director of research at the United States Sugar Corporation and Southern Gardens Citrus. Mike is one of the keynote speakers at next month's Citrus Australia Conference.

Oct/Nov 2012

"Pathology experts plan priority projects"

Synopsis:
A team of central citrus pathology stakeholders met at a workshop in Brisbane to share the latest in technical information and start the groundwork for key R&D projects focusing on biosecurity preparedness, endemic rind blemish diseases and pathogen screening techniques that protect the industry's budwood.
The Australian citrus industry's recently launched *Research and Development Strategic Industry Plan* (*2012-17)* has put Biosecurity at the forefront of its four objectives.
Biosecurity projects, which involve updating contingency plans that deal with key threats, are of crucial importance.

R & D Plan 2012-17 Special Feature:

	Objective 3: Developing production practices that are cost effective & increase fruit yields. While promoting sustainability and biosecurity awareness. "Natural enemies arm-up in the battle to control citrus gall wasp" **Synopsis:** Citrus gall wasp (CGW) is a silent enemy that has slowly spread itself into the southern growing regions of Australia. While it does not have the alert status associated with diseases such as citrus greening, chemical control is difficult due to the nature of the insect. "Shielding the industry's genetic material" **Synopsis:** Dutifully protecting Australia's citrus genetic material is Auscitrus, a not-for-profit self-funding operation based at Dareton NSW that works to maintain the industry with a source of disease-free, true-to-type genetic material. Ultimately its aim is to protect the Australian industry from the spread of exotic and endemic graft transmitted diseases. While Australian nurseries are, for the most part, aware of the disease risks associated with citrus trees, there are several areas where a potential disease issue may sneak through, particularly when pressure is placed on the nursery to minimise the cost of their tree. "Two effective control methods joining the crusade against Qfly" **Synopsis:** The completion of a large research project addressing Sterile Insect Technique (SIT) has paved the way for significant improvements when using sterile insects in the fight against the Queensland fruit fly (Qfly). Coupled with this method, is a technique likely to provide more economic and effective management of Qfly populations as part of an Integrated Pest Management Program where the native fruit fly parasitoids are released in large numbers. "Compost - a two-fold affect in controlling Kelly's citrus thrips" **Synopsis:** Citrus growers looking to reduce their reliance on chemical products for plant nutrition and pest management will be pleasantly surprised by the outcomes of research into the use of compost in citrus production. Increased yield and fruit sizes, as well as reduced levels of Kelly's citrus thrips (KCT) are just some of the benefits observed by South Australian Research Development Institute (SARDI) entomologist, Dr Peter Crisp and colleague Greg Baker.
Dec 2012/Jan 2013	"Arming the orchard for HLB" **Synopsis:** Is Australia prepared for Huanglongbing (HLB)? This challenging question opened Citrus Australia's recent National Conference at Leeton in NSW. Speaking on the tough but important issue was Mike Irey, from Southern Gardens Citrus in Florida, who is a strong advocate of the control and prevention of HLB.

	Mike warned growers that if HLB did arrive in Australia it would be difficult to detect – and would already have spread. However, while delegates were very much alerted of the disease's ability to devastate an industry, Mike clearly outlined how Australian citrus growers could be prepared.
Feb/Mar 2013	"Qfly awareness – emerging in the Riverina" **Synopsis:** Riverina growers have made it through their first summer in the role of 'watchdogs' as they slowly take-up the challenge to fight Queensland fruit fly (Qfly) themselves. For many Riverina growers, it has taken time to adjust to managing the preventative work previously performed by the New South Wales Department of Primary Industries (NSW DPI) such as spraying, baiting, trapping and pest monitoring. The formation of Riverina Biosecurity Committee Incorporated – with representatives from the Leeton and Griffith Citrus grower groups, the Winegrapes Marketing Board and the Stone Fruit growers of the region (mostly prunes) – came to fruition in October when it was announced the group could be 'gifted' the majority of funds left over after the dissolution of Riverina Citrus. **Citrus learnings from Spain – *Feature Article on 12th ISC Congress held in Spain, November 2012*** "Pest and biosecurity profiles captured at congress" **Synopsis**: ***Fruit fly:*** Fruit flies are arguably the biggest pest group affecting citrus production and trade around the world, subsequently there were many presentations at the congress on the topic. There are 1043 known species, including 500 *Bactrocera* species which are related to our main harmful fruit fly, Queensland fruit fly (Qfly). The need to remove blanket agrichemical control of fruit flies around the word has led to more integrated control approaches, and Spain, is a good example. ***Managing the threat of Huanglongbing:*** Past International Society of Citriculture congresses have featured whatever major biosecurity threat was facing world citriculture at the time: blight, citrus canker, citrus tristeza virus, citrus variegated chlorosis and many other pathogens. While all of these still pose significant threats to citrus in many countries, they have paled in significance due to the onslaught of Huanglongbing (HLB). This bacterial disease is spread mainly by the vector Asian citrus psyllid (ACP), and devastates infected orchards in a very short time. The first major industry to be affected by HLB was Brazil in 2004, but Florida followed soon after in 2005.
Apr/May 2013	"How to change varieties – nursery tree selection" **Synopsis:** A critical decision point when developing an area of land for planting or replanting is what planting material to use. Selecting healthy planting material is critical to ensure maximum return on investment for the orchard's

	development. Many diseases can be invisible in an orchard situation and will only show-up on specific rootstock combinations or, through slow growth of nursery trees after planting. Even an apparently healthy orchard tree may have been recently infected with a dwarfing viroid, but has not shown symptoms as yet.

Website: Industry Updates/Resources

The Citrus Australia website hosts a number of industry media releases and updates as well as a comprehensive resource section on pest and diseases.

The following is an example of industry updates available on the website:

19-Dec-12: High health budwood "revolutionised" Spanish citrus industry

14-Dec-12: Backyard gardeners have fruit fly role

8-Dec-12: Citrus greening, a shared threat worldwide

8-Dec-12: Fruit fly in Riverland, committee's focus

8-Dec-12: Spain shows up Australia's 'lucky' side: a Queensland perspective

7-Nov-12: Fruit fly breakthrough "a giant leap" for citrus biosecurity

23-Oct-12: New appointment to address Riverina fruit fly control

22-Oct-12: Preparing to meet the citrus greening "test"

10-Oct-12: Arming Australia with the tools to fight citrus greening

26-Sep-12: Lessons from South Africa: controlling mealybugs

10-Sep-12: Citrus pathology workshop in Brisbane

10-Sep-12: Integrated Pest Management: the view from South Africa

31-Aug-12: Growers urged to take action on fruit fly now

27-Aug-12: More time needed for fruit fly decisions

27-Aug-12: Riverina fruit fly workshops prove popular

4-Apr-12: New fact sheet: Management of flooding and waterlogging in citrus orchards

Plant Health Australia

Citrus Australia is a member of Plant Health Australia (PHA) and a signatory to the Emergency Plant Pest Response Deed (EPPRD).

The citrus industry has worked collaboratively with PHA in the development of the PHA PLANTPLAN, Citrus Biosecurity Plan and Orchard Biosecurity Manual for the Citrus Industry as well as the development of awareness and training materials.

Stephen Dibley, PHA Program Manager conducted a *Biosecurity Awareness Workshop* for Citrus Australia directors and senior staff in Mildura Vic on 4 March 2013.

The workshop included an outline on the EPPRD; pest categorisation; owner reimbursement costs; cost sharing; and emergency response.

This workshop in addition to ongoing awareness and training sessions held by PHA around Australia as part of their National EPP Training Program enables industry to stay up to date on biosecurity awareness including roles and responsibilities under the EPPRD and response guidelines from PLANTPLAN.

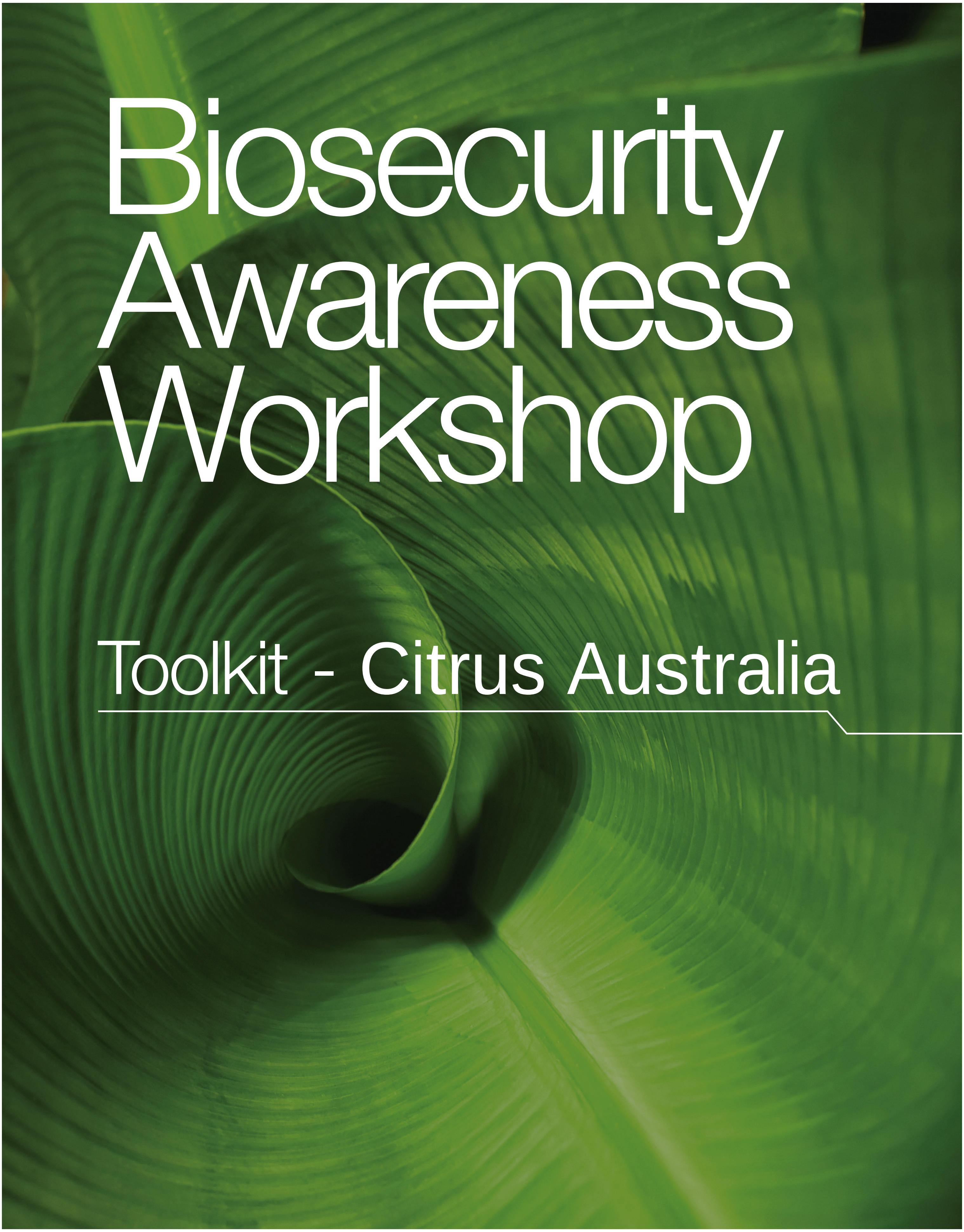
Conclusion and Recommendations

Biosecurity has been identified as a high priority for the Australian citrus industry. This project has played a major role in the development of targeted strategies including the development of materials to support an awareness program.

It is critical to the sustainability of the citrus industry that the Australian citrus industry's high health / low pest and disease status is maintained through continued industry biosecurity and incursion management planning; awareness and response to strategies; provision and use of high health status planting material; and, a commitment to industry sustainability and risk minimisation.

In order to maintain these priorities, an ongoing commitment by the industry must be made to ensure that it has the ability and resources available to develop sound and effective management planning and implementation strategies.

Citrus Australia has worked in collaboration with Plant Health Australia (PHA) in developing a new project to ensure the ongoing implementation of these strategies. The project will be managed by PHA who will continue to work with industry on this high priority area.



Biosecurity Awareness Workshop

Toolkit - Citrus Australia

Plant Health
AUSTRALIA

National EPP Training Program

To support our Members in their biosecurity preparedness, Plant Health Australia (PHA) delivers the *National EPP Training Program* to industry and government representatives, growers and other biosecurity stakeholders. Training can be tailored to representatives who may be involved in national decision making committees, such as the National Management Group and Consultative Committee, through to potential Industry Liaison Officers in the Local Pest Control Centre during an emergency response.

PHA delivers a range of training sessions, as described to the right. These vary in length from one hour to one day, and PHA is happy to come to you. To get the most out of this training program, PHA can tailor training to our Members' requirements, or run training in conjunction with, and support, other activities run by Members. We are also able to advise and support any other biosecurity training activities.

More information

This training is delivered at the invitation of our Members, both government and industry, with most covered as a core (subscription-funded) activity. Additionally, some of this training is available through the online training system, *BOLT*. This is open to anyone, and can be accessed through **www.phau.com.au/training**.

For further details or to discuss potential training options, contact Stephen Dibley at **sdibley@phau.com.au** or on 02 6215 7709.

Training Programs

Biosecurity Awareness Workshop

PHA's general biosecurity awareness workshop includes the roles and responsibilities of the Emergency Plant Pest Response Deed (EPPRD) signatories, specific response guidelines from PLANTPLAN and an overview of the plant biosecurity system. This can also include identification of risk mitigation activities and biosecurity planning.

Decision Making Committees

Information on the roles and requirements of the national decision making committees in an emergency response (specifically the National Management Group and the Consultative Committee on Emergency Plant Pests) is provided to participants in this session. This is relevant for both industry and government representatives.

Industry Liaison

During a pest emergency response, industry must provide representatives to provide industry liaison functions in control centers. This session provides an overview of the response arrangements and what will be required of industry liaison representatives.

On-farm General Biosecurity Awareness

This session provides information focusing on biosecurity best-practice for farm, orchard and plantation activities, and is based on content contained in PHA's farm biosecurity manuals.

PHA12-022

EPPRD Training

Citrus Australia

Mildura, Vic

March, 2013

Improving national biosecurity outcomes through partnerships

Plant Health AUSTRALIA

Session outline

Improving national biosecurity outcomes through partnerships

Plant Health Australia

Government members

Associate members

Industry members

Improving national biosecurity outcomes through partnerships

The Emergency Plant Pest Response Deed

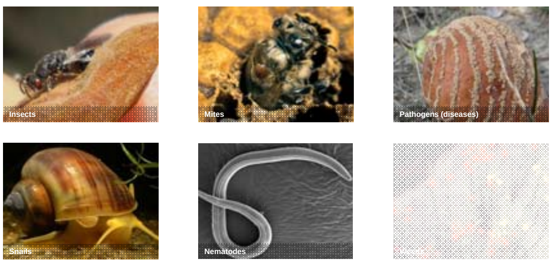
For a coordinated Emergency Plant Pest response with engagement from all Affected Parties

Improving national biosecurity outcomes through partnerships

Plant Health AUSTRALIA

Definition of a pest

All insects, mites, snails, nematodes, pathogens (diseases) and weeds that may harm plants, plant products or bees



* Not currently covered under the EPPRD

Improving national biosecurity outcomes through partnerships

Key principles of the EPPRD

- Mechanism to **facilitate rapid responses** to Emergency Plant Pests (EPPs)
  - Facilitate immediate reporting
  - Facilitate early response to an EPP
  - Parties who fund have a role decision making
  - Defined funding responsibilities
- Mechanism for agreed principles for proportional funding and an **agreed mechanism for Cost Sharing,** acknowledging
  - State/territory agencies responsibilities for managing responses
  - Need for goodwill and cooperation
  - Cost Sharing not intended for consequential losses

Improving national biosecurity outcomes through partnerships

EPPRD Signatories

Government members

Associate members

Industry members

When does the EPPRD operate?

- Operates for responses to **Emergency Plant Pests** (EPPs) with the view to **eradication**
- An **EPP*** is a plant pest that has a **nationally significant** impact (economic or environmental) and is also:
  1. A new pest to Australia
  2. A different variation or strain of established pest
  3. A previously unknown pest, or
  4. A confined or contained pest

* Summary only. Full definition Clause 1 of the EPPRD

Purpose of PLANTPLAN

Consistency and compatibility
- Management of EPP incursions
- Operations and procedures between governments and industries
- Emergency response plans

Improved technical validity
- Underlying assumptions in the development of strategies to respond to EPP incursions

Provide guidance
- Training operational personnel
- Development of SOPs for personnel in response management

Pest Categorisation

Who pays for the EPP response?

Who pays for eradication?

- Affected Industry and Government Parties **share** the costs based on the **Category** of the pest
- The Category is a measure of the **public versus private** good of eradicating an EPP
  - Determined by the **Categorisation Group**
- The Category of the pest is **NOT**:
  - A measure of the importance of the pest
  - Linked to the likelihood of eradication

vs.

Pest Categories

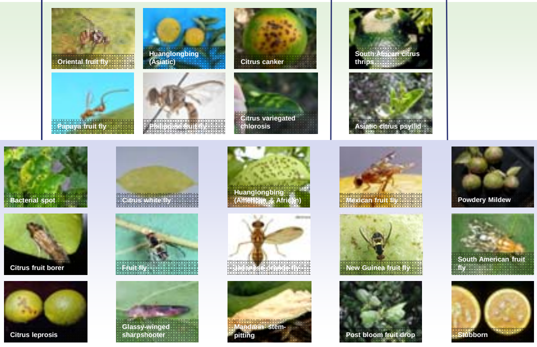
Public impact / Private impact

Category	Funding	Examples
Category 1	100% Government	Sudden oak death
Category 2	80% Government, 20% Industry	Khapra beetle
Category 3	50% Government, 50% Industry	Banana freckle
Category 4	20% Govt., 80% Industry	Variegated cutworm

Default

Citrus HPPs

Category 1	Category 2	Category 3	Category 4
100% Government	80% Government : 20% Industry	50% Government : 50% Industry	20% Government : 80% Industry



Owner Reimbursement Costs

Encouragement for growers to report suspicion plant pests

Improving national biosecurity outcomes through partnerships

Owner Reimbursement Costs

- Reimbursement to **owners** under the EPPRD
  - To encourage growers to **report** of suspect EPPs
- Relate to crops or other property that is **directly** damaged or destroyed as a result of implementing an NMG-approved **Response Plan**
- Payments made on an **agreed valuation** approach

ORCs – Orchard trees

ORCs may include:

- Loss of profit from the crop destroyed
- Direct additional costs
- Replacement of capital items
- Loss of profits from a fallow period
- Tree destruction costs
- Tree replanting costs
- Loss of profits during non-bearing period
- Stored product destroyed

Minus:

- Harvesting and other crop production costs

ORC Evidence Frameworks

Endorsed	Finalisation/Approval	Draft
Chestnuts *(orchard trees)*	Apple and pear	**Citrus**
Grains *(annual broadacre)*	Banana	Nursery
Honeybee *(bees and hives)*	Cherry	Olives
Macadamia *(orchard trees)*	Cotton	Vegetables
Sugarcane *(perennial broadacre)*	Pineapple	
Viticulture *(orchard trees)*	Strawberries	
	Walnuts	
	Almonds	
	Pistachios	

Cost Sharing

What is eligible for Cost Sharing in an EPP response?

