

Final Report

Biosecurity preparedness for oriental fruit fly

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Biosecurity preparedness for oriental fruit fly (FF18001)

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Public summary

Fruit flies are the most economically damaging insect pests of Australian horticulture, rendering fruit unmarketable and severely restricting interstate and international trade. Effective management requires an integrated approach combining surveillance systems, pre- and post-harvest control measures, and rigorous export certification systems. Among these pests, the Oriental fruit fly (*Bactrocera dorsalis*, OFF) is recognised as one of the world's most invasive and damaging species, posing a serious biosecurity threat to Australia. Over the past 15 years, OFF has rapidly expanded across Southeast Asia and sub-Saharan Africa, where annual trade losses from its spread are estimated at US\$2 billion, with additional multi-million-dollar crop losses reported in regions such as Hawaii.

Although OFF is not established in Australia, repeated interceptions in northern regions-particularly the Torres Strait Islands and northern Queensland-demonstrate the pest's incursion potential. Historical data show that had OFF established populations during the 1995–1999 incursions, annual control costs could have reached AU\$7-8 million. These figures underline the urgency of proactive preparedness measures to maintain Australia's fruit fly-free status and protect valuable horticultural markets.

In response, project FF18001 was initiated to assess and strengthen Australia's national biosecurity preparedness for OFF and similar exotic fruit fly species. This project took a comprehensive approach that included reviewing global best practices for exotic fruit fly management, evaluating risks of incursion and establishment under Australian conditions, and developing critical biosecurity tools. Efforts also focused on building international collaborations, engaging key stakeholders, and supporting planning through biosecurity simulations and communication materials. Notably, Plant Health Australia (PHA) played a central role in facilitating biosecurity exercises conducted in Sydney (NSW) and Cairns (QLD), and in reviewing proposed movement guidelines for commodities.

The project was a collaborative effort involving Macquarie University (MU), the New South Wales Department of Primary Industries (NSW DPI)-currently New South Wales Department of Primary Industries and Regional Development (NSW DPIRD), and the South Australian Research and Development Institute (SARDI)/Primary Industries and Regions South Australia (PIRSA), with PHA as a key delivery partner. The outcomes of this work will have long-term benefits for the horticulture sector by enhancing the speed, coordination, and effectiveness of responses to any exotic fruit fly incursions, thereby reducing potential economic impacts and preserving market access.

New resources generated through the project include a peer-reviewed scientific review, a national biosecurity plan, a cross-commodity contingency plan, proposed movement guidelines for commodities, and detailed reports from biosecurity simulation exercises. These outputs are available through Hort Innovation and Plant Health Australia and will serve as valuable references for industry and government agencies in future preparedness and response activities.

Keywords

Preparedness; Exotic Fruit flies; Incursion risk; Movement guidelines; Simulation exercise; Emergency response

Introduction

Fruit flies are among the most destructive and economically important pests affecting horticultural industries worldwide, with over 350 species recognized as significant threats. In particular, *Bactrocera dorsalis* (the Oriental Fruit Fly, or OFF), a native pest of Asia, has gained importance due to its broad host range and ability to rapidly establish in new areas. OFF is present in at least 65 countries and has been found to attack over 300 plant species, making it one of the most damaging fruit fly pests globally. While OFF has not yet established in Australia, it poses a serious risk, particularly as it is already widespread in nearby regions such as Papua New Guinea and parts of South Asia and Africa.

Australia's proximity to these infested regions increases the likelihood of OFF and other exotic fruit fly species being introduced into the country, particularly through international trade, tourism, and migration of goods. This risk is further compounded by factors such as climate change, land use practices, and seasonal wind patterns that may facilitate the spread of fruit flies, especially to vulnerable areas such as the Torres Strait Islands. In fact, seasonal winds from Papua New Guinea are a key driver of the regular incursions of exotic fruit flies into the Torres Strait. As such, understanding wind dispersion patterns is crucial for improving pre-border surveillance and preparedness.

The incursion of exotic fruit fly species like OFF would have significant economic consequences for Australian horticulture, threatening both domestic production and export markets. Despite the short-term nature of some incursions, the impact can still be profound, as the pests can severely restrict market access and disrupt trade. Successful eradication programs, while possible, are costly, and the chances of success diminish significantly the longer a pest species is allowed to establish itself. For example, in 1995, OFF was detected in Cairns, Queensland, after likely being present in Australia for up to 15 months. It took four years and \$100 million to eradicate it from the region (Cantrell et al. 2002).

In response to these ongoing risks, Australia has implemented national surveillance programs, including the exotic fruit fly trapping program at international ports and in key regions such as Cape York, as well as a dedicated strategy for the Torres Strait Islands. These programs play a vital role in early detection, but their success relies heavily on the ability to coordinate national efforts and adapt to changing threats. Additionally, Australia's biosecurity laws and strategies aim to minimize the impact of plant pests and diseases, emphasizing preparedness, rapid response, and recovery.

The rationale for this project lies in the need to enhance Australia's biosecurity preparedness, particularly in relation to the threat posed by OFF and other exotic fruit flies. The project focuses on understanding the entry, spread, and potential establishment of these pests in Australia, through a review of current national and international management practices. It further aims to refine response strategies and improve coordination across various jurisdictions involved in fruit fly management. This includes developing a comprehensive biosecurity plan, contingency protocols for pest incursions, and movement guidelines for commodities, all of which are essential for minimizing the risk of an exotic fruit fly incursion.

The significance of this project lies not only in improving Australia's biosecurity preparedness but also in safeguarding the horticultural industry from future threats, ensuring continued access to international markets and reducing the reliance on chemical pesticides. As global market demands change, Australia's ability to maintain its fruit fly-free status presents both challenges and opportunities. Successfully preventing the establishment of OFF and other exotic pests will provide long-term benefits to the Australian supply chain, enhancing competitiveness in the global marketplace while preserving the integrity of the environment and agricultural systems.

To strengthen Australia's national biosecurity framework against exotic fruit fly, this project published a peer-reviewed review paper on biosecurity and management of exotic fruit flies, produced a comprehensive biosecurity plan, a contingency plan, proposed movement guidelines of commodities, and the implementation of biosecurity exercises in NSW (Sydney) and QLD (Cairns). Ultimately, its outcomes provide valuable insights into effective pest management strategies, helping to ensure the sustainability and resilience of Australia's horticultural industries to the biosecurity threats such as OFF.

The project is a collaboration between Macquarie University (MU), New South Wales Department of Primary Industries and Regional Development (NSW DPIRD) and South Australian Research and Development Institute (SARDI) Primary Industries and Regions SA (SARDI-PIRSA). Plant Health Australia (PHA) is an external partner playing major role in the biosecurity exercise.

Methodology

Biosecurity measure requires steps to prevent national border from the entry, spread, and establishment of harmful pests and diseases. Australia's extensive coastline and global connectivity expose it to significant biosecurity risks from exotic pests, weeds, and diseases. Biosecurity involves applying measures offshore, at the border, and onshore to prevent their introduction and spread. The Australian government uses screening technologies, quarantine programs, surveillance, and detector dogs as frontline defences. Ongoing research, international collaboration, and targeted monitoring in high-risk areas further support these efforts to protect Australia's environment, agriculture, and social wellbeing. This project, FF18001, contributed to the national effort to strengthen Australia's biosecurity preparedness against exotic fruit flies, particularly OFF. This project undertook a series of coordinated actions aimed at strengthening national readiness against the OFF. The actions included reviewing global management practices, building international collaborations, engaging stakeholders, and supporting response planning through simulations and communication tools.

The project conducted a comprehensive review of scientific literature and expert insights to identify best practices and gaps in exotic fruit fly surveillance, management, and incursion response. International engagement was strengthened via webinars, expert consultations, and participation in the 11th International Symposium on Fruit Fly of Economic Importance (ISFFEI) held at Macquarie University, Sydney, Australia. A map of potential high and low risk areas of OFF entry and establishment in Australia was developed utilizing the CLIMEX model for OFF. Global case studies were used to assess incursion responses and inform a national gap analysis. A cross-commodity contingency plan was co-developed with stakeholders and aligned with national frameworks. Biosecurity exercises, led by Plant Health Australia, were conducted in Sydney (NSW) and Cairns (QLD) to test preparedness and coordination. Science-based protocols were developed for commodity movement during incursions, informed by pest biology and climate data. Targeted communication materials were also produced to support awareness and consistency in response messaging. Below are the snapshots of major activities, split in parts, undertaken to achieve the project deliverables.

Part 1: Review and develop criteria

A comprehensive review of scientific literature, grey sources, and expert insights was conducted to gather global knowledge on exotic fruit fly surveillance, risk assessment, and incursion response (Fig. 1). This process identified best practices and preparedness gaps relevant to Australia. The findings informed engagement strategies and planning frameworks. A peer-reviewed paper was produced to consolidate the evidence.

Cervantes Agritech was assigned to develop a detailed mapping on potential high and low risk areas for OFF entry and establishment by using CLIMEX model for OFF. The mapping consists of a GIS-quality map of the CLIMEX Compare Locations model run on a 0.05° grid. This model combines the CLIMEX Ecoclimatic Index (EI) and the Annual Growth Index (GIA). Together they represent the potential for establishment (EI) and ephemeral population spread (GIA). The specific goals were to run the CLIMEX and compare locations model of OFF developed within the FF-IPM project for Australia using a fine-scaled 30-year climatology based on SILO data centred on 2005. Two model scenarios were run (natural rainfall and top-up irrigation) and a composite dataset was created using the Global Map of Irrigated Areas (Siebert et al. 2013).

Additionally, data sources for Australian airports and seaports that have international connections were collated while the CLIMEX model of OFF was run using the Compare Locations/Years module to develop timeseries maps of weekly and annual climate suitability, considering the spatially explicit location of irrigation.

Part 2: Build upon established links

International collaborations with OFF and fruit fly experts were strengthened through webinars, stakeholder workshops, and participation in the 11th ISFFEI. International links have been established with organizations relevant to OFF R&D and management. IAEA, USDA, FF in Silico IPM project (Horizon 2020), ministry of Agriculture Mauritius (SIT on OFF). Experts from those organizations participated in person or online at the 11th ISFFEI and Australian National Planning Workshop for Exotic Fruit Fly workshop that was held at Macquarie University. These engagements facilitated the exchange of knowledge on surveillance, diagnostics, and Area-Wide IPM approaches. Insights were adapted to suit Australian biosecurity priorities. These partnerships enhanced access to proven tools and response models.

Part 3: Review management practices, incursion responses and impacts

An international review was conducted to examine OFF management practices, incursion responses, and economic impacts (Fig. 2). Case studies from affected countries were analysed to understand what has worked effectively. The findings were compared against Australia's existing protocols. A gap analysis informed improvements to enhance incursion readiness.

Part 4: Liaison

Industry and government stakeholders were engaged to co-develop a cross-commodity draft contingency plan for *B. dorsalis*, guided by a national reference group. The plan addressed surveillance, diagnostics, containment, and eradication measures. It was aligned with the Plant Health Australia (PHA) framework. PHA also led biosecurity exercises in New South Wales (Sydney) and Queensland (Cairns) to test preparedness and response coordination.

Part 5: Develop science-based scenarios for movement protocols

Science-based movement scenarios were developed for host commodities in the event of an OFF incursion, using pest biology, climate suitability, and host range data. Protocols were informed by global and local datasets. A gap analysis highlighted deficiencies in current practices. Information was collated from the ICAs and other relevant documents. There are existing protocols related to movement of commodities that are not accessible publicly. To identify the gaps in the existing protocols, experts from PHA, SA and NSW DPI were reached out to gather insights from their experiences. In parallel, communications were made with Walther Enkerlin, IAEA to learn international experiences. Recommendations were made to support secure commodity movement during response. Project collaborators from SARDI/PIRSA has experiences and expertise in reviewing and identifying gaps in protocols in the current ICAs for host commodities entering SA. NSW DPIRD project personnel also have access to market access and fruit transportation protocols that ensure Medfly is not introduced into NSW. These experiences from both the partners were used to collate real-time operational data across jurisdiction for the current fruit movement protocol for treatment in Australia. Of the note, the “Australian Code of Practice for Fruit Flies” allows easy changes in management practices and encourages novel approaches such as systems approaches, pest free production place and areas of low pest prevalence. The codes are likely to be adopted as a protocol. A final draft of the science-based movement protocol was then submitted to PHA for their review.

Part 6: Produce support material for communication

Communication materials were developed to support biosecurity messaging among government, industry, and the broader community. These included summaries of OFF biology, risks, surveillance priorities, and management responses. Materials were tailored to equip media and agency personnel with consistent, science-based messaging. Outputs supported preparedness and stakeholder engagement.

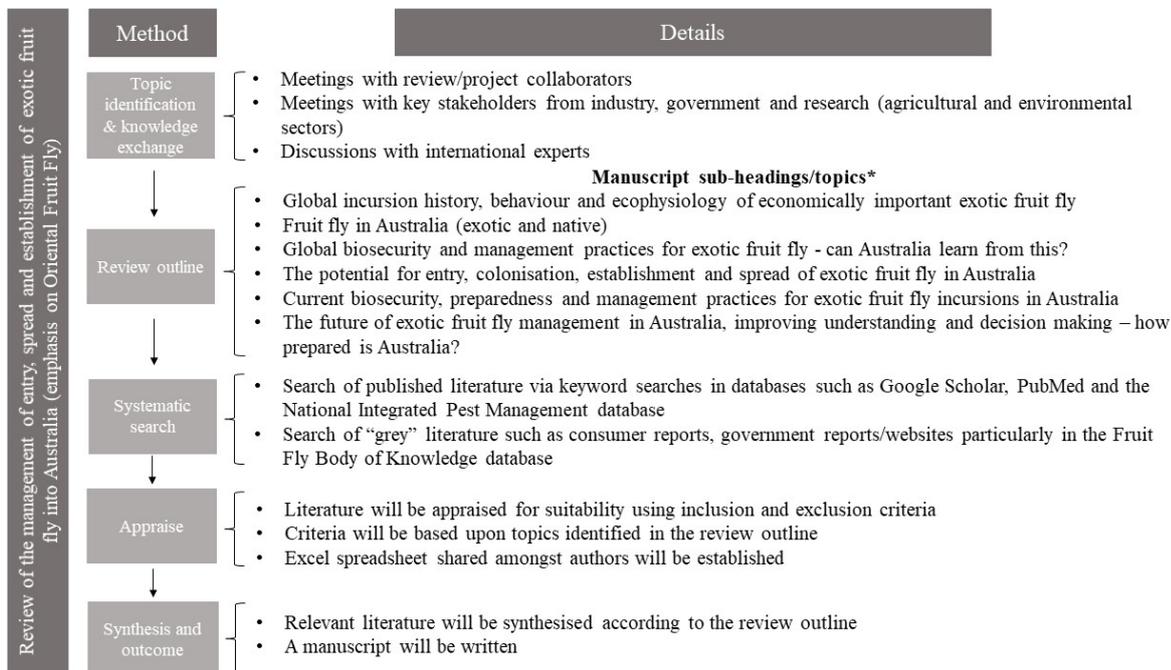


Fig. 1. Overview of Review- Biosecurity and management practices.

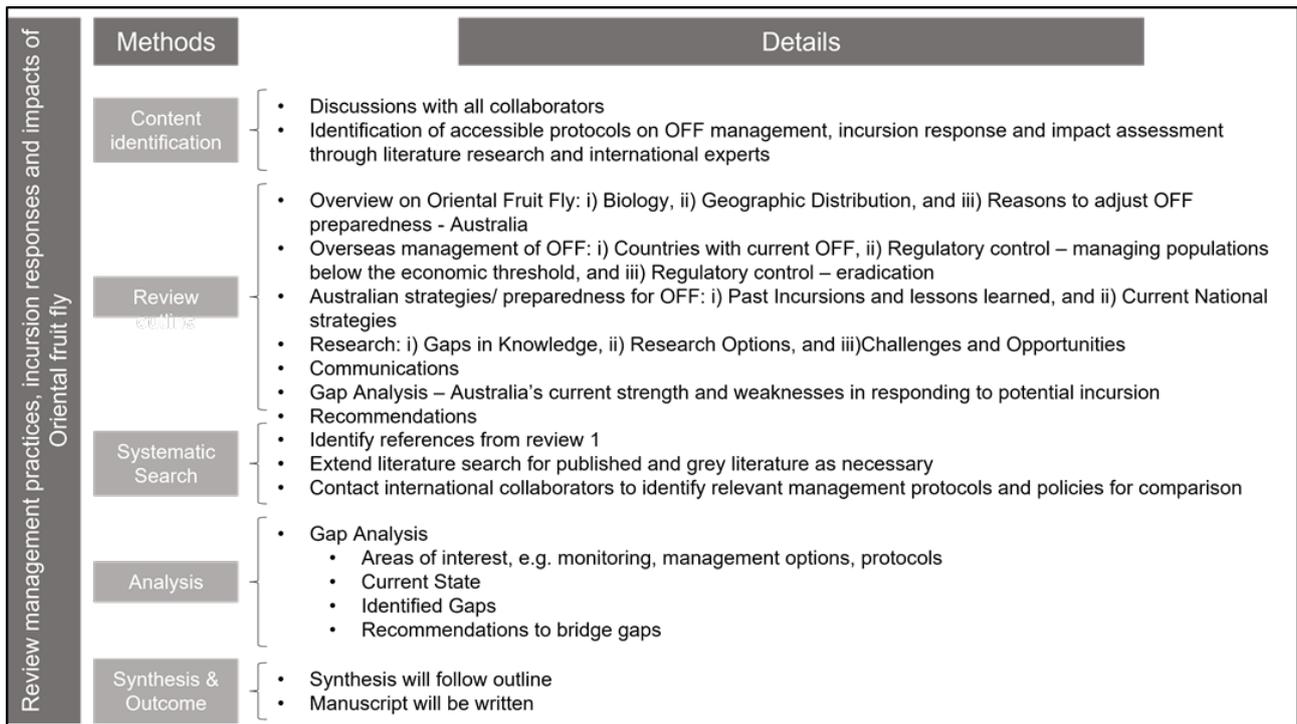


Fig. 2. Overview of Review- OFF management, incursion response and impact assessment.

Results and discussion

The project has been successful in achieving all the deliverables as outlined in the project summary. Tangible outcomes of the project are a scientific review paper published on biosecurity and management of OFF, a report on review of OFF incursion, gap analysis, and overseas management practices, a cross commodity contingency plan, a detailed mapping of potential high and low risk areas for potential entry and establishment, a proposed movement guideline, a report on biosecurity simulation exercise, and fact sheets on biology of OFF, monitoring and surveillance, control and management.

Achievements

Stakeholders' communication and engagement plan

Oriental Fruit Fly affects a diverse group of stakeholders ranging from the public and individual farming businesses through to industry representative bodies, local, state, and federal government agencies as well as international government National Plant Protection Organizations (NPPO) and trading partners to mention a few. To ensure that this project meets its requirements for engagement and that the outputs developed are appropriately communicated and best positioned for adoption, a stakeholder engagement plan was developed at the project initiation (**appendix 1**). This developed plan draws upon the International Association for Public Participation (IAP2) Public Participation Spectrum as a guide to inform the development of the engagement goals and participation levels of the various stakeholders engaged or impacted by this project. In the plan, *stakeholder type* indicates the broad classification of the stakeholder e.g., industry vs government. *Stakeholder level* provides an indication of the level of proximity the stakeholder will have with the project. *Primary stakeholders* have a degree of influence over the project outputs for example government agencies have influence over the development and approval of incursion contingency plans to ensure that they are fit for purpose and approved for adoption via the state biosecurity response agencies. Secondary and tertiary stakeholders are increasingly removed from the project and have lower capacity to influence the project outputs, though may still utilise and indeed benefit from them. *Engagement level* is indicative of the amount of influence a stakeholder has over the project and varies from inform at the lowest level through consult, involve, collaborate, and empower at the highest level. Primary stakeholders of the project are empowered to make decisions with respect to the project whereas those who are informed of the project have limited ability to make decisions or to influence the project. *Engagement types* detail the mechanisms and vehicles through which engagement will be conducted. Many such mechanisms are part of existing formalised communication structures designed to facilitate communication streams to government (e.g., NFFC / National Plant Biosecurity Committee) to industry (IRB communications) and to the public (releases to media outlets and government communication channels).

The key messages developed through the project vary depending upon the stakeholder level (Primary, Secondary, Tertiary). Messages for primary stakeholders are centred around supporting the development and endorsement of appropriate contingency and management plans for OFF. Additional messaging with primary stakeholders is orientated to developing and leveraging the networks and knowledge held by these stakeholders. For secondary stakeholders' project messaging is focused on the employment of project outputs to prepare growers at the individual business, regional and national/industry level to respond to and manage an oriental fruit fly incursion. For secondary stakeholders within the research community key messaging centres on the development and strengthening of relationships, particularly with researchers operating in regions where OFF is present, and response actions have been implemented to manage incursion activity. Tertiary stakeholders of the project require to be informed of the outputs of the project.

Review and develop criteria

Knowledge base on behaviour, entry, spread and establishment potential of exotic fruit flies, especially OFF

Part 1 Review (Component 1: Review and develop criteria)

This part of the project produced a scientific review manuscript that documents the best management national and international practices for biosecurity against exotic fruit fly, and to provide an assessment of the potential for entry, spread and establishment of exotic fruit fly (with a focus on OFF) in an Australian context. The review employed a systematic approach as laid out in the Fig. 1. Dr Jessica Hoskins from NSW DPIRD primarily undertook the review with input from Dr Polychronis Rempoulakis (currently IAEA) and a significant contribution from Dr Bernie Dominiak and Dr Mark Stevens (NSW DPIRD).

The review paper “Biosecurity and Management Strategies for Economically Important Exotic Tephritid Fruit Fly Species in Australia” (**appendix 2**; link: <https://www.mdpi.com/2075-4450/14/10/801>) addresses a critical knowledge gap in Australia's preparedness for exotic fruit fly incursions, particularly the OFF. While Australia has effective detection tools and general management policies, the study identifies the absence of species-specific emergency response plans as a significant limitation. This gap could delay response times during an incursion, potentially leading to more severe economic impacts. By comparing global management strategies with Australia's current practices, the paper highlights the need for tailored response plans to enhance Australia's biosecurity framework.

The key recommendations from the review include developing species-specific emergency response plans to enable rapid action during incursions, strengthening early detection and surveillance systems at entry points, and promoting international collaboration for knowledge exchange. Continued investment in research is vital to improve understanding and management of OFF, while stakeholder engagement and training will support coordinated and informed biosecurity responses across industry and government.

Part 1 Review (Component 2: A map of potential high and low risk areas of OFF entry and establishment in Australia developed)

A more detailed mapping of Australia utilizing the CLIMEX model for potential high and low risk areas of OFF entry and establishment was achieved. Cervantes Agritech was assigned for the work, and the final output has been appended with this report (**appendix 3**). The associated video files are submitted to HI through email correspondence.

The modelled climate suitability for OFF in Australia is presented in Fig 3a,b. The maps represent the climatic potential for establishment (Ecoclimatic Index, EI) and ephemeral population spread (Annual Growth Index, GIA). The yellow to red areas are where on average over the years from 1991 to 2020 we might expect OFF to have been able to establish persistent populations. In practice, this means that the marginally suitable sites ($1 < EI < 5$) may only have been able to support a population during more favourable years, or that populations in these areas may have been restricted to suitable microhabitats. The areas where $GIA > 0$ and $EI = 0$ indicate regions where OFF would only have been capable of population growth during favourable seasons, but not capable of persisting throughout the year.

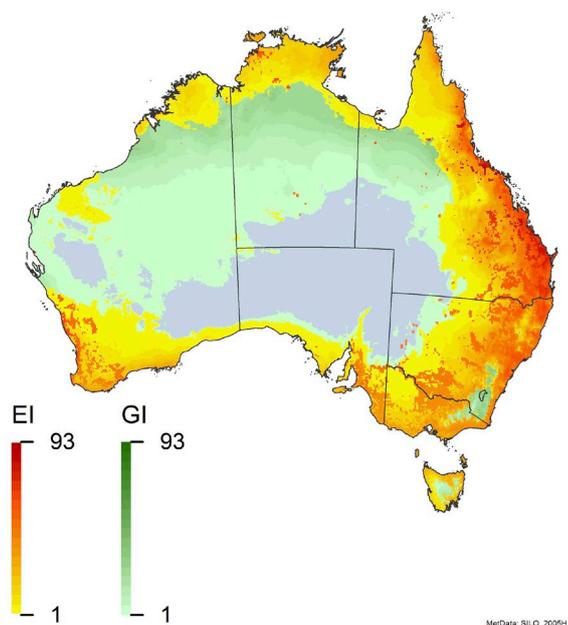


Fig 3a. Climate suitability for *Bactrocera dorsalis* in Australia modelled using CLIMEX. The map is a composite of irrigated and natural rainfall scenarios, using the Global Map of Irrigated Areas (Siebert et al. 2013). Grey areas are unsuitable for

growth year-round. Source climate data from SILO for the 30-year average centred on 2005.

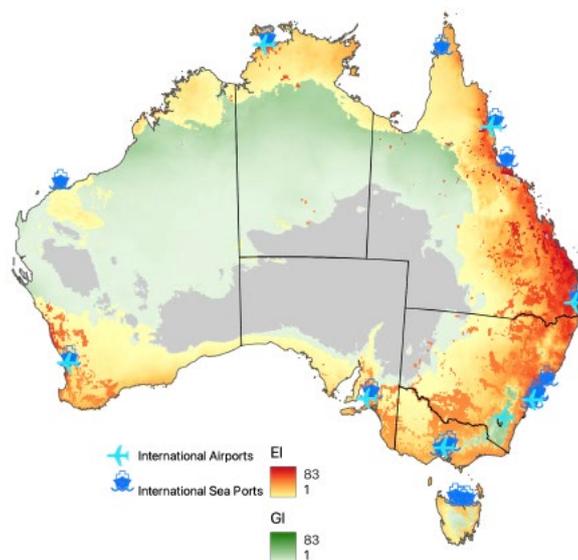


Fig 3b. Climate suitability for *Bactrocera dorsalis* in Australia modelled using CLIMEX overlain with Australian international air and sea ports. The map is a composite of irrigated and natural rainfall scenarios, using the Global Map of Irrigated Areas (Siebert et al. 2013). Grey areas are unsuitable for growth year-round. Source climate data from SILO for the 30-year average centred on 2005.

The interannual variability in climate suitability for OFF is substantial, driven mostly by occasional weather systems driving rainfall into the arid interior of Australia. The limited natural dispersal ability of OFF means it would not be able to take advantage of these extensive but transient expansions of the climatically suitable habitat. For details on the result and discussion of modeling, please see the appendix.

Build upon established links

The project partners have a very good reputation and presence in the international fruit fly community, as demonstrated through numerous past and existing collaborations, participation of key members in advisory committees reviewing publications and major projects. Key international experts were engaged-particularly those based at institutions leading research and development on OFF or implementing Area-Wide Integrated Pest Management (AW-IPM) programs to control OFF populations. Those contacts were followed up to develop strong linkages for collaborative research and the exchange of information relevant to OFF preparedness. Links have been established with organizations relevant to OFF R&D and management: IAEA, USDA, FF in Silico IPM project (Horizon 2020), ministry of Agriculture Mauritius (SIT on OFF). Experts from those organizations participated in person or online at the 11th ISFFEI and Australian National Planning Workshop for Exotic Fruit Fly workshop that was held at Macquarie University. The workshop was organized a week after (ISFFEI) (21-23 Nov 2022) that was hosted by one of the partners of this program (NSW DPIRD), with participation in the organizing committee from both Macquarie University and SARDI/PIRSA. The program outline (**appendix 4**), and the list of participants (**appendix 5**) are included in this report. Since the first symposium in 1982, the aim of this event is to bring together fruit fly scientists, researchers, and those involved in plant protection agencies and phytosanitary operational programs, to share knowledge, technologies and experiences regarding fruit flies. In the past 38 years, these symposia have contributed not only to the development and improvement of environmentally friendly control methods and management strategies to minimize the negative effect of fruit fly pests worldwide but also to the conformation of a strong and collaborative community of fruit fly workers.

The international component of the project facilitated in achieving the following: a. In collaboration with the Australian project partner's team, develop a series of web-based activities (webinars, workshops) to provide OFF relevant expertise to Industry representatives, Australian fruit fly governance bodies and the public. The web-based activities were facilitated by collaborative efforts and visits of Australian project partners in countries where there are operational pest control measures in place for OFF with emphasis on IPM, SIT and similar methods.

Best risk management practices suitable for Australian context identified and reported, including management guide for OFF

The review of management practices, incursion responses and impacts strongly builds upon Part 1 (review and develop criteria) and Part 2 (build on established link) of this project. This review provides an in-depth overview and comparison of management practices, incursion responses and impacts of OFF worldwide based on international experience and research of existing protocols. Response examples are reviewed and analysed for each of their components, e.g. monitoring, management, recovery and communication. Based on the collected information a gap analysis was conducted to analyse Australia's current strengths and weaknesses in responding to potential incursions of OFF. The gap analysis compared Australia's current performance with the potential performance and identified areas that can be improved. The review was led by Dr Nancy Cunningham (SARDI-PIRSA) with input from all collaborators. The comprehensive review document (**appendix 6**) consists of four important informative chapters: 1) Overview of OFF, 2) Overseas management of OFF, 3) Australian strategies/preparedness for OFF, and 4) Gap analysis. This review highlights OFF as a major global biosecurity threat and emphasizes the need for proactive preparedness in Australia. It reviews successful overseas management strategies such as area-wide management, male annihilation, sterile insect technique, and baiting, recommending their adaptation to the Australian context.

While Australia has strong general biosecurity systems, the review identifies gaps in species-specific contingency plans, inter-agency coordination, and stakeholder awareness. It calls for targeted OFF preparedness, enhanced diagnostics and surveillance, and stronger international collaboration to mitigate future incursion risks.

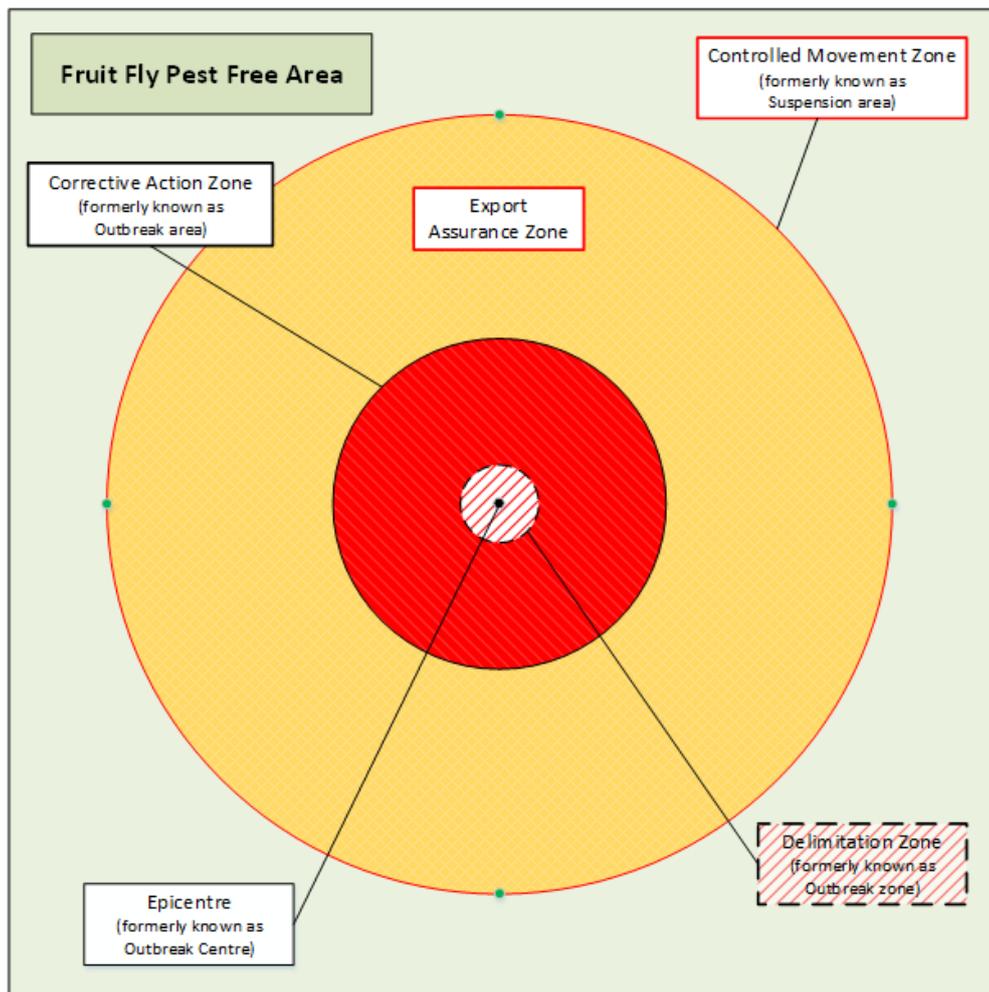
Cross-commodity draft contingency and/or management plans for OFF

A cross-commodity draft contingency plan was prepared (**appendix 7**) with a purpose to provide Australian horticulture with essential information regarding the biology of pests and available control measures, ensuring preparedness for a potential incursion of the OFF into Australia. It offers guidelines and options for developing a Biosecurity Response Plan specifically tailored to address this pest. The document, currently in draft form, requires review by the PHA (Plant Health Australia), PHC (Pest and Disease Control), NFFC (National Fruit Fly Council), and the National Management Group before implementation. It has been specifically developed for the Horticultural Industry. It is important to highlight that this plan extensively references PHA's existing "Response strategy for exotic fruit fly," with a specific focus on the OFF. Some modifications may be necessary to ensure the relevance of the information in the event of an incursion. This document serves as a potential amendment to PHA's response strategy, specifically addressing the horticulture industry. It should be used in conjunction with the existing response strategy in the event of an incursion.

Science based movement guideline

The proposed movement guideline (**appendix 8**) provides advice on the prevention of pest spread through protocols that ensure secure transport and monitoring of risk materials, e.g. host produce and waste. The guideline considers two phases of management: i) management up to the declaration of an outbreak (prevention) and ii) after the declaration of an outbreak (eradication). The movement guideline aims to ensure the effective management and prevention of the entry and spread of exotic fruit flies. These guidelines are science-based, consider climatic conditions, reproductive behaviours of the pests, and international best practices. The guidelines have been prepared following rigorous discussion with SARDI/PIRSA and NSW DPI, key collaborators in this project. Of note, the guideline provides guidance for the development, implementation and verification of integrated measures for movement control of OFF as a preparedness to minimize the potential spread of OFF. It also outlines the performance standards registered establishments must meet to gain and maintain approval for handling exotic fruit fly goods.

This document must be read in conjunction with the Departmental Policy: Management of plant export registered establishments; Guideline: Audit of plant export registered establishments; Guideline: Maintenance of phytosanitary security for horticulture exports.



Controlled Movement Zone established after the declaration of an outbreak.

Biosecurity plan and exercise

Plant Health Australia (PHA) led exercise Motus and conducted multiple simulation biosecurity exercises across Sydney and Cairns to test current and potential requirements for managing an OFF incursion. The exercise involved extensive collaboration between industry and government representatives and examined the response by government and industry to a detection in Sydney, New South Wales (NSW) and in Mareeba, Queensland (QLD). Discussions and activities during the exercises focused on the following objectives: 1) Understanding the immediate actions that would need to be undertaken by both government and industry in the early phase of a response to maintain business continuity. 2) Examining the impacts on business continuity through identifying the effects on production and movements at a regional and state level. 3) Testing recommended fruit fly commodity movement protocols (from an infested area for treatment prior to going to market) that have been developed under the FF18001 project. Each of these objectives were tested in the scenarios, except for objective 3, which did not occur as the draft protocols contained insufficient level detail to enable participants to provide constructive feedback. As a result, the scenarios were modified to instead ask participants to capture what information would be required to support the development of functional movement protocols in the future.

Key findings from the exercises included the importance of clear and consistent communication, the need for pre-agreed movement protocols, and the significance of engaging all stakeholders, including local councils and community leaders. This report emphasises the value of a unified approach between government and industry to ensure a common understanding and acceptance of response actions. Several recommendations have been made to improve biosecurity preparedness that require input from state and territory governments, Department of Agriculture, Fisheries and Forestry (DAFF), affected industries, researchers, the National Fruit fly Council (NFFC) and Plant Health Australia (PHA), exemplifying how OFF requires a national approach.

Overall, the Exercise Motus Report demonstrates the commitment of PHA and its partners to safeguarding Australia's horticultural sector from the threat of exotic fruit flies. The collaborative efforts and insights gained from this exercise will undoubtedly strengthen the nation's biosecurity framework and ensure a swift and effective response to future biosecurity threats. It is important to note the importance of reporting early to reduce the impact of the exotic plant pest and prevent spread. The Emergency Plant Pest Response Deed (EPPRD) is a formal, legally binding agreement between Plant Health Australia (PHA), the Australian Government, all state and territory governments and plant industry signatories, covering the management and funding of responses to Emergency Plant Pest (EPP) Incidents. *Bactrocera dorsalis* is an exotic plant pest, and if detected, parties are obligated to respond to eradicate the pest as required under the EPPRD. Please see **appendix 9** for the detailed report.

Communication plan

An effective Oriental fruit fly incursion management system relies heavily on the effective communication and adoption of relevant information. This is particularly needed at the technical level to ensure that stakeholders involved in both high-level incursion management as well growers on the ground receive relevant information to control potential outbreaks. Communication strategy was developed by SARDI/PIRSA to assist improvement of decision making to ensure best practice management for the incursion and for affected horticultural industries. High quality communication techniques improve engagement and implementation of relevant management systems and widen the adoption of new innovative fruit fly management technologies. Information can be used to distribute information to a wider group of stakeholders beyond those directly involved with incursion management. This includes consumers, wholesalers, retailers, exporters, importers, transport operators and treatment providers.

The plan was developed with a goal to provide technical information fact sheets (**appendix 10a, b, c, d**) on Oriental fruit fly to allow effective adoption of information for incursion management teams, growers and for easy adaptation for a broad range of audiences. The plan specifically focuses on **How, Why, What and When** parameters, and utilises existing fruit fly incursion management systems to update information as needed. Additionally, it encourages adoption of new/innovative Oriental Fruit Fly incursion management protocol. The contents of communication information sheet is shown in table 1.

Table 1. Communication Information Sheet

Communication information sheets	
Topic	Contents
Biology	<ul style="list-style-type: none"> ➤ Distribution (reliant on CABI for updated information) ➤ Host information ➤ Fruit fly competition (with/between species) ➤ Seasonality ➤ Complex of species
Control	<ul style="list-style-type: none"> ➤ Biocontrol (including establishment parasite species throughout Australian Horticultural regions. ➤ Chemical treatments including timing, withholding periods for crops and resistance issues ➤ Bait sprays and spray application techniques ➤ Male Annihilation Technology (very effective with Oriental Fruit Fly) ➤ Sterile Insect Technology and irradiation ➤ Female specific attractants
Surveillance	<ul style="list-style-type: none"> ➤ Trapping ➤ Lures
Management Protocols	<ul style="list-style-type: none"> ➤ General information on incursion management and references to National and state-based management plans ➤ Trigger thresholds for incursion management

Outputs

The FF18001 project produced a range of technical and strategic outputs to support Australia's preparedness for an OFF incursion. Key outputs included:

- A peer-reviewed scientific publication summarising global management strategies for OFF
- A draft contingency plan based on reviews by NSW DPI and SARDI/PIRSA, outlining OFF biology, potential response options, and alignment with PHA's national strategy
- Proposed commodity movement protocols to help manage the transport of goods during an OFF outbreak
- The delivery of Exercise Motus, a major simulation exercise involving industry and government stakeholders, testing biosecurity response actions in NSW and QLD
- Engagement and knowledge-sharing with international experts involved in OFF R&D and area-wide IPM programs
- Fact sheets on biology, monitoring and surveillance, control and management of OFF

These outputs represent critical building blocks for developing OFF-specific preparedness and response frameworks.

Table 2. Output summary

Output	Description	Detail
Project governance documentation	M&E framework Stakeholder engagement plan Project logic Risk management plan and risk register	Lodged in the Hort Innovation delivery partner portal along with milestone report
Six milestone reports	Every six months	Lodged in the Hort Innovation delivery partner portal
A review report on biosecurity and management of OFF	Documents the best management national and international practices for biosecurity against exotic fruit fly, and to provide an assessment of the potential for entry, spread and establishment of exotic fruit fly (with a focus on OFF) in an Australian context	Lodged in the Hort Innovation delivery partner portal, and published https://www.mdpi.com/2075-4450/14/10/801
CLIMEX modeling	Detailed mapping of Australia utilizing the CLIMEX model for potential high and low risk areas of OFF entry and establishment	Lodged in the Hort Innovation delivery partner portal along with milestone report
A review report on Current Management Strategies and GAP analysis	Includes a comprehensive information on OFF and gap analysis	Lodged in the Hort Innovation delivery partner portal along with milestone report
A contingency plan	Includes excerpts from the aforementioned reviews to develop a plan that consists of details on	Lodged in the Hort Innovation delivery partner portal along with milestone report

	biology, hosts, and geographic distribution of OFF	
A draft movement guideline	A guideline for the commodity movement reviewed by PHA and relevant stakeholders	Lodged in the Hort Innovation delivery partner portal along with milestone report
Biosecurity exercise MOTUS report	An exercise MOTUS report on Biosecurity of OFF conducted in QLD and NSW	Submitted along with the final report as appendix

Outcomes

The FF18001 project strengthened Australia’s biosecurity readiness by improving knowledgebase on OFF, national coordination, awareness, and response capability against Oriental fruit fly. Outcomes included:

- Improved biosecurity preparedness against incursion risk of exotic fruit flies documented and implemented through a coordinated and established network among the national and international fruit fly experts
- Gap analysis in movement protocol documented, a pathway for business continuity in an event of incursion identified
- Knowledge base on behaviour of exotic fruit flies, especially *B. dorsalis*, documented and best management practices that improve likelihood of incursion, eradication, containment and/or management of exotic fruit flies recommended
- A valid base for decision making for future biosecurity investments on exotic fruit flies established
- Increased collaboration between industry, state/territory governments, and Plant Health Australia
- Stronger integration with national and international biosecurity efforts, ensuring alignment with global standards

These outcomes have helped position the horticultural sector for faster, more effective responses to future OFF threats, safeguarding production and market access.

Table 2. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Improved biosecurity preparedness against incursion risk of exotic fruit flies documented and implemented through a coordinated and established network among the national and international fruit fly experts.	Number and proportion of critical gaps in preparedness, identified through response simulation exercises and reviews. Articles published, guidelines drafted, Consultation/feedback on the draft obtained.	Aligns directly with strategic priorities aimed at safeguarding market access, reducing pest-related risks to production, and strengthening national response capabilities.	Review paper/reports, Movement Guideline, Biosecurity exercise report
Gap analysis in movement protocol documented, a pathway for business continuity in an event of incursion identified.	Articles published, guidelines drafted, Consultation/feedback on the draft obtained.	Aligns with market access and continuity by establishing a pathway for business continuity, it aligns with priorities to maintain domestic and international market flows even in the face of biosecurity threats.	Review paper/reports, Movement Guideline, Biosecurity exercise report
Enhanced knowledgebase on overseas experience with OFF leading to greater stakeholder understanding of the immediate actions required during and OFF	Articles published, report documented, Protocol/guidelines developed and communicated.	Aligns with efforts to proactively prepare for exotic pest threats through education and scenario-based planning.	Number of industries and growers participating in Biosecurity exercises.

incursion.			
A valid base for decision making for future biosecurity investments on exotic fruit flies established.	Established knowledgebase, published reports, biosecurity exercises, contingency plans	Aligns with informed decision-making grounded in research and analysis and a foundation for allocating resources effectively toward the highest-risk or most impactful areas.	All the essential documents submitted as appendices or published as scientific paper from this project
Increased collaboration between industry, state/territory governments, and Plant Health Australia.	Biosecurity exercises conducted; movement guideline reviewed.	Aligns with strengthened stakeholder partnerships and improved national coordination, fostering consistent biosecurity preparedness and response efforts across industry, government, and Plant Health Australia.	Biosecurity exercise Motus report
Stronger integration with national and international biosecurity efforts, ensuring alignment with global standards	Reviews, movement protocols, gap identification	Aligns with enhanced cooperation of Australia's biosecurity strategies with global frameworks, supporting more effective management of exotic threats like the OFF through shared knowledge and best practices.	List of national and international experts participating in IFFSEI

Monitoring and evaluation

Table 3. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
To what extent has the project identified high risk entry points/source of OFF to ensure capability to effectively mitigate the risks posed by OFF in Australia.	With a comprehensive review, experts' opinion, and CLIMEX modeling the project has contributed significantly to identify high and low risk entry points/source of OFF	<p>Improve coordination and sharing of surveillance, interception, and trade data across states and territories to better assess emerging risks and potential entry points.</p> <p>Regularly update risk models with new climatic, trade, and pest data to refine predictions about OFF establishment and spread under different scenarios.</p>
To what extent has the project improved knowledge and awareness on biosecurity preparedness and prevention measures against OFF?	Significantly with the peer-reviewed publication and comprehensive gap analysis, and exercise MOTUS	Update database based on recent publications and update technical aspects such as monitoring tools, machine learning, remote sensing accordingly
To what extent has the project addressed the end-users (horticultural growers) need of maintaining improved horticultural productivity and market access of the produce?	Project not only established updated information on OFF, but also conducted exercise learnings to equip Australian Horticulture Industry with arsenals for emergency responses should there be OFF incursion	Facilitate uptake of knowledge and risk mitigating practices
To what extent was the project effective in engaging with relevant growers' community/ industries?	The project significantly engaged relevant industries and growers' community through biosecurity exercises, shared opportunity during preparation of contingency plans, and proposed movement protocols	Extension of the developed communication sheets to broader community to inform the growers and industries of the OFF biology, control, monitoring and management

Recommendations

- Extension of the project outputs such as communication sheets developed under this project to enhance end-users' knowledgebase and to prepare for potential OFF incursions.
- Engage in awareness and training programs to understand immediate response actions and maintain business continuity during a biosecurity event.
- Participate in future simulation exercises to strengthen readiness and ensure representation in national planning.
- Refine and validate commodity movement protocols based on feedback from Exercise Motus and future testing.
- Continue international collaborations to leverage global expertise and integrate successful overseas strategies into local preparedness.
- Conduct targeted studies on OFF behaviour under Australian conditions to close knowledge gaps.
- Support the finalisation and dissemination of the draft OFF contingency plan in collaboration with PHA, PHC, and NFFC.
- Invest in further development of decision-support tools to enable quicker and more informed responses.
- Promote coordinated research funding to address biosecurity gaps and support a national response framework.

Refereed scientific publications

Journal article

Hoskins, J.L.; Rempoulakis, P.; Stevens, M.M.; Dominiak, B.C. Biosecurity and Management Strategies for Economically Important Exotic Tephritid Fruit Fly Species in Australia. *Insects* 2023, 14, 801. <https://doi.org/10.3390/insects14100801>

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Intellectual property

No project IP or commercialisation to report.

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Dr Ben Zurbo (NSW DPI) and Dr Kathrina Merkel (SARDI/PIRSA), a member of the project's governance group, contributed significantly to the review of the proposed movement guideline. Dr Solomon Balagawi (currently QDAF) coordinated the meetings with national and international experts. Dr Yasmin Chalmers (PHA) played a crucial role in the timely delivery of the biosecurity exercise report. Dr Greg Chandler, Head of Biosecurity R&D (Hort Innovation), provided consistent support and guidance throughout the life of the project, while Dr Patsavee Utaipanon R&D Manager (Hort Innovation) offered valuable assistance and patience during its final stages.

Appendices

- Appendix 1. Stakeholders' communication and engagement plan
- Appendix 2. Review paper- published
- Appendix 3. CLIMEX model
- Appendix 4. Program Outline -workshop
- Appendix 5. List of participants
- Appendix 6. Review document - Current Management Strategies and GAP analysis
- Appendix 7. Contingency plan
- Appendix 8. Movement guideline (Confidential)
- Appendix 9. Exercise MOTUS report
- Appendix 10a. Biology Fact sheet
- Appendix 10b. Surveillance Fact sheet
- Appendix 10c. Management Protocol
- Appendix 10d. Control Fact sheet

FF18001 Biosecurity Preparedness for Oriental Fruit Fly

Stakeholder engagement plan

Background

Oriental Fruit Fly (*Bactrocera dorsalis*) is a major international pest of horticulture and presents considerable risk to Australian horticulture. A 1995 incursion centred in Queensland witnessed considerable time, money and energy expended in an eradication program which ultimately took 4 years and millions of dollars to succeed and negatively impacted the horticultural sector in this region.

By its nature Oriental Fruit Fly affects a diverse group of stakeholders ranging from the public and individual farming businesses through to industry representative bodies, local, state, and federal government agencies as well as international government National Plant Protection Organizations (NPPO) and trading partners to mention a few.

To ensure that this project meets its requirements for engagement and that the outputs developed are appropriately communicated and best positioned for adoption, this stakeholder engagement plan has been developed. The developed stakeholder list is not exhaustive however, through the life of the project the stakeholder engagement plan will be periodically reviewed and updated as appropriate to reflect changes to the stakeholder landscape and progression of the project.

This developed plan draws upon the International Association for Public Participation (IAP2) Public Participation Spectrum¹ as a guide to inform the development of the engagement goals and participation levels of the various stakeholders engaged or impacted by this project.

Stakeholder type indicates the broad classification of the stakeholder e.g., industry vs government.

Stakeholder level provides an indication of the level of proximity the stakeholder will have with the project. Primary stakeholders will have a degree of influence over the project outputs for example government agencies will have influence over the development and approval of incursion contingency plans to ensure that they are fit for purpose and approved for adoption via the state biosecurity response agencies. Secondary and tertiary stakeholders are increasingly removed from the project and have lower capacity to influence the project outputs, though may still utilise and indeed benefit from them.

Engagement level is indicative of the amount of influence a stakeholder has over the project and varies from inform at the lowest level through consult, involve, collaborate, and empower at the highest level. Primary stakeholders of the project are empowered to make decisions with respect to the project whereas those who are informed of the project have limited ability to make decisions or to influence the project.

Engagement types detail the mechanisms and vehicles through which engagement will be conducted. Many such mechanisms are part of existing formalised communication structures designed to facilitate communication streams to government (e.g., NFFC / National Plant Biosecurity Committee) to industry (IRB communications) and to the public (releases to media outlets and government communication channels).

Stakeholder List

Stakeholder Name	Stakeholder Type	Stakeholder Level	Engagement Level	Engagement types
Hort Innovation	Project funding agency	Primary (Funder)	Empower	Project Steering committee Milestone reporting & Final Report Final Reports Research Manager communications as required Communication to industry and public via Hort Innovation Communications team (e.g., press releases and relationships with media & IRB's) Leverage connections with other fruit fly projects e.g., via SITplus group
Macquarie University	Public University	Primary (Project lead)	Empower	Project Steering committee Milestone reporting Final Reports Research Manager communications as required Media Releases Leverage SITplus collective
Department of Primary Industries (NSW)	State government Agency	Primary (Project partner)	Empower	Project Steering committee Milestone reporting Final Reports Research Manager communications as required Media Releases and sharing of project collateral developed via established communication channels e.g., social media and on ground extension
South Australian Research & Development Institute (SARDI)	State government Agency	Primary (Project partner)	Empower	Project Steering committee Milestone reporting Final Reports Research Manager communications as required Media releases and dissemination of communication collateral developed via communication channels e.g., social media / on ground extension.
Primary Industries and Regions SA (PIRSA) Biosecurity SA	State government Agency	Primary (Project partner)	Empower	Project Steering committee. Milestone reporting. Final Reports. Research Manager communications as required. Development of communication/extension collateral for use by industry & public.
Department of Agriculture Water and Environment (DAWE)	Federal Government Agency	Primary	Involve	Leverage for project insights, communication channels for project extension.
- Northern Australia Quarantine Strategy (NAQS)	Sub organisation of DAWE	Primary	Involve	Leverage for project insights and to be kept abreast of developments. Ensure that outputs are aligned with and leverage OFF/ Exotic Fruit fly initiatives.
- National Plant Biosecurity Committee	Intergovernmental committee	Primary	Collaborate	Collaborate to review/develop cross commodity contingency/management plans for OFF/exotic fruit flies
Agriculture Victoria	State Government Agency	Primary	Involve	Liaise to ensure that project outputs (contingency/management plans) are fit for purpose and ultimately endorsed/supported. Involve in development processes to gain state insights and to leverage networks and relationships.
- Regional Fruit Fly Management groups (Yarra Valley, Sunraysia & Goulburn Murray Valley)	Community action groups funded via Vic Government	Secondary	Consult/ Involve	Leverage of existing communication and on ground extension networks with growers and public
Department of Primary Industries and Regional Development (WA)	State Government Agency	Primary	Involve	Liaise to ensure that project outputs (contingency/management plans) are fit for purpose and ultimately endorsed/supported. Involve in development processes to gain state insights and to leverage networks and relationships.

Queensland Department of Agriculture and Fisheries (QDAF)	State Government Agency	Primary	Involve	Liaise to ensure that project outputs (contingency/management plans) are fit for purpose and ultimately endorsed/supported. Involve in development processes to gain state insights and to leverage networks and relationships.
Department of Primary Industries, Parks, Water and Environment, Tasmania	State Government Agency	Primary	Involve	Liaise to ensure that project outputs (contingency/management plans) are fit for purpose and ultimately endorsed/supported. Involve in development processes to gain state insights and to leverage networks and relationships.
Department of Industry, Tourism and Trade (NT)	State Government Agency	Primary	Involve	Liaise to ensure that project outputs (contingency/management plans) are fit for purpose and ultimately endorsed/supported. Involve in development processes to gain state insights and to leverage networks and relationships.
Plant Health Australia (PHA)	Govt. / Industry Partnership coordinator	Primary	Collaborate	Project meetings Preparedness Exercise Collaborate to review/develop cross commodity contingency/management plans for OFF/exotic fruit flies
- National Fruit Fly Council (NFFC) (PHA)	Sub-committee of PHA	Primary	Collaborate	Leverage communication channels for output dissemination and ensure that developed contingency plans have support from the council to maximise adoption. Collaborate to review/develop cross commodity contingency/management plans for OFF/exotic fruit flies
International Research Community	Researchers	Secondary	Inform / Consult	Research papers/ Reviews Research Symposia engagement
Peak Horticultural Industry Representative Bodies (IRB)	Industry Representative Body (National, State & Local)	Secondary	Consult / Involve	Industry sectors affected by OFF Preparation of communications, and resources for dissemination via established industry communication channels
National IRB				
AUSVEG, APAL, ABGC, Citrus Australia, Australian Mango Industry Association, Summer Fruits Australia, Avocados Australia, Australian Processing Tomato Research Council, Cherry Growers of Australia, Custard Apples Australia, Australian Lychee Growers Association, Australian Melon Association, Australian Nashi Growers Association, Papaya Australia, Passionfruit Australia Inc, Persimmon Australia, Australian Table Grape Association, Berries Australia Limited, Australian Horticultural Exporters Association				
State/Regional IRB				
GrowCom (QLD), NSW Farmers, AUSVEG VIC AUSVEG SA, NT Farmers, Vegetables WA, Fruit Growers Victoria, Bundaberg Fruit and Vegetable Growers, FNQ Growers				
Horticultural Growers/Farmers	Industry	Secondary	Consult	Leverage existing communication channels via IRB's, industry journals/publications and government agencies to promote and extend project outputs.
Local Government	Local Government	Tertiary	Inform	Media releases and extension of project outputs as required.
General Public	General Public	Tertiary	Inform	Media releases and extension of project outputs as required

Key Messages

The key messages developed through the project will vary depending upon the stakeholder level (Primary, Secondary, Tertiary).

Messages for primary stakeholders will be centred around supporting the development and endorsement of appropriate contingency and management plans for Oriental Fruit Fly and other exotic fruit flies. Additional messaging with primary stakeholders will be orientated to developing and leveraging the networks and knowledge held by these stakeholders which can be used to enhance the outputs of the project.

For secondary stakeholders project messaging will be focused on the employment of project outputs to prepare growers at the individual business, regional and national/industry level to respond to and manage an oriental fruit fly incursion. For secondary stakeholders within the research community key messaging will centre on the development and strengthening of relationships, particularly with researchers operating in regions where oriental fruit fly is present and response actions have been implemented to manage incursion activity.

Tertiary stakeholders of the project will be informed of the outputs of the project however this will be minimal. In the event of an incursion during the life of the project a re-evaluation of the stakeholder levels assigned to these groups would be required and most likely see their importance increase.

ⁱ International Association for Public Participation (IAP2) 2014 *IAP2 Spectrum of Public Participation* Sourced from www.iap2.org/resource/resmgr/foundations_course/IAP2_P2_Spectrum_FINAL.pdf

Stakeholder List

Stakeholder Name	Stakeholder Type	Stakeholder Level	Engagement Level	Engagement types
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- National Fruit Fly Council (NFFC) (PHA)	Sub-committee of PHA	Primary	Collaborate	Leverage communication channels for output dissemination and ensure that developed contingency plans have support form the council to maximise adoption.

				Collaborate to review/develop cross commodity contingency/management plans for OFF/exotic fruit flies
International Research Community	Researchers	Secondary	Inform / Consult	Research papers/ Reviews Research Symposia engagement
Peak Horticultural Industry Representative Bodies (IRB)	Industry Representative Body (National, State & Local)	Secondary	Consult / Involve	Industry sectors affected by OFF Preparation of communications, and resources for dissemination via established industry communication channels
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AUSVEG, APAL, ABGC, Citrus Australia, Australian Mango Industry Association, Summer Fruits Australia, Avocados Australia, Australian Processing Tomato Research Council, Cherry Growers of Australia, Custard Apples Australia, Australian Lychee Growers Association, Australian Melon Association, Australian Nashi Growers Association, Papaya Australia, Passionfruit Australia Inc, Persimmon Australia, Australian Table Grape Association, Berries Australia Limited, Australian Horticultural Exporters Association				
State/Regional IRB				
GrowCom (QLD), NSW Farmers, AUSVEG VIC AUSVEG SA, NT Farmers, Vegetables WA, Fruit Growers Victoria, Bundaberg Fruit and Vegetable Growers, FNQ Growers				
Horticultural Growers/Farmers	Industry	Secondary	Consult	Leverage existing communication channels via IRB's, industry journals/publications and government agencies to promote and extend project outputs.
Local Government	Local Government	Tertiary	Inform	Media releases and extension of project outputs as required.
General Public	General Public	Tertiary	Inform	Media releases and extension of project outputs as required

Review

Biosecurity and Management Strategies for Economically Important Exotic Tephritid Fruit Fly Species in Australia

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Simple Summary: Australian horticulture is at risk from incursions by exotic tephritid fruit fly species, particularly oriental fruit fly. An incursion by exotic fruit flies is likely to result in global trade restrictions and will cause significant economic losses. In this study, we investigated global management strategies for exotic fruit fly species and compared them with available local strategies in Australia to identify areas where Australian management practices could be improved. We identified that although Australia has a good understanding of the main exotic fruit fly threats, there remains no species-specific emergency response plan available to implement in the case of an incursion. Australia has effective tools for exotic fruit fly detection, an early warning surveillance network is in place across Australia and control measures used successfully for eradication elsewhere are available in Australia. However, the speed at which Australia could respond to an incursion is currently limited by the lack of a response plan, and this could have major implications for the effectiveness of management strategies for containment and eradication, likely leading to a more severe and costly incursion outcome.



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Abstract: Exotic tephritid incursions are of high concern to Australia's biosecurity and its horticultural industries. It is vital that Australia remains ready to respond to incursions as they arise, as an incursion of tephritid fruit fly species will result in significant economic losses. In this review, we compared Australian incursion management strategies for fruit flies with global management strategies and identified possible areas where improvements could be made in an Australian context. Overall, Australia has a good understanding of the main tephritid threats, of which *Bactrocera* species from across the Torres Strait (northern Australia) are of most concern. Effective tools for tephritid detection and early warning surveillance at points of entry are in place at ports and in horticultural areas Australia-wide and provide the basis for initiating biosecurity responses in the event of an incursion. Area-wide control measures used in successful eradication attempts globally are available for use in Australia. However, a specific tephritid emergency response plan identifying suitable response measures and control options for species of concern is not yet available. We have identified that Australia has the policies and management tools available to respond to an exotic tephritid incursion, but the speed at which this could be accomplished would be greatly improved by the development of species-specific emergency response plans.

Keywords: incursion; management; emergency response; *Bactrocera dorsalis*

1. Introduction

Tephritid fruit fly species are a serious threat to global food production. Fruit fly infestations cause significant economic losses, reduce commodity quality, and disrupt trade,

which in turn affects livelihoods, food security and market access [1,2]. To date, Australia remains largely free of economically damaging exotic fruit fly species, such as the Oriental fruit fly (OFF; *Bactrocera dorsalis* (Hendel)). This freedom from most exotic tephritids means that Australian horticultural commodities can maintain premium prices and Australian horticultural industries are worth ~AUD 15 billion annually [3]. If an incursion by exotic fruit flies were to occur, even for a short time, market access for export produce would be challenged [4] and this would result in significant economic losses [5]. As such, it is vital that Australia has good biosecurity and management strategies in place to monitor for and respond to fruit fly incursions as they arise.

At present there are five exotic fruit fly species that have been identified as biosecurity priorities for Australian horticulture: *Anastrepha ludens* (Loew) (Mexican fruit fly), *Bactrocera carambolae* (Drew & Hancock) (carambola fruit fly), *Bactrocera dorsalis* (Hendel) (Oriental fruit fly (OFF)) (Note that *Bactrocera dorsalis* is considered the senior synonym of *Bactrocera papayae* Drew & Hancock, *Bactrocera invadens* Drew, Tsuruta & White, and *Bactrocera philippinensis* Drew & Hancock, with *Bactrocera carambolae* Drew & Hancock considered a separate species included in the *B. dorsalis* species complex [6].), *Bactrocera trivialis* (Drew) (New Guinea fruit fly) and *Zeugodacus cucurbitae* (Coquillett) (melon fly) (see Table 1) [7]. These species were identified during the development of the National Priority Plant Pests list by the Australian Government [7]. To be considered a priority pest, exotic species must be injurious to plants/plant products, have the potential to cause significant negative effects on the economy, environment or community, and have the potential to enter, establish and spread within Australia [7].

International horticultural trade and tourism from Australia's nearest neighbours (predominantly countries in Asia) are the most probable pathways for an incursion by these tephritid species [8,9], although wind-assisted dispersal across the Torres Strait is also significant [10,11]. Except for the Mexican fruit fly [12,13], all the above species are present in Asia. *Bactrocera* species (particularly OFF) are of most concern to Australia, as species in this genus have a long history of invasion and establishment globally (e.g., [14]). OFF, regarded as the most damaging and aggressive fruit fly [15], has the highest incursion risk due to its presence throughout Asia [16], invasion and establishment in Indonesia [17] and Papua New Guinea [18], and because of the historical incursion and subsequent eradication of OFF (then *B. papayae*) in far north Queensland, Australia in the 1990's [19].

Here, we aim to review Australia's capacity for preventing and managing an incursion of exotic tephritid fruit flies. Observations of the history of incursions and subsequent eradication attempts, such as the incursion of OFF into Africa [14,20] or medfly (Mediterranean fruit fly, *Ceratitis capitata* (Wiedemann)) into almost every continent [21,22], can assist in developing best practice management strategies for control and damage mitigation. We provide a summary of national and international tephritid fruit fly incursion management practices, a summary of the history of economically damaging fruit flies in Australia and an outline of the potential of an incursion into Australia by exotic fruit fly. The aim of this study is not to provide an extensive review of exotic fruit fly management practices, as this has, to varying degrees, already been achieved (for examples see [13,23–25]). Rather, it is to examine if current Australian measures are adequate to manage an incursion by exotic fruit flies and, if not, to suggest modifications that will improve Australian management practices.

Table 1. The top five exotic tephritid fruit fly species of biosecurity concern to Australia, their distribution, hosts, ideal climate and known attractants.

Species	Distribution		Commercial Host/s	Climate	Lure
	Native	Invasive			
<i>Anastrepha ludens</i> (Loew) Mexican fruit fly	Mexico (other areas of North America possible)	United States (transient-under eradication in California and Texas) and Panama	Polyphagous. Major commercial hosts citrus and mango	Tropical and warm temperate	No para-pheromone lure known but captured in traps with ammonia based lures [26–29]
<i>Bactrocera carambolae</i> (Drew and Hancock) carambola fruit fly	ASIA including Malaysia, Thailand, Indonesia, Timor-Leste, Vietnam, Singapore, Myanmar, India, Cambodia	French Guyana, Guyana (eradicated 1994), Brazil, Suriname, Brunei, Bangladesh	Polyphagous >100 hosts [12]. Major commercial hosts carambola, mango, jackfruit, sapodilla, guava [30]	Tropical and sub-tropical [31]	Methyl eugenol [30]
<i>Bactrocera dorsalis</i> (Hendel) Oriental fruit fly (OFF)	Southeast Asia	>75 countries in Asia, North America, South America, Africa [32] and Oceania (Christmas Island, Papua New Guinea, Palau, Hawaii and Tahiti)	Polyphagous >300 cultivated fruit and vegetable host species. Most edible fruit is susceptible [12,33]. Some major hosts include mango, stone fruit, apple, citrus, cherry, carambola, cashew, banana.	Tropical and warm temperate	Methyl eugenol [7]
<i>Bactrocera trivialis</i> (Drew) New Guinea fruit fly	Papua New Guinea and Indonesia [34]		Polyphagous, recorded on 17 host plants [33]. Major commercial hosts chilli, grapefruit, mango, peach, guava [33,34]	Tropical	Cuelure [30]
<i>Zeugodacus cucurbitae</i> (Coquillett) melon fly	India	>40 countries including in Africa, Asia, Oceania (Papua New Guinea, Mariana Islands, Solomon Islands, Nauru, Kiribati, Guam, Hawaii [35]). Eradicated from Japan [36] North America (California)	Polyphagous but predominantly cucurbits. Recorded on 44 hosts [12,33] Main commercial hosts include watermelon, rockmelon, cucumber, pumpkin, bitter melon, edible <i>Luffa</i> , ivy gourd, wax gourd, bean and tomato.	Tropical and warm temperate	Cuelure group (melolure in Hawaii) [37]

Information summarised from CABI-Invasive species compendium www.cabi.org/isc/ (accessed on 15 January 2023) where correct and Plant Health Australia Fruit fly Identification website www.fruitflyidentification.org.au (accessed on 15 January 2023) and other identified sources, most up to date and correct information used.

2. Incursion and Environmental Suitability

2.1. Incursion and Dispersal Ability

The threat of incursion exists for all countries due to increasing global trade in fruit and vegetables [32,38,39]. Frequently, tephritid incursions follow a jump-diffusion model [40] where tourism (e.g., [9]) or trade provide the long-distance jump, followed by dispersal into the local environment, often with human assistance [11]. In Australia, local human

movements appear responsible for Queensland fruit fly (Qfly, *Bactrocera tryoni* (Froggatt)) dispersal of up to several hundred kilometers (e.g., [41]). Internationally, human movements have contributed to the dispersal of medfly to most continents [21] and the spread of OFF through most of the Pacific Islands [42].

While trade and tourism represent the most likely incursion pathways for exotic fruit flies, wind is also thought to play a role, especially in Australia. In general, the influence of wind on fruit fly dispersal is not well understood and reports are contradictory. Some indicate wind does not redistribute tephritids across land (e.g., [43]), while others provide evidence for downwind dispersal [10,44]. Mark and recapture studies show that most fruit fly species do not move far from their release sites, being limited to distances of 2–4 km [43,45] although dispersal ability appears to be largely species-specific. There are a few instances where fruit flies, particularly *Bactrocera* species, have dispersed large distances. OFF and Qfly have been found at distances of 50 km and 94 km, respectively, from their release sites [43,46], although most reports indicate dispersal distances of less than 1 km. Conversely, other species such as melon fly and Mexican fruit fly do not disperse aerially over significant distances. Mark and recapture studies on the melon fly have demonstrated a dispersal distance of between 50 and 800 m from release sites [47,48], while Mexican fruit flies dispersed up to 9 km, but typically traveled less than 250 m [49].