Improving national biosecurity outcomes through partnerships

Response phases & Cost Sharing

Emergency response

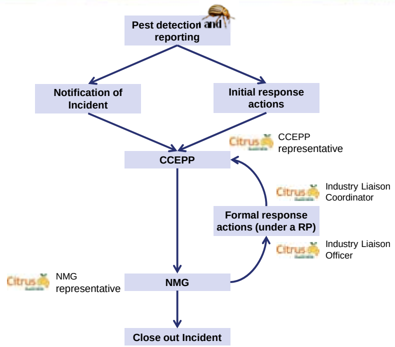
The role of Affected Industry Parties in an EPP emergency response

Confidentiality

- Confidentiality is **key factor** in meetings
- Confidentiality **Deed Poll must be signed**
  - Ideally signed prior to meeting
- Parties **must not** divulge or communicate confidential information, except:
  - To employees or representatives on strict need-to-know basis
  - To extent necessary to allow government party to report to parliament
  - As necessary to allow for conduct of legal proceedings
  - As required by law
  - **To aid in the implementation of the EPPRD**

CONFIDENTIAL

EPP emergency response



What is the CCEPP?

- Key **technical coordinating body** during EPP responses
- Membership of CCEPP
  - Chair (CPPO, DAFF)
  - CPHM of each state or territory
  - **Representatives from Affected Industry Parties**
  - Plant Health Australia
  - Members may be accompanied by advisors

NMG role and membership

- Has responsibility for the **key decisions**
- **Commits funding** to a response
- Each NMG is **Incident dependent**
  - Affected Industry Parties may vary

Organisation	Representative
Australian Government (Chair)	Secretary of DAFF
State/territory governments	CEOs
Affected Industry Parties	Presidents, Chairs or Authorised Officers
PHA (non-voting)	Chair
Observers	Advisors with specific expertise

Voting

- Members vote on **proposed Response Plan**
- Those that will, or may, **contribute to Shared Costs** have the right to vote

Organisation	Representative
Australian Government (Chair)	Secretary of DAFF
State/territory governments	CEOs
Affected Industry Parties	Presidents, Chairs or Authorised Officers
PHA (non-voting)	Chair

Decision making

Response Plan	Decisions by **consensus**

Consensus means in respect of a decision that none of those parties present when an issue is considered are opposed to the decision (although some entitled to be present may not be present and some may abstain)

Consensus means in respect of a decision to be taken on an issue, that none of those persons present when the decision is taken are opposed to it, although:
a) persons present during the discussion may have expressed contrary views;
b) achieving the consensus may have required a measure of compromise to ensure a workable outcome; and
c) some entitled to be present may not be present and some may abstain from participating in the decision.

Cost Sharing	Decisions must be **unanimous**

Unanimous means all Parties or persons entitled to vote on an issue have voted in the same fashion in respect of that issue

Industry Liaison

- "**On the ground**" industry involvement
- Consultation and **advice role**
- **Embedded** in control centres
- Good **communication** a key attribute

What's next?

General information	www.planthealthaustralia.com.au
Training	Stephen Dibley (02) 6215 7709 sdibley@phau.com.au
EPPRD	Susanna Driessen (02) 6215 7706 sdriessen@phau.com.au

Fact sheet

Plant Health AUSTRALIA

Categorisation

What is Categorisation?

The EPPRD specifies that, in the event of an EPP incursion, Affected Government and Industry Parties must share the cost of an approved Response Plan.

The relative share of the total cost of a Response Plan that will be covered by Government and Industry respectively is dependent on the relative public and private benefits that would be obtained from eradication of the EPP in question.

EPPs are assigned to one of four Categories, described below.

The Category of an EPP is a measure of public versus private benefits of eradication. And from that, the proportion of funding that must be contributed by Affected Government and Industry Parties in the event of an incursion.

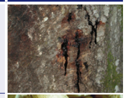
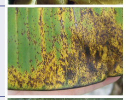
The Category of an EPP is not a measure of the importance of the pest nor is it indicative of the likelihood of eradication in the event of an incursion or the amount of effort that will be put into a Response.

What happens if an EPP has not been categorised prior to an incursion?

In the event of an incursion involving an uncategorised EPP, cost sharing between Affected Government and Industry Parties will commence at a 50:50 (Category 3) ratio until the EPP is formally Categorised.

A list of the current Categorised EPPs can be found in Schedule 13 of the EPPRD.

What are the four Categories?

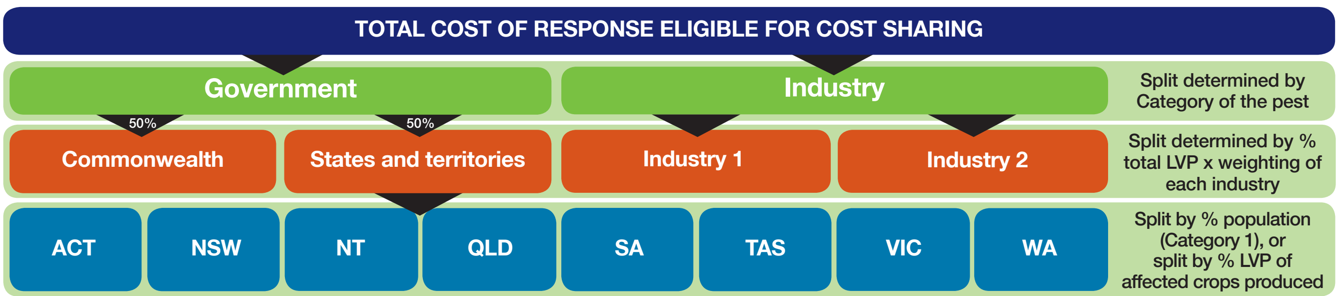
	CATEGORY	FUNDING	EXAMPLES	
Public Impact	Category 1	100% Government		Sudden oak death
	Category 2	80% Government : 20% Industry		Khapra beetle
	Category 3	50% Government : 50% Industry		Banana freckle
Private Impact	Category 4	20% Government : 80% Industry		Varigated cutworm

What is the Categorisation process?

The Categorisation process consists of two stages; determination of the Category by the Categorisation Group and approval by the Relevant Parties (those who will pay if there is an incursion). The Categorisation Group develops a recommendation on the Category of an EPP based on all available information and the decision must be made by consensus. The Relevant Parties must all agree before the EPP is formally Categorised and included in Schedule 13 of the EPPRD.

GLOSSARY	
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed
PCQ	Pest Categorisation Questionnaire

How much does each individual party pay?



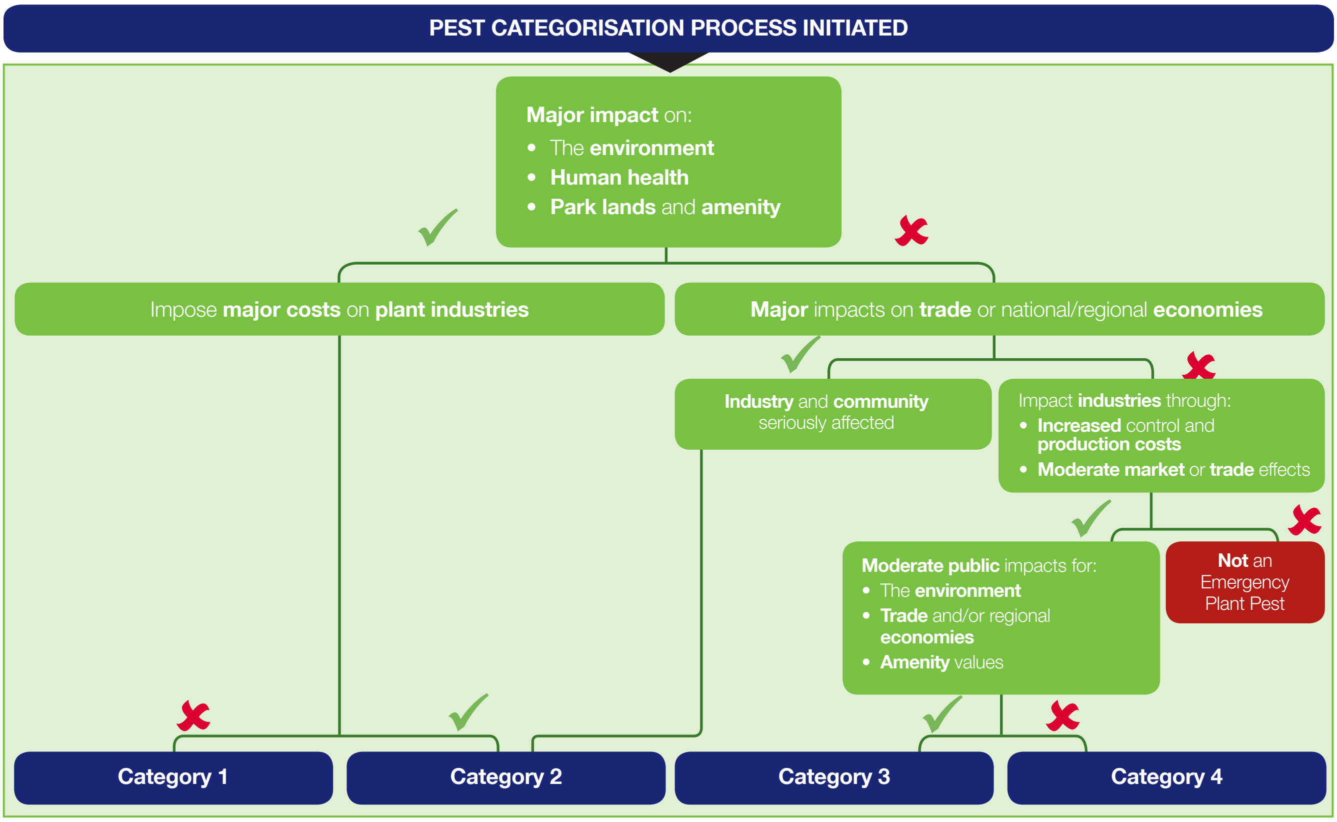
The PCQ consists of seven main questions supported by sub-questions, about the degree of impact the EPP is likely to have on productivity, product quality, production cost, economy and trade, environment and amenity values and human health in Australia.

PCQ results are compiled by Plant Health Australia and are included in the Categorisation Group deliberations. The Category for the EPP determined by the Categorisation Group is presented as a recommendation to the Relevant Parties (those who would pay if there was an incursion) for endorsement.

Who is in the Categorisation Group?

The Categorisation Group is made up of Industry and Government representatives with relevant technical expertise as well as representatives with relevant economic expertise. Plant Health Australia provides the Chair, Standing Member for Industry and the Secretariat roles for this Group.

Figure 1: *Pest Categorisation decision tree*



‘Affected’ Industry Parties

When is an Industry Party ‘Affected’?

In relation to an EPP, an Industry Party is ‘Affected’ if the Industry Party’s members’ Crops are or may be affected by the EPP.

Representatives of an Affected Industry Party sit on the CCEPP and are involved in the decision making process, under the EPPRD. Members of an Affected Industry Party are eligible for Owner Reimbursement Costs under the EPPRD, however, the Affected Industry Party is required to contribute to the costs of the implementation of the Response Plan (Cost Sharing).

The term ‘Affected’ **does not** include an Industry Party whose members are impacted by a Response Plan but not the EPP itself. These Industry Parties are, however, invited to the CCEPP Meetings but only in an observatory capacity and Members of such an Industry Party may still be eligible for Owner Reimbursement Costs under the EPPRD.

EPPs relating to bees

In the event of an Incident involving an EPP relating to Bees, in addition to the Australian Honey Bee Industry Council, an Industry Party is considered to be Affected if the Incident will or may affect pollination of the Crops of the members of that Industry Party.

GLOSSARY	
ABS	Australian Bureau of Statistics
CCEPP	Consultative Committee on Emergency Plant Pests
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed

Case Studies

As the disease progresses, older leaves die and form a skirt around the lower part of the plant

Jeff Daniells

Internal browning of stems and corms, the key diagnostic symptom of Panama disease infection

Jeff Daniells

Panama disease, Tropical race 4

Panama disease (also known as Fusarium wilt) is caused by the soil-borne fungus *Fusarium oxysporum* f. sp. *cubense*. It is considered to be the most destructive disease of banana in modern times. Tropical race 4 infects most banana varieties and is a serious threat to the Australian Cavendish banana Industry.

The Australian Banana Growers’ Council and Nursery and Garden Industry Australia will be Affected Industry Parties in the event of an Incident involving this EPP. The Affected Parties from a government perspective based on ABS data would be the governments of Australia, Queensland, New South Wales, Western Australia and the Northern Territory as those jurisdictions contain banana Industries.

Case Studies (continued)

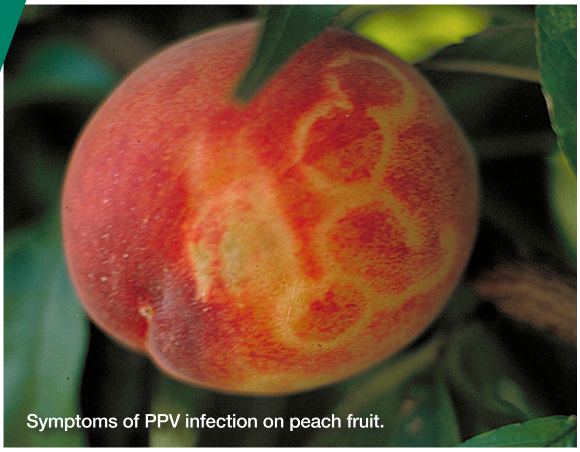
Plum pox virus

Plum pox virus (also known as Sharka) is caused by the *Plum pox virus* (*Potyvirus*) which is transmitted by the aphid vectors *Aphis spiraecola* and *Myzus persicae*, both of which are widespread throughout Australia. It is one of the most destructive diseases of stone fruits and has a very wide host range among Prunus species. Major hosts include apricots, nectarines, peaches, plums and cherries. Almonds can be infected with Plum pox virus, but show few, if any, natural symptoms.

In the event of an Incident involving this EPP, Summerfruit Australia, the Canned Fruit Industry Council, Cherry Growers of Australia, the Almond Board of Australia and Nursery and Garden Industry Australia will be Affected Industry Parties. The Affected Parties from a government perspective based on ABS data would be the governments of Australia, Queensland, New South Wales, Victoria, Tasmania, South Australia, Western Australia, the Northern Territory and the Australian Capital Territory as those jurisdictions contain stonefruit and/or almond Industries.

Myzus persicae winged adult.

European and Mediterranean Plant Protection Organization Archive, Bugwood.org



Symptoms of PPV infection on peach fruit.

European and Mediterranean Plant Protection Organization Archive, Bugwood.org

PHA11-053

What is the CCEPP?

The CCEPP is a technical group made up of the Australian Chief Plant Protection Officer (Chair), the Chief Plant Health Mangers of each state and territory, the Industry Party Affected by an incursion and Plant Health Australia. Additionally, any Industry Party that may be affected by the implementation of the Response Plan is also invited to attend the CCEPP but does not have any decision making rights. The Terms of Reference of the CCEPP are stipulated in the EPPRD but simply, it has primary responsibility for co-ordinating the national technical response to EPPs and advising the NMG on EPP issues in accordance with the EPPRD.

After detection of a known or suspect EPP, CCEPP meets and, based on the information available, they determine the feasibility of eradication and make a recommendation to the NMG. In making this recommendation, they consider:

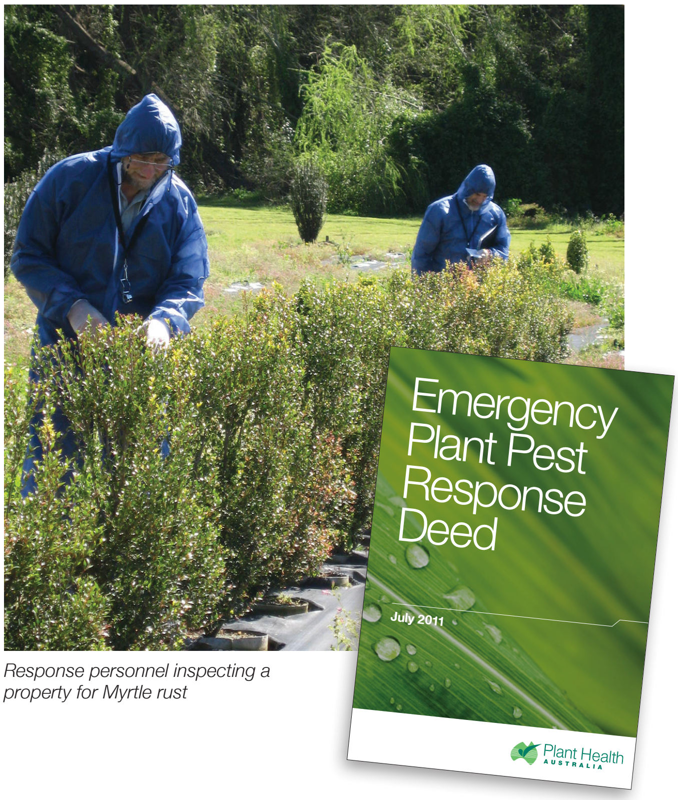
- technical feasibility
- likelihood of success
- costs but not decisions about the funding of the Response Plan and overall benefits of eradication
- predicted impact (economic, production, environmental and social) of the incursion if unrestricted

GLOSSARY	
CCEPP	Consultative Committee on Emergency Plant Pests
DAFF	Department of Agriculture, Fisheries and Forestry
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed
NMG	National Management Group
SAP	Scientific Advisory Panel

If insufficient technical information is available, the CCEPP may form a SAP to advise them on specific scientific issues to assist them in formulating a recommendation.