For Australia, the influence of winds on dispersal may be more important across waterways, such as the Torres Strait [10,11]. There is strong evidence that prevailing wind patterns during the Australian northern wet season (November to April) facilitate the movement of exotic tephritids from southern areas of the Papua New Guinea (PNG) mainland onto the Torres Strait Islands [18]. The closest islands, Boigu and Saibai, lie less than 6 km from PNG, with the rest of the islands spread out over 150 km between Cape York on the Australian mainland and PNG. Trapping of fruit flies conducted as part of Australia's surveillance network on the Torres Strait Islands frequently intercepts OFF, melon fly and New Guinea fruit fly [11,18]. It is possible that wind-assisted dispersal of exotic flies to the southerly Torres Strait Islands could lead to an incursion on the Australian mainland.

2.2. Climate, Fruit Fly Ecology, Hosts, and Incursions

Climate and host availability are the two most important factors governing the establishment and spread of fruit fly species during an incursion event. Understanding the response of fruit fly species to various climate scenarios in terms of their adaptability can allow for predictions of how incursions will develop for different species. For example, OFF has a reduced capacity (lower trait plasticity) to adapt to increasing temperatures when compared to medfly [50]. This difference in trait plasticity may indicate that high temperatures will favour medflies in some locations, even though thermal tolerance to high temperatures itself is greater in OFF (e.g., medfly [51]; OFF [2]) (see Table 2 for examples). These differences in trait characteristics have applications in models attempting to forecast distributions for exotic fruit fly species, such as CLIMEX [4,52], GARP [53] or MaxEnt [54,55]. These models can be used to predict climate-dependent limitations for survival and population growth, allowing incursion surveillance measures to be focused on regions with appropriate conditions for fly population establishment.

Models, such as those previously mentioned, suggest that with increasing global temperatures tropical areas are likely to become less suitable for many fruit fly species, as temperatures will exceed thermal limits for survival. Conversely, temperate areas will become more suitable due to a reduction in unfavourable winter conditions (e.g., extreme frost events) allowing for overwintering by adults [16,56] and consequently population establishment. Within Australia, most models of climate suitability for native tephritid fruit fly species (especially those of economic importance) indicate future temperature conditions will facilitate range expansion from Queensland and northern areas of NSW into southern NSW and Victoria along the eastern seaboard and to higher elevations along the Great Dividing Range [54,57,58]. Northern Queensland is predicted to become less

acceptable to many local tephritids, but potentially more acceptable to the establishment of exotic species, particularly OFF (e.g., [53,54]).

Table 2. Examples of species traits that can be used in models predicting fruit fly establishment likelihood and distribution.

Trait		<i>Bactrocera dorsalis</i> * (Hendel) Oriental Fruit Fly (OFF)	<i>Bactrocera tryoni</i> (Froggatt) Queensland Fruit Fly (Qfly)	<i>Ceratitis capitata</i> (Wiedemann) Mediterranean Fruit Fly (medfly)
Critical thermal limits	min	7.3 °C (larvae) [2] 9.1 °C (adults) [2]		6 °C (adults) [51,59]
	max	45.23 °C (larvae) [2] 46.16 °C (adults) [2]		42 °C (adults) [51,59]
Lethal limits	lower	−8 °C (larvae) [2] −6 to −6.5 (adults) [2,50]		−7 to −3 °C all life stages [60]
	upper	42 to 45 °C (adults) [2,50]	38–40 °C (all life stages) [61]	37 °C all life stages [60]
Developmental temperature thresholds	lower	8.8 °C, 11.8 °C, 12.1 °C, 12 °C (eggs) [62–65] 5.6 °C, 9.4 °C, 10.5 °C (larvae) [62–64] 8.7 °C, 9.3 °C, 10.9 °C (pupae) [62–64]	12 °C (all life stages) [65]	10 to 11 °C (egg) [63,66] 5 °C, 10.2 °C (larvae) [63,66,67] 9 °C (pupae) [63]
	upper	30 to 35 °C (all life stages) [62]	37 °C (eggs) [61,65] 35 °C (larvae) [65] 34 °C (pupae) [65]	35 °C (larvae) [2]
	optimum	24–30 °C (all life stages) [62,68]	25–30 °C (all life stages) [61]	24–27 °C (all life stages) [62,68]

* Includes data from *Bactrocera dorsalis* synonymy.

Despite forecasts that an area is or will be climatically suitable for range expansion by native or exotic tephritids, establishment can be limited by host availability or by interspecific competition for hosts from local fruit fly species. In an Australian context host availability alone might not be a limiting factor for establishment as the exotic tephritids in our study are polyphagous (Table 1; Table 3), i.e., OFF affects more than 250 fruits and vegetables [32], and the most likely entry points for an incursion are airports and seaports which are typically in or near capital cities and which are generally surrounded by peri-urban and food production areas with a wide variety of hosts [69].

Competition for hosts between native and exotic fruit fly species has the potential to curb the establishment of exotic species. Research [70,71] suggests that the ability of an invading species to overwhelm resident species is partly based on their reproductive capacity, or the number of adult flies produced per kg of fruit (termed the *host reproduction number* (HRN) [72]). OFF has frequently become the dominant tephritid species after introduction to a new country or region [42], outcompeting resident fruit fly species [2,71,73]. OFF has a high HRN in many hosts (see Table 4 for examples) and a competitive advantage over other species, which is largely due to its ability to infest unripe fruit (e.g., [74,75]). Laying eggs in unripe fruit means that OFF can often claim resources before other species [71,76]. HRNs are available for other fruit fly species (see [72] for medfly HRN), but information is limited. For Australian incursion management, a comparison of Qfly (the most economically damaging and widespread endemic fruit fly species) and exotic fruit fly HRN values would be beneficial to increase the accuracy of determining the invasion and establishment potential of exotic fruit fly taxa [77]. A caveat to this is that in certain locations such as northern Australia, especially in island habitats, host type may be very limited. In these areas, the benefits of using HRN for optimising fruit fly management may also be limited, especially in areas where hosts are similar across fruit fly species.

Table 3. Australian pest species of tephritid fruit fly, their distribution, hosts, preferred climate and attractant (lure type). *C. capitata* and *B. frauenfeldi* are the only non-native species. Note *B. aquilonis* and *B. neohumeralis* are sibling species of Qfly [69,78] and *B. aquilonis* is genetically indistinct from Qfly [79].

Species	Distribution		Host/s	Climate †	Attractant
	Native	Invasive			
<i>Bactrocera aquilonis</i> (May) Northern Territory fruit fly	Northern areas of Western Australia and the Northern Territory		Polyphagous [80], major host billy-goat plum (<i>Terminalia ferdinandiana</i>). Major commercial host bitter gourd and guava	Tropical	Cuelure
<i>Bactrocera bryoniae</i> (Tryon)	West Papua, Papua New Guinea, Queensland, Northern Territory, New South Wales and northern Western Australia [81], and Torres Strait Islands [35]		Polyphagous, recorded on 9 hosts [80], main host chilli	Tropical, sub-tropical	Cuelure group (melolure in Queensland [82]) and Wilson's lure [34]
<i>Bactrocera frauenfeldi</i> (Schiner) mango fruit fly	Federated States of Micronesia, Kiribati, Marshall Islands, Palau, Nauru, Solomon Islands, Moluccas, Papua New Guinea.	Invasive to Queensland and Torres Strait [83]	Polyphagous, 109 known hosts. Commercial hosts mango, banana, citrus, carambola, guava, papaya, edible <i>Syzygium</i> , star apple, sapodilla and abiu [33,80]	Tropical	Cuelure group (melolure [82])
<i>Bactrocera jarvisi</i> (Tryon) Jarvis' fruit fly	Queensland and northern tropics [84] including Western Australia, Northern Territory, Torres Strait Islands and NSW south to Sydney [80]. West Papua and Papua New Guinea [33]		Polyphagous. Recorded on 84 hosts. Main host cockatoo apple (<i>Planchonia careya</i>). Commercial hosts include mango, guava, papaya, persimmon, soursop, avocado, banana, pomegranate, apple, peach, pear, coffee, citrus and edible <i>Syzygium</i> [80]	Tropical, sub-tropical, warm temperate	Zingerone [85] and weakly to cuelure [84]
<i>Bactrocera kraussi</i> (Hardy)	Torres Strait Islands and northeast Queensland south to Townsville [80]		Polyphagous. Recorded on 106 hosts. Commercial hosts include mango, banana, grumichama, feijoa, carambola, peach, citrus and tamarind [80]	Tropical	Isoeugenol and weakly to cuelure [82]
<i>Bactrocera musae</i> (Tryon) banana fruit fly	Torres Strait Islands and northeast Queensland south to Townsville [80], Papua New Guinea and associated islands [34], West Papua [35]		Polyphagous. Recorded on 16 hosts. Primary economic host banana, occasional hosts papaya and guava [80]	Tropical	Methyl eugenol

Table 3. Cont.

Species	Distribution		Host/s	Climate †	Attractant
	Native	Invasive			
<i>Bactrocera neohumeralis</i> (Hardy) lesser Queensland fruit fly	Eastern seaboard [69,78] south to Coffs Harbour, Papua New Guinea		Polyphagous recorded on 160 hosts. Commercial hosts include mango, custard apple, rollinia, date palm, persimmon, mulberry, banana, carambola, passionfruit, loquat, apple, plum, peach, pear, citrus, coffee, star apple, sapodilla, abiu, capsicum and tomato [34,80]	Tropical, sub-tropical	Cuelure group [34]
<i>Bactrocera tryoni</i> (Froggatt) Queensland fruit fly (Qfly)	Queensland, New South Wales and Victoria [86], Northern Territory [87].	Invasive to New Caledonia, French Polynesia, Pitcairn Island [34]	Polyphagous recorded on over 200 hosts. Major commercial crops include mango, custard apple, papaya, carambola, passionfruit, loquat, apple, peach, coffee, star apple, sapodilla, capsicum, chilli and tomato [34,80]	Tropical, sub-tropical, warm temperate	Cuelure group [82]
<i>Ceratitis capitata</i> (Wiedemann) Mediteranean fruit fly (medfly)	African sub-Saharan countries.	Invasive to >60 countries- Middle East, Europe, Egypt, Americas, and Australia (Western Australia and incursions into South Australia [86]).	Polyphagous (any type of fleshy fruit-location dependant), major commercial hosts cherimoya, bell pepper, citrus, coffee, fig, apple, stone fruit, Japanese plum, guava, cocoa.	Mediterranean and warm temperate (elevated tropical regions)	Trimedlure/ capilure, EGO lure and terpinyl acetate [87], enriched ginger oil (EGO) [88]
<i>Zeugodacus cucumis</i> (French) cucumber fruit fly	Northern Territory, Queensland, Torres Strait Islands, northeast New South Wales [80]		Polyphagous recorded on 40 hosts. Major commercial hosts include papaya, cucumber, pumpkin, squash, zucchini, guada bean, passionfruit and tomato	Tropical, sub-tropical	Not attracted to male lures, cucumber volatile blend attractive to both sexes [89,90]

Data obtained from the Australian Handbook for the Identification of Australia fruit fly [30] and associated website fruitflyidentification.org.au (accessed on 15 January 2023) unless otherwise stated. † Based on presence data.

Table 4. Examples of very good host plants for *Bactrocera dorsalis* and associated host reproduction number (HRN) from different regions. HRN is calculated as the number of adults who emerged per 1 kg of fruit and very good hosts have a HRN value exceeding 100 [91]. HRN is for affected fruit in the field.

Host	Africa	Asia and the Pacific
<i>Annona muricata</i> —Soursop [92]	454	
<i>Carica papaya</i> —Pawpaw [93]		142
<i>Chrysobalanus icaco</i> —Icaco [94]	125	
<i>Diospyros blancoi</i> —Velvet apple [94]	140	
<i>Eriobotrya japonica</i> —Loquat [92]	325	
<i>Mangifera indica</i> —Mango [92]	505	
<i>Musa</i> sp.—Banana [12,95]	130	247
<i>Nephelium lappaceum</i> —Rambutan [95]		370
<i>Pometia pinnata</i> —Pacific lychee [95]		195
<i>Psidium guajava</i> —Guava [42,96]	156	247
<i>Sclerocarya birrea</i> —Marula [12]	238	
<i>Syzygium jambos</i> —Jambos, Rose-apple [94,95]	141	225
<i>Terminalia catappa</i> —Tropical almond [12]	653	
<i>Vaccinium corymbosum</i> —Blueberry [95]		1228

3. Management Strategies for Tephritid Fruit Fly Incursions

3.1. Emergency Response Plans

Effective control of exotic fruit fly incursions starts with an emergency response plan, which many countries have in place to guide their response operations. Plans typically involve identification, trapping (to delimit the incursion), host sampling surveys to identify the incursion zone, the establishment of a quarantine zone (usually with several levels or buffer zones including an exclusion zone) and then eradication (e.g., [97,98]). Australia has a generic emergency response plan, the *Australian Emergency Plant Pest Response Plan* or *PLANTPLAN* [99]. *PLANTPLAN* sets out general guidelines to follow in the event of an incursion by a plant pest. In summary, this includes identification of the pest (initial and confirmatory morphological or molecular diagnostics), determining the geographic extent of the incident, establishing quarantine zones (restricted areas, control areas and pest-free areas), establishing movement restrictions (for vehicles/machinery/produce) and finally control strategies (see Table 5 for fruit fly control examples). To date, mainland Australia does not have a generic or species-specific emergency response plan for exotic fruit fly species. There is, however, a detailed response plan (not an emergency plan because it manages ongoing seasonal incursions) for exotic fruit flies called the *National Exotic Fruit Fly in Torres Strait Eradication Program: Response Plan 2021–2026*. This plan describes the response activity required for detection and control of OFF, melon fly and New Guinea fruit fly and is based upon historical detections and proven eradication activities refined over the last 25 years in this area. While the implementation of this plan is useful to prevent incursions into Australia and acts as an early warning system, it does not cover the response to any mainland incursions [18], and as such the addition of a specific emergency response plan (as part of a National Action Plan) for exotic fruit fly species is required for mainland Australia.

Table 5. List of area-wide control options for fruit flies.

Control Strategy/Type	Description
Surveillance	Lure-based traps (para-pheromone or ammonia-based) used to monitor areas of concern (i.e., ports of entry, horticultural areas [100] for an incursion. Usually set up in a grid pattern [101].
Quarantine zones	Areas that restrict the movement of potentially infected fruit and vegetables to create “fly free” zones, this could be a country, an area of high horticultural value or an incursion area within a country [86].
Cultural control	The use of physical control techniques, such as crop sanitation and hygiene e.g., wrapping fruit, removal, and destruction of fallen fruits, digging up the ground to destroy pupae.
Cover sprays	Spraying pesticides directly onto affected crops.
Male annihilation technique (MAT)	Para-pheromone lures (e.g., methyl eugenol) and an insecticide (e.g., malathion) are impregnated into caneite (compressed fibreboard) [102], cordelitos (cotton wicks), coconut husks, compressed cardboard [18] or plastics [103] to lure and kill males so that mating is compromised [104].
Bait application technique (BAT) or protein bait sprays	An insecticide (malathion [105], spinosad [106], fipronil [107]) and protein source (protein hydrolysate [103] or protein autolysate [108]) is applied to the foliage of host crops, usually only along the borders of the crop or in targeted areas.
Sterile insect technique (SIT)	Mass-rearing and releasing millions of sterile flies into a wild population of flies, the intended outcome that females will mate with sterile males and not produce fertile eggs which in turn reduces the population [109].
Biological control agents (BCAs)	Natural control agents such as predators, parasitoids (wasps and flies), fungi, nematodes, bacteria and viruses to reduce populations [25].

3.2. Border Control and Surveillance

International border controls, entry restrictions, policies and treatment protocols are employed globally by countries to stop the entry of infested produce (fruit and vegetables) carried by travellers or in commercial consignments (e.g., [110,111]). Commercial fruit consignments are usually required to be treated using a recognised disinfestation technique to eliminate any live insects within the fruit. There are three main disinfestation techniques: irradiation [112], temperature treatments [113,114] and fumigation (e.g., methyl bromide) [115]. Methods used for disinfestation typically vary between crops due to associated damage, quality loss or acceptance of treatments by trading partners. Irradiation is highly effective against many tephritids with an internationally accepted dose of 150 Gy [112,116]. Temperature disinfestation is a non-polluting strategy but is time-consuming, may affect quality and typically has a large energy footprint. Methyl bromide is an ozone-depleting substance and is scheduled for phase-out under the Montreal Protocol. Despite quarantine treatments currently having a critical use exemption, the use of methyl bromide is likely to become increasingly restricted [115], and many countries including the European Union have banned its use for quarantine purposes on imported products.

Interceptions by border control are very successful in preventing incursions. Australia has some of the strictest biosecurity border controls in the world. The *Department of Agriculture, Fisheries and Forestry* (DAFF) and *Australian Border Force* manage pre-border checks of produce which involve declaration, manual inspection, X-ray inspection, inspection by detection dogs and destruction or treatment of seized goods [117]. In Australia, between 2012 and 2018, 1.9 million items of biosecurity concern were seized at airports. Between 2014 and 2017 there were over 37,000 border interceptions of pests (most of which were insects). Of these interceptions, most pests (45%) were brought into Australia by air cargo followed by sea cargo and containers (35%), the remainder a combination of interceptions

from international air passengers and mail. Less than 1% of interceptions were for high-priority plant pests [117]. Border controls are vital in preventing incursions as propagule pressure (the initial population size) is linked to establishment success—the smaller the propagule the less likely a population will establish [77].

Should fruit flies bypass pre-border controls, targeted surveillance is used to detect flies or provide evidence of early establishment. Surveillance varies widely between countries. Australia, New Zealand and the USA (California and Florida) all have extensive surveillance networks in place (see [101] for a review; [118] for a map of the surveillance network in Australia). Typically, surveillance networks consist of grids interspersed with traps (e.g., McPhail, Lynfield, or Steiner traps) laced with a lure and an insecticide (e.g., malathion, fipronil, spinosad). Lures can be species or genus-specific, such as para-pheromone lures designed to attract males only or ammonia-based lures for non-lure-responsive species, which capture both sexes. Most if not all fruit flies are attracted to ammonia-based lures, and baits of ammonia laced with insecticides are commonly used for control or eradication of fruit fly populations (see Section 3.3 *Eradication and control*). However, para-pheromone lures are typically much more effective in terms of detecting target species for surveillance purposes. Ammonia-based lures are an old technology used before para-pheromones became available and are typically used where no para-pheromone lure has been developed for a particular species. The para-pheromone lures methyl eugenol, cuelure and trimedlure/capilure are widely used to attract OFF, Qfly and medfly males, respectively. In contrast, the Mexican fruit fly has no known para-pheromone lure, but ammonium acetate, hydrolysed protein, torula yeast and putrescine-based lures work as attractants [26–29]. Tables 1 and 3 list the lures used for the species mentioned in this review.

Fruit fly trap and lure selection is influenced by the target fly species and by environmental conditions, leading to different trap/lure combinations being used in different countries or regions. USA surveillance programs (in California, Florida and Texas) use Jackson traps in combination with trimedlure and BioLure® (ammonia-based) for medfly, BioLure® for *Anastrepa* spp., cuelure and methyl eugenol for *Bactrocera* spp., and McPhail traps baited with torula yeast to monitor Mexican fruit fly [119]. The *New Zealand Fruit Fly Detection Program* uses Lynfield traps baited with cuelure to attract Qfly and melon fly, methyl eugenol to attract OFF, trimedlure/capilure to attract medfly, and ammonia-based lures as a general lure for species not attracted to para-pheromones [120,121] (see below for details of Australian trap/lure combinations).

Typically, surveillance networks employ grids of traps at densities of between one and eight traps per km² at major ports of entry and in high-risk areas (i.e., urban areas and horticultural zones), depending on designated risk [101,122]. The effectiveness of a trapping grid in detecting incursions is dependent on the sensitivity of the grid, which in turn is determined by the type and combination of lures used (some combinations of lures can reduce efficacy (e.g., [123]), grid size, trap density, monitoring frequency, geography and climate [124]. Additionally, the use of any particular trap/lure combination in lure-based eradication designed for one fruit fly species may lead to an increase in the likelihood of the establishment of other species. The suppression of resident fruit fly populations may reduce competition for invading species [125], and the traps and lures in place may not be suitable for the control of the new invading species [126]. Trapping guidelines have been issued by the *Food and Agriculture Organisation* and *International Atomic Energy Agency* [124] and stipulate trap density for effective monitoring, control/suppression and eradication.

The fruit fly surveillance network in Australia is complex, as it is largely funded by the federal government but run independently by the Australian states and territories. The federal program is responsible for international border control and runs the *National Plant Health Surveillance Program* (NPHSP) (previously the *Australian National Exotic Fruit Fly Surveillance Program*), and the *Northern Australia Quarantine Strategy* (NAQS) (see [86,101]). The NPHSP was established after the 1995 incursion of OFF in Cairns and consists of a network of 4800 traps equally baited with a malathion toxicant and cuelure, capilure or

methyl eugenol lures set up at one trap per 25 km² within 20 km of major ports of entry around Australia [101] (see [127] for a location map).

NAQS became operational in 1989 and remains the key Australian program today to monitor incursions from non-regulated pathways into northern Australia [101]. The NAQS fruit fly monitoring network currently comprises 125 permanent traps spread out over 20 islands at 46 sites, as well as across 13 sites in the northern tip of Cape York Peninsula, Queensland [18,127]. Additional response traps are added in the event of an incursion.

Each state and territory in Australia additionally runs its own fruit fly surveillance programs, mostly to monitor the spread of existing but regionally restricted fruit fly populations (i.e., Qfly and medfly). These programs act as an early warning system for incursions and also demonstrate the absence of fruit fly species for international trade purposes [69]. In combination, the trapping surveillance networks of the Australian states and territories consist of more than 25,000 traps baited with a combination of methyl eugenol, cuelure and capilure, set up at a density of 6 traps per km² in high-risk urban areas and at 1 trap per km² in horticultural zones [69,100,115].

Surveillance trap architecture varies between locations due to local environmental conditions, predominantly rainfall frequency. The Lynfield trap is used throughout NSW [69], in most southern regions [128] and in many parts of southern and central Queensland [129]. In northern Australia, Lynfield traps are suboptimal due to heavy monsoon rain and Paton and Steiner traps are used instead [11]. Recently, Biotraps[®] were found to be equivalent to Lynfield traps in New Zealand and southern Australia in terms of efficacy [130] and cone traps were also found to be equivalent to Lynfield traps [131]. These trap designs may replace Lynfield traps as their availability declines [132]. Based on national guidelines, most states inspect their fruit fly traps fortnightly. Traps for the Torres Strait grid are checked monthly during the “dry” season (July to December) and fortnightly during the “wet” season (January to June) [18]. Data from programs (excluding NAQS trapping data) are sent to the federal government agency, the DAFF to include in a restricted-access national database called AUSPestCheck[®] run by *Plant Health Australia* (PHA), the national coordinator of the government-industry partnership for plant biosecurity in Australia.

3.3. Eradication and Control

According to the *Global Eradication and Response Database* (GERDA), [133] there have been approximately 189 incursion responses and eradication attempts for the exotic fruit flies mentioned in this study; nine for Mexican fruit fly in Mexico and the USA, eight for melon fly in the USA and Japan, approximately 55 for OFF (including synonyms) in USA, Japan, Australia, New Zealand and French Polynesia and 117 for medfly in New Zealand, USA, Australia and South America (for a summary see Table 6, for full information on successful eradications see <http://b3.net.nz/gerda> accessed on 15 March 2023). By summarising the methods used, we found that a combination of management technologies including cultural control (e.g., wrapping fruit, early harvesting, crop sanitation, soil raking), establishment of quarantine zones, the male annihilation technique (MAT), the bait application technique (BAT), the sterile insect technique (SIT) and biological control agents were used in an area-wide manner in successful eradication programs (see below and Table 5 for definitions). The most common eradication methods included various combinations of MAT, BAT and SIT.

Table 6. Successful eradication programs for the five tephritid fruit fly species of biosecurity concern to Australia and methods used in the eradication process.

Species	Location	Incursion/s	Eradication Program/s	Method/s of Eradication
<i>Anastrepha ludens</i> Mexican fruit fly	California, USA (multiple locations)	2000s	Multiple programs 1990–2009	BAT (spinosad), quarantine and movement control and SIT
	Mexico (multiple locations)	1980s	1992–1994	Natural enemies (parasitoids), BAT, host removal and destruction, quarantine and movement control, and SIT
	Texas, United States (multiple locations)	2008, 2011, 2013	2008–2013	BAT (spinosad or malathion), host removal or destruction, and SIT
<i>Bactocera carambolae</i> carambola fruit fly	Guyana	unknown	1988–2002	BAT, MAT, quarantine and movement control
	Brazil	1996	1998–1998	BAT
<i>Bactrocera dorsalis</i> Oriental fruit fly *	Rota Island, USA	unknown	1962–1963	MAT (methyl eugenol and naled impregnated cane fibre squares)
	Guam	unknown	1963–1965	SIT
	Mariana Islands, USA	unknown	1964–1964	MAT and SIT
	Kikajima Island, Japan	1929	1968–1978	MAT
	Amami Islands, Japan	1946	1974–1978	MAT
	San Diego, California, USA	1974	1974–1975	MAT, BAT, quarantine and movement control,
	Okinawa Islands, Japan	1919	1977–1985	SIT
	Mauritius	1996	1996–1998	Destruction of infested fruit, MAT, BAT, cover sprays, soil drenching [134]
	Nauru	1992	1998–1999	MAT (fipronil and methyl eugenol)
	Queensland, Australia (Cairns (primary incursion site), Mt Isa, Humpty Do and Darwin)	1995–1997	1995–1999	Quarantine and movement control, MAT (fibreboard blocks with methyl eugenol and malathion), BAT (malathion)
	Torres Strait Islands, Australia	Ongoing seasonal incursions [18]	Multiple programs 1996–ongoing [18]	MAT (caneite blocks laced with malathion), BAT (malathion or spinosad) [18]
	Florida, USA	1964 ongoing (multiple minor incursions) [122]	Multiple programs 1995–2016	MAT (methyl eugenol and naled), soil drench (diazinon and later lambda-cyhalothrin), host removal and destruction, BAT (spinosad), quarantine and movement control [122]
	California, USA (multiple locations in Los Angeles and Sacramento)	2006–2013	Multiple programs 2006–2013	MAT, quarantine, and movement control
	Easter Island	2010	2010–2011	BAT (spinosad), MAT, destruction of infested fruit
	South Africa (multiple locations)	2010	2010–2011	MAT (fibreboard blocks with methyl eugenol and malathion), BAT (GF-120 and LokLure with malathion), orchard sanitation

Table 6. Cont.

Species	Location	Incursion/s	Eradication Program/s	Method/s of Eradication
<i>Bactrocera tryoni</i> Queensland fruit fly	Easter Island, Chile	1971	1972	BAT (hydrolysed protein and malathion), MAT (cuelure and malathion impregnated cordelito)
	South Australia, Australia (multiple urban sites—re-occurring minor incursions from NSW)	1987–1994	Multiple programs 1987–1994	BAT (maldison with protein attractant), removal and destruction of fruit, cover spray (fenthion)
	Perth, Western Australia, Australia	1989, 2011	1989–1990, 2011	BAT (spinosad, Naturalure), MAT and SIT
	Cook Islands	2001	2001–2003	Destruction of infested fruit, quarantine and movement control, BAT
	Ti Tree, Northern Territory (re-occurring minor incursions)	2000–2009	Multiple programs 2000–2009	BAT (spinosad and malathion baits), cover sprays, removal and destruction of infested fruits
	South Australia, Australia (multiple urban sites—re-occurring minor incursions from NSW)	2002–2014	Multiple programs 2002–2014	Removal and destruction of fruit, BAT (maldison with protein attractant) and SIT, black plastic on soil under trees to break lifecycle
	Auckland, New Zealand	2015, 2019	2015, 2019	Quarantine and movement control, host collection and disposal, MAT (methyl eugenol and dichlorvos) and BAT (fipronil or spinetoram) [135]
<i>Ceratitis capitata</i> Mediterranean fruit fly	New Zealand (multiple sites)	1906, 1907 and 1996	Multiple programs 1906–1907, 1996	Presumed to be fruit destruction and soil drenches of kerosene (early eradications). BAT (malathion), host removal and destruction.
	Bermuda	1907	1907–1963	BAT (malathion and protein attractant), ground application of dieldrin, MAT baits with trimedlure and dichlorvos
	Florida (multiple locations), USA	1929 ongoing (re-occurring minor incursions)	Multiple programs 1930–2011	Ground application of arsenical molasses followed by copper carbonate, host removal and destruction, BAT (malathion and later spinosad), soil drench of dieldrin and later on diazinon and spinosad, quarantine and movement control
	Texas, USA	1966	1966	BAT (malathion and protein attractant)
	South Australia, Australia (multiple locations)	1968 ongoing (re-occurring minor incursions)	Multiple programs 1968–2019	BAT (malathion and later spinosad), SIT, cover spray (fenthion) and ground drench (chlorpyrifos and later lambda-cyhalothrin), quarantine zone, removal and destruction of fruit (treatment with malathion)
	California, USA (multiple locations)	1975 ongoing (re-occurring minor incursions)	Multiple programs 1975–2006	BAT (malathion and later spinosad), SIT, host removal and destruction, quarantine, and movement control

Table 6. Cont.

Species	Location	Incursion/s	Eradication Program/s	Method/s of Eradication
<i>Ceratitis capitata</i> Mediterranean fruit fly	Alice Springs, Northern Territory, Australia	1976, 1981 & 1986	Multiple programs 1976–1986	BAT (malathion), host removal and destruction, cover sprays of trichlorfon, fenthion (for destroyed fruit) and dimethoate, MAT (trimedlure and dichlorvos)
	Guatemala (multiple locations)	1977	1977–2013	BAT (malathion and later spinosad), SIT
	Chile (multiple locations)	1963 ongoing (re-occurring minor incursions)	Multiple programs 1990–2013	BAT (malathion and spinosad), SIT, host removal and destruction, quarantine and movement control, soil drench
	Tacna, Peru	1957	1990–2007	SIT
	Argentina (multiple locations)	1992 and 1997	Multiple programs 1992–2012	BAT, host removal and destruction, SIT, cover spray, quarantine and movement control
	Belize	1987	1997–2001	BAT (malathion and later spinosad)
	Managua, Nicaragua	1994	2004–2012	BAT, quarantine and host removal
	Dominican Republic	2015	2015–2017	SIT
	<i>Zeugodacus cucurbitae</i> melon fly	Rota Island, United States	unknown	1962–1963
Southwestern Islands, Japan		1972	1972–1993	SIT [136]
Nauru		1992, 2001	1998–2001	MAT (caneite blocks with methyl eugenol/fipronil) and BAT (fipronil)
Kern County, California, United States		unknown	2010–2011	MAT

All data are summarised from the Global eradication and response database (GERDA) [133] unless otherwise stated. * Includes data from *Bactrocera dorsalis* synonymy.

MAT is a low-cost management strategy designed to attract and kill males so that mating is severely compromised [104]. MAT is used predominantly in orchards and urban control of fruit flies [19]. MAT uses para-pheromone lures (e.g., methyl eugenol or cuelure) in combination with an insecticide (e.g., malathion). The lure and insecticide are impregnated into caneite (compressed fibreboard), cordelitos (cotton wicks), coconut husks [18], compressed cardboard [18,137] or plastics [103]. The choice of material to be impregnated depends on rainfall, geography and local availability. Areas of high rainfall require more frequent replacement of MAT assemblies. Where access is difficult, MAT assemblies using cordelitos can be dropped from aircraft and remain active for several months. The Torres Strait Islands program in Australia uses caneite blocks impregnated with malathion and methyl eugenol or cuelure [18] for control of exotic fruit flies. Likewise, caneite blocks impregnated with malathion and methyl eugenol formed a very effective part of the Cairns eradication of OFF in the 1990s [19,102].

BAT or protein bait sprays are another key component of fruit fly control, where a toxicant and attractant are applied to the foliage of host crops, usually only along the borders of the crop or in targeted areas. The toxicants and attractants used vary between countries, but toxicants may include malathion [105], spinosad [106,138] or fipronil [107]. Both male and female flies are attracted to protein sources emitting ammonia, so often the attractant used is a protein-based material. Either protein hydrolysate [103] or protein autolysate [139] is typically used, although protein hydrolysate may be phytotoxic due to

its high acidity. In Australia, the type of protein used in BAT to control Qfly was changed from protein hydrolysate to protein autolysate for exactly this reason [108]. Malathion is the most frequently used BAT toxicant in Australia [11,18,127,140]. However, as the ability to use pesticides becomes more restricted by the *Australian Pesticide and Veterinary Medicines Authority* (APVMA) due to environmental and human health concerns, Australian chemical control of fruit fly is moving towards toxicants such as spinosad (a toxicant derived from the actinobacterium *Saccharopolyspora spinosa* Mertz and Yao (Pseudonocardiales: Pseudonocardiaaceae) that is non-toxic to mammals but highly effective against arthropods (e.g., [18], for a review of chemical use against fruit fly in Australia see [141]).

SIT is the process of mass-rearing and releasing large numbers of sterile flies (preferably males only) into a wild population, the intended outcome being that wild females will mate with sterile males and then not produce fertile eggs, which in turn reduces the population [109]. SIT is an expensive and complex control method, but also a more environmentally sensitive option for fruit fly control. It requires specialised facilities and proven rearing, transportation and release techniques to minimise losses of sterile flies. This method of control has been used successfully for eradication as well as in reducing population size [136,142]. Australia has used SIT to suppress outbreaks of local fruit fly species since the 1960s [143,144] and currently has two SIT facilities available, one in South Australia and one in Western Australia, that produce sterile Qfly and medfly adults.

3.4. Economic Costs of Fruit Fly Incursion Management

The costs of fruit fly incursion management including preventative measures such as surveillance, eradication costs and loss of profits vary considerably but tend to range from millions to billions of dollars, depending on the location and the extent of the incursion. It is typically much less costly to invest in good incursion prevention measures than to initiate an eradication response. In Australia, an exotic fruit fly incursion would result in production disruptions, potential loss of domestic and international markets and income losses, together estimated at between AUD 269 million and AUD 2.1 billion, depending on the area affected and the success of the eradication attempt [18]. The cost of surveillance in mainland Australia in 2002 was estimated to be between AUD 1.3 and AUD 7 million per year [145] and the total cost of the NAQS surveillance program from 2021 to 2026 is estimated at AUD 4 million [18]. The eradication of OFF from Australia in the 1990s cost an estimated AUD 34 million [19], with a further AUD 100 million in costs incurred through increased production expenses, reduced productivity, and market access closures [18].