During an eradication campaign, the CCEPP oversee the preparation and implementation of the Response Plan. The CCEPP also advise the NMG when the EPP has been eradicated and when proof of freedom has been achieved.

At any stage of the incursion, the CCEPP may decide that eradication cannot be justified and will recommend to the NMG that eradication should either not be attempted or should cease. In the latter situation, the CCEPP should also provide advice to the NMG on when Cost Sharing should no longer apply and on alternative management options.



Response personnel inspecting a property for Myrtle rust

What is the NMG?

The NMG is a policy group made up of the Secretary of DAFF (Chair), the CEOs of each of the state and territory Agriculture departments, the Chair or President of the Industry Party Affected and the Chair of Plant Health Australia. Importantly, only those Parties participating in Cost Sharing have a vote at the NMG though all attendees can participate in the discussions. For example, in the case of an EPP of bananas, only those states and territories in which bananas are grown will participate in cost sharing and therefore have a vote at the NMG. The Terms of Reference of the NMG are stipulated in the EPPRD but simply, it has primary responsibility for the making of decisions with regards to an eradication campaign.

After receiving a recommendation from the CCEPP, the NMG makes a decision on further action.

If the NMG decides to proceed with the eradication campaign, a Response Plan identifying the required resources and costs involved will be developed and submitted to the NMG by the CCEPP for approval.

The EPPRD includes Agreed Limits for expenditure on eradication campaigns based on the national farm gate value of the Industry/ies involved. The NMG reviews the eradication campaign throughout its operation to ensure that the program is on track from technical and financial perspectives.

Based on advice from the CCEPP, the NMG determines and declares if a EPP has been successfully eradicated or, is unable to be successfully eradicated. If an EPP cannot be eradicated, the NMG may also make a decision regarding another course of action, like transition to long term management.

What is a SAP?

The CCEPP may appoint a SAP to provide technical information and recommendations to assist with various decision making processes. The terms of reference of the SAP are the specific questions that the CCEPP requests them to answer. The members of the SAP may change throughout an eradication campaign as different questions may need to be answered at different times. Issues the SAP may be asked to address could relate to pest biology, diagnostic methods, surveillance methodologies and pest epidemiology as well as any suggest Emergency Containment options that could be incorporated into the Response Plan.

PHA11-053

PLANTPLAN

INVESTIGATION PHASE

A pest is detected and reported to the Chief Plant Health Manager of the state/territory agriculture department

The process of identification is initiated and the relevant people and organisations are notified of the suspected detection

ALERT PHASE

Identification of the EPP is confirmed, the CPPO is notified, and the outbreak is declared

The CPPO notifies Affected Parties from Government and Industry and convenes a meeting of the CCEPP

The CCEPP determines the feasibility of eradication and makes a recommendation to the NMG

The CPPO notifies Affected Parties from Government and Industry and convenes a meeting of the CCEPP

If the NMG decides to proceed with eradication, the CCEPP will oversee the preparation of an EPP Response Plan by the Lead Agency(s). The resource requirements needed to implement the response and costs for the eradication program will be identified

The NMG will approve the EPP Response Plan and national cost sharing arrangements to fund the response

OPERATIONAL PHASE

The Lead Agency(s) in the state(s)/territory(s) in which the incursion occurs will implement and manage the EPP Response Plan overseen by the CCEPP

The Lead Agency(s) will provide regular reports to the CCEPP on the progress of the campaign

If relevant, a SAP will evaluate the effectiveness of the response and its implementation

STAND DOWN PHASE

After the coordinated response is complete or if a review determines that eradication is not feasible, records of expenditure and technical reports are provided to Plant Health Australia so that final costs can be calculated

As a provision of the EPPRD, all signatories are required to use PLANTPLAN, a technical Response Plan that describes the Australian approach to responding to EPP incursions. The procedures, roles and responsibilities described in PLANTPLAN are generic for all plant pest emergencies.

PLANTPLAN describes four phases of response to an EPP incursion (see diagram left).

GLOSSARY

CCEPP	Consultative Committee on Emergency Plant Pests
CPPO	Chief Plant Protection Officer
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed
Lead Agency	the agency leading the Response Plan as the Incursion is within their jurisdiction
NMG	National Management Group
SAP	Scientific Advisory Panel

PHA's Biosecurity Online Training

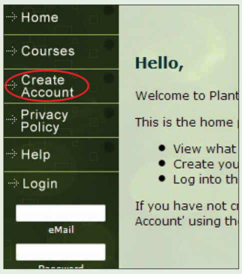
Plant Health Australia's *Biosecurity Online Training (BOLT)* system provides free access to e-learning courses related to plant biosecurity to all stakeholders. Currently there are two courses available:

- **Foundation** – a summary of the plant biosecurity system and the Emergency Plant Pest Response Deed
- **Reporting a suspect Emergency Plant Pest** – when and how to report a new plant pest

To access *BOLT*, visit the PHA training page **www.phau.com.au/training** and follow the prompts.

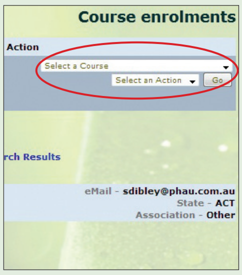
① Creating your account

- On the *BOLT* homepage, click on "Create Account" in the left hand sidebar
- Follow the instructions on screen, fill in the information requested, then press "Submit"
- Once you have created your account, login to the system



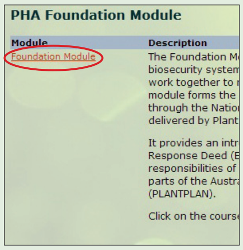
② Enrolling in courses

- Login to *BOLT*
- Click on "Course Enrolment" in the left hand sidebar
- Select the course you want to enrol in from the drop down menu at the top right, "Enrol" from the drop down menu below and click the "Go" button to complete
- You will be enrolled in the course without seeing any changes on screen
- Repeat with other courses if you wish



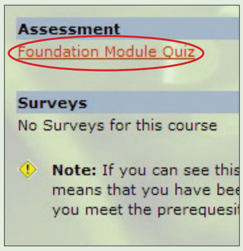
③ Accessing the course content

- Click "Courses" on the left hand sidebar
- You will only see the courses you are enrolled in
- Enter the relevant course home page by clicking on its title
- From the course homepage you can access the content by clicking the course title, which will open in a new window or tab in your browser



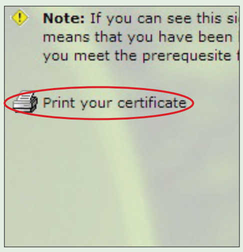
④ Attempting the quiz

- Return to the course homepage (as above)
- Enter the quiz by clicking the link under the "Assessment" heading
- Answer the questions by selecting the checkbox next to the appropriate answer, and then hit "Submit"
- The results of the quiz will then be presented, including whether you have passed the assessment
- Click "Continue" link to return to the courses page



⑤ Completing the course

Following the successful completion of the quiz, you will be able to generate a certificate of completion by clicking on the printer icon labelled "Print your certificate" at the bottom of the courses page.



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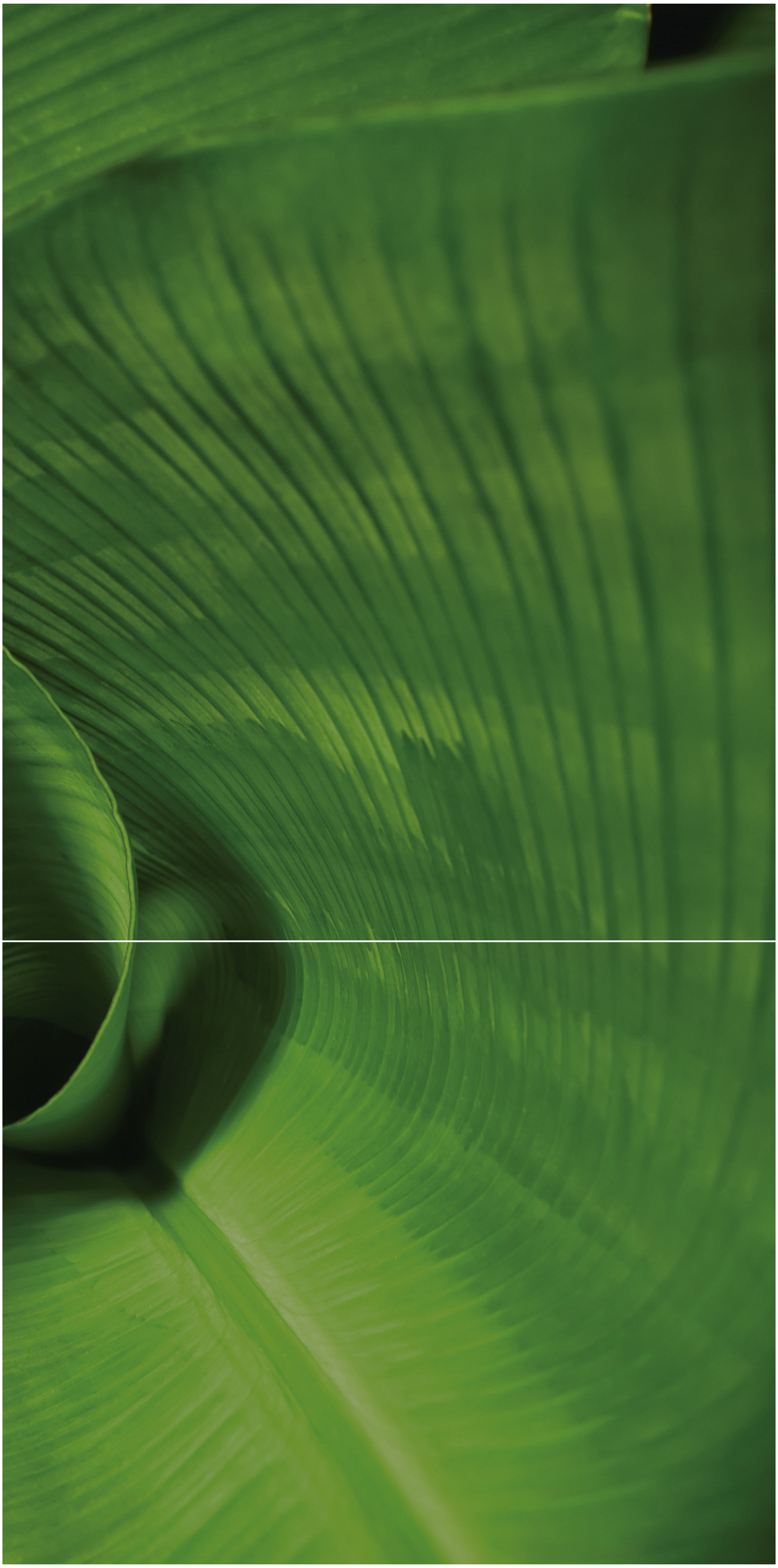
Have you spotted anything unusual?

EXOTIC PLANT PEST HOTLINE
1800 084 881



Plant Health AUSTRALIA

Achieving national biosecurity outcomes through partnerships

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PHA09-017

Model-based search strategies for plant diseases: a case-study using citrus canker (*Xanthomonas citri*)

RH: Incorporating risk when developing search strategies

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Journal: Diversity and Distributions

Special Issue: Innovations in Risk Assessment for Conservation

Date: 29th March 2012

ABSTRACT:

Aim: The main aim of biosecurity emergency response to an incursion is to achieve pest- or disease-free status as quickly as possible. Usually, this involves tracing known movements (trace events) to and from an infected or infested property (IP) that could spread the pest or pathogen. During an incursion, emergency response managers prioritize individual trace events, allocating surveillance resources to follow-up trace events in order of priority. Generally, prioritizing trace events is difficult, done subjectively, and the accumulating risk of pest or disease spread if multiple movement events exist between two areas, as well as probable (but unknown) movement events, are not adequately accounted for. We present a simulation model in which different dispersal mechanisms spread a pest or pathogen between areas. We use model outputs to test different search strategies, using citrus canker (caused by *Xanthomonas citri* (Hasse) Vauterin) as a case study. We develop scenarios based on the last outbreak of citrus canker in Australia, which occurred in Emerald, Queensland, in 2004.

Location: Australia.

Methods: Model parameters were elicited from published scientific reports. We used model outputs to assess three search strategies to determine how best to contain citrus canker spread. Parameters governing disease detectability and host susceptibility were varied in a sensitivity analysis.

Results: In all simulation scenarios, the “adaptive radius” rule performed best, whereby a circular search area was placed around the IP where the disease outbreak was first detected, with a radius proportional to the estimated number of months the property was infected. Importantly, none of the search rules tested for the citrus canker case study detected all IPs without completely searching all properties with susceptible hosts in the region.

Main conclusions: We identify a simple rule of thumb for searching during a citrus canker outbreak that is robust to uncertainty, and that leads to efficient resource allocation and relatively rapid eradication. Whilst the simulation model can be parameterised for many outbreak situations, no general rules can be established using the results of this study for tracing other pests or pathogens. The model has created a framework that may be used to explore other contexts and disease dynamics, leading perhaps to more general rules for disease outbreak management.

Keywords:

Citrus canker, dispersal, establishment, probability, risk, simulation model, trace priorities, *Xanthomonas citri*.

INTRODUCTION

Pest or pathogen (hereafter, referred to as a pathogen) dispersal is a complex process, whereby non-infected areas may be exposed to a pathogen via numerous pathways, which may be human-assisted (e.g., infected or infested farm machinery) or natural (e.g., wind). Increasing the frequency of dispersal mechanisms between an infected area and a non-infected area increases exposure to the pathogen (Gertzen *et al.* 2011). Importantly, exposure does not guarantee infection, which is a chance process affected by many factors such as whether environmental conditions favour survival of the pathogen, or if host species are present in the exposed area.

During an incursion of a pathogen, emergency response managers need to determine rapidly the extent of the incursion (Mangano 2011) by inspecting exposed areas. Exposure pathways are any means that allows the entry or spread of a pest and include ‘trace events’ (i.e., known movements of items such as animals, personnel, vehicles and equipment that may potentially spread the pathogen, Patyk *et al.* 2011) and other potential dispersal mechanisms (e.g., wind). The term ‘day 0’ is given to the estimated date of initial infection. Traces and movements along exposure pathways are directional. ‘Forward’ traces or movements are away from an infected area occurring since day 0 that may have spread the pathogen to other areas. ‘Backward’ traces or movements are to the infected area and occurring prior to day 0 that may have introduced the pathogen. Exposure pathways link potentially infected areas. Managers inspect these potentially exposed areas and when they find additional infected areas, they take appropriate actions (e.g., destroy all infected host species), aiming to eradicate the disease as quickly as possible (Keeling 2005). To allocate resources efficiently (Hagerman 2010), emergency response managers set priorities for following up trace events (called “trace priorities”), such that areas with high probability of having the pathogen are given a higher priority and inspected for disease before lower priority areas. Unknown movement of items along pathways may also be followed-up where they expose susceptible hosts to the pathogen.

Increasingly, models are being used to simulate disease dispersal and investigate aspects that different management actions have on e.g. the cost of eradication, or assessing the timeframe or likelihood of successful eradication given different management actions. Such models may be deterministic and useful for understanding basic infection dynamics but have limited predictive ability, since any one epidemic is unlikely to follow an 'average pattern' (Garner and Hamilton 2011); or stochastic, where input parameters are represented by statistical distributions (Carpenter 2011) and natural variability and uncertainty in the input parameters is accommodated (Garner and Hamilton, 2011).

Most applications of models to investigate spread have focused on animal and human diseases. For example, AusSpread is a stochastic, state transition susceptible-latent-infected-recovered (SLIR) model, and can be used to simulate scenarios for policy planning, vulnerability analysis and decision-making, and has been used to assess the effectiveness of various control strategies for foot-and-mouth disease (FMD, Garner and Beckett, 2005). Similarly, the North American Animal Disease Spread Model (NAADSM) is a stochastic, simulation based model that has been used to guide policy decisions to a variety of animal diseases including FMD, Aujezsky's disease and avian influenza (Reeves *et al.* 2011). Garner *et al.* (2011) also developed a model to assess the effectiveness of vaccination strategies for equine influenza. Similar studies have been undertaken for human diseases (e.g., small pox, Ferguson *et al.* 2003). There are fewer examples in the plant health sector (Jeger *et al.* 2007), but see Fox *et al.* (2009) who investigated surveillance protocols for Chilean needle grass (*Nassella neesiana*), and these are typically generated as complex, single solutions and lack the general framework to develop rules for searching across a range of scenarios. The animal health sector benefits by sometimes having extensive data sets obtained from censuses and systems for tracking livestock (Garner and Beckett, 2005).

Setting trace priorities for plant pathogens is difficult. Firstly, for many diseases, there can be a long time lag between when the pathogen was introduced (day 0), and when disease was detected (in some cases, years). This has important consequences for prioritizing trace or other movement events: if the estimate of day 0 is uncertain, the priorities will likewise be uncertain.

Secondly, there is typically incomplete knowledge regarding movement events. This includes the timing of movement events (e.g., a property owner declared a movement event occurred but the date was uncertain), whether the events actually occurred (e.g., a property owner falsely declaring no movement event occurred when in fact it did, or the movement of wild host animals on to and away from an infected property), and the implications of the type of movement for the risk of pathogen spread (e.g., some movement events may pose greater risk of disease spread than others and the risk of spread may be uncertain). In addition, the pathogen may spread through pathways other than the known movement of items described by trace events, for example, via wind dispersal.

Thirdly, there may be incomplete knowledge of the preferred habitat and host species of the pathogen, and where its hosts and habitat are located. For example, citrus canker is a disease of plants in the Rutaceae family caused by *Xanthomonas citri* (Hasse) Vauterin. In Australia, the location of host species may be known (e.g., commercial citrus grown in orchards), or not (e.g., citrus trees grown in backyards, or the distribution of the native host *Citrus glauca* in bushland). If unknown, infected populations may remain and if they can act as a source for re-infection eradication attempts may be futile.

The complexity of plant disease dynamics and the urgency of management actions mean that setting priorities for trace events, and allocating surveillance resources, for plant disease typically are decided subjectively. While subjective judgment can be reliable in contexts in which repetition and feedback are substantial, most plant disease incursions are essentially novel. The novelty and complexity make decision makers especially susceptible to contextual and cognitive frailties, rendering judgments potentially unreliable (Slovic, 1999; Perry *et al.*, 2001; Wilkinson *et al.* 2011). This creates an urgent need for simple rules of thumb that result in robust and effective strategies for searching.

We present a simulation-based, spatially explicit, stochastic, state-transition model, in which several dispersal mechanisms (e.g., wind or the movement of diseased plant material) can spread a disease from infected to susceptible host populations. Patterns of disease dispersal emerge by running many iterations of the model, over a range of scenarios. We evaluate three search strategies, to determine how best to contain pathogen spread, focusing on performance of each strategy in the first two weeks following a disease outbreak. We focus on the immediate two weeks following disease outbreak because we considered this as a critical period, during which the extent of the disease outbreak needs to be learnt as quickly as possible. In the subsequent weeks after this critical period, the appropriate searching strategy may change as new information on trace events and other possible pathways is obtained by e.g., interviewing land-owners.

In Australia, the detection of citrus canker triggers immediate quarantine restrictions and disrupts the movement of fresh fruit (Dempsey *et al.* 2002). The last outbreak of citrus canker in Australia was in Emerald, Queensland, in July 2004 (Gambley *et al.* 2009). During the five years it took to eradicate citrus canker, approximately 495,000 citrus trees planted over 1,100 hectare, 4235 citrus trees planted on 1238 residential properties, and 175,000 *C. glauca* trees in native bushland were destroyed, in the 3,150 square kilometre pest quarantine region around Emerald (Senate Rural and Regional Affairs and Transport Legislation Committee, 2006). We develop our model and the scenarios to test searching strategies based on this real case study.

METHODS

The disease: Citrus canker

Citrus canker is characterised by lesions on leaves, shoots, branches and fruit of several susceptible species within the Rutaceae family (Goto 1992, Gottwald *et al.* 2002, Das 2003). Citrus canker bacteria may persist for a time on the plant surface without entering susceptible plant tissue. For infection to occur the bacterial cells must impact susceptible plant tissue with enough force to penetrate the stomatal aperture (e.g., during high wind events, with wind speeds greater than 8ms^{-1}, Serizawa and Inoue, 1974), or enter susceptible plant tissue via wounds caused by damage to plant tissue (e.g., wind abrasions, or pruning) or injury caused by insects (e.g., leaf miner, Hall *et al.* 2010, Jesus *et al.* 2006). Upon entering susceptible plant tissue, the bacteria can rapidly multiply, creating lesions at the infection site. When wet, the lesions may ooze bacteria, providing inoculum for further infection (Gottwald *et al.* 2002). The appearance of visual symptoms is highly variable, from as early as 7-10 days post-infection (Graham *et al.* 2004, Gottwald *et al.* 1989), to as long as 60 days (or longer) under adverse conditions (Gottwald and Graham 1992, Dalla Pria *et al.* 2006). Symptoms vary depending on susceptibility of host species (Graham *et al.* 2004), the plant tissue and timing of infection (Koizumi 1972).

In the presence of suitable rainfall events, temperature ranges between 20 to 30^{o}C are considered optimal conditions for citrus canker bacteria (Bock *et al.* 2005), but the bacteria can survive between 12 to 40^{o}C (Dalla Pria *et al.* 2006). Typically, no bacteria survive in temperatures greater than 42^{o}C (Dalla Pria *et al.* 2006), and cooler temperatures and drier conditions reduce the number of bacteria (Bock *et al.* 2005). Bacteria that ooze onto plant surfaces may die within hours from exposure to direct sunlight. Bacteria may survive, if sheltered from direct sunlight, on various inanimate surfaces such as metal, plastics, cloth and processed wood for up to 72 hours (Graham *et al.* 2000). Citrus canker bacteria can form biofilms which may protect bacteria against harsh environmental conditions and potentially bactericide treatments applied in the field and during the fruit-disinfection process (Cubero *et al.* 2011). This implies dispersal of canker bacteria can occur via machinery and infected equipment (e.g., pruning and hedging equipment), contributing to spread of citrus canker within citrus trees and within orchard blocks.

General model description

The simulation model is based on graph theory, whereby a network of nodes is used to represent areas of interest (AOIs) that may contain potential host species or suitable habitats that are spatially clustered together (e.g., an orchard), or that may act as a pathway for pathogen dispersal (e.g., a packing shed). The model uses discrete time steps, and at each time-step, multiple processes may affect individual nodes (Harvey *et al.* 2007).

In any time step, a proportion of nodes may be infected, and the disease status of these nodes may be known (i.e., whether the disease is present and is readily detectable, or confirmed to be absent) or unknown (i.e., whether the pathogen is present and undetectable, or the disease is absent). One or more dispersal mechanisms may transport the pathogen from infected (and infectious) nodes to susceptible nodes. Region-specific weather records are used to model environmental conditions in each time step that influence infectiousness, dispersal mechanisms, and node susceptibility (Figure 1). The outputs of the model (i.e., a simulated pattern of disease dispersal) are used to examine three different surveillance rules for searching for infected nodes.

A network of nodes

Each node comprises a unique spatial location within the network, and is defined by several features including: type (e.g., orchard, backyard, etc.), area, the number of susceptible host plants and their variety (in the case of citrus canker, the variety of citrus is known to influence susceptibility), and the mean age of host plants within the node. Using mean age may underestimate some risks; hosts of all ages may be susceptible but young trees tend to have more growth flushes and hence more periods of susceptibility. Host plants within a node grow older during the simulation period. The user can define any number of node types, as long as the dispersal and establishment mechanisms for each node type are also defined and parameterised.

Point of entry

The user determines the initial point of entry of the pathogen into the network of nodes by either selecting a node at random (to simulate a natural incursion event), or by selecting one or more specific nodes to represent likely entry (e.g., importation of infected plant material into an orchard).

Incubation

Once a node is infected, it may become infectious after a specified incubation period (which can be set to zero, in which case nodes are infectious immediately after becoming infected). Once infectious, nodes may infect other disease-free, susceptible nodes, via a number of dispersal and establishment mechanisms.

Infectiousness

Before the risk of disease spread from an infected node is appreciable, there must be a sufficient level of pathogen inoculum present (i.e., although in theory it takes a single bacterium to spread and create another infection, this is unlikely). Increasing "infectiousness" implies the propagule pressure is higher, leading to greater risk of spreading the disease (Gertzen *et al.* 2011).

When the *i*th node is initially infected, or re-infected following weather conditions that destroy all inoculum at the node, the number of trees present (n_i), and their mean age (a_i) and tree canopy area (A_i) determine infectiousness, C_i:

$$C_i(n_{i,}, a_i, A_i,) = \ln(n_i)\ \frac{A_i}{a_i} \qquad \text{(Equation 1)}$$

After the initial infection, or re-establishment of the disease, a multiplicative function is used to model infectiousness. Infectiousness within the current time step *t*, at node *i*, depends on infectiousness in the previous time step *t-1* and weather conditions. Further information regarding infectiousness is provided in Potts *et al.* (2012).

Dispersal mechanisms

Once a contagious node is sufficiently infectious, a dispersal event may transmit the inoculum from the contagious node to an uninfected node. A variety of dispersal mechanisms are available and may be parameterised by the user (e.g., wind or the movement of diseased plant material). The probability of transmission via the mechanism in question can be based on the distance and angle between the source and destination node, or it may be a simple Bernoulli trial with a fixed probability of success (i.e., of spreading the disease). Dispersal mechanism parameters can vary at each time step. Further information regarding dispersal mechanisms is provided in Potts *et al.* (2012).

Node susceptibility

For a node to become infected, it must be susceptible. That is, there must be suitable habitats or host plants at the destination node for the pathogen to establish there, and host plants must be in a growth-stage that is susceptible to infection and environmental conditions must be conducive. The user can specify the relationship between node susceptibility and the number of host plants at the node, their size and growth stage. We explain node susceptibility in relation to the citrus canker case study below. Further information regarding susceptibility is provided in Potts *et al.* (2012).

Detectability

Detectability relates to two processes. Initially, a new disease in a region is unlikely to be detected, since people are unlikely to be actively searching for it and its symptoms, if they are observed, may go undiagnosed. This initial detectability is modelled as being proportional to an infected node's infectiousness.

After initial disease discovery, detectability will be higher, as awareness is increased and surveillance officers and property owners begin to search actively for the disease on host species. We model this detectability for the *i*th node (d_i) as a function of the duration of infection at the *i*th node (t_i, i.e., the time between when the *i*th node first became infected, to when it was inspected for disease presence) and the infectiousness of the *i*th node (C_i), given the minimum time period required for visual symptoms to appear (t_{thres}):

$$d_i(t_i, C_i | t_{thres}) = \begin{cases} 0 & when\ t_i < t_{thres} \\ h_i(C_i \mid \theta_1, \theta_2) & when\ t_i \geq t_{thres} \end{cases} \qquad \text{Equation 2}$$

The user can define the shape of the function, h_i, e.g., logistic, for which the user specifies detectability of the disease if present (θ_1), and a shape parameter for the logistic curve (θ_2). We specified h_i as:

$$h_i(C_i; \vartheta) = \frac{1}{1 + \left(1/\vartheta_1\right)\exp\{-\vartheta_2 \times \ln(C_i)\}} \qquad \text{Equation 3}$$

We assume there are no false positive disease detections. Further information regarding detectability parameters is provided in Potts *et al.* (2012) but also see "Simulation Scenarios" below and *Table 1* for more discussion on model parameters θ_1 and θ_2).

Searching strategies

We ran the simulation model numerous times, recording for each simulation which node was initially infected, and the subsequent infection pattern of other nodes. Using this information, we tested the efficacy of search strategies by recording the number of infected nodes detected – since we know which nodes are infected in the simulator – and the number of nodes visited in the search strategy. Effective search strategies result in fewer nodes visited and more infected nodes found. Ideally, inspectors would only visit infected nodes, so that the number of nodes visited would be equal to the number of infected nodes, resulting in all infected nodes being found with minimum surveillance effort. We investigated the effectiveness of three searching strategies:

1. *Adaptive radius*: A circular search area was established around the first detected node (N.B., this is not necessarily the node that was the first infected). The radius of this circle was proportional to the number of months, t_I, since the node was first infected $r = t_I d$, where d is an arbitrary distance. This type of search makes no assumptions about search direction (forward or backward tracing). In the citrus canker example, we varied d from 50 m to 1,000 m in intervals of 50 m. We used a truncated normal distribution to model the increasing uncertainty in estimating day 0, with increasing time since infection (mean = true time infected, and standard deviation = true time infected divided by four).
2. *Closest n nodes*: a given number, n, of nodes closest to the node where the disease was first detected were searched, with inter-node distance calculated as Euclidian distance from node-edge to node-edge. This type of search makes no assumptions about search direction. In the citrus canker example, we varied the number of closest n nodes from 1 to 100, in steps of 1.
3. *Adaptive search of probability space*: Using knowledge of dispersal and establishment probabilities, a matrix of all possible dispersal and establishment probabilities was calculated from each node, to every other node, in the network. This two-dimensional square matrix has dimensions

equal to the number of nodes in the network. Each element in the matrix is the probability of disease dispersal *and* establishment from a source node to a destination node. If dispersal and establishment properties are equal between different node types (i.e., non-directional), then the matrix would be symmetrical. In the citrus canker example, we varied the number of nodes searched from 1 to 15.

Simulation scenarios

We ran two simulation scenarios for the dispersal and establishment of citrus canker, each based on hypothetical rearrangements of a real incursion (Emerald, Queensland; Figure 2), but modified to reflect a wider range of initial conditions and environments. We parameterised the simulation model using expert opinion and literature published on the dispersal of *X. citri* and factors affecting the susceptibility of hosts (*Table 1*). In the first simulation study, we used local weather data from Emerald. In the second simulation study, we used weather data from Mildura, Victoria. Typically, Emerald has warmer and wetter summers (conducive to citrus canker dispersal), whereas Mildura is much drier. Rainfall in Mildura is higher in winter, but this is also when it is much colder. Weather data were taken from between July 2009 to July 2010 from the Bureau of Meteorology (Figure 3). Weather conditions are important for citrus canker, and interact with node infectiousness (*Table 1*) and susceptibility.

Susceptibility of the receiving node, g_s, Equation 4, was modified by temperature in a given time step, T_t, and mean tree age, a_i at the *i*th node. The probability of establishment is related to temperature by adapting the Dalla Pria *et al.* (2006) generalized beta relationship between inoculum load and temperature using:

$$\boldsymbol{g_s(T_t, a_i; \phi) = \phi_1[(T_t - \phi_2)^{\phi_3}(\phi_4 - T_t)^{\phi_5}]} \qquad \text{(Equation 4)}$$

where ϕ is a vector of parameters ($\phi_1, \dots, \phi_5$). Citrus trees grow in flushes, where new growth tissue is more susceptible to citrus canker infection. Older citrus trees typically experience fewer growth flushes, so ϕ_1 was modified until plants reached 10 years in age, a_{max}, by:

$$\phi_1 = \{ \begin{matrix} \phi_1 - {}^{a}/_{2000} \; with\, 0 < a \leq a_{max} \\ \phi_1 - {}^{a_{max}}/_{2000} \; with\, a > a_{max} \end{matrix}$$

Other parameters in Equation 4 were obtained from Dalla Pria *et al.* (2006): $_1$ = 0.0264, $_2$ = 12.725; $_3$ = 1.465; $_4$ = 40.55, and $_5$ = 0.7575).

Increases in susceptibility arising from tree damage caused by machinery or pruning were modelled implicitly by dispersal mechanisms (i.e., the “infected farm equipment” dispersal mechanism (Table 3 and Figure 4) had a higher probability of dispersal to account for the tree damage that occurs during hedging and pruning). Each simulation was run for two years (i.e., 104 time-steps) and repeated 1000 times. For each simulation, the time step at which a dispersal event occurred, the node the disease came from, the node(s) it infected and the dispersal mechanism, were recorded.

RESULTS

Since infection is a stochastic process, each realisation of the model leads to a different epidemic with different nodes being infected on different days, just as any two real epidemics are different (Harvey *et al.* 2007). In simulations of both hypothetical scenarios (which we refer to as ‘Emerald’ and ‘Mildura’), either no spread occurred from the point of initial infection (Emerald: 3.1%; Mildura: 42.7%), or the disease spread but remained undetected during surveillance (Emerald: 0.1%, Mildura: 18.5%).

As time progressed in each simulation, the number of nodes infected that were detected increased as a non-linear proportion of the total number of nodes that were infected (**Figure** 5). The detected proportion was typically greater in Emerald, where weather conditions were more conducive to citrus canker spread, than Mildura where fewer nodes became infected.

The matrix developed using the third searching strategy ("adaptive search of probability space") suggested some nodes had a very high probability of dispersal and establishment (shaded dark grey, Figure 7) whereas most nodes had a low probability of dispersal and establishment (shaded light grey, Figure 7). Importantly, the source node type (x axis) does not necessarily result in an overall higher probability of dispersal and establishment success, a process that is also governed by proximity to other (destination) nodes on the network (y axis), and the frequency that dispersal mechanisms occur between the source and destination nodes. In Figure 7, we've highlighted the "commercial nursery" node, which in our simulated region was geographically isolated from other nodes in the network. This spatial separation resulted in fewer successful dispersal and establishment events from dispersal mechanisms with higher probabilities of success (e.g., wind and infected farm machinery) but that acted over shorter distances (Figure 4), when compared to other nodes in the network that were closer together (e.g. nodes 126 and 127 were geographically closer together so when one node got infected, the other node was also likely to become infected due to frequent, short-distance dispersal mechanisms resulting in a higher probability of dispersal and establishment success between these two nodes). If the model were parameterised differently such that the frequency of dispersal mechanisms changed (e.g., movement of budwood) then this matrix of probabilities would also change.

We compared the performance of searching strategies by comparing the proportion of infected nodes found with the proportion of nodes searched. Regardless of which simulation parameters were used and regardless of the probability of the detectability of citrus canker if present (set at 1.0, 0.7 and 0.3), the "adaptive radius" search method outperformed the other search methods (Figure 6). When the weather was cooler in the winter months (i.e., Mildura), susceptibility of host species was generally lower and detectability was high (Figure 6), the benefit of the top two performing methods was less ("adaptive radius” and “Pr space”). As detectability decreased, the variability in the worst performing method (“closest *n* AOIs”) increased.

DISCUSSION

Complex processes govern pest and disease dispersal, and representing this with a simplified model will always have limitations. This has led to the development of some complex models, but model complexity is a balance between the questions that managers need to answer and the quality and extent of available data (Keeling 2005). Models cannot replicate a host of subtle details and local information used by experts to develop trace priorities and decide on a strategy for searching (Keeling 2005), and an emergency response manager should remain the final arbiter. Models such the one developed here can provide an assessment of general sets of risk-based search strategies in a transparent, explicit and accountable manner, a framework within which managers can develop other, more nuanced strategies that account for factors not included in the model.

The model we present was developed with flexibility in mind, thus allowing one to investigate the behaviour different strategies for searching / prioritising tracing of citrus canker in other regions, and for other plant pests and diseases. Potts *et al.* (2012) fully describe the model. Potential model extensions include the implementation of control measures (e.g., destroying all host plants within a node) and calculating the cost of implementing control measures.

Parameterising the infectiousness, dispersal mechanisms, and host susceptibility model parameters using data collected on citrus canker, we found that regardless of other input parameters, the “adaptive radius” search strategy outperformed the other strategies we tested. The “adaptive radius” rule set we investigated is similar to the approach in Gottwald *et al.* (2001) that stipulates a 1,900 ft removal zone around every infected host species for each 30-day period following initial infection. Importantly, none of the search strategies we investigated (including the “adaptive radius” strategy) consistently found all infected nodes without searching all susceptible nodes in the region.

We also found model outputs were sensitive to area-specific weather, but the “adaptive radius” rule set consistently performed the best of all strategies we tested. Since performance was sensitive to area-specific weather, we recommend strategies for searching need to be explored for each region using area-specific weather data. It may be that the general prescriptions developed here are robust for a very wide range of weather conditions and disease behaviours, however, this is an empirical question that can only be resolved by further experimentation, simulation and evaluation. To be useful in policy development, models must be fit for purpose and appropriately verified and validated (Garner and Hamilton 2011), and should be assessed in the context for which it was developed (Reeves *et al.* 2011). As such, any extrapolation of our results should be considered very carefully, and should include further interrogation of the model and its inputs.

To eradicate the pathogen it is imperative that all nodes containing susceptible host species are known and the spatial location of all hosts mapped for the disease of interest. If areas contain susceptible hosts, and these are unknown (or hidden) to managers, then eradication may be impossible if these susceptible populations become infected and act as a continual source of future re-infection. Our model includes the possibility of including hidden nodes. Such nodes are likely to be relatively important in determining the success of control efforts of plant diseases.