4. Fruit Fly in Australia

4.1. History of Economically Important Fruit Flies in Australia

Of the 301 tephritid species native to Australia [146] only eight are considered problematic to Australian horticultural industries [30] (Table 3). The most widespread and damaging of these tephritids is Qfly [140]. Qfly is thought to be native to Queensland and the north New South Wales coast. Historically, southern Australia was climatically suitable for Qfly establishment, however, range extension did not occur until after European settlement [40] brought the unregulated domestic trade of fruit and vegetables [86]. Qfly was first reported in NSW in 1819, but it was not considered a pest in NSW until 1852, with the first major outbreak occurring in 1884 [34]. Qfly is also present in the Northern Territory [140] and has been found periodically in (and eradicated from) South Australia, Western Australia [128,140] and Tasmania [147].

There have been two noteworthy incursions of exotic fruit flies into Australia. The first major incursion was by medfly. Medfly is considered the second most economically damaging fruit fly in Australia, after Qfly. Medfly was first introduced into Western Australia in 1896 and New South Wales in 1898 [148] and had spread to Victoria by 1909 [149]. It disappeared from the eastern states by the 1950s, probably due to a combination of control measures (most likely fruit destruction and soil drenches) and competition from Qfly [140]. Since that time there have been sporadic and swiftly eradicated outbreaks of medfly in

South Australia (mostly around Adelaide) and in the Northern Territory [133,149]. In general, for national management and international trade purposes, Medfly is considered restricted to Western Australia, while Qfly is restricted to eastern areas of Australia (Northern Territory, Queensland, NSW, Victoria) and South Australia and Tasmania are free from both pests.

In the second major incursion, OFF (then *B. papayae*) was detected in papaya (*Carica papaya*) near Cairns in northern Queensland in October 1995, and again (as *B. philippinensis*) in the Northern Territory in November 1997 [19]. A national eradication response was mounted by state and federal government agencies and by 1999 OFF was eradicated from mainland Australia [19,146]. To date, mainland Australia remains free from OFF, however as mentioned previously interceptions and eradication of OFF (and other species) still occur yearly in the Torres Strait Islands [18,118].

4.2. National Fruit Fly Programs and Policy

The *Australian Plant Health Committee* (PHC) is the peak government plant biosecurity policy and decision-making forum. It provides strategic policy, technical and regulatory advice and national leadership on all plant biosecurity matters to protect Australia's plant health and economic benefits derived from fruit and vegetable exports. In 2011, at the request of the *National Biosecurity Committee* (NBC), PHC assumed responsibility for managing policy for endemic fruit flies and the *Australian Fruit Fly Technical Advisory Subcommittee* (AFFTAC) was commissioned to develop *Australia's National Fruit Fly Management Protocol* (ANFFMP). AFFTAC provides the necessary technical support for a nationally coordinated approach to surveillance and management of fruit flies, in line with Australia's international import and export market access conditions and policies.

To manage ongoing fruit fly concerns in Australia a *National Fruit Fly Council* (NFFC) jointly funded by government and industry through their Research and Development Corporation (Hort Innovation) was established in 2015. The NFFC connects growers and fruit fly management groups across states and territories to control fruit flies in Australia on a national scale. The NFFC has produced a *National Fruit Fly Strategy* (NFFS) [150] to provide a framework for the cost-effective and coordinated management of fruit flies in Australia. It is designed to maintain Australia's freedom from exotic fruit fly species, minimise the incidence and spread of local fruit fly species, support market access and facilitate a national approach to fruit fly management and research [150]. Other relevant plant protection organisations, such as *Plant Health Australia* (PHA), are responsible for developing and publishing important documents on the identification of native species of fruit fly (i.e., the *Australian Handbook for Identification of Fruit Flies*) and factsheets on the control measures that can be used against them.

In the event of an incursion of fruit flies Australia relies on a committee of experts called the *Consultative Committee for Emergency Plant Pests* (CCEPP) [151]. The CCEPP was developed as a response to the 1995 incursion of OFF to support a national response to fruit fly incursions. Before this time fruit fly management by the Australian states and territories was managed independently [19]. The CCEPP is designed to make recommendations for incursion management and oversees the preparation of a response plan (post-incursion) based on the general emergency response plan for plant pests (*PLANTPLAN*, [99]). This strategy is informed by a *National Management Group* (NMG) of Australian and international experts who will guide the incursion response based on the latest scientific information. The NMG usually stays engaged with the response and assists in the declaration of successful eradication if this is achieved.

4.3. Fruit Fly Incursion in Australia

Exact invasion pathways often remain unknown when an incursion occurs (e.g., [19]). As mentioned previously tourists, visitors and returning Australians from the Torres Strait Islands and Asia into northern Queensland are considered the most likely sources of an incursion [118]. Darwin (Northern Territory) and Cairns (Queensland) have international

airports that service both tourism and airfreight and in addition to various potential incursion pathways, northern Australia also has excellent environmental conditions for fruit fly establishment and spread. Northern Australia has a tropical climate that is preferred by most exotic tephritids (see Tables 1 and 3), and a wide range of hostplants are readily available. This area is particularly suitable for OFF establishment and additionally, the proximity to the Torres Strait Islands offers a potential stepping stone for OFF from PNG [18].

Surveillance traps are in place across Australia and contain fly-specific lures suitable for most species of concern, such as methyl eugenol which is attractive to OFF [11,115]. Mainland Australia seems well placed to detect any incursion, provided the surveillance trapping grid is maintained. Part of a good surveillance system is predicting where entry is most likely to occur to target priority areas for surveillance. There are several older models available that predict environmental suitability for OFF in Australia (e.g., [53,54]), however, models of environmental suitability are lacking for other species of concern and these types of models require frequent updating with the latest data to improve accuracy. Predictions for OFF indicate that the northern coastline of Australia is currently the most suitable [53], however, most of the eastern seaboard of Australia will be suitable for OFF establishment within the next 50 years [54,152].

Host availability is a key factor for fruit fly colonisation and establishment [153,154]. In most climatically suitable areas of Australia, there are no host limitations. However, there may be competition for hosts for invading fruit fly species. Qfly is established in most Australian horticultural areas and there are at least seven other endemic pest tephritids in northern Australia (Table 3; [55]), all of which currently compete for host resources [125]. An indication of the likelihood of establishment success might be gained by comparing the HRN of species of concern (e.g., OFF) with the HRN of native Australian tephritids [91]. Comparisons of OFF and Qfly on the more common and preferred host species such as mango would be of particular value. Unfortunately, HRN values for most fruit fly species present in Australia (other than Qfly and Medfly) are yet to be determined even for major hosts, and the competitive potential of these species cannot be easily assessed. This is important as it is thought that competition from native tephritid species masked the detection of the 1997 incursion of OFF in Cairns, which is estimated to have occurred 2.5 years prior to discovery [19].

Limiting factors to the spread of OFF in Australia are likely to be related to water availability, host availability and temperature. Areas of lower humidity cause moisture stress in tephritids and this would hypothetically restrict most exotic fruit flies to coastal areas of Australia since inland Australia is mostly arid. Lower temperatures that occur in southern Australia (which currently has a more temperate climate) would typically cause cold stress [154], with temperatures in large areas of southern Australia falling below the minimum requirements for development and survival (see Table 2). However, the availability of irrigation in the drier areas of southern Australia, both in towns and on farming land, climate change, the heat island effect of urban areas and host availability in backyard gardens may aid in survival and establishment in areas where natural conditions would have previously made this unlikely [152–154]. Anthropogenic environments (particularly in rural locations) need to be considered when attempting to model the establishment and spread of exotic fruit fly species in Australia. Models incorporating anthropogenically modified environments (e.g., [155]) show the establishment of fruit fly populations to be possible in areas where models incorporating only general climate data predict low or no establishment potential. Likewise, consideration of areas where the establishment is known to not occur, despite modelling predictions to the contrary, needs to occur. During the 1995 incursion OFF demonstrated an apparent inability to establish in natural rainforest habitats in far north Queensland, despite the large number of fruiting trees available in rainforest areas adjacent to horticultural crops. OFF establishment was restricted to areas of human habitation [19,156], which aided significantly in its successful eradication.

Australia has been successful in managing outbreaks of local fruit flies (Qfly and medfly) across state borders [115]. To control or locally eradicate Qfly and medfly, Aus-

tralia uses various combinations of MAT, BAT [18], SIT [157], quarantine zones [19,140], surveillance, fruit removal and destruction [133], community awareness and engagement and, where necessary, financial penalties for transporting unauthorised produce into or out of quarantine zones [19]. These methods are all used in the control and eradication of exotic fruit fly species in global locations (Table 6) and could be used in the management of an incursion into Australia by exotic fruit fly species.

5. Conclusions

The high risk of a new incursion by OFF or by other exotic fruit fly species remains one of the primary drivers for continued targeted surveillance and quarantine measures at ports of entry into Australia [69,100]. Australia relies heavily on surveillance grids and border controls to prevent incursions of exotic tephritids. The maintenance of an effective surveillance and early warning system remains the best way to optimise Australia's ongoing freedom from exotic fruit flies. The current surveillance system was established in the 1990s with reference to earlier environmental conditions, tephritid species and trapping methods. To be effective, the surveillance system in Australia needs to be utilising the latest and most effective lure types [158], best trap architecture, optimal grid spacing, appropriate pesticides [141,159], and trap locations based on detailed species distribution models and climate forecasts, with emphasis on busy ports of entry. A review of the national trapping grid was completed in 2018 by the DAFF, however, the results of this review, along with up-to-date information on the surveillance grid and its effectiveness, are not yet publicly available. Notwithstanding the above, we acknowledge that the current surveillance system seems to be effective, as there have been no serious incursions since the grid was established.

Specific areas of improvement other than those already mentioned, include a better understanding of the effect of interspecific competition between exotic and native species of fruit fly through the generation of additional HRN data. These data may help us better understand the establishment, detection and spread of exotic fruit fly species, as well as facilitate more closely targeted lure use. Lure type is particularly important for those species not attracted to the para-pheromone lures that are used in the Australian surveillance grid, such as Mexican fruit fly. Although Mexican fruit fly is not as high a biosecurity risk as OFF, Australia seems less prepared for Mexican fruit fly than for other priority species. This reflects the fact that whilst this species is listed as one of those of most concern to Australia, it is not present in Asia from where the greatest incursion risks are likely to originate. Additionally, the Mexican fruit fly is low on the 'tephritid hierarchy' [160] and is likely to have difficulty establishing in an environment saturated with *Bactrocera* spp. Surveillance for Mexican fruit fly (and other non-lure responsive species) could potentially be improved with the addition of ammonia-based lures that attract a wide range of fruit fly species to the Australian surveillance grid. This approach is being used by New Zealand in their fruit fly surveillance program [120,121].

Australia has a robust set of management strategies and policies available for the surveillance, containment, and eradication of local fruit fly species. To some degree, this has been extended to exotic fruit fly species. Australia-wide management protocols, strategies and plans for exotic fruit fly species, such as those discussed here, have benefited from the experience gained in implementing control measures directed towards preventing the internal spread of Qfly and medfly in Australia. Measures that have been used to successfully eradicate exotic tephritids (including OFF) globally also provide a sound basis for future incursion responses. National participation in management programs, the development of policy and collaboration by industry and government mean that Australia is reasonably well placed to deal with an incursion by exotic fruit fly. However, the lack of a specific emergency response plan means that the reaction to a post-border detection of exotic fruit flies will likely be delayed while research is conducted into the best management strategies for containment and eradication, potentially leading to a more severe and costly incursion outcome. A targeted emergency response plan would be relatively easy to

develop and established management strategies for pest tephritids currently present in Australia would provide it with a strong foundation.

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The potential distribution of *Bactrocera dorsalis* in Australia modelled using CLIMEX

Report prepared for New South Wales Department of
Primary Industries

29 May 2022

1 Introduction

Cervantes Agritech Pty. Limited has been engaged by New South Wales Department of Primary Industries to undertake climatic niche modelling using CLIMEX to estimate the current potential distribution of the Oriental fruit fly, *Bactrocera dorsalis*. The intention is to understand potential hotspots of biosecurity risk that can be targeted for surveillance.

The specific aims of this project were to:

1. Run the CLIMEX Compare Locations model of *B. dorsalis* developed within the FF-IPM project for Australia using a fine-scaled 30-year climatology based on SILO data centred on 2005. Two model scenarios will be run (natural rainfall and top-up irrigation) and a composite dataset will be created using the Global Map of Irrigated Areas (Siebert et al. 2013).
2. Collate data sources for Australian airports and seaports that have international connexions.
3. Run the CLIMEX model of *B. dorsalis* using the Compare Locations/Years module to develop timeseries maps of weekly and annual climate suitability, considering the spatially explicit location of irrigation.

2 Methods

2.1 Climate data

Daily weather data from 1 January 1991 to 31 December 2020 in Australia was downloaded for 281 963 locations from the silo weather data repository (<https://www.data.qld.gov.au/dataset/silo-climate-database>). The weather variables were daily maximum and minimum temperature, average daily vapour pressure and total rainfall. The daily data were converted to monthly summary values to create a monthly time-series. The monthly summary variables were then further refined to create a 30-year climatology. For the climatology, the vapour pressure and temperature variables were used to estimate relative humidity at 09:00 and 15:00. The spatial resolution of these datasets is 0.05° x 0.05° (approximately 5 km x 5 km).

2.2 Irrigation

The Global Map of Irrigated Areas developed by Siebert et al. (2013) was used to define areas in Australia that are assumed to be irrigated. The spatial granularity of this dataset is 5 arc minutes (5', approximately 8 km x 8 km). However, the true spatial resolution of the GMIA is considerably coarser because it relies upon administrative statistical reporting areas. Consequently, the irrigation areas are a little "blocky" on maps compared with the fine-scale climate data from the SILO database. The GMIA dataset also includes some large statistical reporting areas where the irrigated area is exceedingly small. We used a threshold of 1 ha for each 5' cell for designation of a cell as "irrigated". These factors mean that the results of this analysis are suitable for risk assessment purposes, but care should be exercised in downscaling the analysis.

The SILO and GMIA datasets differed in terms of their cell sizes and the reference locations. The spatial discord between the irrigation and climate datasets was managed by associating information from the GMIA dataset with each SILO climate pseudo-station where the centroid fell inside a 5' GMIA cell.

For the irrigation scenario, a value of 2.5 mm day⁻¹ was implemented as a top-up. Under this scenario, in any week where the rainfall was less than 17.5 mm week⁻¹ (7 x 2.5 mm day⁻¹), irrigation was applied to bring the rainfall up to 17.5 mm for the week. In CLIMEX this impacts the soil moisture model, and consequently the Moisture Index, the Growth Index and ultimately the Ecoclimatic Index.

2.3 Port locations

The locations of airports with international linkages were collated from <https://ourairports.com/airports.csv>. The locations of seaports with international linkages were collated from <https://datacatalog.worldbank.org/dataset/global-international-ports>.

2.4 Modelling software

CLIMEX Version 4.1 (Sutherst and Maywald 1985, Kriticos et al. 2015) was used for the climate modelling. The Compare Locations model was used to estimate the long-term average risk patterns, and the Compare Locations/Years model was used to characterise the interannual and seasonal spatio-temporal risks.

2.5 CLIMEX model for *Bactrocera dorsalis*

A CLIMEX model for *B. dorsalis* by De Villiers et al. (2016) was revised in the FF-IPM project in the light of recent reports on the geographical range of the fly in China, which extends further northwards than datasets used in De Villiers et al. (2016). This modified parameter set was used in this project.

2.6 Composite risk mapping

The effects of irrigation on the spatio-temporal risks posed by *B. dorsalis* were assessed by using the GMIA dataset to draw results from the irrigated and natural rainfall scenarios, using a method described by (Yonow et al. 2016).

2.7 Compare Locations/Years

The *B. dorsalis* model was run with a time series of SILO data. In one scenario the model was run for 20 years from 2001 to 2020, saving out the Ecoclimatic Index (EI) and the Annual Growth Index (GI_A). These annual data layers were combined using the GMIA as described in 2.6 above to create an annual timeseries illustrating the interannual variability in the area suitable for year-round occupation by *B. dorsalis*.

In the second scenario, a five-year simulation from 2016 to 2020 was run, saving out the Weekly Growth Index (GI_w) data. The time series datasets were also converted to animated GIF and MP4 files.

3 Results

3.1 Historical climatic hazard

The modelled climate suitability for *B. dorsalis* in Australia is presented in Fig 1. This map represents the climatic potential for establishment (Ecoclimatic Index, EI) and ephemeral population spread (Annual Growth Index, GI_A). The yellow to red areas are where on average over the years from 1991 to 2020 we might expect *B. dorsalis* to have been able to establish persistent populations. In practice, this means that the marginally suitable sites ($1 < EI < 5$) may only have been able to support a population during more favourable years, or that populations in these areas may have been restricted to suitable microhabitats. The areas where $GI_A > 0$ and $EI = 0$ indicate regions where *B. dorsalis* would only have been capable of population growth during favourable seasons, but not capable of persisting throughout the year.

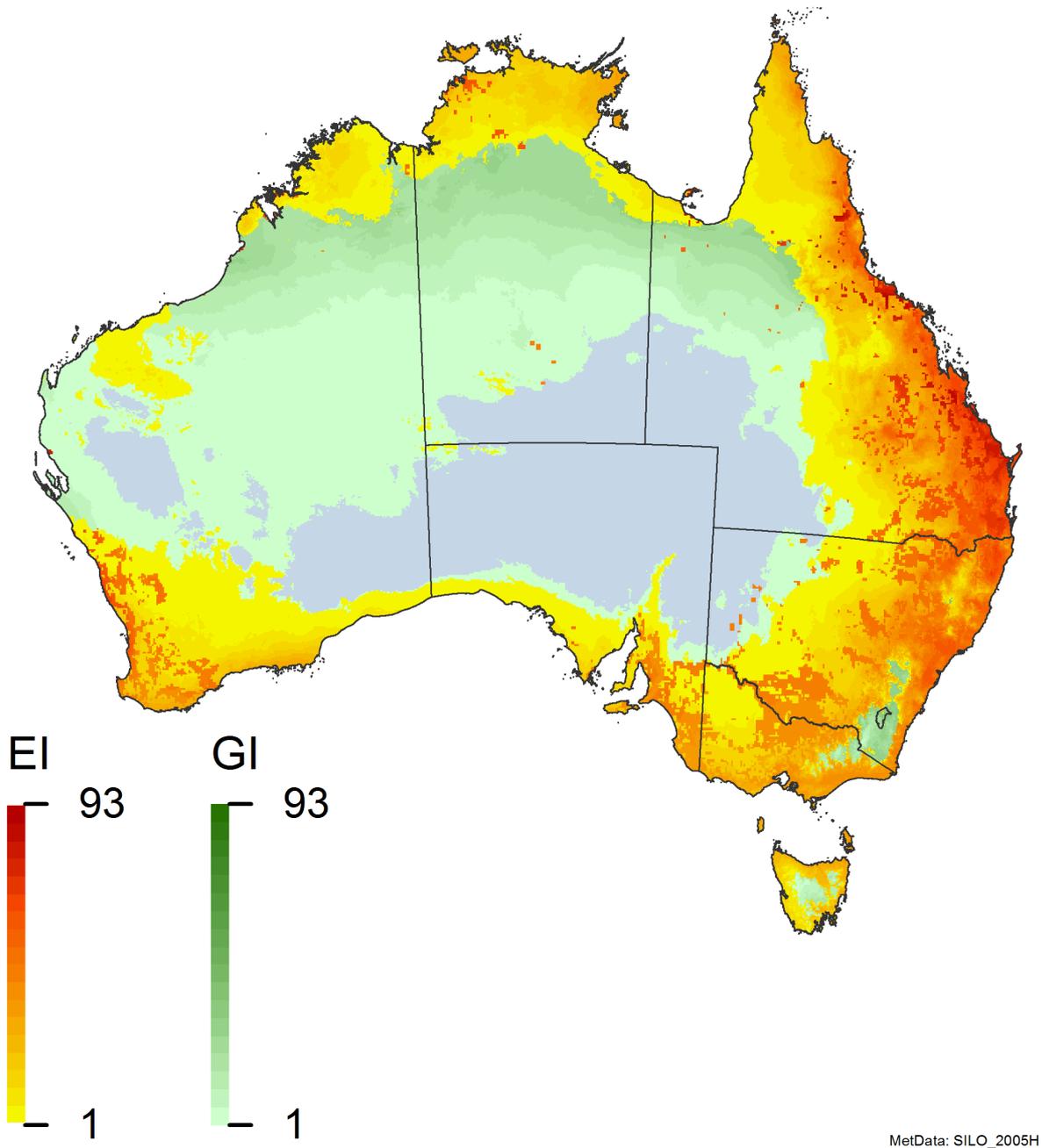


Figure 1 Climate suitability for *Bactrocera dorsalis* in Australia modelled using CLIMEX. The map is a composite of irrigated and natural rainfall scenarios, using the Global Map of Irrigated Areas (Siebert et al. 2013). Grey areas are unsuitable for growth year round. Source climate data from SILO for the 30-year average centred on 2005.

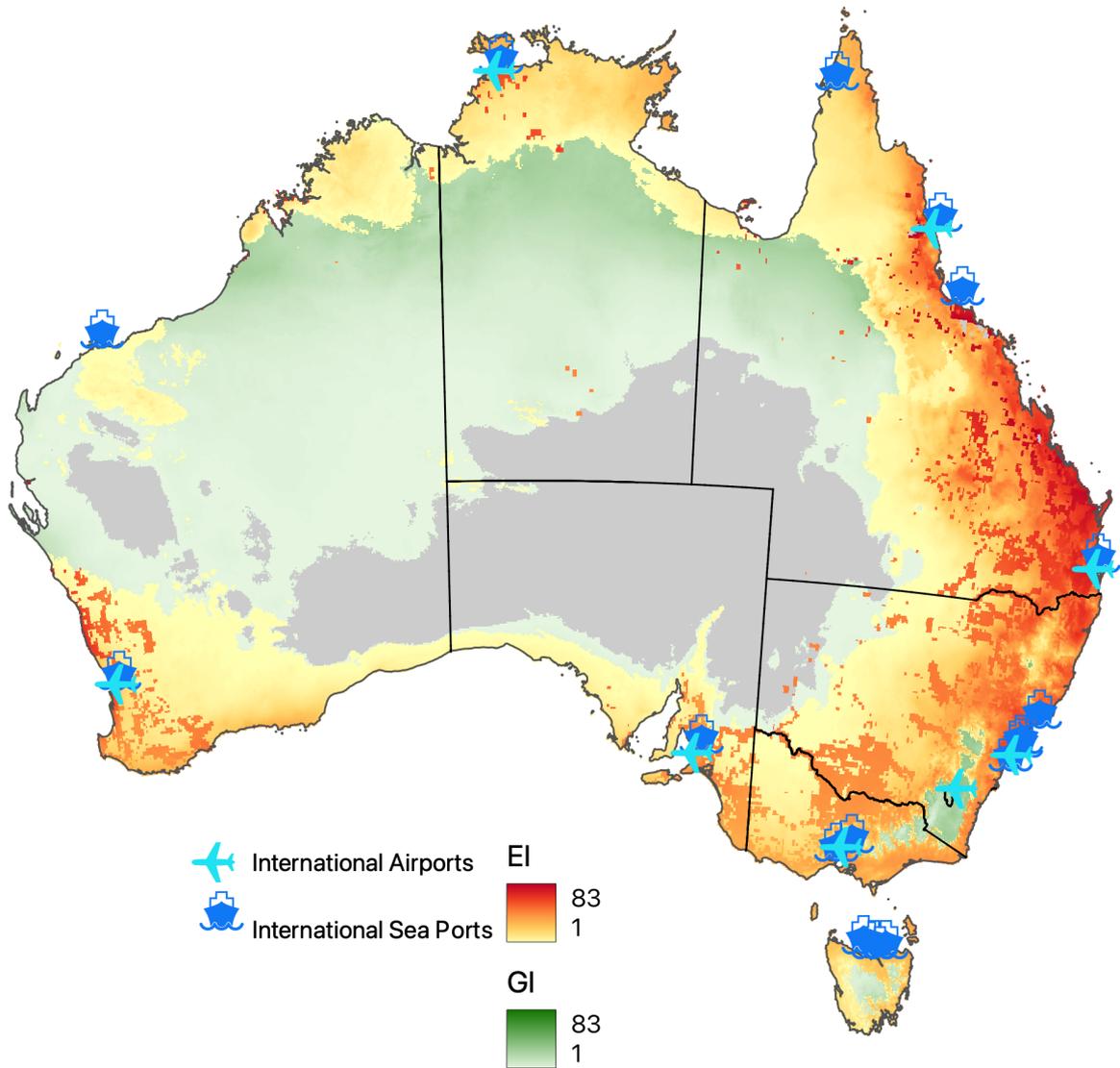


Figure 2 Climate suitability for *Bactrocera dorsalis* in Australia modelled using CLIMEX overlain with Australian international air and sea ports. The map is a composite of irrigated and natural rainfall scenarios, using the Global Map of Irrigated Areas (Siebert et al. 2013). Grey areas are unsuitable for growth year round. Source climate data from SILO for the 30-year average centred on 2005.

3.2 Climatic variability

Individual maps for weekly and annual timesteps were produced. An example map for the growth index is included (Fig 3). The interannual climate suitability maps are provided in Fig 4. These maps indicate marked variability around the long-term average.

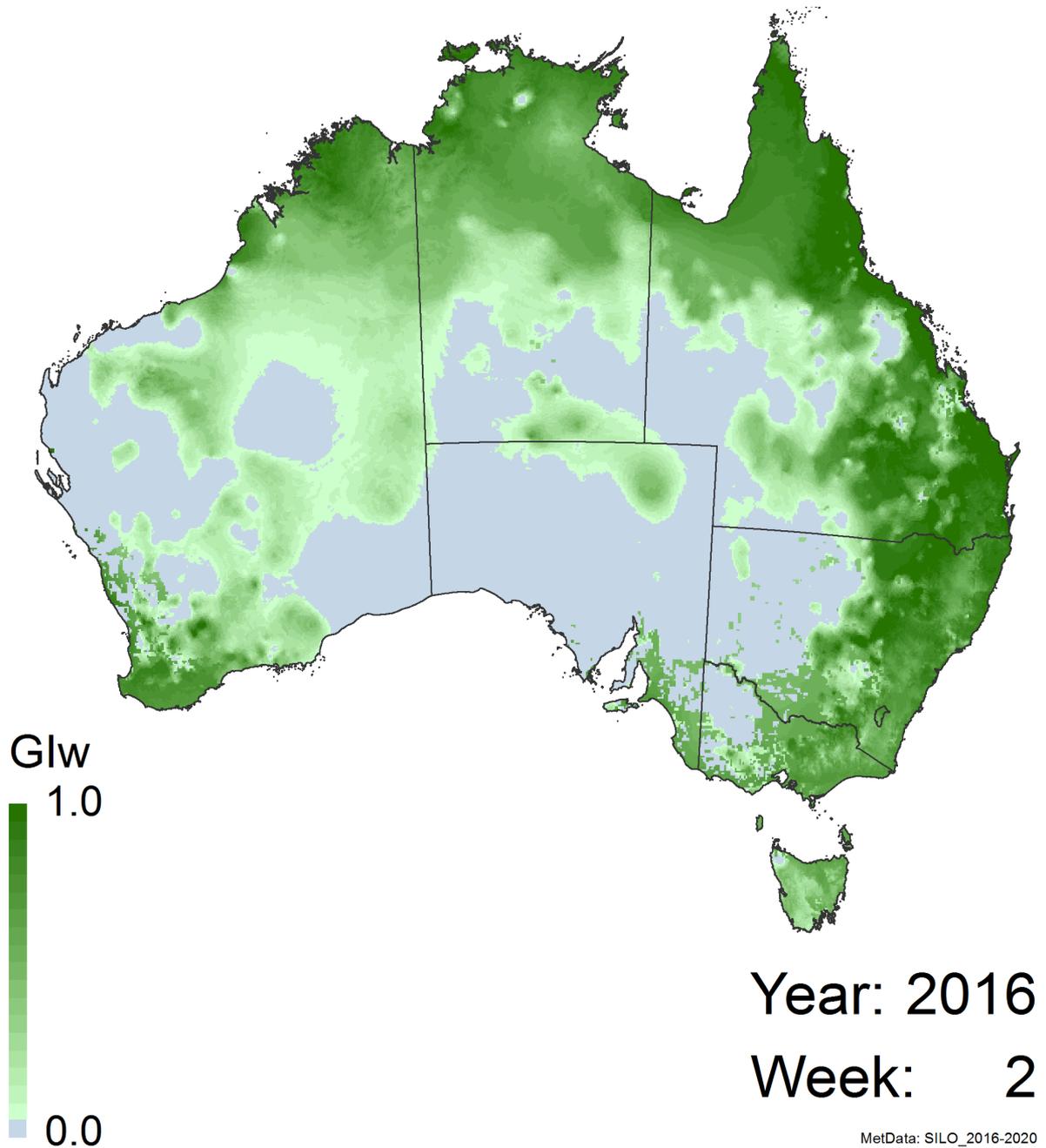
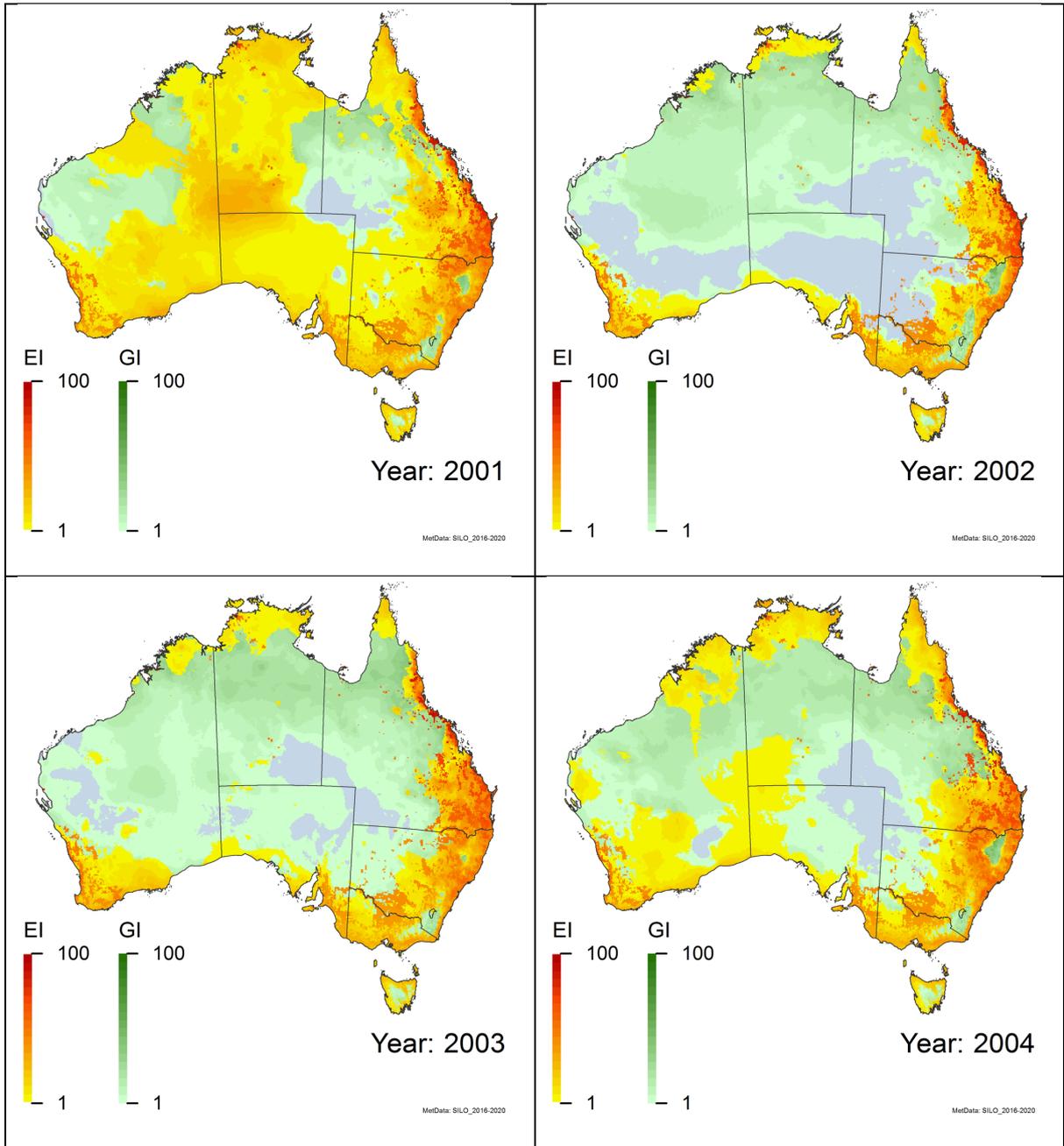
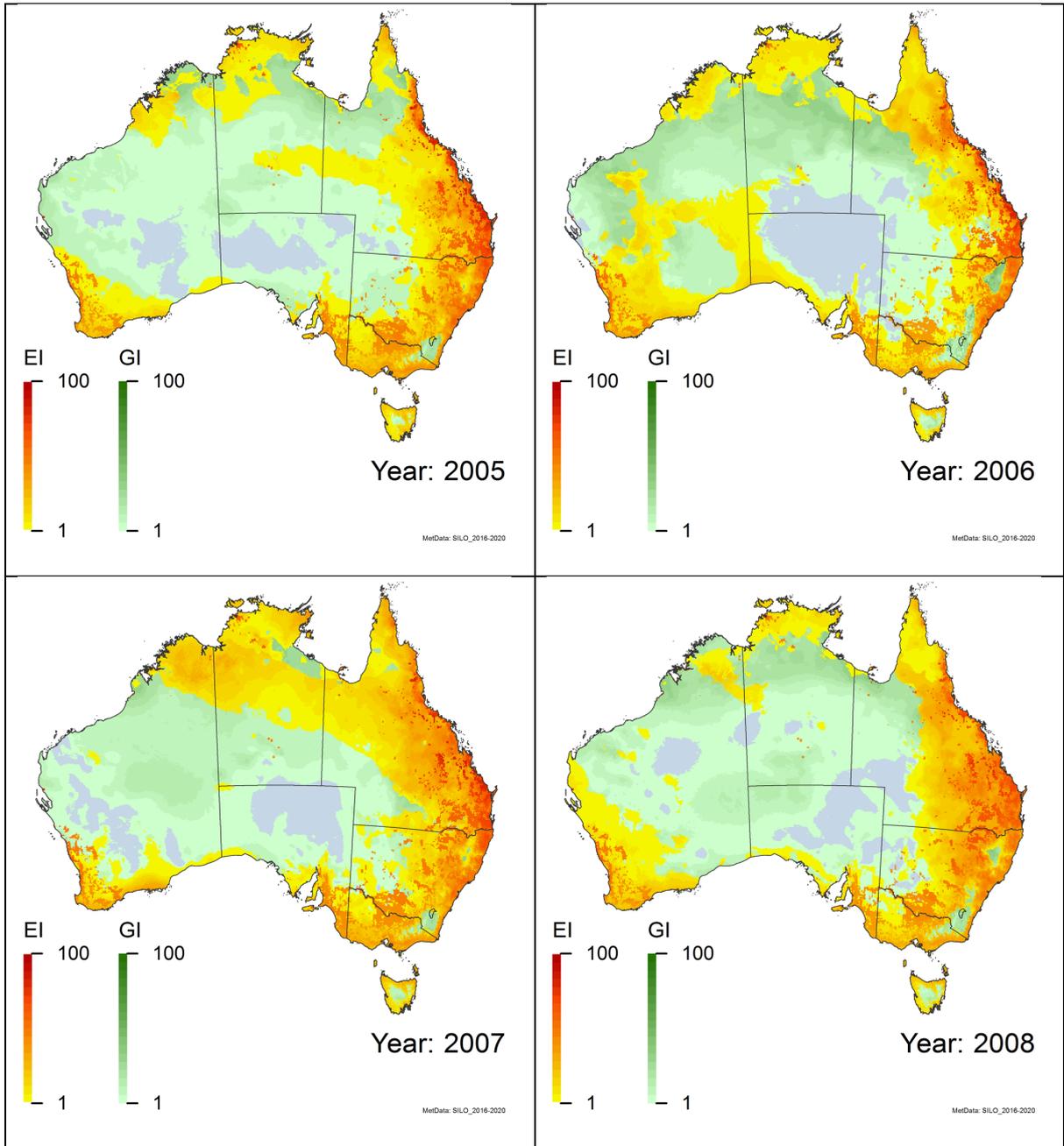
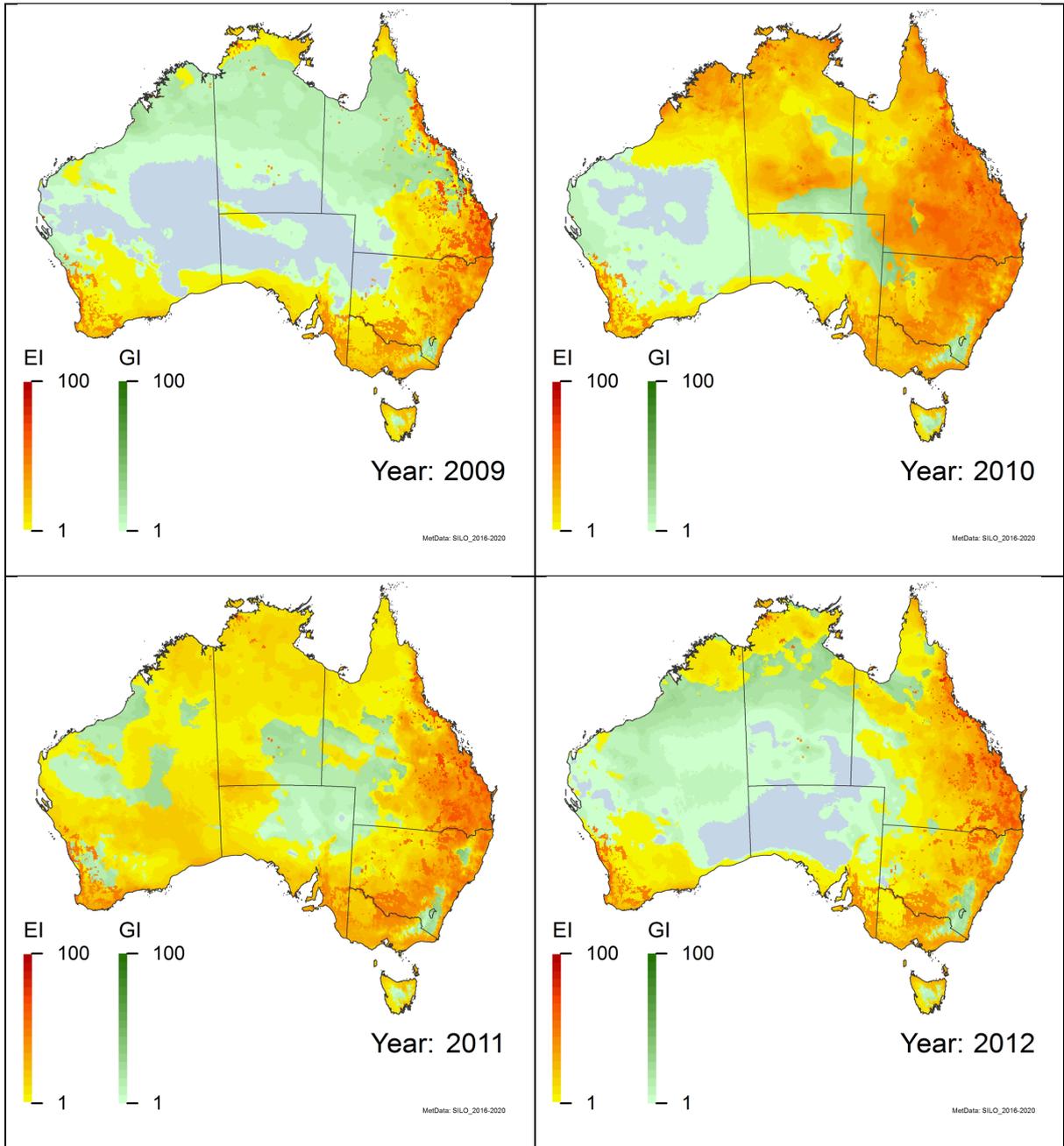
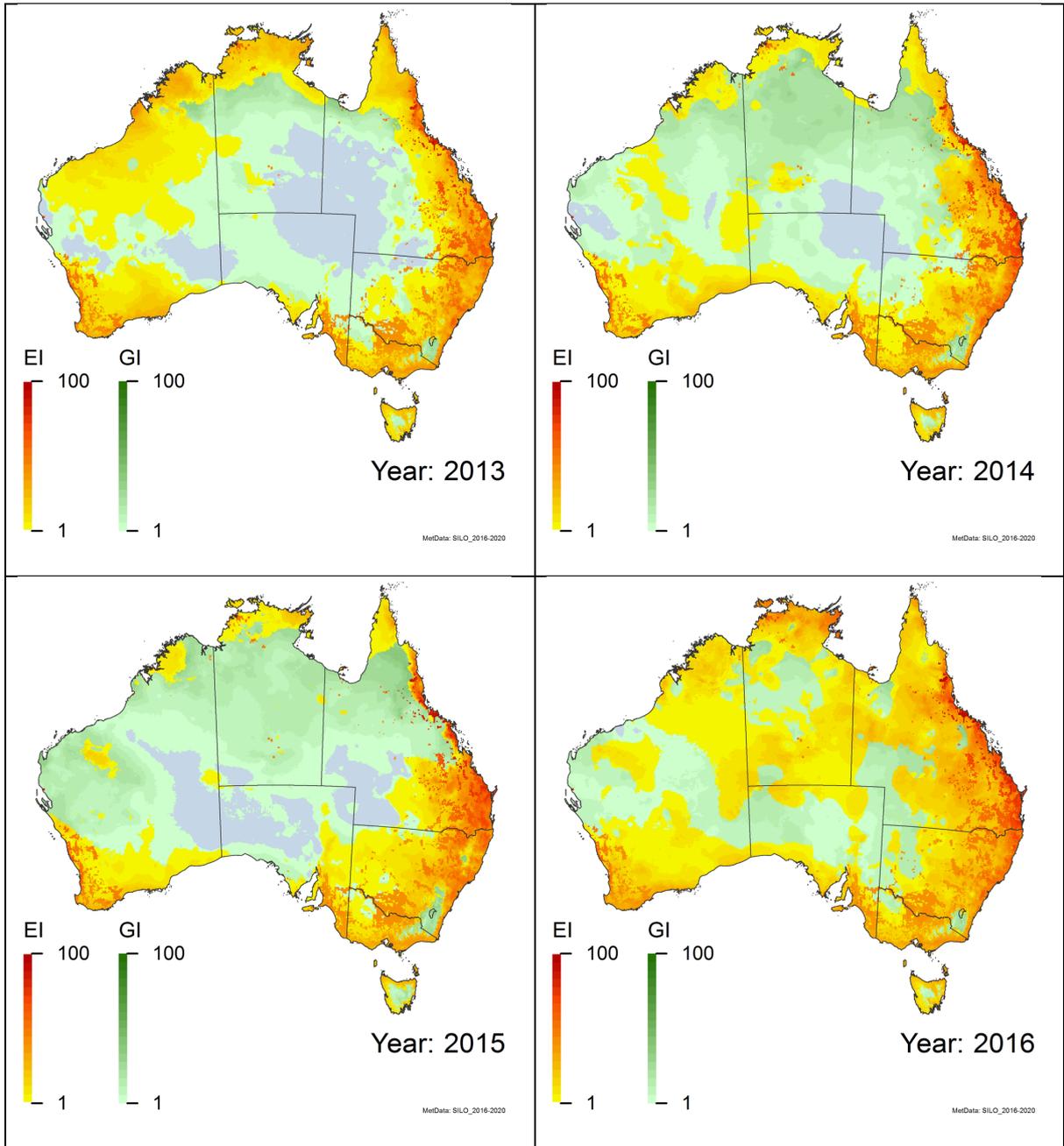


Figure 3 Weekly Growth Index for *Bactrocera dorsalis* modelled using CLIMEX for week 2, 2016. Source climate data from SILO.









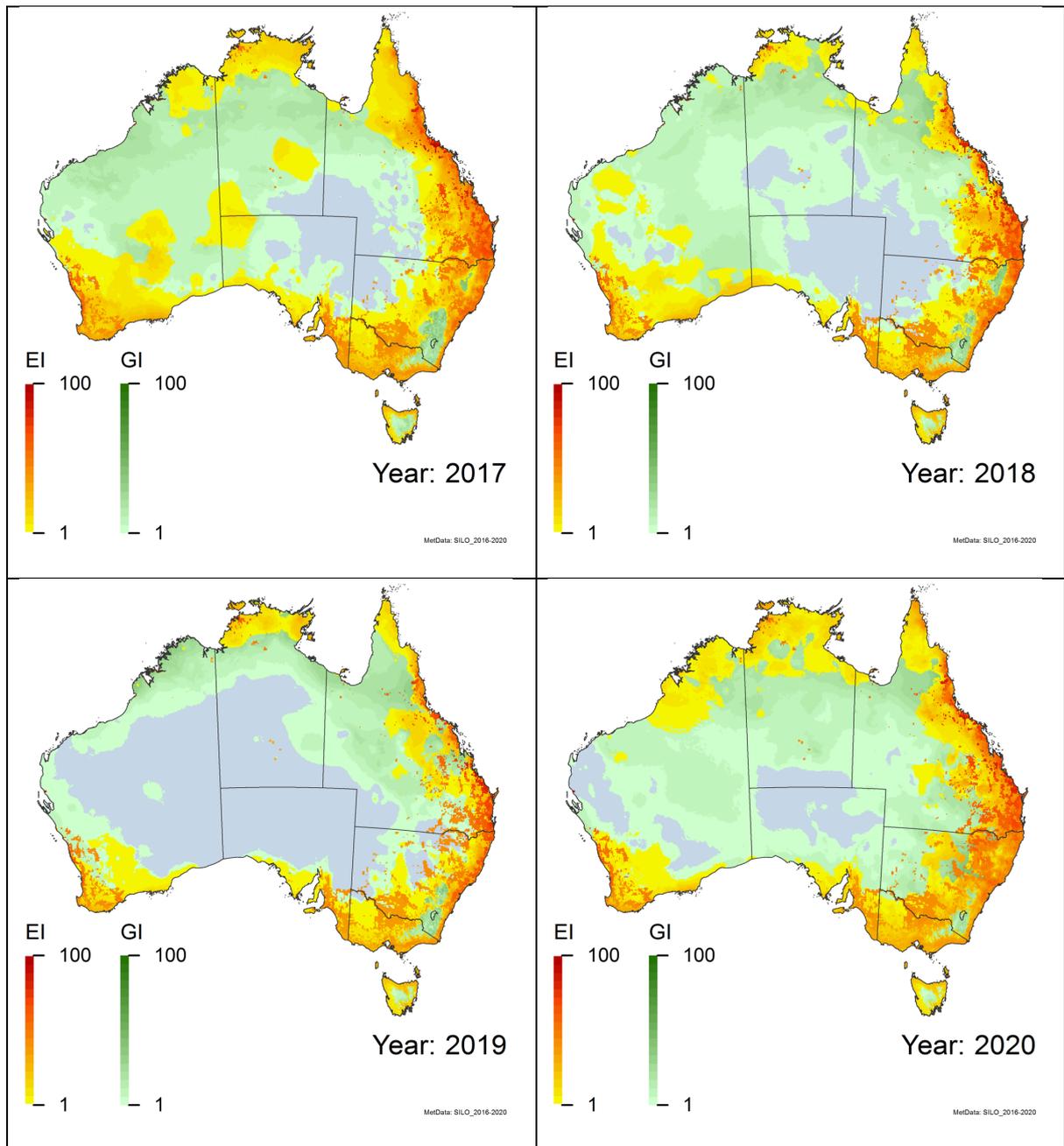


Figure 4 Modelled climate suitability for *Bactrocera dorsalis* establishment and growth from 2001 to 2020. Source climate data from SILO.

4 Discussion

The climate-related establishment hazard for *B. dorsalis* in Australia depicted in Fig 1 indicate a high level of threat to Australia's horticultural industries. The apparent hazard is exacerbated by irrigation schemes, especially in the eastern and southern states.

The recent reports of *B. dorsalis* in central and northern China prompted some studies to clarify the northern limits for overwintering populations in China. These studies resulted in

the cold stress parameters for the CLIMEX model of *B. dorsalis* being refined. In the Australian context, this resulted in a more southerly potential range in Australia compared with previous modelling (e.g. De Villiers et al 2016).

To understand the risks posed by *B. dorsalis* to Australian horticulture we would need to understand considerably more than the climate-related hazard posed by its potential to establish and grow. We would need to understand the likelihood of it arriving to Australia and escaping beyond the biosecurity border, and we would need to better understand the potential for it to spread to areas where suitable hosts are available. To characterise either the hazard or the risk we would also need to understand the horticultural assets that would be exposed to the spread of *B. dorsalis* and to be able to estimate a damage function based perhaps on the value of the crops and the number of generations *B. dorsalis* could complete in each location.

All of the international air and sea ports are near climatically suitable areas for the establishment of *B. dorsalis* (Fig 2). This highlights the importance of offshore phytosanitary measures, and effective border inspection and surveillance at ports and devanning sites for imports that could be contaminated with live *B. dorsalis*.

It is not straightforward to understand the Australian horticultural assets at risk from *B. dorsalis* should it become established. The growing areas for horticultural crops are not presently well characterised with geospatial data. In the past, the Agstats dataset was a useful dataset for understanding where agricultural (and horticultural and silvicultural) enterprises were conducted. Unfortunately, this dataset was discontinued. The National Agricultural Statistics Review led by the Australian Bureau of Statistics (ABS) and the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (<https://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/7105.0.55.004Main+Features12015?OpenDocument>) has resulted in a roadmap to improve agricultural statistics. In the meantime, there are some current horticultural initiatives to develop spatially accurate datasets of horticultural production areas for tree crops and protected cropping using a combination of earth observation data industry data, image analytics, ground validation and citizen science (e.g. <https://www.horticulture.com.au/hort-innovation/news-events/New-map-to-help-safeguard-nations-protected-cropping-industries/>).

The interannual variability in climate suitability for *B. dorsalis* is substantial, driven mostly by occasional weather systems driving rainfall into the arid interior of Australia (Fig 4). The limited natural dispersal ability of *B. dorsalis* means it would not be able to take advantage of these extensive but transient expansions of the climatically suitable habitat.

5 Acknowledgements

This project used an updated CLIMEX model for *B. dorsalis* generated in the FF-IPM project, an EU-funded project under the Horizon 2020 framework. Mr Noboru Ota, CSIRO, kindly assisted with preparation of the climate data and reformatting of results.

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Australian National Planning Workshop for Exotic Fruit Fly (EFF)
Macquarie University, 25 Wally's Walk, Macquarie Park, NSW 2109
(Room C120/121 combined, Arts Present-Building C, Macquarie University)

MONDAY, 21 NOVEMBER 2022 (IAEA workshop also attended by the Australian participant)

All Australian planning team members for preparedness of Exotic Fruit Fly will be attending the Third FAO/IAEA RESEARCH COORDINATION MEETING. This meeting will be hosted by the IAEA experts at Macquarie Uni on the Monday, 21st November 2022 (see agenda below)

SESSION I (CONT.) SIT and MAT integration: laboratory and field assessments (Chairperson: Christopher Weldon)

- 08:30 – 09:00 **Peter Prentis:** Transcriptome analysis of the effects of cuelure feeding on *Bactrocera tryoni* and their offspring.
- 09:00 – 09:30 **Phil Taylor:** To be provided
- 09:30 – 10:00 **Helene Delatte:** Biocological parameters including dispersal behaviours of *Bactrocera dorsalis* in Réunion Island

COFFEE BREAK

- 10:30 – 11:00 **Alvin Hee:** Developing non-methyl eugenol-responding male Oriental fruit flies supplemented with semiochemical exposure for improved SIT
- 11:00 – 11:30 **Suk Ling Wee:** Improvement of *Bactrocera dorsalis* management by semiochemicals for simultaneous application of SIT and MAT
- 11:30 – 12:00 **Lloyd Stringer:** Estimating the effect of reduced sensitivity of sterile-released Queensland fruit fly to cuelure and increased interval between sterile fly releases on wild population growth

LUNCH

SESSION I (CONT.) SIT and MAT integration: laboratory and field assessments (Chairperson: Phil Taylor)

- 13:00 – 13:30 **Christopher Weldon:** Simultaneous application of mat and sit for management of *Bactrocera dorsalis* in South Africa: environmental and physiological considerations
- 13:30 – 14:00 **Supaap Pinkaew:** Cost-effective treatments support the Male Annihilation Technique and the Sterile Insect Technique for the Establishment of a Fruit Fly Low Prevalence Area in Thailand
- 14:00 – 14:30 **Nicholas Manoukis:** Effective behavioural phenotyping of methyl eugenol response by Male *Bactrocera dorsalis*.
- 14:30 – 15:00 **Atsushi Honma:** The countermeasures against *Bactrocera dorsalis* complex re-invasion in Japan and the need for introduction SIT

COFFEE BREAK

15:30 – 16:00 **Todd Shelly:** Evaluation of a genetic sexing strain of the oriental fruit fly as a candidate for simultaneous application of male annihilation and sterile insect techniques

16:00 – 17:00 General discussion

TUESDAY, 22 NOVEMBER 2022 (Australian EFF preparedness planning workshop)

08:30am Welcome & Introduction

08:45am Background, Workshop Structure & Objectives

- Provide strategies for preparation of the Australian National Action Plan on Exotic Fruit Fly.
- Provide background preparation for the Oriental Fruit Fly Biosecurity Exercise

09:00am Presentations by invited international guest speakers

09:00 – 09:20 **Nausheen Patel:** *Bactrocera dorsalis* detection in Mauritius, previous eradication measures, ongoing surveillance / suppression programmes

09:20 – 09:40 **Sandeep Singh:** A 19-year experience on management of Oriental fruit fly in Punjab, India

09:40 – 10:00 **Nikos Papadopoulos:** *title yet to be provided*

10:00 – 10:20 **Rory MacLellan:** Case study on preparedness planning, monitoring & surveillance, and eradication activities of Queensland fruit fly incursion in New Zealand

10:20 – 10:35 quick COFFEE BREAK (international guests will leave room)

10:35 - 12:15 Australian Biosecurity planning team, break into allocated groups to discuss,

1. Strengths of current EFF management system
2. Weaknesses of current EFF management system

Feedback from each group with collation of outcomes

12:15 – 13:00 LUNCH BREAK

13:00 – 14:45 Brief summary of first session and intro to next 2 sessions (5mins) involving discussion on;

3. Opportunities to improve current EFF management system
4. Threats to achieving improvements to EFF management system

Report back from groups

14:45 – 15:15 Summary and next steps forward

15:15 CLOSE

EFF preparedness workshop - Invitee List

- The names in pink fonts are participants that were invited but unable to attend
- The yellow highlighted names are participants that participated remotely/ online
- The other are participants that present in-person at Macquarie meeting room

NAME	ORGANISATION	TITLE
International Guest Presenters		
Nausheen Patel	Ministry of Agro Industry & Food Security, Reduit, MAURITIUS	Scientific Officer (Entomology)
Dr Sandeep Singh	Punjab Agricultural University, INDIA	Senior Entomologist
Prof. Nikolaos Papadopoulos	Department of Agriculture Crop Production and Rural Environment, University of Thessaly, GREECE	Director of the Laboratory of Entomology and Agricultural Zoology
Rory MacLellan	Biosecurity New Zealand	Principal Advisor - Plant Health Biosecurity Surveillance Incursion & Investigation Team Diagnostic & Surveillance Services Directorate
Australian Organizational Participants		
Christopher Anderson	NSW DPI	
Bishwo Mainali	Macquarie Uni	
Polychronis Rempoulakis	NSW DPI	
Katarina Merkel	SA	
Susanna Driessen	PHA	
Jessica Arnold	PHA	National Manager Risk and Resilience
Tim Hurst	Ag Victoria	
David Cousins	WA	
Zarmeen Hassan, AUSVEG,	AusVeg	
Matt Calverley	Federal DAFF	
Guy Westmore	Tasmania	
Sally Heaton	NT	
Brian Thistleton	NT	
Dave Hubbard	SA	
Isarena Schneider	Federal DAFF	
Stefanie Oberprieler	Federal DAFF	
Melissa Starkie	QDAFF	
Brett Jackson	QDAFF	
Jo Lee	Federal DAFF	

Brendon Reading	Federal DAFF	
Naomi Wynn	PHA	
Jenny Shank	PHA	
Stuart Burgess	PHA	
Chris O'Conner	PHA	
Leonie Martin	NSW DPI	
Shannon Mulholland	NSW DPI	
Rachel Taylor-Hukins	NSW DPI	
Polychronis Rempoulakis	NSWDPI	
Solomon Balagawi	NSW DPI	
Alan Nakivell	NSW DPI (contractor)	
Michelle BeLisle	Dairy Australia (contractor)	
Nancy Cunningham	SA	
Australian Industry Participants		
Lessica Lye	Citrus Australia	
Jenny Treeby	Australian Table Grapes Association	

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SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

Biosecurity preparedness of Oriental Fruit Fly: Current Management Strategies and GAP analysis

Katharina Merkel, Nancy Cunningham, Peter Crisp and Jordyn Giddins

26/5/2024

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Abbreviations commonly used in this document

APPD – Australian Plant Pest Database

EPPO – European and Mediterranean Plant Protection Organization

EU – European Union

FAO – Food and Agriculture Organization of the United Nations

IAEA – International Atomic Energy Agency

IPM – integrated pest management

IPHM – integrated postharvest management

MRL – maximum residue limit

PHA – Plant Health Australia

NPPO – National Plant Protection Organization

WHO – World Health Organization

Executive Summary

This project was commissioned to indicate current strategies for control of Oriental Fruit Fly (*Bactrocera dorsalis*) which has already had one incursion into Australia in 1995 and eradicated in 1999 (then known as Asian papaya fruit fly *Bactrocera papaya*). In addition, the project aims to establish a pathway to preparedness should another incursion occur in Australia.

There are a number of reasons to have contingency planning for pest incursions, although the major drawback to developing these plans is the large number of pest species that would require risk analysis – and that their establishment would be considered a threat to Australian horticulture. Part of this had been the development of a list of insects that are grouped as High, Medium and Low risk. Oriental Fruit Fly is considered a high priority fruit fly pest species due to its potential economic impact from market access losses and the cost requirements for quarantine restrictions and eradication programs.

Oriental Fruit Fly is considered a high risk pest species due to several characteristics:

- i. Highly invasive; native to Asia it's now found in parts of America, Oceania, most of sub-Saharan Africa and more recently Europe
- ii. High reproductive potential; short life cycle with several generations per year and many offspring per female
- iii. Rapid dispersal ability; very mobile as well as assisted dispersal
- iv. Broad host range; potential to impact several industries in the horticultural sector

The challenge for Australian quarantine border protectorate has led to individual plans for states being developed depending on their required needs. Including dealing with incursions of pest fruit fly species as they arise.

The major inhibition to the development of contingency plans at a national level for pests of plants is the very large number of organisms that could become pests if they were able to establish in Australia. This was recognised by the Quarantine Review Committee (Lindsay Report 1988, p. 114) but it was recommended that the effort should be made. So far no national strategy exists specifically for Oriental Fruit Fly but there are a series of state-based strategies that could be combined to create a national standardized approach to OFF management.

Plant Health Australia maintains a target list of exotic insects through the plant pest surveillance virtual coordination centre. In addition, it provides an advanced tool – AUSPestCheck – to collect, analyse and display plant pest surveillance data (including exotic fruit flies).

The National Plant Biosecurity Status Report (PHA 2020) contains a list of national priority pests with exotic fruit fly (lure and non-lure responsive) number 4 on the priority list. The list allows decision makers to focus on particular biosecurity activities that will reduce risk to Australian Agriculture by allowing a national focus for standardisation for prevention and preparedness for pest incursions on the priority list.

Obtaining effective management and control of Oriental Fruit Fly requires knowledge of the most effective means of fruit fly management and or eradication. A successful management/eradication program can provide significant benefits to Australian horticultural industries through assured

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market access and increased value (fruit fly free status). This is important because commercial horticultural industries are more inclined to invest in maintaining programs that maximise ROI. However, to maximise the benefits to industry, the details of successful strategies, particularly for yet to be established pests, may not be widely available. This means that individual industries currently develop their own strategies to reduce pest impacts.

This study identified a few prerequisites that are consistent with successful fruit fly management programs. They are:

- Potential loss of markets due to fruit fly incursions
- Accurate and detailed grower/industry monitoring
- Universal uptake of treatment protocols
- (most effective methods for OFF control listed here)
- Widespread collation and reviews of the data collected from above sources
- Long-term collaboration between growers, researchers and industry bodies.

The above prerequisites require a high level of information gathering and coordination.

Examples of management protocol targets include:

The Australian horticultural industry is geographically climatically and culturally diverse (e.g., different IPM practices, geographic locations and management protocols). Surveys have confirmed that a large array of management protocols are used to control different fruit fly species. The best strategy to progress a standardized OFF program is for researchers to build alliances with industry across a wide body of horticultural commodities.

The following table rates major regions against the prerequisites required before commencing an Oriental fruit fly program. This may of course vary commodity by commodity and it may be required that a similar table be created for individual high return export commodities. Separate programs for these individual markets may be tailored to regions or drawn from commodity specific requirements.

Part of this preparedness literature review involves a GAP analysis.

Outcomes

- 1) To determine through GAP analysis priorities for research
- 2) Encourage an expanded uptake of a national/standardised OFF management program.
- 3) Encourage sharing and collation of data across states.

Uniformity of current OFF/fruit fly strategies.

The strategies for managing fruit flies across Australian jurisdictions show a level of uniformity, reflecting a well-coordinated national approach to biosecurity. This uniformity is driven by the need for consistent and effective measures to protect the country's agricultural industries from highly invasive pests. Although specific management plans for *B.dorsalis* are a focus for more high risk states and territories (Queensland, NSW and Northern Territory) the fly is high on Australia's invasive biosecurity list and other states have the framework to support potential future incursions with support through the National Fruit Fly Strategy (NFFS).

The National Fruit Fly Strategy 2020-2025 promotes coordinated actions and resource sharing among Australian jurisdictions, incorporating measures such as pheromone traps, biological controls, and public awareness campaigns for early detection and rapid response. Regular meetings and information exchange among state and federal agricultural departments ensure inter-jurisdictional collaboration, maintaining a unified approach to quarantine protocols, risk assessments, and eradication plans. This consistent strategic framework across Australia ensures a robust and effective national biosecurity system for managing potential incursions of *B. dorsalis*.

Data sharing

In 2024 the National Fruit Fly Strategy identified supporting the national system as one of its priorities. Data sharing amongst jurisdictions is paramount to an effective national strategy to combat invasive species such as *B.dorsalis*. The strategy emphasizes the importance of transparent and timely communication of surveillance data, research results, and emergency response activities across states and territories. This collaborative approach is managed through various platforms, committees and networks and ensures effective data exchange and collective decision making.

The Australian government Department of Agriculture, Fisheries and Forestry (DAFF) coordinates centralized databases to assist with this data exchange and dissemination across all jurisdictions. This includes the Australian Plant Pest Database (APPD) and the National Plant Biosecurity Surveillance System (NPBSS). These databases provide up-to-date data on pest detections, population trends, and control measures. However, GAP analysis identified that much of Australia's data held by states and territories was decentralized and could be improved upon through a cohesive national strategy framework of communication.

Regarding communication, regular inter-jurisdictional meetings and workshops facilitate the sharing of best practices, enhancing the overall effectiveness of any strategy. Through these mechanisms, Australia can maintain a unified and proactive stance against *B.dorsalis*, leveraging shared knowledge and resources to protect its horticultural industries and ecosystems.

GAP Analysis summary

Prior to recommendations for research, it is important to consider national strategic planning regarding financial and resource planning, a review of national surveillance systems and encourage knowledge sharing across jurisdictions – including diagnostic protocols, and general communication with the scientific community, agricultural industries and the general public.

Several other gaps were identified:

1. National stock take of facilities, physical resources, staff (including training) and diagnostic capabilities.
2. Refinement of business protocols to ensure industry has the tools to tackle incursions.
3. Unified communications strategy (Initial stages as part of this literature review and gap analysis)

Research can focus on:

1. Identify and examine new innovative technologies for OFF detection.
2. Examine registered chemical controls.
3. Further examination under Australian conditions of:
 - a. Sterile Insect Technology for OFF
 - b. Male suppression/ Male annihilation

Conclusion

This report identifies management protocols from overseas and within Australia, research gaps as well as identifying industry collaborators with the strongest prerequisites critical to gaining early success. The emphasis should be on providing support tools for the horticultural industries affected (technical data, preparedness documents and management protocols for incursion), but there must also be research into how OFF management protocols will assure continued market access for Australian growers.

Overall, Australian horticulture appears to be well placed to build on current exotic fruit fly management protocols.

Chapter 1 Introduction

Oriental Fruit Fly, *Bactrocera dorsalis* (Hendel) (Diptera: Tephritidae) is a polyphagous species native throughout the Asian region. However, it has now spread to over seventy-five countries including the Americas, Oceania and most of Africa (sub-Saharan). It has a short life span, broad host range and a high reproductive potential, making it one of the world's most invasive species of insects. In many of the countries following introduction, the Oriental Fruit Fly has quickly become the most dominant fruit fly species often displacing native species and causing large amounts of economic damage to a host of horticultural crops.

In Australia Oriental Fruit fly is a species of quarantine significance and even though there is no population currently existing in Australia, incursions from flies on imported goods are regular occurrences.

Australian horticulture generates considerable export tonnage to numerous countries with exports valued at around \$3 billion dollars a year (ABARES Agricultural Commodities: March quarter 2022 report; Rural Bank, 2024). To export produce, Australian horticultural industries need produce of excellent quality and free of pest and disease. This has been achievable partly because of Australia's strict quarantine protocols to prevent pest incursions. A breakdown in quarantine and the establishment of exotic fruit flies on the Australian mainland could potentially affect two thirds of this export value (Business Queensland, 2022). As a consequence of this significant economic impact, Australian agriculture maintains a national fruit fly management strategy in partnership with state and territory governments with links to affected horticultural industries. This ensures that fruit fly management remains vigilant, and that market access continues without interruption for Australian horticultural exports.

Current national strategies for fruit fly management favour:

- 1) Continued distribution mapping
- 2) Interstate quarantine restrictions for horticultural commodities
- 3) Maintenance of pest free area management activities
- 4) Domestic and offshore surveillance and trapping networks
- 5) Relevant research and development

Australia also maintains 'Pest Free Areas' (PFA) where fruit fly is not established and ongoing management strategies for pest fruit fly is employed by industries in that area. These PFA are recognised internationally and produce from those areas does not require extra phytosanitary treatments to be applied before exporting out of the country. PFAs are maintained by routine surveillance and rigorous diagnostics.

During fruit fly outbreaks, governments can provide a rapid response in line with national protocols in order to maintain fruit fly freedom and allow biosecurity to eradicate the fly. Currently there are early warning systems for several species of exotic fly and for Queensland fruit fly in states like SA and WA. There are also surveillance networks throughout the northern region of Australia.

The Australian government and its states and territories are committed to reduced reliance on agrichemicals for fruit fly control. Other strategies being refined or developed include Sterile Insect Technology and Male Annihilation Technology.

From an Australian perspective, changing market demands surrounding quarantine and the establishment of exotic fruit flies presents both a challenge and an opportunity. Unless this challenge is met, the horticultural industry will face problems exporting its produce in the future. However, if the goal of maintaining OFF fruit fly freedom can be achieved, the marketing advantages for the entire Australian supply chain will be significant.

1.1 Terms of Reference

The study had the following terms of reference:

- (i) To survey, document and assess existing fruit fly protocols across the Australian horticultural sector that was relevant to the development and implementation of a national OFF management plan.
- (ii) To research and document international usage and current OFF strategies used in horticultural commodities outside Australia.
- (iii) Review international standards set down by the IAEA (male lures, MAT and SIT procedures).
- (iv) To provide insight into potential challenges and opportunities likely to be faced in the development of a preparedness action plan.

1.2 Information Collection

Information contained in this report was obtained by the following methods:

(a) Primary Information Collection

Information was collected through examining state protocols for all states (and the Northern Territory)

(b) Secondary Information Collection

Personal communication state by state and international collaborators working in fruit fly management.