The need for an efficient, consistent and nationally-coordinated approach to manage information during routine biosecurity surveillance activities and emergency responses to incursions of animal or plant diseases in Australia led to the development of the web-based software application BioSIRT (Biosecurity Surveillance Incident Response and Tracing, see: http://www.daff.gov.au/animal-plant-health/emergency/biosirt). Users of BioSIRT include Commonwealth, state and territory agencies that are responsible for management of animal and plant diseases that may threaten the environment and economic activities. BioSIRT can be used to record known trace events and assign priorities to traces based on the trace direction, number of movement events, contact type (i.e., direct, indirect) and the date of movement relative to day 0. Trace priorities are automatically assigned within BioSIRT, by matching combinations of these input variables with a look-up table of predefined (and subjective) priorities. The model presented here is a first step towards enhancing tools such as BioSIRT such that prioritisation of follow up of all exposure pathways (i.e., known trace events and potential movement events) reflect the risk of spread and establishment, leading to more efficient and effective emergency responses. This model is an important step towards developing a general framework for assessing trace priorities and implementing effective search strategies in plant health emergencies in Australia.

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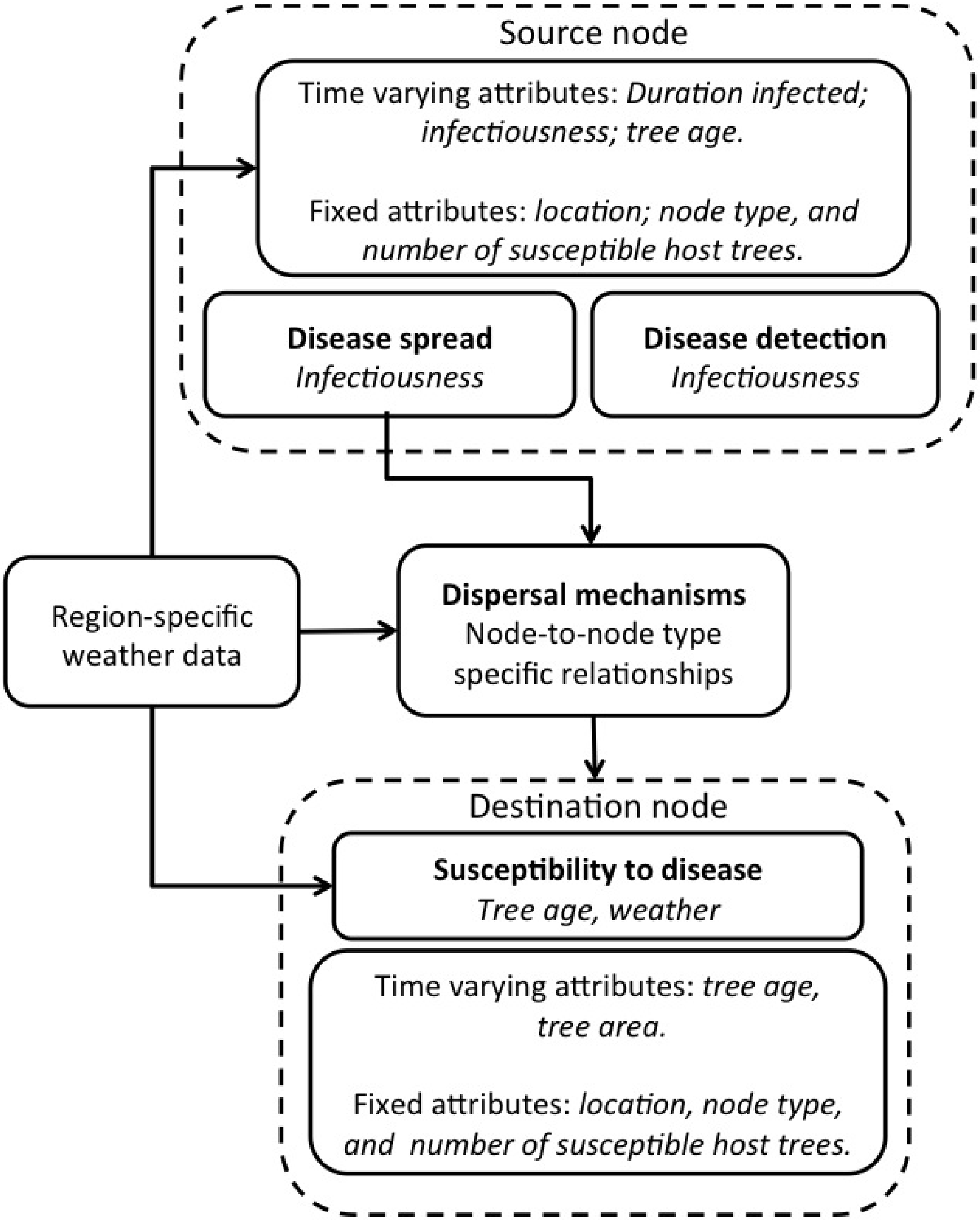


Figure 1. Schematic of disease model dispersal and establishment structure. How source node type, long it has been infected, and the number, size and age of host species present govern its infectiousness. Dispersal mechanisms are node-type dependent and influenced by region specific weather data. Whether the pathogen establishes at the destination node is governed by host susceptibility to the pathogen.

Figure 2. Map of hypothetical citrus-growing region (based on Emerald, Queensland), with areas containing host species represented as a network of nodes. Each node (solid black dot) is defined by a spatial location and area, and contains a number of citrus plants, with a mean-tree age. Areas shaded dark grey and light grey are commercial citrus growing areas, and properties that contain commercial citrus areas, respectively.

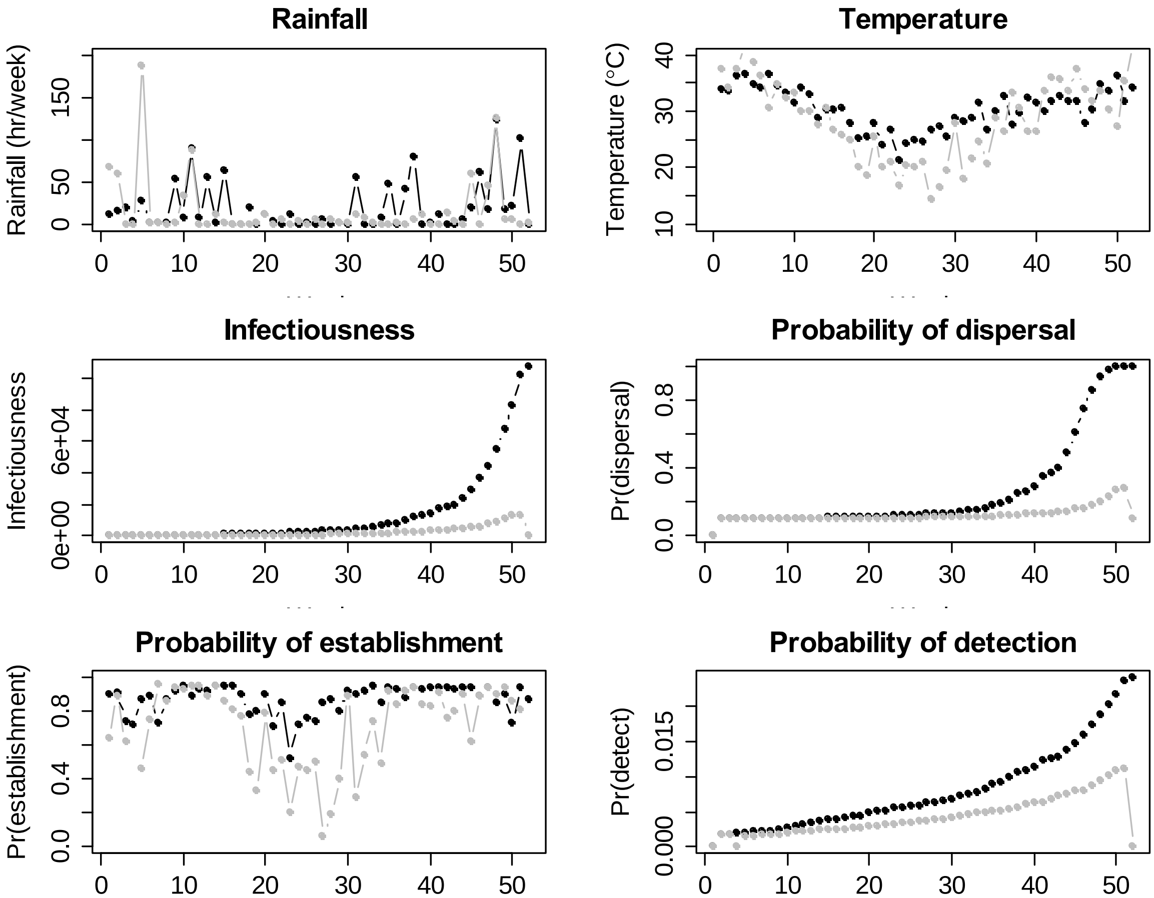


Figure 3. Weekly rainfall duration (Panel 1) and temperature (Panel 2), as related to infectiousness (Panel 3), probability of dispersal (Panel 4), probability of establishment (Panel 5) and probability of detection (Panel 6). X-axis weeks from 1 July 2009) are from the Australian Bureau of Meteorology for Emerald, QLD (black line) and Mildura, VIC (grey line). Given these input parameters, infectiousness (panel 3) is calculated for a node containing 1,000 two-year old trees. Dispersal probability is dependent upon infectiousness, and duration of infection. Establishment probability is based upon citrus variety, mean tree age and temperature. Detection probability is proportional to ln(infectiousness).

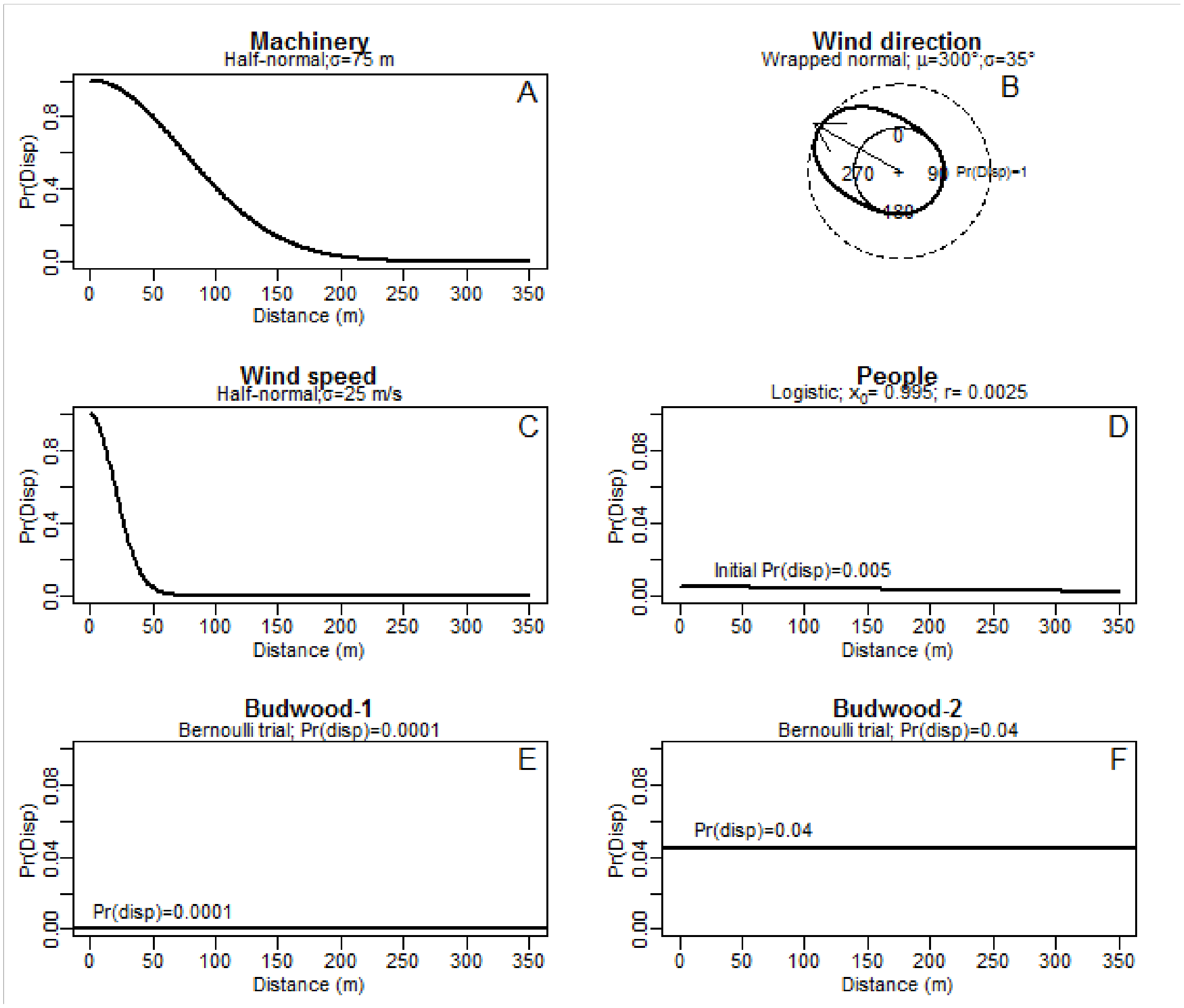


Figure 4. Five example dispersal functions, with probability of dispersal, Pr(Disp), on the y-axis. Wind direction and wind speed based dispersal are varied at each time-step based on weather data (Figure 3). The budwood pathway (panels E and F) have node-type dependent parameters with Budwood-1 parameterised with Pr(disp)=0.0001 for citrus block to citrus block and citrus block to commercial nursery pathways. Whereas Budwood-2 was parameterised Pr(disp)=0.04 for commercial nursery to all other node types. NB varying y-axis scales: panels A and C have Pr(disp) range 0 to1, panels D to F have Pr(disp) range 0 to 0.1.

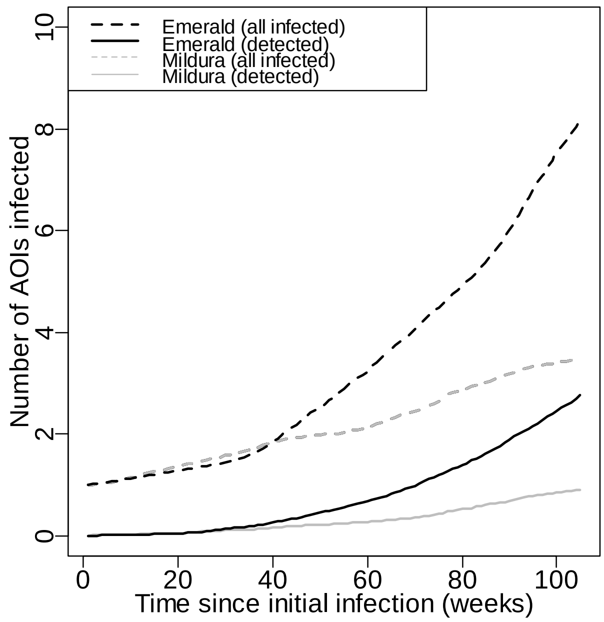


Figure 5. As time progresses in the simulations since time of true 'day 0' for the first infected node (x- axis), the number of nodes infected that are detected increases as a non-linear proportion of the total number of nodes that are infected.

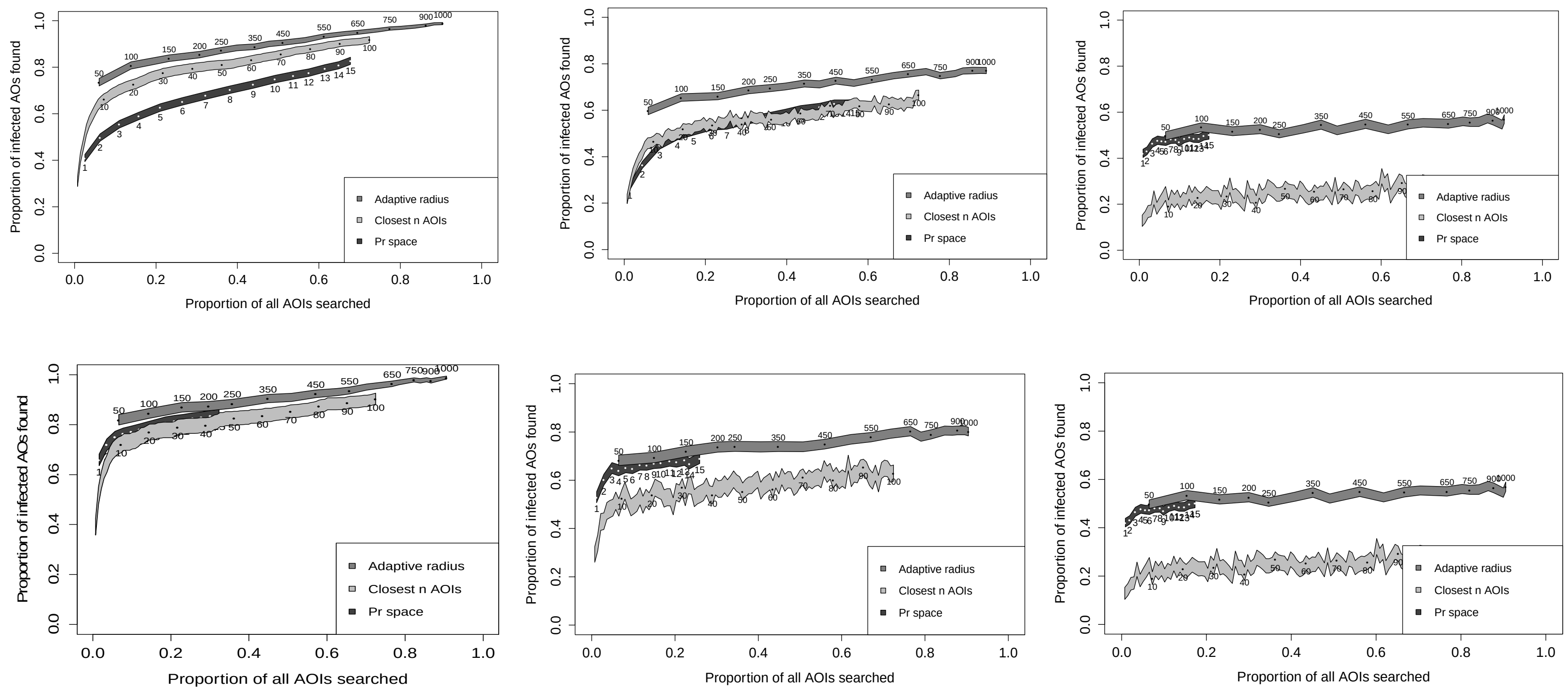


Figure 6. Performance of the searching rule sets, as measured by the proportion of infected nodes that were detected (y-axis) vs. all nodes searched (x-axis). Top and bottom rows used Emerald and Mildura weather conditions, respectively. The left, middle and right columns had detection probabilities of 1.0 (i.e., perfection detection), 0.7 and 0.3, respectively.