Chapter 2 Overview of Oriental Fruit Fly

2.1. Taxonomy

The current scientific name of Oriental fruit fly is *Bactrocera dorsalis* (Hendel, 1912) (Manrakhan, 2020). *B. dorsalis* is part of the Oriental fruit fly species complex, which forms a group within the subgenus *Bactrocera* (Manrakhan, 2020). Therefore, the name may be referred to as *Bactrocera (Bactrocera) dorsalis* (Manrakhan, 2020). Many synonyms of *B. dorsalis* have been identified, including *Bactrocera invadens* (Drew, Tsurutus & White), *Bactrocera papayae* (Drew & Hancock), *Bactrocera philippinensis* and *Dacus dorsalis* (Hendel, 1912) (Manrakhan, 2020). The taxonomic tree for Oriental fruit fly is as follows: Class: Insecta, Order: Diptera, Family: Tephritidae, Genus: *Bactrocera*, Species: *Bactrocera dorsalis* (Manrakhan, 2020).

2.2 Hosts

Many host species exist for *B. dorsalis*; Oriental fruit fly has been recorded on over 490 plant species in 81 families (*Oriental fruit fly*, 2021), with official host species lists only differing country to country. Hosts include both commercial and non-commercial plants. Oriental fruit fly infests both fruiting plants as well as fruit and vegetable produce (post-harvest) (*Oriental fruit fly*, 2021). An infestation in fruit can be identified by possible small discoloured (brown or black) or water-soaked patches on the fruit skin (necrosis) around the point of oviposition and/or decomposition of the fruit with the fruit dropping from the host plant prematurely (Manrakhan, 2020; *Oriental fruit fly*, 2021). During an outbreak in Queensland, Australia in the 1990's, *B. dorsalis* was found to breed in 35 host plants, resulting in damage to many different types of fruit including coffee berries and green papaya/pawpaw (*Oriental fruit fly*, 2021).

2.3 Geographic Distribution

The family Tephritidae has many identified species which are significant economic pests of agriculture. The Genus *Bactrocera* has a large presence in the pest complex of species (Drew and Romig, 2016; Doorenweerd et al., 2018). with *Bactrocera Dorsalis* an increasingly important economic pest. A 2018 review of the Global distribution and invasion pattern of oriental fruit fly showed that *Bactrocera Dorsalis* had increased from five countries in 2010 to 75 countries within Asia, Africa, North America, South America and Oceania (Zeng et al, 2018). Current distribution can be seen in figure 2.1

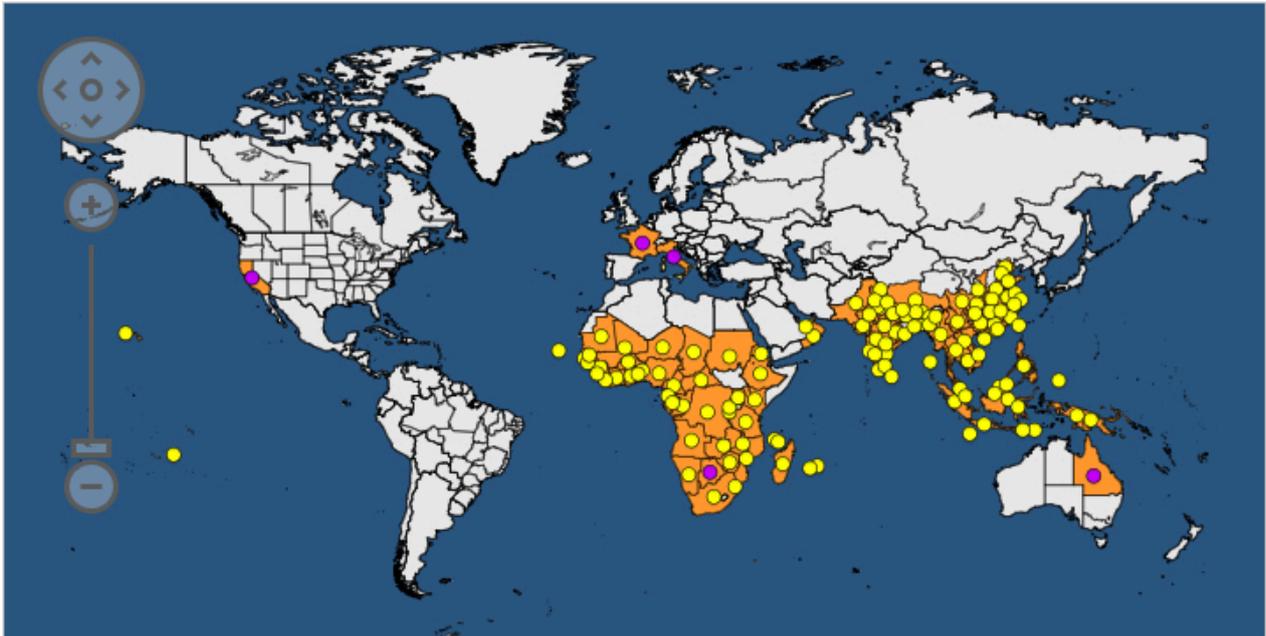


Figure 2.1: World distribution of *Bactrocera dorsalis*. (Also includes past records of synonyms *B. invadens*, *B. papayae* and *B. philippinensis* Source: EPPO Global Database) Also now includes transient *B. dorsalis* occurrences.

2.4 Invasion History

Pest fruit flies exist all over the world and are found on every continent except Antarctica.

B. dorsalis was originally considered to be from China (Aketarawong et al, 2007, 2014) and moved into to the rest of Asia along coastal routes. However, research into the complicated taxonomy of *B. dorsalis* by Qin et al. (2018) observed that the high levels of genetic diversity and gene flow observed between Asian populations of *B. dorsalis* have historically shadowed its potential region of origin. However, they identified South Asia (India + Bangladesh) as the likely centre of origin for the species. Because *B. dorsalis* has often been known by other names the suggestion is that the first likely record of oriental fruit fly was from “East India” (*India orientali*) under the synonymous name of *Musca ferruginea* by Fabricius in 1794 (Clarke et al, 2019).

Figure 2.2 shows the invasion history of *B. dorsalis* throughout the Asia-Pacific region.

The emergence of flies has been found to occur between 8:00-10:00 AM (Bess & Haramoto, 1961). The newly emerged flies are inactive for approximately one hour before becoming active and feeding (at 23-30°C) (Bess & Haramoto, 1961). At 25°C, the pre-oviposition period is 6.6 days (Vargas et al., 1984). Most eggs may be laid within the first 3 weeks following emergence (Bess & Haramoto, 1961), though females can produce eggs for 2 months (Bess & Haramoto, 1961; Vargas et al., 1984). Adult *B. dorsalis* can live for 2-3 months (Bess & Haramoto, 1961; Vargas et al., 1984).

At 25°C and in laboratory conditions, the net reproductive rate of Oriental fruit fly was found to be 418.5, while the generation time was 37.4 and the intrinsic rate of increase was 0.16 (Vargas et al., 1984). In the same setting, the stable age distribution was 31.6 %, 49.3 %, 15.3 % and 3.8 % for eggs, larvae, pupae and adults, respectively (Vargas et al., 1984).

The life stages of *B. dorsalis* are affected by environmental conditions. *B. dorsalis* may fail to complete a life stage or have lower vigour if development occurs in unsuitable environmental conditions or, in contrast, may complete a life stage quickly and have high fitness if development occurs in suitable environmental conditions. For example, *B. dorsalis* undergoing pupation can be affected by soil moisture. A study by Hou et al. (2006) found that adult flies emerged the earliest from their puparium at a soil moisture of 30 %, whereas emergence was slowest and survival rate dropped at 70 % soil moisture. No adults emerged at soil moistures 0 %, 80 %, 90 % and 100 %, and adult flies that emerged at 10 % and 20 % soil moisture levels declined in vigour. Therefore, it is likely that the development of *B. dorsalis* larvae and/or pupae are affected by too little water in the soil, while their survival is affected by too little or too much water in the soil (Hou et al., 2006). The relationship between soil moisture and larvae/pupae development and survival may help us determine where *B. dorsalis* populations will have a higher survival rate, and therefore greater impact on crop hosts, and vice versa.

In addition to soil moisture all life stages of *B. dorsalis* are affected by temperature. In general, the developmental time of *B. dorsalis* at each life stage decreases with increasing temperature and vice versa (Rwomushana et al., 2008; Vargas et al., 1996). This indicates that there is a direct relationship between developmental rates of immature stages and temperature (Vargas et al., 1996). For example, the total development time for Oriental fruit fly was found to be 75.74 days at 15°C, 31.5 days at 20°C, 21.19 days at 25°C and 17.76 days at 30°C (*B. invadens*) (Rwomushana et al., 2008). This indicates that *B. dorsalis* may have quicker developmental times in warmer areas compared to cooler areas.

However, Oriental fruit fly have development thresholds. The lower development threshold is 8.8°C for eggs, 9.4°C for larvae and 8.7°C for pupae (*B. invadens*) and is suspected that the upper development threshold is between 30-35°C, though the effects on development may depend on length of exposure (Rwomushana et al., 2008). This indicates that the development of *B. dorsalis* may be inhibited in areas with extreme cold and/or warm temperatures. Exposure to extreme temperatures may be mitigated by behavioural adaptations such as seeking shaded environments, resulting in temperature thresholds no longer being a limiting factor for establishment of *B. dorsalis* (Motswagole et al., 2019).

Rwomushana et al. (2008) and Fiaboe et al. (2021) reported that the optimal temperature for development was between 25-30°C and 20-30°C, respectively. Vargas et al. (1996) found that successful development occurs at 16-32°C where survival rates are high (>50 %); Fiaboe et al. (2021)

found similar results, where *B. dorsalis* successfully developed between 15-33°C. Therefore, areas which fall within the optimal temperature range for Oriental fruit fly would likely be subject to successful establishment and population growth of *B. dorsalis*. Additionally, *B. dorsalis* can survive for short periods of time at extreme temperatures, however high mortality rates are quickly reached. Ullah et al. (2022) found that it took three consecutive days of exposure to temperatures of 3°C and 38°C to reach 50 % mortality, and five consecutive days of exposure to the same temperatures to reach 100 % mortality.

Exposure to extreme temperatures for very short periods of time can both benefit and disadvantage *B. dorsalis* adults. One study found that mild heat stress (38°C for 2 hours) applied to pupae improved female adult cold tolerance (minimum critical thermal minima and chill coma recovery time), but impaired the longevity, critical thermal maximum and heat knockdown time of female and male adults (Mutamiswa et al., 2022). An increased cold tolerance in females following heat stress indicates that female adults may be more cold tolerant and therefore have a wider thermal activity window for behaviours such as flying, foraging and oviposition, and may have a survival advantage in winter over males (Mutamiswa et al., 2022). However, the decrease in heat tolerance following heat stress from *B. dorsalis* adults indicates maladaptive phenotypic plasticity (Mutamiswa et al., 2022) and therefore a narrow thermal niche (Pieterse et al., 2017). These studies indicate that Oriental fruit fly can survive in environments where extreme temperatures are reached for short periods of time, and which can have both negative and positive effects on the ability of *B. dorsalis* to survive and develop across temperatures.

Clearly, temperature and soil moisture (water availability) are important factors influencing the development, survival and distribution of *B. dorsalis*. A study by De Villiers et al. (2016) used CLIMEX to map dry stress and cold stress indices for *Bactrocera dorsalis* globally, as well as in Australia (Figure 2.3). Similarly, De Villiers et al. (2016) mapped the climate suitability globally and within Australia considering different irrigation scenarios (Figure 2.4). These figures indicate that there are areas within Australia where the development, survival and distribution of Oriental fruit fly may be inhibited by cold stress, dry stress and different irrigation scenarios, where the water provided by irrigation systems likely effect soil moisture and water availability. This indicates the areas in Australia which may be more vulnerable to Oriental fruit fly invasion and establishment, which may help guide detection and management efforts (Figure 2.3; Figure 2.4).

In addition to the above, recently, there have been studies done on how gut bacteria effects the foraging behaviour, development and survival of *B. dorsalis*, which in future may lead to bacteria-oriented control methods against Oriental fruit fly (Akami et al., 2019; Man Zhao, 2022).

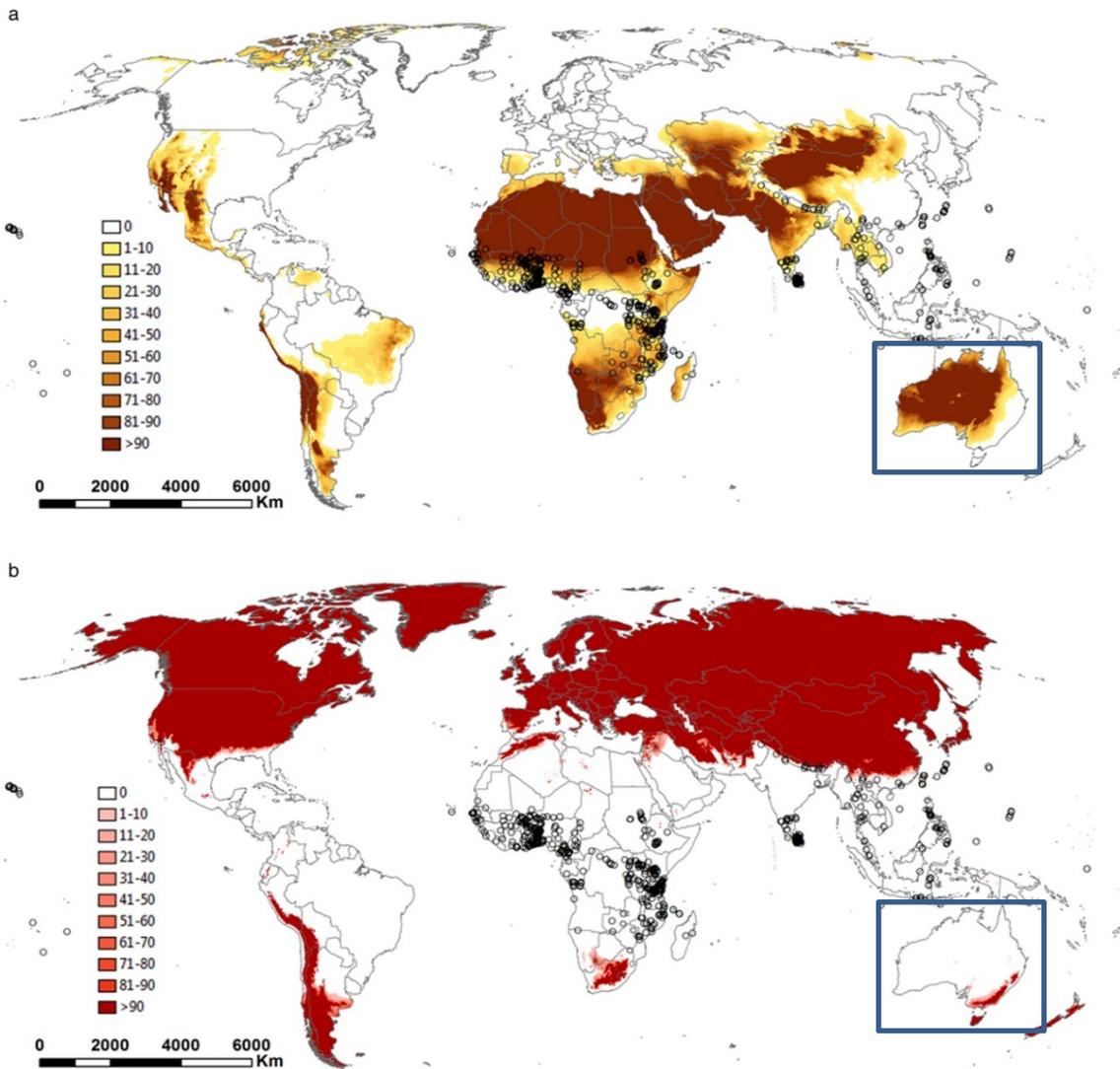


Figure 2.3. Annual (a) dry stress and (b) cold stress indices for *Bactrocera dorsalis* within Australia and globally. Image and description retrieved from De Villiers et al. (2016). Blue squares were added around Australia

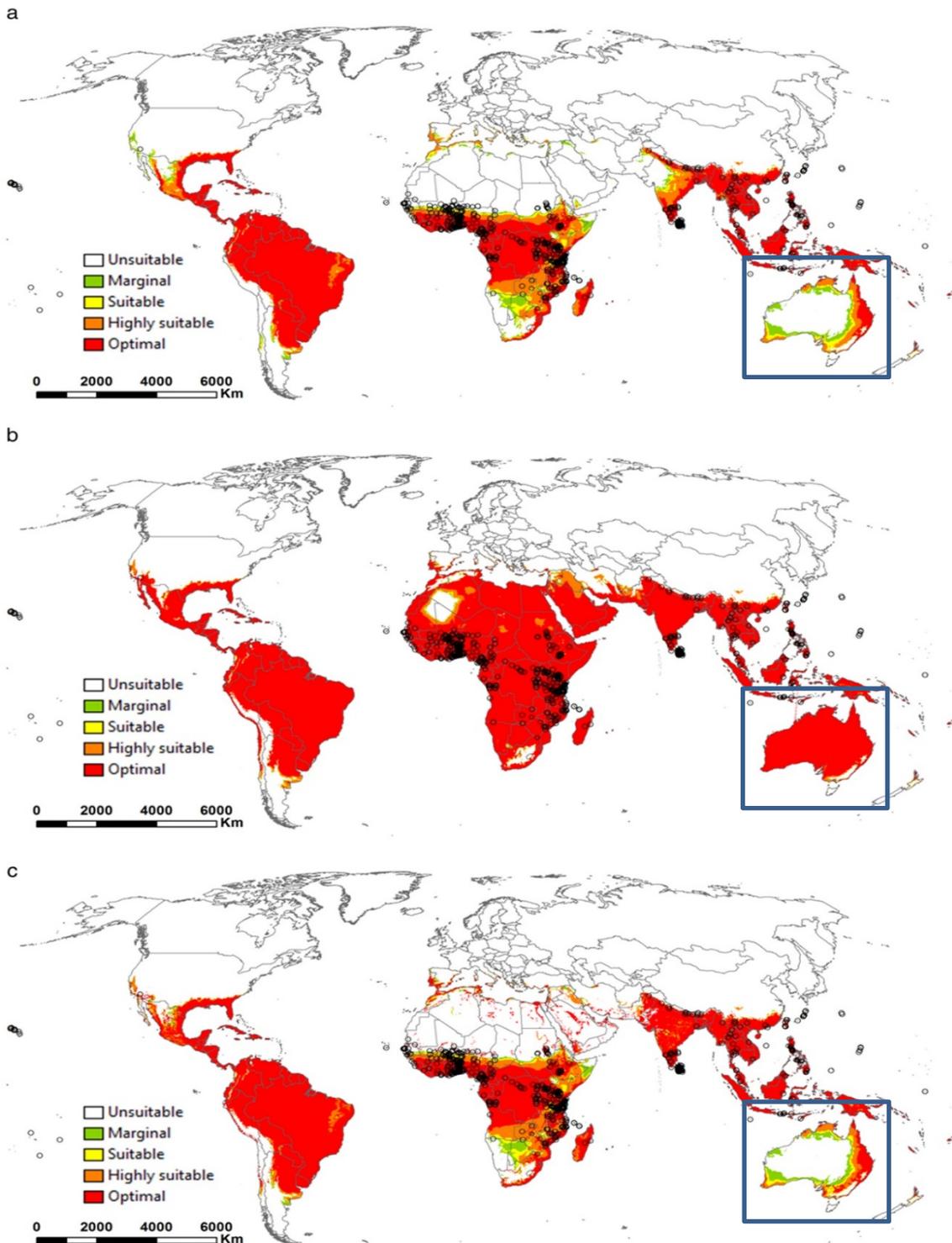


Figure 2.4. The projected climate suitability for *Bactrocera dorsalis* within Australia and globally, (a) without irrigation, image (b) with 2.5 mm top-up irrigation year-round, and (c) with a composite risk irrigation scenario (the ecoclimatic index (EI) of the natural rainfall scenario was mapped for areas without irrigation, and the EI an irrigation scenario was mapped for areas with irrigation). The CLIMEX EI was used. Unsuitable: EI = 0; marginal: EI = 1-4; suitable: EI = 5-9; highly suitable: EI = 10-29; optimal: EI = 30-100. Image and description retrieved from De Villiers et al. (2016). Blue squares were added around Australia.

Table 2.1. Detection and management strategies of *B. dorsalis* in Australia with regards to *B. dorsalis*' life cycle and demography.

Parameter	Detection	Management
Life cycle	Check fruit for the presence of adults, oviposition sites, eggs and larvae. Check soil for pupae	Apply appropriate management measures for each life stage e.g., traps and toxic bait applications to manage adult populations
Soil moisture – larvae and pupae	Monitor presence of larvae and/or pupae in soil that is ideal for their development	Drying or saturation of soil at base and surroundings of host plants to reduce populations
Temperature	Identify temperature ranges of each Australian state and assessing the ability of <i>B. dorsalis</i> to develop according to such temperatures (in conjunction with other influential factors). Monitor with trapping devices in areas which are optimal conditions for <i>B. dorsalis</i>	Prioritise population management strategies in areas in which <i>B. dorsalis</i> are most likely to successfully develop and establish, such as areas where the temperature is within <i>B. dorsalis</i> ' optimal temperature range

2.5.2 Habitat

B. dorsalis larvae prefer to pupate in moist soil with large particle sizes, and in shaded areas (Alyokhin et al., 2001). Pupation depth can depend on soil moisture and substrate type. Alyokhin et al. (2001) found that larvae pupated within the upper 4 cm of the soil (50.5 % clay, 31.6 % loam, 17.9 % sand), though no effect of moisture level was detected here. Similar results were found by Hou et al. (2006), however, pupation depth was dependent on soil moisture; when soil moisture (32 % sand, 40.7 % silt, 26.8 % clay) ranged from 0-70 %, pupation occurred at less than 4 cm of depth, but when soil moisture was above 80 %, 54.2-61.7 % of larvae pupated on the surface (Hou et al., 2006). Another study using very sandy alluvium found that most *B. dorsalis* larvae pupated within the first 0-0.55 cm of dry sand, and 0.55-1.1 cm of wet sand (Jackson et al., 1998); similarly, another study using sand (moisture levels not specified) found that larvae burrowed to a depth of 1-5 cm (Bess & Haramoto, 1961). Although pupation depth depends on soil moisture and substrate type, across these studies, *B. dorsalis* generally appears to pupate within the first 4-5 cm of the soil. *B. dorsalis* larvae have been found to pupate within 20 cm of the release point, however larvae may travel further from the point in which they drop from the fruit in field conditions (Alyokhin et al., 2001). It is likely that *B. dorsalis* larvae pupate in clumps to develop within suitable environmental conditions (Alyokhin et al., 2001).

Adult Oriental fruit fly are known to habit both crop areas and surrounds. In Hawaii some studies found that, although *B. dorsalis* was present in crop areas, fly numbers were higher outside of production areas where guava was present (Vargas et al., 1989, 1990). In addition, the number of Oriental fruit flies on farms increased during peak abundance of wild guava (Vargas et al., 1990). It is thought that the fruiting of guava surrounding farms provides a reservoir for *B. dorsalis*, and when overpopulation occurs, *B. dorsalis* moves into agricultural areas (Vargas et al., 1990). Oriental fruit fly can be found in non-host sites. For example, Oriental fruit fly was found in ironwood (*Casuarina equisetifolia* L.) forest, java plum (*Syzygium cumini*) forest (Vargas et al., 1989, 1990) and scrub (Vargas et al., 1989). Similarly, roosting hosts for Oriental fruit fly has been identified: cassava (*Manihot esculenta*) (McQuate, 2011), panax sp. (*Polyscias guilfoylei*) (McQuate & Vargas, 2007; Stark, 1995), tiger's claw (*Erythrina variegata* L.), castor bean (*Ricinus communis* L.), Canada cocklebur (*Xanthium strumarium* L.), Brazilian pepper tree (*Schinus terebinthifolius* Raddi), ti plant (*Cordyline terminalis* (L.) Chev.), guava and several *Citrus* spp. (McQuate & Vargas, 2007).

Table 2.2. Detection and management strategies of *B. dorsalis* in Australia with regards to *B. dorsalis* habitats at different life stages.

Parameter	Detection	Management
Soil habitat – larvae and pupae	Monitor presence/absence of pupae in the first 5 cm of soil below and near host plant canopies (shaded areas) through soil sampling techniques	Usage of soil with smaller particle size; applying insecticides in soil below host plant canopies (shaded areas)
Non-host plants/roosting hosts – adults	Trapping techniques to monitor the presence/absence of adults among non-host plants/roosting hosts surrounding agricultural areas	Plant attractive non-host plants/roosting hosts around agricultural areas to provide alternate habitat areas, which may draw adults away from crops. Bait can be applied to these plants to reduce adult populations without risking damage to produce

2.5.3 Host/Non-Host Attraction, Mating and Oviposition

Oriental fruit fly is most attracted to and more likely to infest ripe fruit. For example, in mango and guava, *B. dorsalis* females were found to be more attracted to the odours of soft, ripe fruit compared to other stages of ripeness (Cornelius, Duan, et al., 2000). Similar results were found in another study in mango, and oviposition attempts occurred more often in ripe mangoes compared to unripe mangoes (Rattanapun et al., 2009). Similarly, in papaya, *B. dorsalis* females were most attracted to spheres with the odour of ripe papayas compared to controls, and landed equally on the three different ripeness stages but spent the most time on and laid more eggs on spheres with the odour from the ripest stage (Jang & Light, 1991). In papaya and guava, infestation rates were found to increase with fruit ripeness, though unripe or partially ripe papaya and guava can still be infested by Oriental fruit fly (Devi & Jha, 2017; Liquido et al., 1989). These studies indicate a clear preference by *B. dorsalis* females to ripe fruit. Fruit ripeness can affect the survival and development of larvae. For example, larval survival was highest and larval development time was shorter in ripe mangoes (Rattanapun et al., 2009). Oriental fruit fly shows preference to oviposit at wounded sites on fruit. For example, in one study, all avocados that had an artificial cut on the skin (exposing the flesh) had evidence of infestation, whereas only 4.8 % of intact avocados were infested by *B. dorsalis* (Oi & Mau, 1989). Similar results were found in mangoes and peaches (Shelly, 1999). Therefore, ripe fruit are most at risk for infestation, particularly if there are wounds/openings on the ripe fruit.

Methyl eugenol (ME) is a highly attractive chemical to *B. dorsalis* males (Shelly et al., 2014) in both natural and pure forms. Methyl eugenol is a naturally derived chemical that can be found in 450 plant species (Tan & Nishida, 2012). *B. dorsalis* males are known to feed on plants containing ME. For example, studies found that Oriental fruit fly males were attracted to and fed on *Fagraea berteriana* and *Cassia fistula* flowers containing ME (Shelly, 2000, 2001a). A review by Shelly (2010) summarised the findings of studies that identified how ME is processed and used by *Bactrocera* species: a study found that immediately after ingestion of ME, the lure is converted into other phenylpropanoids (Hee & Tan, 2006). These are transported to the rectal gland (Hee & Tan, 2006), which is where pheromones are stored and produced (Kobayashi et al., 1978). ME metabolites have been detected in the volatile emissions, or “smoke”, in *Bactrocera* males (Kuba & Sokei, 1988), with one of the phenylpropanoids having been detected in the spray of *B. dorsalis* (Nishida et al., 1988). Males that feed on ME or flowers containing ME have a sexual competitive advantage compared to males that do not feed on ME (Shelly, 2000, 2001a, 2001b), at different spatial scales (Shelly, 2001a); males that fed on ME attracted females from as far as 12 m away (Shelly, 2001a). Attraction to ME by *B. dorsalis* males is age dependent, where male fly response to ME increases with age (Shelly et al., 2014). There is conflicting data on the responsiveness to ME in immature male flies, however (Shelly et al., 2014). Because of its potency to tephritid species, methyl eugenol is commonly used for the detection and surveillance of invasive species, quarantine surveys and delimitation, suppression and eradication, and ecological studies such as dispersal, population dynamics, phenology, adult survivorship and faunal surveys (see references in Shelly et al., 2014, page 38-39). Zingerone has also been found to attract Oriental fruit fly. *B. dorsalis* was found to be attracted to the flower *Bulbophyllum baileyi*, which contains zingerone (Tan & Nishida, 2007). However, zingerone is a weak attractant compared to ME with *B. dorsalis* (Tan & Nishida, 2007). The attraction to protein odours has been assessed against fruit odours. Two studies found that *B. dorsalis* females were attracted to both protein and fruit odours; however, the level of attraction to the odours often depended on several physiological factors (Cornelius, Nergel, et al., 2000; Roh et al., 2021). These

studies indicate that *B. dorsalis* females are attracted not only to fruit odours, but protein odours as well. Oriental fruit fly has been found to be attracted to non-host plants via semiochemicals. For example, mated female Oriental fruit fly was found to be attracted to fresh mature whole panax (*Polyscias guilfoylei*) leaves, due to the volatile compounds present (Jang et al., 1997); attraction to panax leaves by males and virgin females was low, however (Jang et al., 1997).

Visual cues are used by fruit fly for finding host fruits. Visual attraction to an object depends on various factors, such as colour and level of UV reflectivity. For example, one study found that Oriental fruit fly captures were higher on yellow and white spheres compared to orange, red, light green, dark green, blue and black spheres that were hung in guava (*Psidium guajava* L.) trees (Vargas et al., 1991). It is suggested that, in the case of the colour yellow, yellow may be an important cue for Oriental fruit fly to find ripe guava (Vargas et al., 1991). The high proportion of females on yellow spheres suggests that they were alighted for oviposition as the reflectance is similar to that of ripe yellow guavas (Vargas et al., 1991). Similar results were found with male Oriental fruit fly with coloured traps baited with methyl eugenol and placed on stakes between guava trees (males were most attracted to white and yellow traps), however when placed in guava trees and hidden by foliage, there was no significant difference between different colours (Stark & Vargas, 1992). A different study found that Oriental fruit fly was most attracted to green, followed by yellow and then orange coloured paper (Wu et al., 2007). UV reflection was found to enhance attractiveness (Wu et al., 2007). The study concluded that traps with sufficient UV reflection within 300-380 nm and 500-570 nm (green stimuli) is most effective in attracting *B. dorsalis* (Wu et al., 2007). Although results are not entirely consistent between studies, it is apparent that *B. dorsalis* is attracted to some colours over others, i.e., yellow has consistently been found to be highly attractive to *B. dorsalis*, and UV reflectance can enhance attractiveness. Combining visually attractive traps with methyl eugenol or similar would be an effective monitoring and management method.

Table 2.3. Detection and management strategies of *B. dorsalis* in Australia with regards to *B. dorsalis* host/non-host attraction, mating and oviposition.

Parameter	Detection	Management
Fruit ripeness	Monitor the presence of oviposition wounds or larvae in ripe fruit	Remove infested fruit and place traps near fruit trees
Methyl eugenol and other attractive chemicals	Place methyl eugenol traps or other attractive chemicals in and near orchards to monitor the presence of flies	Place methyl eugenol traps or other attractive chemicals in and near orchards to reduce population levels
Visual attractants	Use visual attractants in combination with chemical attractants in and near orchards to monitor the presence of flies	Use visual attractants in combination with chemical attractants in and near orchards to reduce population levels

2.5.3 Phenology and Population Dynamics

There is evidence that Oriental fruit fly does not have continuous activity through the year. A review by Clarke et al. (2022) summarised phenology data across multiple studies conducted in the northern hemisphere in different regions (references therein). On average, there were zero or a very low number of catches from December to March, a rapid population increase between March to May/June, and a gradual population decline towards December (Figure 2.5) (Clarke et al., 2022). Clarke et al. (2022) identified three consistent patterns across the nine sites: 1) there is one peak per year across most sites, with two peaks being a rare occurrence, 2) there is a 4-to-5-month period where adult flies are rare or absent from traps, and 3) population peaks for individual sites are not normalised around the warmest months of the year. This pattern would be reversed in the southern hemisphere with populations peaking in January/February (De Villiers et al., 2016; Theron et al., 2017). These studies indicate that Oriental fruit fly activity levels peak and dip throughout the year. Similar patterns can be found in the tropics. Clarke et al. (2022) summarised the following findings from studies conducted in Hawaii. In Hawaii, adult abundance, as well as fruit infestation, was found to be seasonal (Bess & Haramoto, 1961). The highest rates of infestation were recorded between April and September, and the lowest rates of infestation were recorded between November and March, despite fruit hosts being available for breeding year-round (Bess & Haramoto, 1961). Similarly, 'summer' infestation of guava was found to be 80 times greater than 'winter' infestation (Haramoto & Bess, 1970). Additionally, the small number of adults present early in the season were found to lay 30 times more eggs than the larger number of adults present later in the season, i.e., the peaks of *B. dorsalis* adults and oviposition did not align (Newell & Haramoto, 1968). As indicated by Clarke et al. (2022), this apparent seasonality of *B. dorsalis* in Hawaii cannot be explained by cooler winter months because the temperature in Hawaii across all seasons are within *B. dorsalis*' optimal range for development, survival and fecundity (Choi et al., 2020; Fiaboe et al., 2021; Samayoa et al., 2018) and temperatures vary minimally between winter and summer (Clarke et al., 2022). Clarke et al. (2022) indicated that in Hawaii, *B. dorsalis* may seasonally change their physiological investment between longevity and reproduction which has continued despite the consistent availability of hosts available in human-modified landscapes (Vargas et al., 1990). Clarke et al. (2022) mentions to note that seasonality is not apparent in *B. dorsalis*' phenology at or very close to the equator (Clarke et al., 2022; De Villiers et al., 2016). In their review, with support from data from references within, Clarke et al. (2022) argues that population changes in Oriental fruit fly is best correlated with developing crops rather than mature crops.