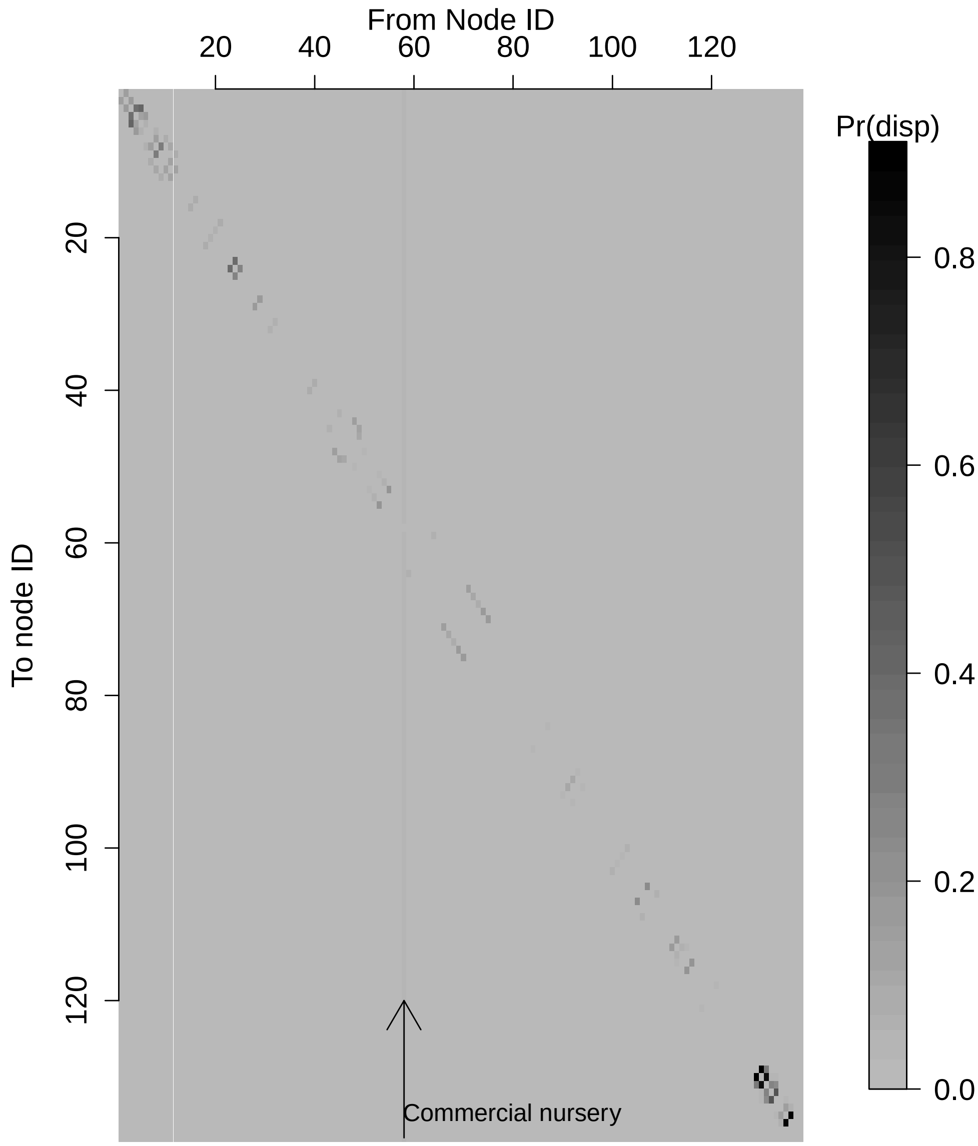


Figure 7 A matrix of the probability of dispersal and establishment success between source nodes (x axis) and destination nodes (y axis), as calculated using the third searching rule "adaptive search of probability space". Each element in the matrix is the probability of disease dispersal *and* establishment from a source to a destination node. Our simulated study region contained one commercial nursery node that was geographically isolated from other nodes on the network, and along with all dispersal mechanisms applicable for all other node types (e.g., wind), could also contribute to disease spread via a distance-independent Bernoulli trial for budwood movement (Figure 4). Consequently, the 'commercial nursery' node had a relatively low and constant probability of dispersal and establishment success to all other nodes of the network. If the frequency of this dispersal mechanism increased, this node type would lead to greater dispersal of the disease across the network. Other nodes with seemingly less risk at spreading the disease had a high probability (shaded black) because they were geographically close to other nodes on the network, and the high frequency of short-distance dispersal events meant if one node became infected, the other node did too – e.g., nodes 126 and 127). With different parameterisations of this model (e.g., changing the frequency of the budwood dispersal mechanism), the results of this matrix would change.

Table 1. Table of model parameters for the citrus canker case study.

Parameter	Definition	Value in citrus canker case study
Time-steps	At each time-step, multiple processes may affect individual nodes; and a proportion of nodes will be either: not infected, infected but not infectious, or infected and infectious.	Weekly.
Geographic region	Defines the extent of the network of nodes.	Based on Emerald, Queensland, and contained 138 nodes of four different types (Figure 2).
Node types	Different node types may have different characteristics, primarily governing susceptibility and types of dispersal mechanisms applicable to specific node types.	Three different node types (citrus block, commercial nursery and backyard (Table 2).
Point of entry	The node that first becomes infected.	Randomly selected node in each iteration.
Incubation	Time period between when the node was infected, and when it can infect other nodes.	Since citrus canker lesions may begin to ooze bacteria from stomatal pores five days after infection, providing inoculum for further infection, the incubation period was set to one time step (i.e., one week).
Infectiousness	Sufficient inoculum load must be present within a node, before there is appreciable risk of infecting other nodes.	To calculate initial infectiousness (Equation 1), we modelled tree canopy area (A_i) as linear growth to a fixed tree age (10 years), and constant thereafter. At subsequent time steps, infectiousness (C_i) was modelled using the relationships between citrus canker lesion density and temperature and rainfall obtained from Dalla Pria *et al.* (2006).
Dispersal mechanisms	A dispersal mechanism transports inoculum from an infectious node to an uninfected node. Dispersal mechanisms can be node-type specific, and directional.	Eight different dispersal mechanisms were parameterised (Table 3, Figure 4).
Node susceptibility	Probability of disease establishment given successful dispersal from an infectious node	Susceptibility is based on temperature and tree age as both influence the number of flushes.
Detectability	The detection probability for passive searching is proportional to node infectiousness.	The time between when a node was infected, and when disease could be detected, t_{thres}, in Equation 1 was set equal to two weeks.
	Detectability during active searching (that occurs after the first detection) is based on the time between when the node was first infected and when it was inspected, and the efficacy of the search protocol.	The detection parameter θ_1 in Equation 2 was varied: 1.0 (perfect), 0.7 and 0.3.

The logistic regression shape parameter θ_2 in Equation 2 was set equal to 0.38.

Table 2. ***Description of node types in the simulation model. Any number of node types can be described by the user (e.g., in some citrus canker scenarios a juicing factory, packing shed or nursery might be required).***

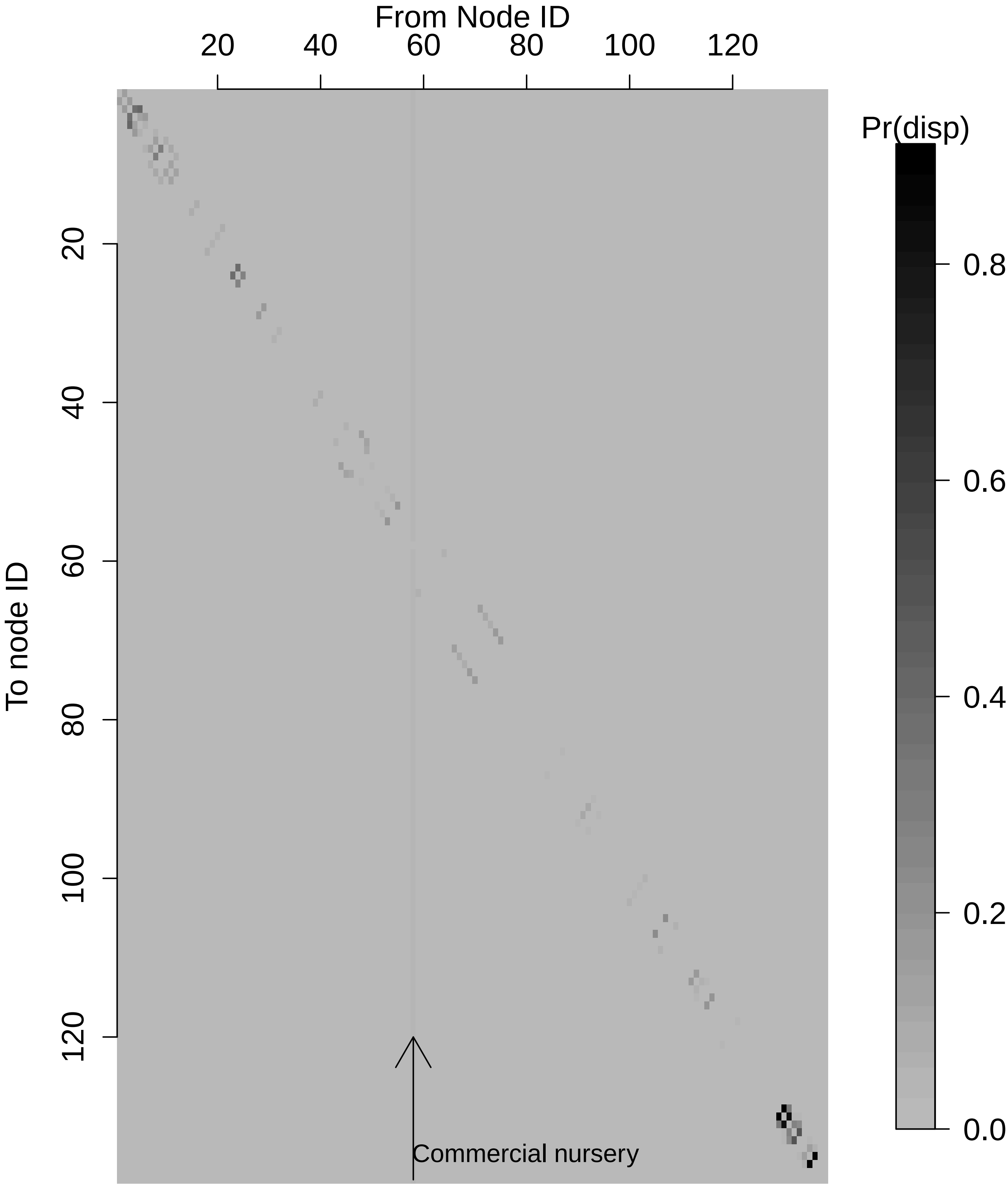
Node	Description
Citrus block	Block of many hundreds or thousands of citrus trees within a commercial setting, primarily for production of fruit or condiment leaves (e.g., kaffir lime). Each is a contiguous area within which a single citrus species is grown.
Commercial nursery	Where citrus material is propagated for planting in citrus blocks or shipping to retail nurseries.
Backyard	Individual citrus trees in backyard settings.

Table 3. ***Dispersal mechanisms accounted for in the citrus canker case study. Any number of dispersal mechanisms can be defined by the user, some of which might be foreseeable for citrus canker dispersal, but not explicitly accounted for in our model (e.g., severe storms which may potential disperse citrus canker bacteria as far as 8 km from the source node, Gottwald et al. 2002, Gambley et al. 2009).***

Dispersal mechanism	Distance
Infected farm equipment (e.g., Hedging or spraying equipment, tractors, fruit bins, fruit clippers)	Short: within tree, and between neighbouring trees (i.e., within nodes). Unlikely to occur between nodes, unless the nodes are neighbouring.
People (e.g., contamination on clothing or picking bags)	As per infected farm equipment. Workers could disperse citrus canker to another region e.g., Emerald to Central Burnett within one day.
Wind-driven rain	Short: observed dispersal distances up to 32 m.
Birds	Civerolo (1981) mentions these as a means of dispersal in a review paper, but bird dispersal is considered a rare event and not explicitly accounted for in our model.
Seeds	Unlikely.
Fruit	Long: Viable citrus canker bacteria have been isolated from lesions observed on fresh fruits imported from Uruguay and Argentina into Spain (Golmohammadi *et al.* 2007). Likewise Ibrahim & Al-Saleh (2009) were able to detect viable bacteria on symptomatic fresh citrus fruits in shipments from Pakistan and China to Saudi Arabia. Movement of fruit is not modelled explicitly in this simulation study, but included implicitly using the 'unknown' dispersal mechanism. Further simulation studies could be undertaken in the future that explicitly incorporate fruit movement.
Unknown	Dispersal mechanisms that occur and that are not explicitly modelled.
Propagation material	Long: most likely cause of long distance dispersal is movement of infected budwood, root stock, etc. (Civerolo 1984, Gottwald *et al.* 2002).

SUPPORTING INFORMATION

BIOSKETCH



From Node ID
20
40
60
80
100
120
To node ID
20
40
60
80
100
120
Pr(disp)
0.8
0.6
0.4
0.2
0.0
Commercial nursery

Department of Primary Industries

Citrus Australia

FACTSHEET

Impacts and management of flooding and waterlogging in citrus orchards

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Photo by Bart Brighenti

The recent heavy rainfall and flooding events in NSW may cause some immediate damage to trees, but may also have significant long term impacts on citrus orchards, particularly those planted on heavy soils or those with impeded drainage.

Previous flooding events in the MIA

Previous flooding and high rainfall events occurred in the Murrumbidgee Irrigation Areas (MIA) in the 1930's and 40's (during the winter months) and the impacts of those events, combined with a tendency to over-water resulted in considerable decline in tree health and the death of many trees. Survey and research work undertaken by Dr. Lilian Fraser concluded that one of the main causes of tree death and decline was due to infection by the root rot fungus *Phytophthora citrophthora*.

At that time most citrus trees were grown on rough lemon or sweet orange rootstocks, both of which are highly susceptible to *Phytophthora* root and collar rots. Tree losses were aggravated by faulty irrigation practices, lack of adequate drainage and uneven soil types (Fraser 1942). Fraser along with horticulturists Benton, Bowman and Kebby in the NSW Department of Agriculture soon established that trees on trifoliata rootstock planted in infested soil in the MIA made very good growth.

Trifoliata is highly resistant to root rot caused by *Phytophthora*, while Troyer and Carrizo citranges although they have less resistance, are still vastly superior to rough lemon or sweet orange. However trifoliata and the citranges succumb to another problem: sudden death (known overseas as dry root rot). While some researchers overseas have suggested that the fungus *Fusarium* plays a role in dry root rot, it has been conclusively established by three years of research conducted on farms in the MIA (Shearman, 2006) that intermittent waterlogging is the underlying predisposing cause of sudden death in that region.

In the past 50 years there have been many changes with regards to citrus plantings in the MIA. New plantings have largely used rootstocks such as trifoliata and the citranges that are better able to cope with *Phytophthora* root rot. Irrigation systems and practices have changed and become more efficient and precise in delivering the right amount of water to match site conditions and tree needs. However soil type can be extremely variable, even within a block — making it difficult to achieve the ideal soil moisture content for all trees or blocks. Butler in his 1979 CSIRO survey of horticultural soils in the MIA noted that very few soils were free from becoming waterlogged, that some areas are difficult to clear of surplus surface water and sudden changes in soil type across paddocks are common. Many new horticultural plantings have probably been made on less than ideal soils for citrus. Even with previous site improvements such as subsurface tile and mole drains and the more recent use of laser levelling and the use of mounding in the tree row – it may not be enough to get through unscathed during the recent high rainfall and flooding events.

What is waterlogging?

Waterlogging occurs whenever water enters the soil at a faster rate than it can drain away. It can be caused by heavy or prolonged rainfall, over-irrigation, flooding or the presence of a permanent or temporary (perched) high water table. The duration and severity of the waterlogging event is influenced by the amount of water entering the system, the topography of the site, soil structure and the water absorbing capacity of the soil.

The soil is made up of different sized soil particles interspersed with different sized spaces or pores. The smaller pores (less than 0.5 mm wide) are usually filled with water while the larger pores are usually filled with air. Good horticultural soils normally have between 10 to 30% of their volume composed of larger pores that are filled with air and 10% is considered the minimum air content for healthy root growth depending on plant species. Waterlogging occurs when both the small and large air pores in the soil become filled with water, usually as a consequence of the water failing to drain away quickly enough from the large pores — resulting in a soil which has little or no oxygen, an environment referred to as anaerobic.

Topography plays an important role in the horizontal movement of water across the landscape, with water tending to collect in the lower, flatter areas — which will normally be subject to waterlogging for longer periods than higher ground.

The vertical movement of the water through the soil profile is largely controlled by soil type and structure. Generally the higher the clay content of the soil, the slower the water will move through it and the longer it will remain wet. Additionally any impermeable layers in the subsoil such as natural clay or rock layers or a compacted layer caused by ploughing or vehicular traffic will also further impede drainage – resulting in a perched water table which causes the soil above to remain saturated.

Waterlogging also has an impact on soil structure by dispersing the clay particles, which further reduces pore space. The subsoil will usually be subject to much longer periods of waterlogging and anaerobic conditions. Care must be taken not to take heavy machinery onto wet soils as this will cause further compaction and deterioration of soil structure.

What happens in waterlogged soils?

There are a number of biological and chemical processes that occur once the soil becomes waterlogged and devoid of oxygen — how important these changes are will depend on the length of time the soil remains saturated.

When soils become saturated, gas diffusion and exchange between the soil and the atmosphere is impeded because the air pores are filled with water. This results in changes in the concentration of gases such as oxygen (O_2) and carbon dioxide (CO_2). Any O_2 present will be quickly depleted by the plant roots and the microorganisms in the soil as they undertake their normal functions. CO_2 levels will increase as a result of respiration by the plant roots and microorganisms. The O_2 depletion rate is also affected by soil temperatures (faster at higher temperatures) and the amount of organic matter and microorganisms present in the soil.