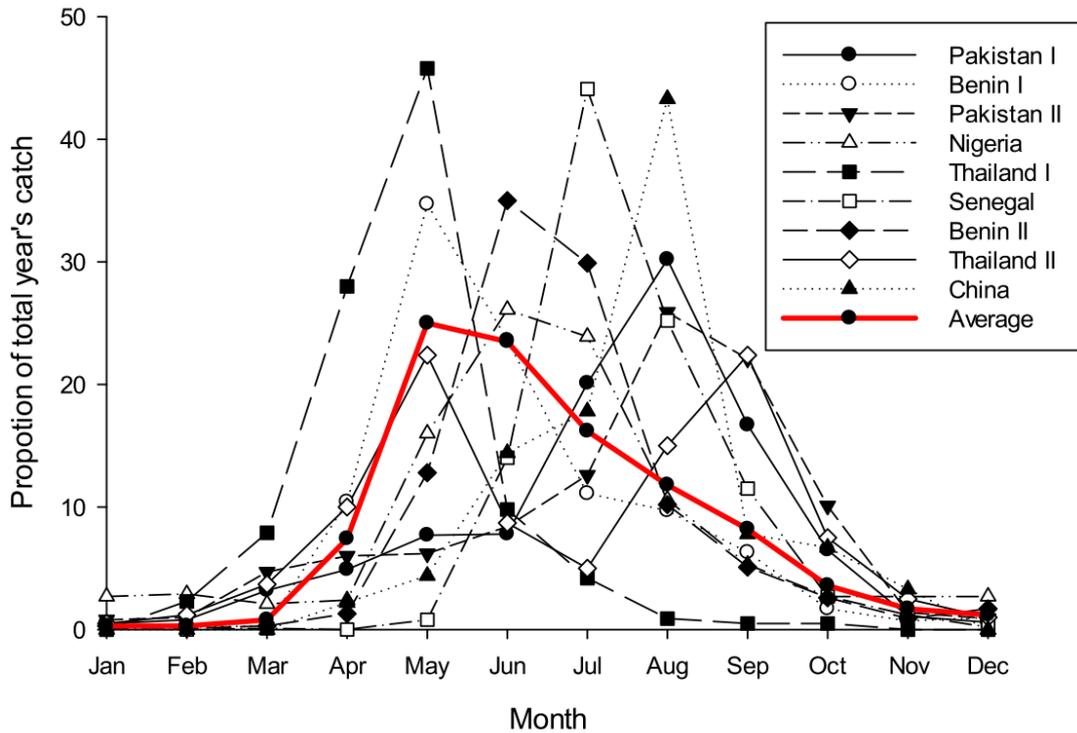


Figure 2.5. Yearly phenology curves for *Bactrocera dorsalis* across nine sites from various studies done in the northern hemisphere, with an average plot of the nine sites. Image and description retrieved from Clarke et al. (2022).

The population dynamics of Oriental fruit fly has been correlated with several weather conditions and climate. In the Yunnan Province in China, studies found that there was a significant positive correlation between monthly fly captures and monthly mean temperature (Chen et al., 2006; Ye & Liu, 2007), monthly mean maximum temperature and monthly rainfall amount (Ye & Liu, 2007); Chen et al. (2006) found a significant negative correlation with monthly mean maximum temperature which contrasts with Ye and Liu (2007). A significant negative correlation between monthly fly captures and monthly mean minimum temperature was also found (Chen et al., 2006). Overall, these studies indicate that Oriental fruit fly population dynamics are highly correlated with several weather and climate factors, particularly temperature and rainfall. There is some evidence of overwintering in Oriental fruit fly studied in Wuhan (climate previously described). In this study by Han et al. (2011) researchers collected fallen oranges infested with Oriental fruit fly and were reared in the laboratory. Larvae, pupae and adults that were recovered were used in an overwintering experiment in a citrus orchard. Han et al. (2011) found that adults and larvae did not survive the cold winter (100% mortality), however some pupae survived. Survival depended on date the pupae were placed in the soil and the depth in which they were placed (Han et al., 2011). The small portion of pupae which survive through winter may bridge the gap between winter and spring, leading to a small population of adult flies being present early in the season (Han et al., 2011). Host shift patterns were also found. For example, in Wuhan, the host shift pattern was as follows: pear (*Pyrus communis* L.), jujube (*Zizyphus jujuba* L.), persimmon (*Diospyros kaki* L.) and sweet orange (*Citrus unshiu* Marcov) (Han et al., 2011). This indicates that *B. dorsalis* can shift hosts within and across seasons.

Table 2.4. Detection and management strategies of *B. dorsalis* in Australia with regards to *B. dorsalis* population dynamics and phenology.

Parameter	Detection	Management
Seasonality	Identify peak periods in each Australian state. Monitor populations using traps leading to and during peak periods	Use traps/toxic bait in crops and surrounding areas leading to and during peak periods
Populations correlated with developing crops	Place trapping devices in crops with immature fruit to monitor fly populations	Use traps/toxic bait in crops and surrounding areas prior to fruiting/during immature fruiting
Weather/climatic factors correlated with population levels	Identify population dynamic patterns with weather/climatic conditions in each state by using traps year-round	Use traps/toxic bait in crops and surrounding areas leading to and during peak periods
Overwintering	Assess overwintering capability in each Australian state. Use traps to monitor populations through colder seasons	Apply toxicants or other population suppression methods to soil during colder seasons. If larvae and adults present throughout colder seasons, use traps/toxic bait in crops and surrounding areas
Host shift	Identify hosts used by <i>B. dorsalis</i> and the possibility for host shifts throughout the seasons	Concentrate applications of traps/toxic baits in all host crops prior to fruiting throughout the year to minimise risk of host shifts

Chapter 3 Overseas Management of Oriental Fruit Fly

3.1 International Standards (IAEA)

Several coordinated research projects to assess the application of Sterile Insect Technology for *Bactrocera* fruit fly management are being run through the IAEA.

- Simultaneous Application of SIT and MAT to Enhance Pest *Bactrocera* Management D41027
- Irradiated Fruit Flies: the Secret to Protecting Thailand's Premium Fruit Exports
- Isolation of Gene Markers Leads to More Effective, Efficient Insect Pest Control
- Update of the technical leaflet released in six languages on the discrimination between two invasive *Bactrocera* fruit fly pests
- Identification of the Male Determining Factor Reduces the Cost of SIT Application Against Insect Pests

In addition to this the IAEA provide:

- Trapping guidelines for area-wide fruit fly programmes
- Fruit Sampling Guidelines for Area-Wide Fruit Fly Programmes
- Guideline for packing, shipping, holding and release of sterile flies in area-wide fruit fly control programmes
- Guidelines for the use of mathematics in operational area-wide integrated pest management programmes using the sterile insect technique with a special focus on Tephritid fruit flies

3.2 Regions

Gutierrez et al (2021), established the likelihood of incursions of tropical fruit flies into areas that may be affected by several factors including overharvesting, mismanagement or climate change. Several regions already engage in control of several species of fruit flies especially in areas with more favourable climate conditions (tropical preferred over temperate regions). How Oriental fruit fly is managed in these regions is dependent on a number of factors, including environment, established programs, resources, affected industries and IAEA support.

3.2.1 Asia

Bactrocera dorsalis is endemic to much of tropical Asia. Countries with established infestations include (CABI 2020; Vargas et al. 2007): Bangladesh, Bhutan, Cambodia, China (southern), Hong Kong, India, Indonesia, Japan (Ryukyu Islands), Laos, Malaysia, Myanmar, Nepal, Ogasawara Islands, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam.

Management has often been in collaboration with IAEA and has resulted in implementing an area-wide integrated fruit fly management programme in many of the affected countries. This includes preharvest orchard management, baiting, trapping, sterile insect technique (SIT) components, Male Annihilation and general surveillance. Table 3.1 illustrates current methods employed by the countries listed above.

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Table 3.1: Current control methods used by Asian countries against *B.dorsalis*.

COUNTRY	EARLY DETECTION	WIDE RESPONSE PLANS	GROWER MANAGED PROTOCOLS	REGULATORY CONTROL	CULTURAL CONTROL	CHEMICAL CONTROL	STERILE INSECT TECHNIQUE)	MALE SUPPRESSION	FIELD MONITORING	EARLY WARNING (PATHWAYS FROM OTHER COUNTRIES)
BANGLADESH	Endemic	x	✓	x	Bagging	✓	x	x	✓	✓
BHUTAN	Endemic	x	✓	x	Baiting hygiene	✓	x	x	✓	x
CAMBODIA	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
CHINA	Endemic	✓	✓	✓	Bagging orchard hygiene	✓	✓	✓	✓	✓
HONG KONG	Endemic	x	✓	x	Bagging orchard hygiene	✓	x	x	✓	x
INDIA	Endemic	✓	✓	✓	Bagging orchard hygiene	✓	x	✓	✓	x
INDONESIA	Endemic	x	✓	x	Orchard hygiene	✓	✓	✓	✓	x
JAPAN (ISLANDS)	Invasive	✓	✓	✓	Orchard hygiene	✓	✓	✓	✓	✓
LAOS	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
MALAYSIA	Endemic	x	✓	x	Bagging orchard hygiene	✓	x	x	✓	x
MYNAMAR	Endemic	x	✓	x	Bagging orchard hygiene	✓	x (part)	x	✓	x
NEPAL	Endemic	x	✓	✓	Bagging orchard hygiene	✓	x	x	✓	x
PAKISTAN	Endemic	x	✓	✓	Orchard hygiene	✓	x	x	✓	✓
PHILIPPINES	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
SRI LANKA	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
TAIWAN	Endemic	✓	✓	x	Orchard hygiene	✓	✓	✓	✓	✓
THAILAND	Endemic	✓	✓	x	Orchard hygiene	✓	✓	x	✓	x
VIETNAM	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	✓

3.2.2 Africa

B. dorsalis is not endemic to Africa. However, more than forty-five countries of sub-Saharan Africa have become infested since the first appearance of oriental fruit fly (as *Bactrocera invadens*) in Kenya in 2003 (see Goergen et al. 2011). The fly's appearance in Africa is suspected to have occurred around the same time it also occurred in Sri Lanka (Mutamiswa et al 2021). The presence of this invasive pest fruit fly has added to the list of pest and disease that hamper the potential growth of African horticulture. Bans on fruit and vegetable export have added to many African countries' financial losses.

The response by many African nations was initially through monitoring and surveillance programs. However, longer term management was needed after this initial emergency response. Research and integrated pest management plans were developed to ensure continued fruit production and marketing. The World Bank funded research into *B.dorsalis* management (World Bank, 2007) including area wide management and early warning pathway surveillance in order to improve quarantine both nationally and internationally. Research into management protocols has developed in a number of countries within the continent. South Africa is considered one of the worlds top twenty fruit producing countries and work on *B. dorsalis* by South African researchers, Manrakhan et al (2012, 2013, 2017, 2018), has focused on providing practical tools for growers in different regions. Attempts at eradication using bait sprays and MAT have been successful in South Africa (Manrakhan, 2011) in some regional areas but risks of reinfestation remains high.

In addition to individual country management protocols, the IAEA has encouraged cross country collaboration in order to maintain markets for valuable crops and ensure that exported fruits and vegetables fall within importing counties phytosanitary requirements.

Management protocols employed across the African continent are summarised in Table 3.2.

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Table 3.2: Summary of management protocols used across Africa against *B.dorsalis*.

EARLY DETECTION	Monitoring and surveillance occurs in some African countries/areas where <i>B.dorsalis</i> is absent (Manarakhan et al, 2015) however a widespread monitoring system as part of an extended management plan including areas where the fly is present <u>and</u> absent in some geographic areas has yet to be developed (Mutamiswa, 2021).
WIDE RESPONSE PLANS	Surveillance, monitoring and development of buffering zones has occurred in parts of Africa (Manrakhan, 2015). Different countries utilize different strategies with some countries particularly in sub-Saharan Africa preferring certain control methods (chemical, cultural or biological control) over widespread response plans.
GROWER MANAGED PROTOCOLS	The majority of fruit growing farmers initiate some form of grower management for fruit fly (and other pests). Some areas within African countries maintain pest free areas of production for production and exportation of fruits to Europe under EPPO guidelines.
REGULATORY CONTROL	Under export conditions exporting African countries are required to follow guidelines of the EPPO and destination importing country regulations (EPPO 2018, 2019).
CULTURAL CONTROL	Orchard hygiene acts as a phytosanitary measure and can suppress populations of <i>B. dorsalis</i> with studies suggesting that populations can be high in fallen fruits such as Mangoes (Rwomushana et al 2008). Bagging remains a popular control of a variety of invasive pests like <i>B.dorsalis</i> .
CHEMICAL CONTROL	Both insecticides are widely used to suppress <i>B. dorsalis</i> with an increase over the past decade (Akotsen-Mensah, 2017). Biopesticides/natural substance use has also increased against fruit flies (Ekesi et al., 2007; Piñero et al., 2009) and is an attractive option for subsistence farming.
STERILE INSECT TECHNIQUE	SIT has not been developed as an area wide management tool for <i>B.dorsalis</i> as yet by any African countries. However, facilities exist for rearing and eradication of other exotic fruit fly species.
MALE SUPPRESSION	MAT has been pivotal in eradication for some South African regions and was successful in Mauritius (Sookar et al., 2014). Ghana and Cameroon have successfully used MAT for managing (but not eradicating) <i>B.dorsalis</i> (Kwasi, 2008; Hanna et al., 2008).

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FIELD MONITORING	Pheromone traps with male lures are used across Africa (Karsten et al., 2018). Many of these traps use methyl eugenol to which <i>B.dorsalis</i> is highly attracted (Manrakhan et al., 2014).
INTEGRATED PEST MANAGEMENT	Integrated Pest Management techniques are widely encouraged throughout the regions but is limited with smaller farming enterprises (Muriithi et al., 2020). IPM programs have been used against <i>B. dorsalis</i> in Tanzania and West Africa (Vayssières et al., 2015).
POSTHARVEST PHYTOSANITARY MEASURES	Heat and cold treatments remain the most used postharvest treatments. Postharvest hot water dipping is used in green mangoes in Mozambique (Dohino et al., 2016) and further research (Ndlela et al., 2017) endorsed this as a control for <i>B.dorsalis</i> . Cold treatments are standard export treatments for a wide variety of commodities to export destinations and have been part of ongoing bilateral agreements between African nations and export destinations.
EARLY WARNING (PATHWAYS FROM OTHER COUNTRIES)	South Africa developed an early warning system and contingency plans to ensure early detection and rapid response to reduce and eradicate populations of <i>B.dorsalis</i> (Ndivhuho et al, 2021). The main benefit to Ndivhuho's study was the identification that an ongoing systems approach through area wide management was needed in order to prevent further incursions

3.2.3 North America

3.2.3.1 Mainland USA

Florida and California

In several regions of the United States, USDA APHIS PPQ and state cooperators engage in year-round or seasonal detection trapping for exotic fruit flies. If an infestation is detected in the State, the California Department of Food and Agriculture conducts eradication projects to prevent environmental and economic damage that would be caused by Oriental fruit fly (CDFA, 2018). Male attractant technique is used for eradication, where bait stations with methyl eugenol are placed around chosen sites (utility poles and street trees) (CDFA, 2018).

Florida has a long history of invasive fruit fly detections with four programs prior to 2016 focussing on *B.dorsalis*. One of those detections triggered an emergency response as it occurred within one of southern Florida’s main agricultural areas. Guidelines and triggers for response to *B.dorsalis* across mainland USA can be seen in Table 3.3 with recommendations that regional fruit fly action plans for species- and region-specific operational requirements should be consulted before action is taken.

Table 3.3 USDA Cooperative Fruit Fly Emergency Response Triggers & Guidelines*

	Emergency Response Triggers			
	Delimitation	Duration of Delimitation (# generations for single fly detections)	Eradication	Quarantine
<i>Bactrocera dorsalis</i> (Oriental FF) Other <i>Bactrocera</i> species responding to methyl eugenol (ME): <i>B. zonata</i> (Peach FF), <i>B. correcta</i> (Guava FF), etc	1 fly	F2	2 flies within a 3 mile (4.8 km) radius during 1 life cycle	If ALL finds are >4.5 miles (7.2 km) from commercial host production area: 8 flies (either sex) within a 3mile (4.8 km) radius during 1 life cycle.
				If any find is <4.5 miles (7.2 km) from commercial host production area: 6 flies within a 3-mile (4.8 km) radius during 1 life cycle.

*APHIS response USDA (2020).

Patterns for response to invasive fruit flies within the mainland USA involves:

- Fruit Fly Detection Trapping
 - Monitored year round
 - High risk areas ports of entry
 - Core and buffer areas
 - Delimitation surveys
- Eradication Measures
 - ME feeding lure and bait spray (MAT)
 - Soil drenches
 - Foliar bait sprays
 - Orchard sanitation
 - Ariel bait sprays
- Regulatory Measures
 - Monitoring of host plants
 - Grower monitoring for phytosanitary treatments

3.2.3.2 Hawaii

B.dorsalis is an established invasive species in Hawaii. There is existing general information for farmers about how they can control fruit fly, including Oriental fruit fly, on their farms—see full list below. This information may be implemented to help manage Oriental fruit fly populations which differs in its response to mainland USA. Suggested management methods include: exclosure, sanitation, monitoring population levels, identifying host plants and fruit fly life cycles, rotate crops, harvesting fruits when under-ripe, and placing traps and other similar control methods (Messing, 1999). SIT is often employed in conjunction with other means of eradication.

Key steps in managing fruit flies in Hawaii (Messing, 1999)

- Prevention—practice sanitation techniques.
- Monitor the levels of pests; determine if you have economic injury; evaluate and use the best strategies.
- Identify the fruit fly species and become familiar with its life cycle and host plants.
- Determine which other plants in the area are fruit fly hosts, and determine when these plants are fruiting.
- If possible, rotate your crops so they do not fruit when other hosts are fruiting and pest populations are peaking.
- Harvest fruits under-ripe when possible (e.g., papayas are usually fruit fly-free if picked when less than 1/4 ripe).
- If fruit flies cause economic injury, apply appropriate controls.
- Divert pests with poisoned border plants, baits, or lures.
- Monitor pests again and reevaluate your strategies

The control of *B.dorsalis* in Hawaii had relied heavily on chemical control. However this approach is changing to incorporate a more systems approach through area wide management through research and extension (Mau et al 2007; Vargas et al, 2016)

3.2.4 Central and South America

Throughout central and south America invasive fruit fly species have taken their toll on the regions fruit and vegetable industry. Mediterranean fruit fly in particular has been an issue and through the IAEA a three year project was launched to assess the pest status of invasive fruit fly and encourage the use of SIT along with other control methods. The project succeeded in making five areas either fruit fly free or 'low prevalence'. *B. dorsalis* is not currently invasive in the region.

3.2.4.1 Central America

The United States of America has had an ongoing concern about the potential of certain species of tropical fruit flies to invade US agriculture. A result of this is that the USDA has run fruit fly emergence and release facilities within several central American countries. This cooperative agreement for the prevention, detection, suppression and eradication of economically important fruit flies has been an important strategy for mitigating incursions into mainland USA and to provide participating countries technical assistance to conduct fruit fly programs. This includes Mexico, Guatemala and Belize as well as countries within the Caribbean region.

The targeted species for these programs is focussed on Mediterranean fruit fly and the Mexican fruit fly (*Anastrepha ludens* Loew) but recent out breaks of oriental fruit fly into the USA (Florida and California) have necessitated renewed interest in management strategies for regions outside the USA. However, updates to action plans for oriental fruit fly from these regions have not been made since 1989 (USDA, 1989).

3.2.4.2 South America

Brazil: a case study country

Fruit flies are the major cause of fruit drop and currently Brazil employs SIT against Mediterranean Fruit Fly in the north east of the country, (Mello Garcia et al, 2024) with pest free areas allowing for exporting of fruit to the USA and China. Other pest species are handled through a systems approach with pest risk mitigation carried out by farmers at the ground level (sprays, sanitation, cultural control, baiting) and phytosanitary measures at the greater production level. Early detection and pest risk assessments occur in large production areas to ensure Brazil's status as one of the main world fruit and vegetable producers and exporters. Currently no specific plans are in place specifically for *B. dorsalis* as other species are considered more of an economic threat.

3.2.5 Oceania

Tahiti and Papua New Guinea

B. dorsalis is widespread within Tahiti having arrived in 1996 around the same time an outbreak had occurred in Queensland. Eradication programs were conducted from 1997 to 2001 but ultimately failed. Host range on the islands was from around 25 different host plants with *B. dorsalis* displacing two other species of invasive fruit flies. Control measures include the deployment of large numbers of traps baited with highly attractive male-specific lures (methyl eugenol) and general preharvest management, baiting, trapping, chemical and cultural control as well as biological control with a *Fopius arisanus* and *Diachasmimorpha longicaudata* (Hymenoptera: Braconidae). *B. dorsalis* is also now widespread throughout French Polynesia.

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Studies suggested that *B.dorsalis* outcompeted *Bactrocera tryoni* another exotic in Tahiti, (LeBlanc et al, 2012, 2013). However further investigation regarding the possibility of it outcompeting *B.tryoni* in Australia (Dominiak, 2024) identified some inconsistencies in reports from the 1996 Queensland incursion and some fundamental differences between the two species that could slow an invasion of *B.dorsalis* and in some instances could be used advantageously as a potential early warning against exotic fly incursions, fly surveillance, better-targeted eradication programs and risk assessments for imports/exports. *B.dorsalis* is established in Papua New Guinea and is Australia's closest neighbour. As a consequence of PNG's closeness and the risk of being a source for potential *B.dorsalis* incursions into Australia, researchers from the Australian Commonwealth Department of Agriculture Fisheries and Forestry, continue to deliver extension materials and training to remote parts of PNG. The program trains farmers and agricultural officers to monitor and manage pest fruit flies including *B.dorsalis*. Providing improved biosecurity to the region provides farmers with tools to reduce populations but also provides a source for monitoring of the spread of *B.dorsalis* into mainland Australia and New Zealand.

Chapter 4 Australian strategies/preparedness for Oriental Fruit Fly

4.1 Current National strategies

4.1.1 Queensland

Torres Strait in Queensland is immediately adjacent to the Western Province of Papua New Guinea, where native populations of target exotic fruit fly species exist (NPDO, n.d.). Fruit flies are able to move into the Torres Strait via wind currents and other natural factors, as well as human assisted pathways (NPDO, n.d.). An incursion by *B.dorsalis* occurred in 1996, prompting management strategies in the Torres Strait thereafter (NPDO, n.d.). Currently, the National Exotic Fruit Fly in Torres Strait Eradication Program response plan has been highly successful in monitoring and eradicating incursions of *B.dorsalis*, along with two other target species (NPDO, n.d.). It has been reviewed to ensure effectiveness and was endorsed by the National Management Group in June 2021 (NPDO, n.d.).

A trapping network exists in high-risk areas in Queensland (DAF, 2017). These areas have a high likelihood of initial infestation if fruit fly were to gain entry (DAF, 2017). High-risk areas include urban areas associated with international ports, and remote parts of Cape York Peninsula (DAF, 2017). Trap inspectors check the traps fortnightly and identification occurs in the lab (DAF, 2017). The results are recorded in a digital database and reported to the Office of the Chief Plant Protection Officer in Canberra (DAF, 2017). If an exotic fruit fly is found, a contingency plan to delimit the incursion and possibly eradicate the exotic species if an outbreak occurs (DAF, 2017).

4.1.2 Western Australia

B.dorsalis is a declared pest in Western Australia and WA has a general Biosecurity Strategy, 2016-2025 the scope of which is to encompass all animal and plant pests, diseases and weeds, and zoonotic diseases with the potential to negatively affect WA's economy, terrestrial and aquatic environments, biodiversity, agricultural resources, human health and social amenity (DPIRD WA, 2016).

Western Australia has an endemic population of the invasive Mediterranean Fruit Fly (*Ceratitis capitata*) with management strategies to minimise impact on WA's horticultural industries.

Strategies for commercial orchards include:

- Monitoring
- Hygiene and sanitation (including removal of infested fruit)
- Cultural control
 - Physical barriers using netting whole trees
 - Bagging of individual fruits
- Chemical control
 - Baiting (protein baits to lure male and female Med flies)
 - Lure and kill

WA also has surveillance grids for Queensland fruit fly and other exotic species

4.1.3 New South Wales / Australian Capital Territory

The New South Wales government has implemented a comprehensive strategy to address the threat posed by *B.dorsalis*. This includes a climate vulnerability assessment to understand how climate change will influence suitability for the spread of *B.dorsalis* (DPI NSW, 2024a). The strategy aims to enhance the resilience of primary industries in the state through development of a robust preparedness plan with surveillance, early detection, and rapid response as key measures. Surveillance programs involve monitoring fruit fly populations using traps and conducting regular inspections in high-risk areas such as ports, orchards, and markets. This is complemented by public awareness campaigns to educate growers and the general public about identifying and reporting any suspicious fruit fly activities. (Fact sheet DPI NSW, 2024b)

The DPI also collaborates with interstate and international agricultural agencies to share information and strategies, ensuring a coordinated approach to managing the threat of invasion by *B.dorsalis*.

To enhance its preparedness, NSW has invested in research and development to improve diagnostic tools and control methods for the oriental fruit fly. This includes the development of pheromone-based traps and biological control agents, such as parasitoids, which target and suppress fruit fly populations. Additionally, like many Australian states, NSW has established stringent quarantine protocols to prevent the entry and spread of *B.dorsalis*. These protocols involve strict inspection of imported produce, the use of treatments like cold storage and irradiation to disinfest fruits, and immediate eradication measures if an outbreak is detected. The coordinated efforts between government agencies, researchers, and the agricultural community underscore NSW's proactive stance in safeguarding its horticultural industries from this significant pest threat .

4.1.4 Victoria and Tasmania

B.dorsalis is considered a 'true' exotic species (AV, 2021). In Victoria, the most likely scenario of *B.dorsalis* introduction is via fruit and vegetable importation (AV, 2021). To manage the risk of invasion, the Department of Agriculture, Water and Environment assesses risks and regulates pathways and commodities for the importation of fruit fly hosts (AV, 2021). Approved treatments are applied if necessary (AV, 2021). Campaigns promoting public awareness, as well as passenger declarations and border inspections for international arrivals, are conducted (AV, 2021).

Additionally, strategic objective and activities are in place for managing exotic fruit flies, summarised in figure 4.1 (AV, 2021). The activities can be viewed in more detail on pages 9-14 in Victoria's Fruit Fly Strategy 2021-2025 report (AV, 2021).

Tasmania has strict measures in place to protect the state from invasive pest and diseases. The state has regulations for incursions of Queensland Fruit Fly and Mediterranean Fruit fly and has involved stakeholders in its current biosecurity plan 2023-2027 (Department of Natural Resources and Environment Tasmania, 2023). It is also a signatory to Australia's National Fruit Fly Management Protocol (ANFFMP), endorsed by Plant Health Committee in December 2021. Although no specifics regarding *B.dorsalis* are part of the plan, Tasmania continues to support its strategies for Australia wide biosecurity through representation on the Australian Fruit Fly Technical Advisory Subcommittee.

STRATEGIC OBJECTIVE AND ACTIVITY AREAS

Overview

This Strategy guides Victoria's approach to the management of fruit fly. It provides for Agriculture Victoria's focus on managing the risk of exotic incursions by prioritising preparedness and prevention activities and strengthening shared responsibility in the management of QFF. To develop the Strategy, Agriculture Victoria considered:

- the performance of the horticulture sector
- the threat posed by fruit fly species exotic to Victoria and Australia (including Medfly)
- the established status of QFF in Victoria
- principles of best practice biosecurity
- related national strategies and agreements
- information provided by studies and analyses
- the local, national, and international landscapes including biosecurity and market access expectations
- stakeholder relationships.

The Strategy strongly aligns with the *National Fruit Fly Strategy 2020-2025*. This is important because Victoria operates as part of a national system to support domestic and international trade and market access.

The strategic objective and activity areas are outlined in Figure 1.

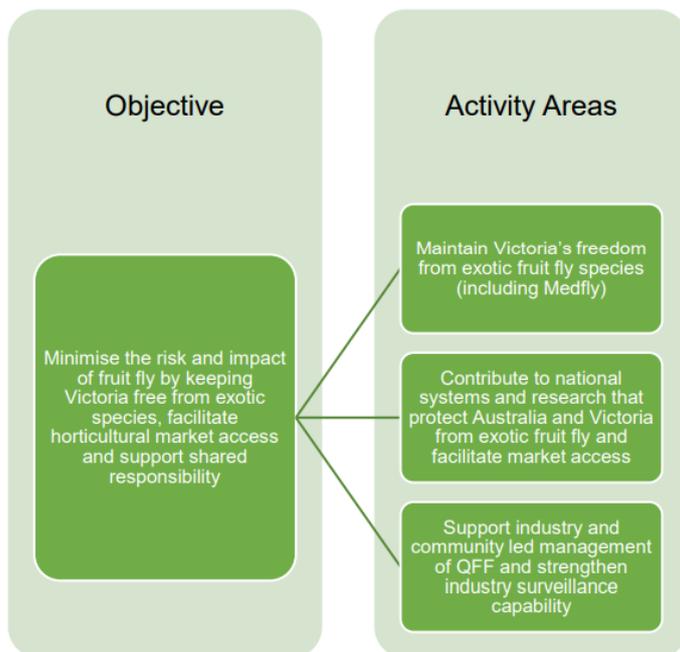


Figure 1. Outline of strategic objective and three activity areas

Figure 4.1. A summary of the strategic objective and activity areas for management of exotic fruit fly, including Oriental fruit fly. Image and description retrieved from AV (2021).

4.1.5 South Australia

The responsibility of South Australia's international borders is the responsibility of the Australian Government, incursions of pests and diseases including that of *B.dorsalis* is managed collaboration with the SA state government (Biosecurity SA manage the early detection systems set up for exotic pests and set in place management tools in order to eradicate the pest.)

Although no specifics for *B.dorsalis* are part of South Australia's Biosecurity Policy 2020-2023 (PIRSA 2020) SA legislation protects plants from pests and regulates their movement into and within South Australia through the Plant Health Act 2009 and Plant Health Regulations 2022.

The method for general fruit fly response within SA is as follows:

- Establishment of surveillance procedures to ensure rapid detection.
- Establishment and implementation of response plans
- Maintaining capacity for response
- Conducting rapid emergency response plans
- General information on fruit fly for both growers and the general public is available through PIRSA (2022)

In addition, the SA government works with other jurisdictions to enact national response plans, is part of a wider response program and conducts research and extension into preparedness for exotic fruit flies.

4.1.6 Northern Territory

The Northern Territory government run the Torres Strait Exotic Fruit Fly Eradication Program seasonally that targets three exotic fruit fly species. Traps aim to detect pest fruit fly species at port of entry and include:

- ME traps
- Capilure (Medfly)
- Cue

Locations for traps include Darwin, Alice Springs and Gove town with the main purpose to detect exotic incursions of fruit fly. The density of traps is highest in built-up areas and followed by areas of horticultural production. The Torres Strait Exotic Fruit Fly Eradication Program is a seasonal program that targets 3 exotic fruit fly species.

Chapter 5 Gap Analysis DRAFT

The intention of this draft GAP analysis is to work the SWOT analysis plans into the GAP analysis and provide recommendations for further areas/targets for research around Oriental Fruit Fly.

5.1 Gaps in Knowledge

5.1.1 General

2. Strategic planning for funding priorities related to Oriental Fruit Fly and includes:
 - a. Succession planning for leaders and lack of knowledge transfer for temporary technical staff to adequately deal with outbreaks.
 - b. National surveillance system needs work on (this falls across gaps in regulatory control, and general early warning preparedness.
 - c. Data sharing between jurisdictions with limited access to information about market access.
3. Diagnostics knowledge sharing re: which labs around Australia have diagnostic capabilities for exotics particularly Oriental Fruit Fly.
4. Communications across states and territories not standardised, with readily adaptable national comms plans. (see Appendix of national communications plan strategy to partly address this issue.)
 - a. Adaptability of technical information
 - b. Public communications – one response – one story

5.1.1 Regulatory Control

1. Delayed outbreak declarations especially in regard to cross-border outbreaks.
2. Lack of follow up after response, currently system built into AIIMS but rarely actioned or implemented.
3. Lack of facilities for:
 - a. Surveillance/fruit rearing/general surveys.
4. Decentralised data management means lack of transparency across jurisdictions.
5. Resource availability (traps, lures, people, control/management and gear for eradication).
6. Improved logistics for stockpiles of materials for outbreaks.
 - a. Operational material.
 - b. Diagnostic material.
7. Surge capacity (scalability).
 - a. Response fatigue.
 - b. Resources training qualifications.

5.1.2 Cultural Control

1. Lack of business continuity and movement protocols for horticultural commodities moving across borders and for international market access standards.
2. Short term funding can mean delayed detection of exotics and reduces the takeup of innovative technologies.
3. Federation states and jurisdictions can impose different rules am with different priorities and this might be encapsulated in differing legislation.
4. Distrust of government legislation and or protocols.

5.1.3 Chemical Control

1. Permits with different legislation in different jurisdictions-improved liaison with APVMA.
2. Product availability (insecticides).
3. Public acceptance of certain chemicals.

5.1.4 Sterile Insect Technique/Male Suppression and Male Annihilation

1. Exotics are not often the focus for research in Australia. Often there is a single species focus with the ability to transfer innovative technologies not practical, or inappropriate.
2. SIT limitations - No developed means for easily deployed SIT in Australia.
3. Climate change with one system not suitable for all climatic regions around Australia (along with the changing environmental conditions in these regions) – examination of SIT and MAT or a combination under Australian conditions.

5.1.6 Early Warning Systems and Field Monitoring

1. National surveillance program needs reinforcing and further development but relies on:
 - a. Early detection
 - b. Funding with research and resourcing affecting capacity to deliver an early detection design
 - c. Recommendations for an optimal early detection design
2. Minimal trapping program nationally.
3. Knowledge of international monitoring and information of outbreaks nearby

5.2 Current structures for OFF preparedness in Australia

General

1. International standards/diagnostics and discrepancy between Australia and other countries can be developed through international networks and innovation
2. Australia has current protocols (*B.dorsalis* specific) with some regulatory framework.
3. Deed arrangements and response capability with experienced staff working in emergency incursion management programs.
4. Risk based approach to EFF and OFF.
5. Peak industry bodies in horticulture are both aware and organised in their approach to quarantine insects of significance.

Research technology (MAT/SIT)

1. Expertise across jurisdictions with strong research capability, diagnostic laboratories and connections with international researchers dealing with exotic fruit fly.
2. Facilities for SIT of Mediterranean and Queensland Fruit Fly already in existence.
3. Ability to learn from other projects in regard to mobile facilities for SIT (Australian Sheep Blowfly Eradication Program on Kangaroo Island).

Monitoring incursions and Trapping guidelines

1. Established surveillance and trapping guide in NT with bones of national surveillance program that can be developed upon
2. Public/established comms for existing species/public awareness
3. Existing EFF Torres Strait program.