When the plant roots do not receive an adequate supply of O_2 their growth is slowed or stopped. Root tips can start to die after 24–48 hours without oxygen. Waterlogging and reduced O_2 levels in the soil affect the roots ability to absorb water and nutrients and when this happens the root sends a signal to the tree which triggers the leaf stomata to close to reduce water loss. Because the roots cannot take up water the leaves begin to wilt. Most research concludes that low O_2 and not excess CO_2 is likely to be the major source of damage associated with short term soil flooding. The effects of waterlogging can be less severe if the water is flowing, because moving water carries dissolved oxygen and also carries away any toxins.

The loss of O_2 makes the soil anaerobic causing changes in biological and chemical processes. If soils remain waterlogged and these anaerobic conditions persist for more than a few days these changes in biological activity and chemical processes may become important. CO_2 and various anaerobic by-products such as sulfur, hydrogen sulfide, methane, and organic acids start to accumulate, some of which affect root growth and function. Of all the by-products produced, hydrogen sulfide appears to do the greatest damage to citrus roots. These changes can also lead to nutrient imbalances. Nitrogen is the first ion to undergo reduction resulting in losses of plant available nitrates. After nitrogen, the oxides of manganese and iron are converted into more soluble forms and in acid soils iron toxicity may be a problem. Soil pH has a big effect on what nutrients will become either more or less available in flooded soils.

Symptoms, effects and tolerance of citrus to waterlogging

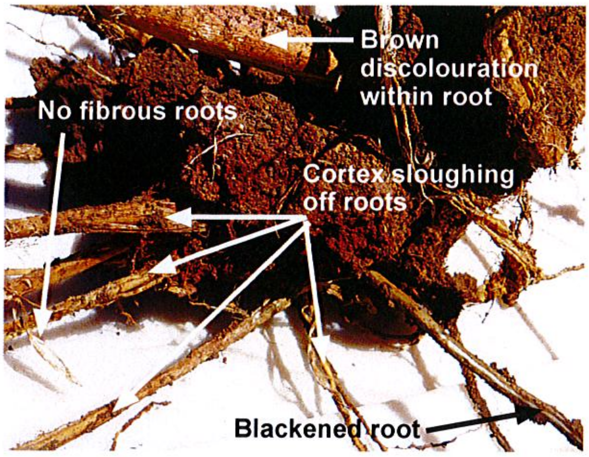
Tree symptoms vary with the frequency and duration of waterlogging and rootstock.

Root distribution in the soil is dependent on soil type, subsoil characteristics, rootstock characteristics and the irrigation regime (frequency and distribution in the root zone). The most active absorption of water and nutrients is carried out by the fibrous or feeder roots and these are typically in the top 15–30 cm of the soil. The healthiest roots are usually in this top layer which should be the first to drain.

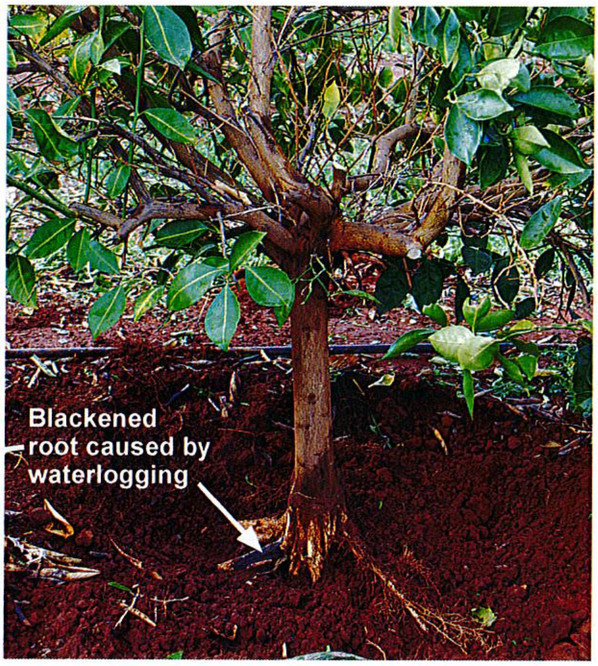
Because waterlogged trees cannot take up water, one of the first symptoms seen is wilting of the foliage and shoots, particularly in warm weather.

If root damage is excessive or soils remain waterlogged for longer periods the tree can show more severe symptoms such as leaf drop, reduced growth, yellow veins, small yellowish leaves and dead twigs — symptoms which are also similar to those caused by *Phytophthora* root rot. The fibrous roots are sloughed off and even the larger roots die or are weakened. Dead areas develop in the larger roots which are initially brown and water soaked and become black as they are invaded by soil microorganisms. Because the above ground parts of the tree mirror what is underneath the soil, trees will respond to any major damage to the root system by reducing the size of their canopy either by dropping leaves or reducing the number and length of shoots.

Citrus rootstocks vary in their ability to tolerate waterlogging which is also partly governed by their susceptibility to or infection by *Phytophthora* root rot. Table 1 gives some general ratings for common citrus rootstocks. How trees will cope and respond to the effects of waterlogging also depends on soil type and pH, the amount of roots damaged and other rootstock characteristics such as the ability to generate new roots. For example vigorous rootstocks such as rough lemon can rapidly replace roots if soil conditions become more favourable.



Citrus roots showing various symptoms of waterlogging damage, including cortex sloughing, brown and black internal discoloration and a lack of fibrous roots.



Structural roots showing blackening from waterlogged conditions.

Rootstock	Waterlogging/flooding tolerance	*Phytophthora* tolerance 1 = Best 5 = Worst	Salinity tolerance	Rootstock characteristics
Benton citrange	poor – intermediate	2	good	shallow rooted
Carrizo and Troyer citrange	poor – intermediate	2	poor	intermediate depth & fibrous
Rough lemon	intermediate – good	4	poor	deep rooted and extensive lateral growth
Sweet orange	poor	5	intermediate	intermediate depth
Swingle citrumelo	good	2	intermediate	intermediate depth
Trifoliata	intermediate-good	1 (highly resistant)	poor	shallow rooted & fibrous

Table 1: Citrus rootstock characteristics and tolerances

Diseases prevalent following wet conditions

A number of mostly fungal diseases can become a problem following wet weather or in conditions of high humidity. The most important of these is *Phytophthora* root rot, but in wet soils, other fungi may exacerbate injury to already damaged roots.

Phytophthora

The fungus *Phytophthora* causes three main diseases in citrus – root rot, collar rot and brown rot.

Root rot

Rootstocks vary in their tolerance to *Phytophthora* root rot. Trifoliata is highly resistant to the fungus, and the citrange rootstocks (Troyer, Carrizo, Benton) and Swingle citrumelo have good tolerance, whilst rough lemon and sweet orange are very susceptible. (see Table 1).

The *Phytophthora* fungus needs moisture to become active and when soil is dry its activity ceases. Temperature and soil pH can also influence activity. *Phytophthora* can thrive in moist soils with a pH of between 5.5 and 7.5. If the fungus is present and soil moisture is high, fibrous roots can be destroyed in a few days and root replacement may not be sufficient to maintain tree health. If the soil is wet for lengthy periods the permanent lateral and larger roots can be infected.

The above ground symptoms of *Phytophthora* root rot include thinning of the foliage (usually starting at the tops of trees), sparse new growth and reduced tree vigour, yellowing, dull or bronzed foliage, yellow veins and dieback of twigs and branches. *Phytophthora* affected trees which are suffering root damage, require lighter more frequent irrigations than healthy trees.

Using phosphorous acid to contol root rot

The only chemical registered for the control of *Phytophthora* root rot in citrus is phosphorous acid applied as a foliar spray. Phosphorous acid (also referred to as phosphonic acid or phosphonate) protects roots against the *Phytophthora* fungus, so trees need to have some healthy roots for it to be effective. Phosphorous acid does not reduce populations of *Phytophthora* in the soil, but has a dual action in the plant — it directly inhibits the growth of the fungus and indirectly stimulates the plants natural defence mechanisms.

Phosphorous acid is highly systemic and mobile, but regardless of application method it moves with the sap flow to that part of the plant most actively growing. "Its movement in the tree is related to photoassimilate/ carbohydrate partitioning which varies with the activity of the competing sinks, i.e. roots, leaves, fruit". (Wolstenholme 2010). Therefore application timing for phosphorous acid sprays is very important and needs to occur when there will be effective translocation from the leaves to the roots. When trees are flowering and setting fruit or when vegetative growth is vigorous, these organs have a stronger need for carbohydrates than the roots. If phosphorous acid is applied at these times it may remain largely in the leaves and not move quickly down into the roots to provide protection from *Phytophthora* root rot . Based on this information, application timing in citrus would be best targeted after any leaf flush has finished. For this reason most product labels recommend applications in either autumn or late winter prior to flowering or any growth flush. For foliar application good leaf cover is necessary.

Rootstocks vary in their tolerance to Phytophthora root rot. Rough lemon (on left) which is very susceptible, showing symptoms of dieback compared to healthy trees on trifoliata (right) which is highly resistant to Phytophthora root rot.

Most research on the use of phosphorous acid to control *Phytophthora* has been carried out on avocados. This research has shown for foliar application of phosphorous acid that:

- High volume sprays applied to the point of runoff was the most effective application method at increasing phosphonic acid levels in the roots (Thomas 2001).
- Phytotoxicity (leaf burn) was related to the pH of the formulation applied. Therefore it should not be mixed with other chemicals and the pH of the final tank mixture should be as close as possible to 7.2 (Whiley *et al* 2001).
- The presence of some copper residues (particularly copper hydroxide) on the leaf increased the risk of phytotoxicity. (Whiley *et al* 2001).

Research on citrus has also shown that foliar application of phosphorous acid can cause some phytotoxic effects (e.g. leaf burn) in young mandarin trees (container grown and field planted). Most product labels carry warning statements about this and lower rates are usually recommended for young trees.

Most product labels also commonly carry the following critical comments *"for effective control apply as a protectant, before above ground symptoms of decline or collar rot become evident. Phosphorous acid should not be applied under high temperatures (>35°C) particularly if humidity is low or to moisture stressed trees".*

For best results and to avoid problems with phytotoxicity follow all label directions carefully.

Collar rot

Spores of the Phytophthora fungus are produced in organic matter on the soil surface and are splashed or carried onto tree trunks causing collar rot. Trees on trifoliata rootstock will only develop symptoms on the scion as trifoliata is largely resistant to collar rot. Ensuring the bud-union is well above soil level is generally the most effective way of preventing collar rot. Scions vary in their susceptibility to collar rot with lemons being the most susceptible, followed by grapefruit, Washington navel and Valencia orange.

Inspection of the trunks at various intervals following flooding is important. The first indication of collar rot is the exudation of gum on the trunk. Superficial paring of the bark with a sharp knife, in the vicinity of the gumming will show the bark to be discoloured and moist, later becoming dead, dry and brittle. Infection most commonly starts near soil level and works its way upwards and around the trunk. However, after a flood, damage can occur anywhere on the trunk and branches where the muddy water reached. Trees may be attacked at all ages, but in mature trees the resulting foliar symptoms may not be evident until the disease has almost ring barked the trunk. Sometimes the infection dies out naturally due to dry weather conditions and a callus layer forms around the lesion. The lesion can also be invaded and enlarged by various wood rotting fungi.

Also check the trunks of young trees that still have tree guards or wraps in place. Soil can be carried up the trunk by ants or flood water and become trapped behind the guards — bringing infected soil into contact with the tree trunk, causing collar rot. Remove the trunk guards and any soil present and apply a protectant copper spray to the tree trunk.

On older trees prune any low hanging branches to a height of 45–50 cm above the soil and remove weeds close to the butt to help improve air circulation and reduce collar rot. Spraying the bark at the base of the trunk with a protectant fungicide such as copper may help prevent infection.

A build up of soil from ant activity, hidden behind the tree guard has led to collar rot.

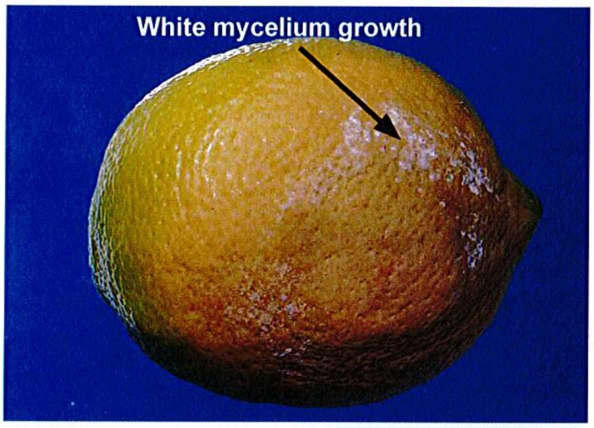
Superficial paring of the bark showing symptoms of dieback from collar rot.

Young tree death from collar rot which was hidden from view behind the tree guard.

Brown rot

Any fallen fruit or low hanging fruit is especially prone to coming in contact with water or water splash carrying the *Phytophthora* fungus. Insects and snails can also carry spores and infect fruit higher in the tree. It is usually fruit which are starting to colour or have coloured which are most susceptible to brown rot. Infected fruit will usually drop. The application of a copper spray particularly to the skirts of trees will protect low hanging fruit from brown rot infection. Do not harvest fallen fruit.

Well-timed copper sprays will also control Septoria and greasy spots, diseases which could also be exacerbated by the recent rains and resulting humid conditions. A copper spray is normally recommended for control of these diseases in March–April in southern growing regions.



Brown rot symptoms on lemon fruit showing white mycelium growth around the edge of infection.

Fruit on the lower branches of trees are very susceptible to infection from brown rot, leading to fruit fall.

Sudden Death

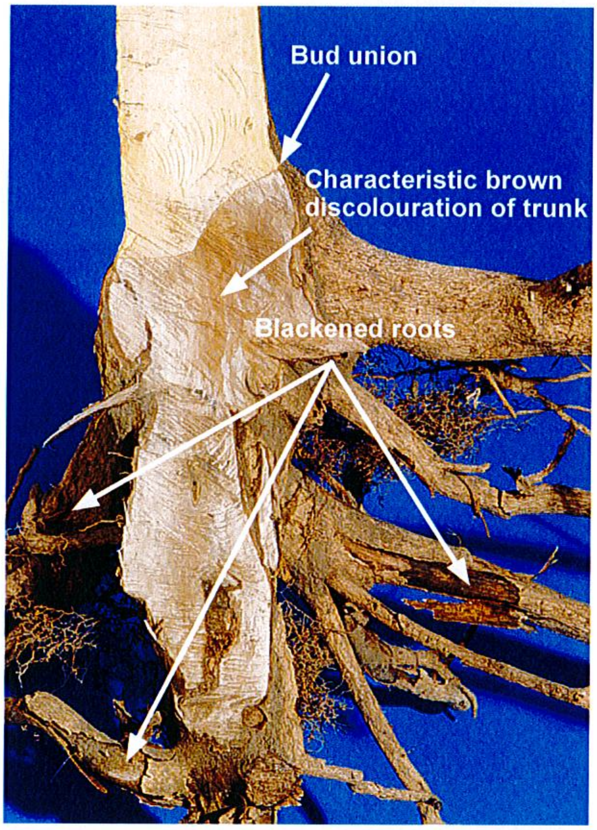
Sudden death is associated with poorly drained soil which has been subject to periods of temporary waterlogging and anaerobic conditions. Affected trees often wilt and die suddenly, usually with the leaves and fruit still attached. Progress of the disease can be less dramatic with a slow down in tree growth or the tree may be unthrifty for some time prior to sudden collapse, often just before fruit are ready to harvest. Affected trees always show one or more dead blackened structural roots from which a characteristic dry brown discoloration extends into and across the butt but not beyond the bud-union. The discoloured wood often has the smell of rancid coconut oil. Fruiting bodies of the ink cap fungus (*Coprinus*) are sometimes seen at the base of trees especially in autumn and are indicative of dead roots and high ammonium levels.

Sudden death affects trees of all scion varieties, but predominantly those on trifoliata and Carrizo and Troyer citrange rootstocks. Trees of all ages have succumbed to the disorder, but the incidence is greatest in 7 to 15 year old trees. Sudden death occurs predominantly on heavier soils or where drainage problems exist, due to perched water tables and/or compacted layers in the subsoil. Intermittent periods of waterlogging and poor aeration lead to a weakening of the root system and deterioration of root health. The incidence of sudden death may increase in the months and years to come as a result of the recent heavy rainfall and flooding events.

A major research project looking at the cause of sudden death in citrus was undertaken by Raquel Shearman in the MIA. Findings from that work indicated that where sudden death was occurring, citrus was being produced in sub-optimal soil conditions. Blocks affected by sudden death had heavier soil textures (medium to heavy clay top soils), duller soil colours and more mottling and manganese nodules — indicating the soils were subject to temporary waterlogging or poor soil aeration. In 10 orchards studied in the Griffith area the average incidence of sudden death was 24%

Sudden death causes trees to suddenly die, usually with their fruit and leaves still attached.

and affected trees tended to occur in clusters or defined areas, rather than randomly throughout a block. The subsoil of sudden death affected blocks was wetter and less aerated and soil compaction was evident. Although some roots penetrated through this compacted layer, it was still causing poor internal drainage, leading to intermittent waterlogging (from perched water tables) resulting in anaerobic soil conditions. Table 2 summarises some of the soil characteristics from the healthy and sudden death affected sites studied.



Transection of sudden death affected root system, showing the brown discolouration entering from the rotting roots, and ceasing at the bud union.

What can be done after flooding & waterlogging?

Short term:

- If possible dig surface drains or trenches to help direct water quickly away from trees or low lying areas.
- Do not take heavy machinery onto soils which are waterlogged as this will cause further compaction and structural damage to soil, exasperating drainage problems.
- On young trees check inside tree guards for any build up of soil, ants and the presence of collar rot. Remove tree guards, clean away soil and apply a protectant copper spray.
- Check the trunks of mature trees for signs of collar rot, remove any soil and tall growing weeds away from trunks and skirt low hanging branches. Ensure the bud union is well above soil level. Apply a protective copper spray to the trunks including above the bud union.
- If trees are suffering from Phytophthora root rot – foliar sprays of phosphorous acid can be applied. Remember trees need good foliage cover and an adequate amount of healthy roots for the phosphorous acid to move into the root system and provide protection against attack. The best timing is when the roots are actively growing, after any major shoot flush is finished. For more details see page 4.
- To prevent brown rot on fruit, skirt low hanging branches and apply a protectant copper spray to tree skirts.
- If trees are suffering root damage or root rot reduce irrigation and fertiliser amounts accordingly. Trees suffering root damage require lighter more frequent irrigations. Monitor soil moisture levels using devices such as tensiometers or gypsum blocks.

	Healthy sites	Sudden Death sites
Soil pit description	Soils dark reddish brown with only a few reddish yellow mottles. Soil colour shows no visual symptoms of previous waterlogging events.	Soils paler and duller in colour especially in the subsoil with frequent red, yellow and orange mottles. Soil colour shows evidence of previous waterlogging events, iron re-oxidation and poor soil aeration.
Soil texture	Clay loam to light clay topsoil	Medium to heavy clay topsoil
Porosity (air/water)		Wetter & less aerated in the root zone. Pores become filled with water after rainfall or irrigation and do not drain, with subsoil becoming anaerobic.
Soil compaction		Contributing to poor internal drainage of soil profile, leading to waterlogging through perched water tables.
Soil chemical factors	Nitrate higher	Ammonium and nitrite nitrogen higher.

Table 2: Description of soils from sudden death and healthy sites. (Shearman, 2006)

- Monitor foliage for signs of any nutrient toxicities or deficiencies and adjust fertiliser programs to suit.
- In southern growing regions a protectant copper spray applied in March–April will help manage brown rot, Septoria and greasy spots, diseases which could be exacerbated by the recent rains and resulting humid conditions.

Long term:

- Prior to planting any new blocks, carefully assess local soil conditions by undertaking a soil survey and digging soil pits across the site – don't plant trees in soils or sites that are unsuitable for growing citrus – citrus trees require good drainage.
- Before you plant – undertake all measures necessary that will help mitigate any future soil waterlogging problems such as the installation of subsurface tile and mole drains and the use of mounds in tree rows.
- Select rootstocks that match local soil conditions.
- When planting trees ensure the bud union is well above soil level.
- Match your irrigation system to local soil conditions – design your system so that you can deliver different amounts of water to match different soil conditions within your farm or block.
- Don't over irrigate – monitor soil moisture levels in the topsoil and subsoil using monitoring tools such as tensiometers or gypsum blocks. For example tensiometers should be positioned at depths of 30 and 60 cm in the tree row.

Always read the label: Users of agricultural (or veterinary) chemical products must always read the label and any Permit before using the product, and strictly comply with the directions on the label and the conditions of any Permit. Users are not absolved from compliance with the directions on the label or the conditions of the Permit by reason of any statement made or not made in this publication.

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CITRUS INDUSTRY BIOSECURITY

DRAFT OPTIONS FOR TRAINING, RAISING AWARENESS AND BIOSECURITY OFFICERS 2011

Plant Health AUSTRALIA

Citrus Australia

Table of contents

Introduction

Implementation of biosecurity activities at the industry level is an important aspect protecting the industry. The Industry Biosecurity Plan (IBP) for the Citrus Industry was developed in 2004, with the revised version 2 released in 2009. This IBP identifies key pest threats to the industry and provides a framework for biosecurity activities that can be implemented.

The production of the Orchard Biosecurity Manual for the Citrus Industry and exotic pest awareness material, such as those on Citrus canker, Huanglongbing and the Asiatic citrus psyllid, deliver key areas of biosecurity implementation.

To support this material and other biosecurity activities, this document provides an outline of potential biosecurity awareness and training activities that could be undertaken in the next 12 months within the citrus industry. These activities are presented as options that could be accomplished individually, in sequence or in parallel, and are designed to build off the groundwork already in place in the industry.

A summary of the potential activities, together with the role of a biosecurity officer is presented in Figure 1.

While the responsibility for the identification of activities, funding and implementation lies with Citrus Australia, PHA will provide support, advice and material where applicable and requested.

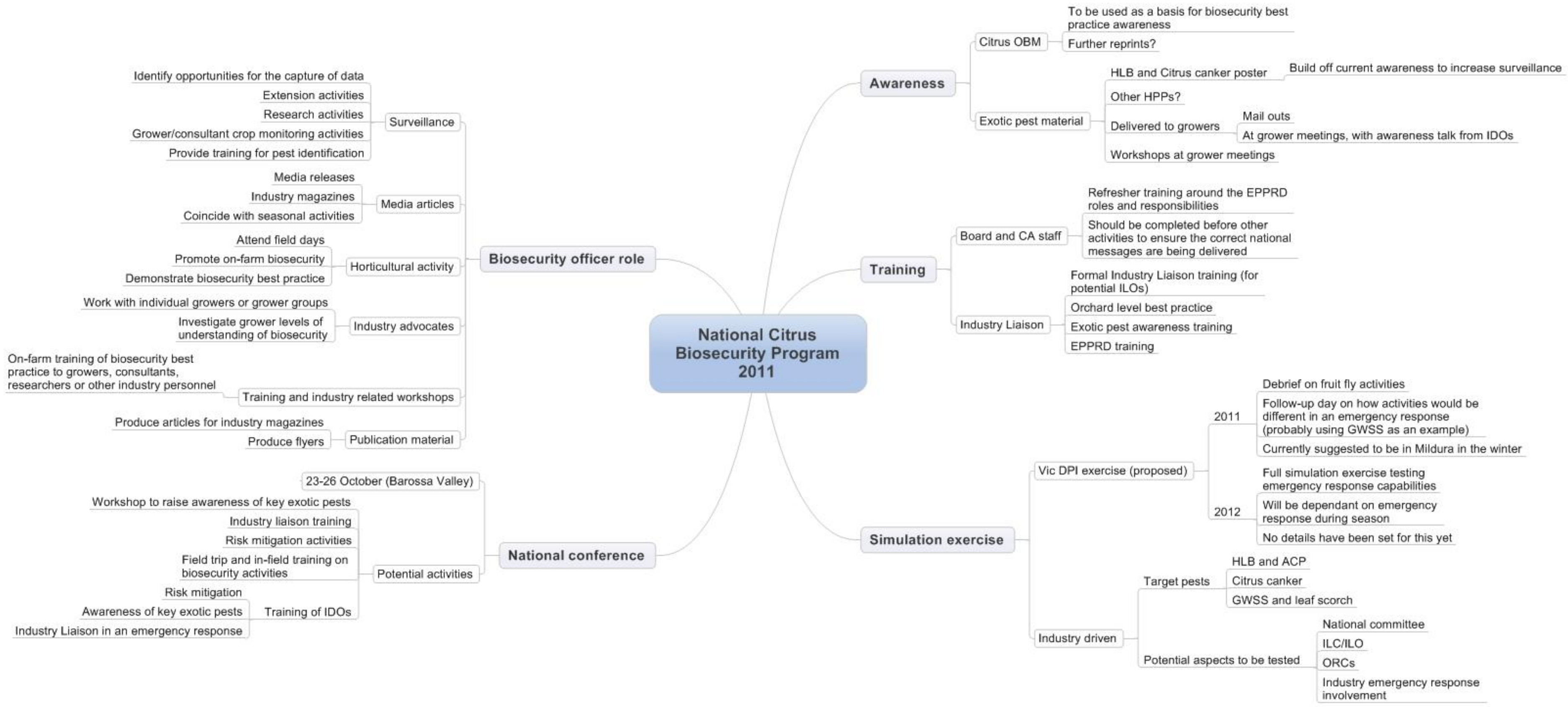

Figure 1. Summary of potential biosecurity awareness and training activities, and biosecurity officer roles, for the citrus industry

Training activities

Emergency Plant Pest Response Deed (EPPRD) training

As a signatory to the EPPRD, Citrus Australia has a number of roles and responsibilities that it needs to understand and undertake, especially during an emergency response to an EPP. There are a number of potential high impact pest threats to the citrus industry on Australia's doorstep, and increase the likelihood of effectively responding to them should they arrive it is important that the key players in a response understand their roles and responsibilities.

As part of the National EPP Training Program, PHA can deliver this training to Citrus Australia and its members. This training will provide context for the other biosecurity activities suggested in this document, and therefore it is recommended that it be completed as the initial action of this program. This training is suited to be presented to members of the Board, management and other staff members of Citrus Australia. Delivery to others, such as IDOs is also beneficial.

As part of the National EPP Training Program, we are also started to develop an Industry Liaison training package. It is hoped that this will be competency-based, but that is yet to be determined. This training would be centred on industry roles in a response, specifically for the Industry Liaison Coordinator and Industry Liaison Officers.

Simulation exercises

Simulation exercises are used to provide training on biosecurity issues using real world examples. This can be completed to increase understanding of the required roles, identify areas of improvement, or to test out emergency response systems. Currently, there are two broad options for simulation exercises for the citrus industry, as described below.

Victorian DPI driven

As part of their preparedness activities, the Victorian DPI designs and runs simulation exercises around plant pest incursions. The most recent of these was "Cereal Killer", which focussed on a wheat pest, which was completed in 2009.

Currently, Vic DPI is planning to run another simulation exercise that will engage a range of horticultural industries. The recent situations around Chestnut blight and locusts have meant that this exercise has been postponed. With this in mind, the current proposed program is as follows:

- 2011:
    - Complete a debrief on the fruit fly activities and response from this season (is done after every major response)
    - The debrief would be followed by a workshop highlighting the similarities and key differences between the fruit fly response and that mounted if an exotic plant pest were detected. This is expected to use the Glassy-winged sharpshooter as an example
- 2012:
    - Complete a full simulation exercise (to the same level as Cereal Killer)

- Is expected to focus on both the government requirements together with the integration of horticultural industries into the response
- PHA will be on the organising committee, and we will be ensuring that our industry members can get as much out of this as possible

In both cases above, representatives from industry will be invited to participate. Although details have not been determined, it is expected that two representatives from each industry will be invited.

Industry driven

Simulation exercises can also be developed and run specifically by the industry. While the scale of these exercises would not be the same as those delivered by government agencies, it allows for issues more directly related to the industry to be analysed.

Some suggested areas that could be tested by simulation exercises include:

- Participation in national decision making committees (CCEPP/NMG)
    - Discussion exercise
- Industry Liaison
    - Identify the roles required in a response
    - Look at the requirements of these roles to help identify people
    - Test industry networks for information flow
    - Identify areas of lacking information within the industry (e.g. transport routes, marketing details, etc.)
- Owner Reimbursement Costs (ORCs)
    - Use the draft ORC framework as a basis
    - Look at how this information is collected and how the industry can help in the process
    - Could be part of the process of getting the framework completed
- In-field activities
    - If an exotic plant pest (e.g. HLB) is detected, what would be the direct impacts to growers
    - Look at implementation of quarantine restrictions, destruction/treatment of product, operations in affected areas, etc.
    - Would require engagement of government representatives
    - Could also be linked in with highlighting surveillance and other risk mitigation activities

Pest awareness training

This would build on the awareness material that has already been produced through Citrus Australia and would call on experts in these pests to train people who are out in the field. The basis behind this type of training is to heighten the awareness that these exotic pests are out there and can cause severe impacts to the industry, together with providing information to allow participants to identify them.

The target audience for this training would be IDOs, consultants and potentially growers who are likely to be the first people to detect new incursions. By completing this training these participants would be able to identify the pest or symptoms easily and know what to do with this information.

Awareness material

Exotic pest material

Citrus Australia has already made an excellent start in the production and distribution of exotic pest awareness material. The poster highlighting Citrus canker, HLB and ACP is an excellent example of providing simple, effective messages around key exotic pests to the industry. However, to ensure the message stays fresh in industry stakeholder's minds, new material should be developed and distributed regularly.

Suggestions for exotic pest awareness material include:

- Pest fact sheets
- "Ute guides"
- Posters
- Giveaways (e.g. sunscreen, magnifying glasses, etc.) that have pest awareness information attached
- Adds/inserts in industry magazines and newsletters

Orchard biosecurity manual

The Orchard Biosecurity Manual for the Citrus Industry was released in 2009 and was distributed widely. While this is a valuable resource, it can provide a basis for further biosecurity activities. This manual can be used as support material for some of the training listed in the sections above.

The value of this content can also be increased by integrating it into other information sources, such as production guides and manuals, which demonstrate that biosecurity activities can be carried out easily in everyday activities.

Biosecurity Officer

This draft work plan has been developed using the Grains Biosecurity Officer (GBO) work plan as a basis. The work plan provides and outline of activities that could potentially be undertaken as part of a Biosecurity Officer role within the citrus industry. This role could be filled by a single or multiple officer(s), or by utilising Industry Development Officers already in place in the industry. Where more than one person would be undertaking the role, it is recommended that a dedicated manager/coordinator be employed to centrally organise the program. For the program to be effective, comparable and consistent messages and activities should be delivered to all citrus industry stakeholders[1].

Work plan

The following components comprise the activities undertaken by the GBOs as part of the Grains Farm Biosecurity Program for the 2010-2013 period. These activities provide examples of what could be completed within the citrus industry by biosecurity officers. Specific details on the activities would be determined for the citrus industry at a later date should they be elected to be undertaken.

Surveillance

Activity	Identify opportunities and develop and provide support for mechanisms for the collection and capture of surveillance data for high priority exotic pests of the grains industry. Sources of surveillance data will include (but may not be limited to) the following: • Government diagnostic laboratory(ies) and or research or extension activities. • Industry and pathology and entomology research activities that are collecting data on endemic pests or agronomic traits • Industry activities such as crop monitoring undertaken by growers or consultants • GBO to collect information on key risk pathways, and work with appropriate agencies (government (AQIS) and industry) to ensure correct reporting of incidents and capture of information GBO to provide training on awareness and basic identification of high priority pest threats to assist surveillance (see Section 3.5) as well as develop and implement mechanisms for capture of data.
Measure of success	Surveillance data from the sources listed above entered into the National Plant Surveillance Reporting Tool (NPSRT) each quarter.

Media articles

Activity	A regular schedule of media releases will be produced to coincide with the different seasonal activities associated with grain production and storage.
Measure of success	Press releases developed and released as part of the Grains Farm Biosecurity Program. Uptake of releases will be monitored to gauge the impact on stakeholder awareness.

[1] In this document the term ‘citrus industry stakeholders’ include all citrus growers, consultants, researchers, contractors, harvesters, export consultants, end product users, chemical, equipment suppliers, and all other stakeholders in the citrus industry

Agricultural activity

Activity	Attendance at key agricultural activities, field days and farm tours to promote on-farm biosecurity or demonstrate biosecurity best practices and distribute awareness information. GBO will use their networks to identify opportunities and mechanisms for value adding to farm tours established by others.
Measure of success	GBOs will attend and present information at a minimum of six agricultural activities during the financial year. Incorporation of biosecurity messages into a minimum of two farm tours per financial year.

Industry advocates – individual growers and grower groups

Activity	A key outcome for this program is the improved management of, and preparedness for, biosecurity risks at the farm gate and throughout the grains industry. This activity will be undertaken by: 1. Working with growers and grower groups • Identify and work with growers implementing farm biosecurity best practice or encourage growers and/or farming groups Australia to improve biosecurity practices. • Identify and work with farming groups, consultancy groups or grower industry networks demonstrating a commitment to biosecurity best practice. 2. Evaluation of the program • Grower evaluation undertaken by PHA to gain an understanding of growers' baseline biosecurity knowledge and practices. • GBO to interview or obtain information from growers and/or industry participants using Turning Point® or other survey methods. • Follow-up interviews with growers to assess biosecurity uptake and/or change in practices.
Measure of success	Industry advocates identified. Interviews conducted and report prepared on each industry advocate by June each year.

Training, information exchange and industry related workshops /courses

Activities	Training and information exchange to be developed and presented to different target audiences to provide biosecurity information or specific advice. Training sessions to be tailored for the following audiences and topics: • Farm groups/growers – Biosecurity awareness sessions covering the importance of biosecurity, reporting procedures, how to implement biosecurity best practice and relevant key pest threats. • Researchers (general) – Biosecurity awareness, reporting and, if required, key pest threats. • Researchers, and staff from National Variety Trial, breeding programs, etc. (surveillance) – Reporting, identification of key pest threats and incorporating surveillance into monitoring and recording practices. • Consultants – Importance of biosecurity, reporting, surveillance, identification of key pest threats. • Other industry participants within the grain supply chain – awareness, biosecurity best practice and surveillance.
Measure of success	Training sessions given to farm grower groups, researchers and consultants or other industry participants within the grain supply chain.

Other activities

Activities	As requested by their state agency or by PHA, GBO to assist in biosecurity or emergency response activities, coordination of meetings, maintain or building networks or to undertake professional development activities. This includes acting as the Industry Liaison Officer or Industry Liaison Coordinator as requested.
Measure of success	Assist with coordination of meetings relating biosecurity, surveillance or pest and disease identification as requested. Where requested, the GBO will assist with biosecurity or emergency response activities or undertake professional development activities.

Publication material for the Grains Farm Program

Activities	A range of communication/ extension material will be produced within the Grains Farm Biosecurity Program to assist in the delivery of biosecurity messages, promote the Program and GBOs and provide specialist technical advice.
Measure of success	GBO to provide assistance with the preparation of articles and extension material from the Grains Farm Biosecurity Program . GBO may also be involved in the preparation of industry newsletters and fact sheets.

Communication within the Grains Farm Biosecurity Program

Activities	Internal communication within the Grains Farm Biosecurity Program will include teleconferences, face-to-face meetings, use of the Grains SharePoint website as well as ad hoc communication via email and phone. Other types of communication activities, including letters to target audiences, advertisements in rural media, articles in industry newsletters, pamphlets, Farm Biosecurity website etc., may be required that assist deliver messages to target audiences.
Measure of success	SharePoint updated on a regular basis and meetings to be held as listed above. Teleconferences held on the last Wednesday of each month unless advised otherwise.

Activities calendar

This document contains a number of suggested activities that could be undertaken by the citrus industry to increase biosecurity implementation and preparedness. In most cases, the delivery of these activities would be dependent on other activities within the industry (e.g. a simulation exercise would not be run during harvest).

As an initial guide, Table 1 provides some suggested timing for some of these activities. At this stage, no events or activities have been finalised.

Table 1. Calendar guide for biosecurity training and awareness activities

Activities	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
EPPRD training	✓	✓						
Industry liaison training	✓	✓				✓	✓	
Simulation (Vic DPI)			✓	✓				
Simulation (Industry)				✓	✓	✓		
Pest awareness training					✓	✓	✓	
Awareness material production		✓	✓	✓	✓	✓	✓	✓