5.3 Challenges and opportunities

Challenges

1. Currently Australian research and many responses have a single species focus. Not having OFF currently in Australia places limitations on research under Australian conditions and the current framework for OFF incursion response needs development across jurisdictions.
2. There is limited funding for capacity development, for research and for preparedness.
3. Although Australia has a wide range of expertise in researchers this has been limited to species specific flies and Australia's unique position means that constant vigilance can lead to response fatigue.
4. Major destabilising global events also prove challenging these can be:
 - a. Climatic
 - b. Economic
 - c. Political
5. There have been two major incursions of *Bactrocera dorsalis* in Australia previously. There is a great deal to be learned from the eradication response deployed in both these programs and how they can be adapted for updated response plans.
6. Misidentification can also place a great strain on preparedness due to:
 - a. Not picking up possible incursions
 - b. Responding to misidentified fruit flies
7. Due to a number of factors, including climate change or adaptation to new country several issues with OFF may arise including:
 - a. Evolutionary changes to the insect
 - i. New host
 - ii. New range
 - b. Resistance to chemicals
 - c. Resistance (non responding to) lures
8. An increasing number of incursions may involve change strategies having to be deployed including the shift from eradication to management.
9. State and territory governments continue to collate data independently creating data silos
10. Political motivations/interference Federation
 - a. Different legislation across states and territories.
 - b. Priorities may differ across different affected horticultural commodities and their current market access priorities. (regions/trade)
 - c. Politics
 - d. Conflicts with science and best practise standards.
11. Closed borders.
12. Running out of timely or appropriate tools to adequately respond to incursions.
13. Peri-urban landscapes can be challenging for responses and are
 - a. State specific
 - b. In need of different communications or technical information dependant on state or audience
14. National protocols across affected industries may be too general for state specific response
15. Lack of
 - a. Treatment options (vs host list)

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- b. Treatment facilities.
 - c. Resources.
16. Miscommunication
 17. Distrust of government
 18. Supply chain issues
 19. Interjurisdictional support/cross industry support (not having industry involvement from day 1)
 20. Trade import barriers
 21. Timeframes to complete/implement responses could be reduced.
 22. Mixed farming priorities (market access) determine preparedness activities
 23. Lack of recovery arrangements in biosecurity
 24. Committee structure across the many horticultural industries has a slow action/decision making process for finalising incursion responses.
 25. There is currently an unclear pathway for innovative options for
 - a. Research
 - b. Response management.

Opportunities

1. Development of a strategic plan for funding with all state and territory stakeholders on priority funding for Oriental Fruit Fly research and for preparedness and incursion management.
2. Develop deep understanding and collaborations with neighbouring countries through:
 - a. International advisory committee involvement.
 - b. Researcher meetings, joint projects, and data sharing.
3. Capacity building
 - a. Researcher succession planning and individual project development.
 - b. Infrastructure
 - i. Quarantine.
 - ii. Creation of joint facilities to be used by multiple responses (across industries).
 - iii. Mobile facilities developed (similar proposed with SIT Australian Sheep Blowfly).
4. National Diagnostics Protocol awareness and adaptation of international diagnostics protocol to recognise an Australian specific NDP
 - a. Exotics/Oriental Fruit Fly
 - b. Validation of diagnostic protocols (morphological and molecular)
 - c. Collections/voucher specimens for national insect collections.
5. Legislative framework pre-drafted prior to an incursion strengthens the framework already developed or in the process of development.
6. Standardisation of operations and data capture across incursions.
7. Australia to become a regional training centre for Oceania operations
8. Tighten strategies for postharvest treatment and other phytosanitary requirements for horticultural market access.
9. Test drive contingency plans or any of the deliverables from projects to industry.

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10. Clarify stockpiles and other labs capacity and resources for response management and for diagnostics.
 - a. State and territory capacity for response.
 - b. Including local experts in diagnostics.
11. Development of an after response action follow up protocol.
12. Pre-incursion agreement with industry
 - a. Faster launch for responses
13. Improve logistics for scalability (structure guide within AIIMS).
 - a. Develop solid fruit fly network for incursions.
 - b. Training and protocol development for temporary staff.
14. Assistance with chemical permits through APVMA and reviews of current chemistries available across jurisdictions.
 - a. Resistance screening for chemistries.
 - b. Developing MAT alternative as part of integrated approach
15. International Real Time Monitoring.
16. Climate suitability monitoring/Dual assessment suitability across climate zones.
17. Review plan to maintain and update standards.
18. Improved public awareness (Industry politicians advocacy).
19. Links to international programs, to universities and researchers studying EFF and OFF.
20. Development of close links responses in other countries (particularly Oceania) eg SIT in PNG.
21. Expanding offshore surveillance funding, education and training – links with universities and through ACIAR programs.
22. Research Implementation of surveillance techniques
 - a. Trap choice
 - b. Lures
23. Training to improve response capacity across states and territories.
24. Volunteer programs
25. Diagnostics innovation both morphological and through molecular diagnostics (eg eDNA metabarcoding).
26. National Data Sharing project to standardised data capture and provide consistency in incursion management procedures.
27. Inform and improve national protocols
28. Plan to broaden scope to include EFFs
29. Gene drives eg producing only male flies
30. Forge formal engagement and networks with international experts MOUs for deployment of experts in response but also for preparedness activities
31. Reciprocal programs study tours and residentials
32. Host lists eg native species and understanding host reproduction number potential
33. AWM coordinators tapping into local knowledge and the associated practicalities of incursion management.
34. Development of improved decision tools for all aspects of incursions.
35. Assessment of standards and scenarios through simulation (games/emergency exercise strategies.)

5.4 Recommendations

The primary aim of this GAP analysis is to assist with the development of preparedness protocols for Oriental Fruit Fly in all Australian at-risk regions and for all affected industries. Preparedness is defined as being able to identify exotic fruit fly species if and when they occur, and having procedures in place along with strategies and resources to respond to incursions/outbreaks. Some of these risks it is possible to undertake anticipatory research and development.

Long-term surveillance and monitoring activities will involve developing or adjusting current management strategies with the addition of a cost/benefit analysis of maintaining such activities. Continued early intervention strategies for OFF incursions is needed and may need to adapt to new research and development with subsequent changes to current practice. Initially, activities likely to provide successful intervention should be given highest priority.

Broadly this can be achieved by:

General:

1. National strategic planning regarding:
 - a. Financial and resource planning
 - b. Effective national surveillance systems
 - c. Information sharing
2. Ensure diagnostics information is shared widely through diagnostics networking system
3. Standardise knowledge sharing and platforms of networking/communication within scientific communities and with distribution of information to the General Public

Regulatory:

1. Tighten outbreak declarations to a reduce timeframes (action-reaction times)
2. Build in follow up responses to incursions/data management and follow through
3. Carry out a national stocktake of
 - a. Facilities
 - b. Physical resources
 - c. Staff (and training)
 - d. Diagnostic capabilities

Cultural:

1. Refine business protocols export and domestic produce under OFF incursion.
2. Investigate innovative technologies for OFF detection.
3. Provide a unified approach to OFF preparedness across jurisdictions.
4. Provide a communications strategy for both industry and general public.

Chemical:

1. Discuss chemical control management strategies with industry and implementing permit applications for appropriate chemistries as soon as practical (forward planning for outbreaks).
2. Ensure available stocks.

3. Ensuring chemical use is incorporated into any future communications plans.

Controls, early warning systems and field monitoring

1. Support research into OFF specific Sterile Insect Technique/Male Suppression and Male Annihilation under Australian conditions (including different climate regions)
2. Support Capacity building for early detection, trapping and adapted international knowledge on OFF management strategies.

In addition, continued information dissemination about exotic fruit flies (and Oriental Fruit Fly in particular) will help improve understanding and management options for affected industries and the general public.

As part of the Oriental Fruit Fly exercise a mitigation strategy table can be designed to summarise results. See Table ()

Risk strategy tables are also important but require whole team input. Resources should be directed to enable progressive sectors of the industry to satisfy prerequisites for an OFF management program. The aim would be to identify varying capacity to the meet those requirements.

Mitigation strategy table during OFF incursion phase – Table summary for OFF exercise.

	NSW	VIC	QLD	WA	SA	NT	Commonwealth
EARLY DETECTION							
EFFECTIVE AND WIDESPREAD RESPONSE PLANS							
ACCURATE AND DETAILED GROWER MANAGEMENT PROTOCOLS							
REGULATORY CONTROL							
CULTURAL CONTROL							
CHEMICAL CONTROL							
SIT (STERILE INSECT TECHNIQUE)							
MALE SUPPRESSION							
FIELD MONITORING							
EARLY WARNING (PATHWAYS FROM OTHER COUNTRIES)							
WIDESPREAD COLLATION OF THE DATA COLLECTED FROM ABOVE SOURCES							
LONG-TERM COLLABORATION BETWEEN INDUSTRY AND RESEARCHERS.							

✓✓✓ high, ✓✓ moderate, ✓ partial, ✗ negligible

Chapter 6 Summary Discussion

The Oriental fruit fly, *Bactrocera dorsalis*, is a highly invasive species native to Asia but has now spread to over 75 countries, including parts of the Americas, Oceania, and Africa. Known for its short life span, broad host range, and high reproductive potential, it often becomes the dominant fruit fly species in new regions, causing significant economic damage to horticultural crops. In Australia, *B. dorsalis* is a quarantine concern, with no current populations but frequent incursions via imported goods. Australia's horticulture industry, valued at around \$3 billion (exports) annually, relies on strict quarantine protocols to maintain pest-free produce essential for export. To mitigate risks, Australia implements a national fruit fly management strategy involving mapping, quarantine restrictions, surveillance, and research. Pest Free Areas (PFAs) are maintained to avoid the need for additional phytosanitary treatments, ensuring market access for exports.

B. dorsalis has a complex life cycle with four stages: egg, larva, pupa, and adult. Female flies can lay over 1,000 eggs in their lifetime, typically within the first three weeks of emergence. Development and survival of *B. dorsalis* is significantly affected by temperature and soil moisture. Optimal development occurs at temperatures between 25-30°C, while extreme temperatures and inappropriate soil moisture levels can hinder development and reduce survival rates.

The habitat preferences and behaviours of *B. dorsalis* are influenced by environmental conditions and host plant availability. Larvae prefer to pupate in moist, shaded soil, and adults can inhabit both crop areas and surrounding environments, often moving into agricultural zones when populations in wild host plants increase. Fruit ripeness and the presence of wounds on fruit are key factors in oviposition, with females showing a preference for ripe, damaged fruit. Methyl eugenol is highly attractive to males and is used for monitoring and control. Temperature and soil moisture are critical for the fly's lifecycle, influencing their distribution and management strategies, which include monitoring soil and temperature conditions and using visual and chemical attractants to control populations.

Australia's proactive fruit fly management has benefited from observing and incorporating overseas research and active area management plans. Management strategies include early warning systems, rapid response protocols, and reduced reliance on agrichemicals through methods like Sterile Insect Technology and Male Annihilation Technology. The approach by Australian authorities aims to meet the challenges posed by exotic fruit fly incursions and maintain Australia's competitive edge in international markets. The research underpinning these strategies involved surveying and assessing existing protocols, researching international practices, and reviewing standards set by the IAEA to assist development of a comprehensive national preparedness plan. Information was gathered from journal articles, websites, technical reports and state and overseas protocols.

All Australian states and territories adhere to guidelines and protocols set by national bodies such as the Australian Government's Department of Agriculture, Fisheries and Forestry (DAFF) and Plant Health Australia (PHA). These guidelines include standardised practices for surveillance, quarantine, and response to detections of *B. dorsalis*.

A key element of any uniform strategy is the National Fruit Fly Strategy, NFFS 2020-2025 (National Fruit Fly Council, 2024), which promotes coordinated actions and resource sharing among different

jurisdictions. The framework for this strategy includes common methods such as the use of pheromone traps, biological controls, and public awareness campaigns to ensure early detection and rapid response. Inter-jurisdictional collaboration is facilitated through regular meetings and information exchange among state and federal agricultural departments. This collaboration helps maintain a unified front in implementing quarantine protocols, conducting risk assessments, and conducting eradication plans. Consequently, while individual states may have specific operational details tailored to their local conditions, the overall strategic framework for managing a *B.dorsalis* incursion remains consistent across Australia, ensuring a robust and effective national biosecurity system tied into the NFFS.

This draft GAP analysis integrates SWOT analysis plans to identify knowledge gaps and provide research recommendations on the Oriental Fruit Fly. The key gaps identified include strategic planning for funding priorities, national surveillance system enhancements, diagnostics knowledge sharing, and standardized communication across states. There are also significant regulatory control issues such as delayed outbreak declarations, decentralized data management, and limited resources for surveillance and response. Cultural control challenges include inconsistent business continuity protocols and short-term funding constraints. Chemical control faces issues with differing permits across jurisdictions and public acceptance of insecticides. Additionally, the analysis highlights the need for developing Sterile Insect Technique and early warning systems tailored to Australian conditions.

To improve preparedness and response, the analysis recommends strategic national planning, enhanced diagnostics and data sharing, and standardized communication platforms. Regulatory recommendations include faster outbreak declaration processes and a national stocktake of facilities and resources. For cultural control, refining business protocols and investigating new detection technologies are suggested. Chemical control strategies should be pre-planned, and research into SIT and early warning systems should be supported. The overall goal is to develop comprehensive protocols for identifying and managing OFF incursions, with a focus on proactive research and effective resource allocation.

With some development, training and strengthening of current plans and strategies, Australian agriculture is in an advantageous position to deal with the threats of potential incursions from oriental fruit fly.

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Appendix 1: Australian National Planning Workshop for Exotic Fruit Fly (EFF) Agenda

Held: Macquarie University, 25 Wally's Walk, Macquarie Park, NSW 2109 (Room C120/121 combined, Arts Precent-Building C, Macquarie University)

Australian National Planning Workshop for Exotic Fruit Fly (EFF)

Macquarie University, 25 Wally's Walk, Macquarie Park, NSW 2109 (Room C120/121 combined, Arts Precent-Building C, Macquarie University)

MONDAY, 21 NOVEMBER 2022 (IAEA workshop also attended by the Australian participant)

All Australian planning team members for preparedness of Exotic Fruit Fly will be attending the Third FAO/IAEA RESEARCH COORDINATION MEETING. This meeting will be hosted by the IAEA experts at Macquarie Uni on the Monday, 21st November 2022 (see agenda below)

SESSION I (CONT.) SIT and MAT integration: laboratory and field assessments (Chairperson: Christopher Weldon)

08:30 – 09:00 **Peter Prentis:** Transcriptome analysis of the effects of cuelure feeding on *Bactrocera tryoni* and their offspring.

09:00 – 09:30 Substituted talk

09:30 – 10:00 **Helene Delatte:** Biocological parameters including dispersal behaviours of *Bactrocera dorsalis* in Réunion Island

COFFEE BREAK

10:30 – 11:00 **Alvin Hee:** Developing non-methyl eugenol-responding male Oriental fruit flies supplemented with semiochemical exposure for improved SIT

11:00 – 11:30 **Suk Ling Wee:** Improvement of *Bactrocera dorsalis* management by semiochemicals for simultaneous application of SIT and MAT

11:30 – 12:00 **Lloyd Stringer:** Estimating the effect of reduced sensitivity of sterile-released Queensland fruit fly to cuelure and increased interval between sterile fly releases on wild population growth

LUNCH

OFFICIAL

SESSION I (CONT.) SIT and MAT integration: laboratory and field assessments

- 13:00 – 13:30 **Christopher Weldon:** Simultaneous application of mat and sit for management of *Bactrocera dorsalis* in South Africa: environmental and physiological considerations
- 13:30 – 14:00 **Supaap Pinkaew:** Cost-effective treatments support the Male Annihilation Technique and the Sterile Insect Technique for the Establishment of a Fruit Fly Low Prevalence Area in Thailand
- 14:00 – 14:30 **Nicholas Manoukis:** Effective behavioural phenotyping of methyl eugenol response by Male *Bactrocera dorsalis*.
- 14:30 – 15:00 **Atsushi Honma:** The countermeasures against *Bactrocera dorsalis* complex re-invasion in Japan and the need for introduction SIT

COFFEE BREAK

- 15:30 – 16:00 **Todd Shelly:** Evaluation of a genetic sexing strain of the oriental fruit fly as a candidate for simultaneous application of male annihilation and sterile insect techniques
- 16:00 – 17:00 **General discussion**

TUESDAY, 22 NOVEMBER 2022 (Australian EFF preparedness planning workshop)

- 08:30am **Welcome & Introduction**
- 08:45am **Background, Workshop Structure & Objectives**
Provide strategies for preparation of the Australian National Action Plan on Exotic Fruit Fly.
Provide background preparation for the Oriental Fruit Fly Biosecurity Exercise
- 09:00am **Presentations by invited international guest speakers**
- 09:00 – 09:20 **Nausheen Patel:** *Bactrocera dorsalis* detection in Mauritius, previous eradication measures, ongoing surveillance / suppression programmes
- 09:20 – 09:40 **Sandeep Singh:** A 19-year experience on management of Oriental fruit fly in Punjab, India
- 09:40 – 10:00 **Nikos Papadopoulos:** *title yet to be provided*

OFFICIAL

10:00 – 10:20	Rory MacLellan: Case study on preparedness planning, monitoring & surveillance, and eradication activities of Queensland fruit fly incursion in New Zealand
10:20 – 10:35	quick COFFEE BREAK (international guests will leave room) 10:35 - 12:
10:35 – 12:15	Australian Biosecurity planning team, break into allocated groups to discuss: <ol style="list-style-type: none">1. Strengths of current EFF management system2. Weaknesses of current EFF management system Feedback from each group with collation of outcomes
12:15 – 13:00	LUNCH BREAK
13:00 – 14:45	Brief summary of first session and intro to next 2 sessions (5mins) involving discussion on; <ol style="list-style-type: none">3. Opportunities to improve current EFF management system4. Threats to achieving improvements to EFF management system Report back from groups
14:45 – 15:15	Summary and next steps forward
15:15	CLOSE

Appendix 2: Australian National Oriental Fruit Fly Proposed Communications

Date: November 2022

Component Lead(s): Dr Katharina Merkel

An effective Oriental fruit fly incursion management system relies heavily on the effective communication and adoption of relevant information. This is particularly needed at the technical level to ensure that stakeholders involved in both high-level incursion management as well growers on the ground receive relevant information to control potential outbreaks.

Part of this communications strategy is to assist improvement of decision making to ensure best practice management for the incursion and for affected horticultural industries.

High quality communication techniques will improve engagement and implementation of relevant management systems and widen the adoption of new innovative fruit fly management technologies.

Information will can be used to distribute information to a wider group of stakeholders beyond those directly involved with incursion management. This includes consumers, wholesalers, retailers, exporters, importers, transport operators and treatment providers.

Goal

Provide technical information fact sheets on Oriental fruit fly to allow effective adoption of information for incursion management teams, growers and for easy adaptation for a broad range of audiences.

Outcomes

This activity will:

HOW - Create a broad structure of how information will be distributed to stakeholders through templates and delivery mechanisms.

WHY - Develop a communication methodology (content structure) for Oriental Fruit Fly incursion management information.

WHAT - Raise awareness of the biology, ecology, control and surveillance processes and provide components for incursion management of Oriental Fruit Fly.

WHEN - Promote the roles and responsibilities of all stakeholders in upholding a national Oriental Fruit Fly incursion management system during an outbreak.

In addition, communications will:

1. Utilise existing fruit fly incursion management systems to update information as needed.
2. Encourage adoption of new/innovative Oriental Fruit Fly incursion management protocols.

Communication information sheets	
Topic	Contents
Biology	<ul style="list-style-type: none"> ➤ Distribution (reliant on CABI for updated information) ➤ Host information ➤ Fruit fly competition (with/between species) ➤ Seasonality ➤ Complex of species
Control	<ul style="list-style-type: none"> ➤ Biocontrol (including establishment parasite species throughout Australian Horticultural regions. ➤ Chemical treatments including timing, withholding periods for crops and resistance issues ➤ Bait sprays and spray application techniques ➤ Male Annihilation Technology (very effective with Oriental Fruit Fly) ➤ Sterile Insect Technology and irradiation ➤ Female specific attractants
Surveillance	<ul style="list-style-type: none"> ➤ Trapping ➤ Lures
Management Protocols	<ul style="list-style-type: none"> ➤ General information on incursion management and references to National and state-based management plans ➤ Trigger thresholds for incursion management

Discussion points

- Hosting of material done state by state
- Rough plan for continued maintenance
- All information sheets will be adaptable.

Template

- Title
- Executive summary
- Short statement of purpose
- Content
- References
- Links
- Maintenance details

Communication recommendation

Fact sheet's purpose definition

The fact sheets offer guidance to response programs and are intended to be adaptable for jurisdictions to use within the programs facilitated by each state/territory.

In case of incursion, the validity and relevance of each fact sheet need confirmation before release.

Appendix 3: Australian National Oriental Fruit Fly Draft Fact Sheets

Fact Sheets are attached separately, please note the fact sheets do not include images (for the most part) due to image licensing issues that may arise between state departments.

Draft communication sheets as part of the exercise.

Fact Sheet 1 – Biology

Fact Sheet 2 – Surveillance

Fact Sheet 3 – Control

Fact Sheet 4 – Management Protocols

Biosecurity preparedness for Oriental Fruit Fly

Contingency plan for Oriental Fruit Fly

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Purpose and background

Impact of Oriental fruit fly

Biology and management

Geographic distributions

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Geographical distribution

Diagnostic information

Control measures

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Purpose and background of the plan

The contingency plan draws largely from comprehensive reviews conducted by NSW DPI and SARDI/PIRSA on the Oriental fruit fly (OFF). Its primary purpose is to equip the Australian horticulture industry with essential information on OFF biology and available control measures to ensure preparedness for a potential incursion. The plan provides guidelines and options for developing a Biosecurity Response Plan tailored to OFF. Currently in draft form, the plan requires review by Plant Health Australia (PHA), the Pest and Disease Control (PHC) committee, the National Fruit Fly Council (NFFC), and the National Management Group prior to implementation. Developed specifically for the horticultural industry, it complements PHA's existing "Response Strategy for Exotic Fruit Flies," with modifications focused on OFF. Upon review, the document may be amended and should be used in conjunction with the existing response strategy in the event of an incursion.

Pest Impact

The Oriental fruit fly (*Bactrocera dorsalis*) is a highly destructive pest that poses significant risks to the horticultural industry. Its impact on crops can be severe, leading to economic losses, trade restrictions, and disruptions in agricultural practices. The OFF infests a wide range of horticultural commodities, with a reported host range over 400 types of fruit and vegetables. Female flies lay their eggs inside the fruit, which then hatch into larvae that feed on the flesh, causing spoilage and rendering the fruit unmarketable. It is to be noted that the incursion of an exotic fruit fly species has an annual likelihood of 21% (Abdalla et al. 2012) and the annual cost of eradication of an incursion is of about \$13 million (Plant and Health Australia 2009). Incursions might be short but can still cause great economical damage by restricting access to markets (Sultana et al. 2020). The annual economic losses caused by the spread of OFF through trade restrictions in Africa are estimated to be around US\$ 2 billion. Similarly, in Hawaii, the infestation of major crops by OFF leads to annual crop losses exceeding US\$ 3 million. Although OFF has not yet established populations in Australia, interceptions in northern Australia serve as a clear indication of the significant threat posed by this highly invasive pest. If OFF had successfully established in northern Queensland during the incursions from 1995-1999, the annual management costs alone were projected to range from AU\$ 7-8 million.

The OFF is an invasive species that spreads rapidly and can tolerate various climates. It competes aggressively with native fruit flies and, once established, quickly becomes the dominant pest among fruit flies. Multiple studies have examined the competition between OFF and other economically significant tephritids. OFF has been found to outcompete species like *Ceratitidis capitata* in terms of longevity and reproductive rate, regardless of the type of fruit. It has also displaced other established tephritids, including *C. capitata* and Queensland fruit fly (Q-fly). However, the outcome of these competitions can be influenced by factors such as host types, temperature, relative humidity, and interactions with other species from different trophic levels. It is worth noting that the displacement of pre-existing tephritids by OFF has been unidirectional, without any reciprocal invasion or displacement observed. These findings underscore the potential threat of OFF incursions and their establishment.

Infestation by the Oriental fruit fly can result in substantial yield losses. The larvae damage the fruit, leading to premature fruit drop, reduced quality, and decreased marketable yield. Of note, the presence of the Oriental fruit fly in an area can lead to trade barriers imposed by importing countries to prevent the spread of this pest. Exporters may face strict quarantine measures, such as mandatory treatments or exclusion from certain markets, affecting the

profitability and competitiveness of horticultural industries. Detection of the OFF in a region triggers costly and time-consuming quarantine and eradication efforts. Infested areas may undergo quarantine restrictions, including movement restrictions on produce, trapping programs, and spraying of insecticides. These measures can disrupt supply chains and impact the livelihoods of farmers and associated industries.

Not to mention, the establishment of OFF in new areas can lead to the destruction of native plant species, affecting biodiversity and ecological balance.

Biology and pest management

Life cycle

The OFF undergoes four life stages: egg, larva, pupa, and adult. The eggs are white, long elliptical in shape, and approximately 1.2 mm long. Larvae are creamy white, ranging in length from 5-15 mm, with younger stages being smaller. Pupae are white to yellow-brown, roughly cylindrical, and about 5 mm long. Adult *B. dorsalis* have a wasp-like appearance, measuring approximately 7 mm in length, with clear wings, a black back, a paler abdomen, and a T-shaped marking on the abdomen.

Female Oriental fruit flies can lay over 1000 eggs during their lifetime, depositing them under the skin of host fruits in batches of 3-15 eggs. The eggs hatch within 1-2 days, and the larvae go through three larval stages, feeding on the fruit and causing premature fruit drop. After completing their development, the third instar larvae leave the fruit, disperse briefly, and bury into the soil to pupate. Pupation occurs within a few hours, and after approximately 10 days, adult flies emerge from the puparium and surface the soil. Adult flies become active after a brief period of inactivity and start feeding. Females can produce eggs for up to 2 months, and adult *B. dorsalis* can live for 2-3 months.

The life stages of *B. dorsalis* are influenced by environmental conditions such as soil moisture and temperature. Soil moisture affects pupation, with emergence being fastest at 30% soil moisture, while survival rate decreases at 70% soil moisture. Temperature plays a significant role in the developmental time of *B. dorsalis*, with shorter development times at higher temperatures. However, the species also has development thresholds, with lower thresholds around 8.8-9.4°C and upper thresholds likely between 30-35°C. The optimal temperature range for development falls between 20-30°C, with successful development occurring between 15-33°C. Extreme temperatures can result in mortality, although short exposures to extreme temperatures can have both positive and negative effects on the adults' tolerance to cold and heat stress.

Temperature and soil moisture are critical factors influencing the development, survival, and distribution of *B. dorsalis*. Mapping studies have been conducted to identify areas vulnerable to Oriental fruit fly invasion and establishment based on factors such as cold stress, dry stress, and irrigation scenarios. Additionally, recent research has focused on the impact of gut bacteria on the foraging behavior, development, and survival of *B. dorsalis*, potentially leading to bacteria-oriented control methods in the future.

Dispersal

The OFF is known for its rapid dispersal ability. It has the capability to spread over long distances, aided by its strong flight capabilities and its ability to infest a wide range of host fruits. The dispersal of OFF populations can occur through natural means such as wind-assisted movement, flight, and colonization of new habitats. Human activities also play a significant role in the dispersal of this invasive species.

The threat of incursions caused by the increased trade in fruits and vegetables is immense. Tephritid incursions, often following a jump-diffusion model, occur when long-distance jumps facilitated by tourism or trade are followed by dispersal into the local environment, often with human assistance. Human movements have contributed to multiple incursions of fruit flies in various countries, such as Australia, New Zealand, and the USA. Human-assisted dispersal of OFF primarily occurs through the transportation of infested fruits and plant material. The fly's eggs, larvae, or pupae can be inadvertently transported in infested fruits, vegetables, or other plant products. This form of dispersal is a significant concern for international trade and agricultural practices, as it can lead to the establishment of OFF populations in new regions.

The establishment and spread of invasive species during incursion events are influenced by factors such as host availability, climate, and fruit fly ecology. Invasive species are adaptable generalists that can survive in a wide range of environmental conditions. Temperature plays a vital role in governing the survival, growth, and reproduction of insects, including fruit flies. Understanding climate conditions and fruit fly ecophysiology is crucial in predicting the potential for invasions and establishment in new environments. Climate suitability models suggest that with increasing temperatures, tropical areas may become less suitable for fruit flies, while temperate areas may become more suitable.

The role of wind in fruit fly dispersal is not well understood. Some reports suggest that wind does not distribute tephritids across land, while others indicate that they move downwind in strong winds. Most fruit flies do not move far from their release site, limited to a range of 2-4 km, although some species like the Oriental Fruit Fly (OFF) and Queensland Fruit Fly (Qfly) have been found at distances of up to 50-94 km from release sites. The influence of wind may be more important across waterways, such as the Torres Strait in Australia, where trapping has intercepted various exotic fruit fly species. As OFF is known to disperse across waterways (e.g. Hicks et al. 2019), it is speculated that the 1995 incursion event in northern Queensland was started in this manner, although the method and origin of the introduction was never officially determined (Cantrell et al. 2002).

Host availability is another crucial factor in fruit fly establishment. Most fruit fly species have a wide range of host species, and areas with peri-urban food production and modified environments, such as capital cities, increase the likelihood of establishment.

OFF has dispersed to over 75 countries worldwide, becoming the dominant tephritid species due to its competitive advantage and ability to affect both ripe and unripe fruit. Mating behavior in OFF involves leks, aggregations of males that females visit solely for mating, and preferred roosting plants include various species such as tiger's claw, panax, castor bean, and guava.

Once established in a new area, Oriental fruit flies can rapidly spread within the local environment. They have a wide climatic tolerance, allowing them to adapt and thrive in various regions. Their ability to reproduce quickly and produce a large number of eggs further aids in their dispersal and population growth. As a result, the Oriental fruit fly can quickly become the dominant fruit fly pest in infested areas, outcompeting native fruit fly species.

Geographic distribution

A comprehensive review conducted in 2018 on the global distribution and invasion pattern of the oriental fruit fly revealed that OFF had expanded its presence from five countries in 2010 to 75 countries across Asia, Africa, North America, South America, and Oceania (Zeng et al., 2018). Figure 1 provides a visual representation of the current distribution.

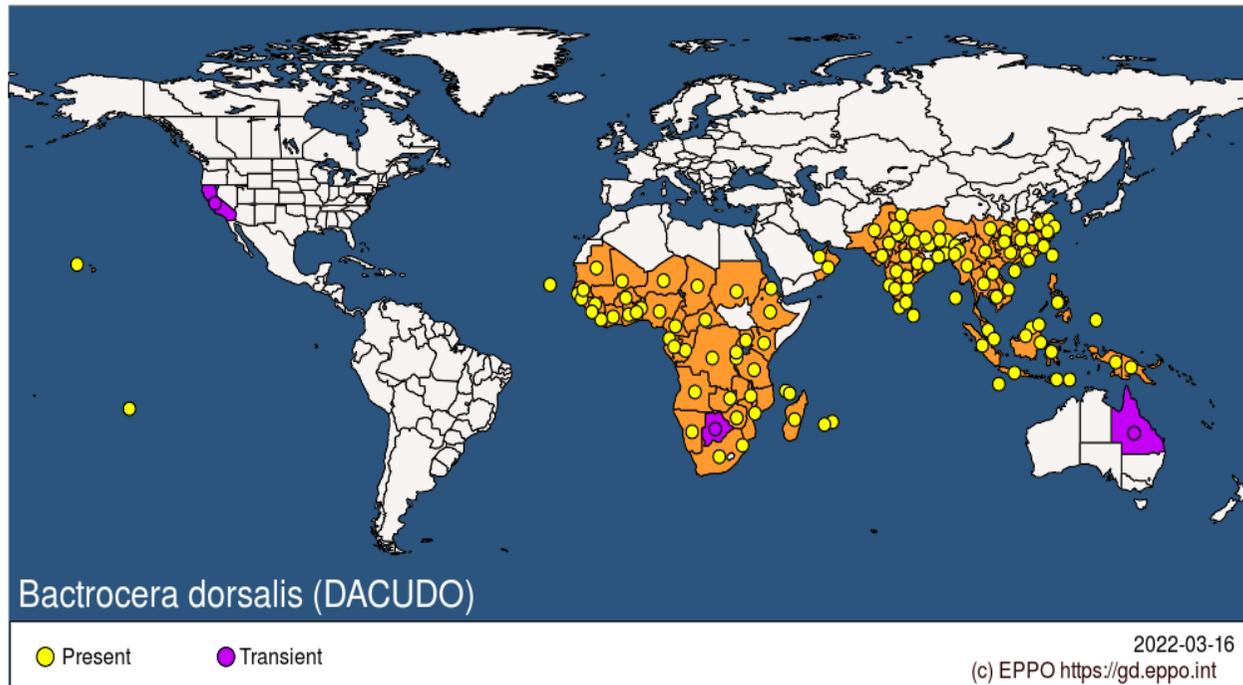


Figure 1: Global distribution of *Bactrocera dorsalis*. (Also includes past records of synonyms *B. invadens*, *B. papayae* and *B. philippinensis* Source: EPPO Global Database)

Hosts

A comprehensive update on the list of hosts of OFF based on scientific evidence gathered from worldwide literature published by the USDA Compendium of Fruit Fly Host Information in 2017, the OFF has been found to be associated with a total of 632 plant species. Among these, 481 plant species belonging to 212 genera in 79 families have confirmed records of infestation under natural field conditions (Table 1). Notably, the fig family (Moraceae; 38 species), the citrus family (Rutaceae; 37 species), the tomato family (Solanaceae; 33 species), and the squash family (Cucurbitaceae; 29 species) are the plant families that provide the most suitable hosts for the Oriental fruit fly. Furthermore, there are 151 plant species, belonging to 96 genera in 51 families, for which the host status of the Oriental fruit fly is still "undetermined." Additional data is required to assess whether these species can serve as hosts for the Oriental fruit fly. The specific list of host species may vary from country to country, as official records differ depending on the region.

The Oriental fruit fly is known to infest both commercial and non-commercial plants, including fruiting plants and post-harvest fruit and vegetable produce (Oriental fruit fly, 2021). Infestations in fruit can be identified by the presence of small discolored patches on the fruit's skin, which may appear brown or black. These patches may be water-soaked and typically surround the point where the fly laid its eggs. Additionally, decomposition of the fruit may occur, causing it to drop prematurely from the host plant (Manrakhan, 2020; Oriental fruit fly, 2021).

During an outbreak of the Oriental fruit fly in Queensland, Australia in the 1990s, researchers found that *B. dorsalis* bred in 35 different host plants, resulting in damage to various types of fruit, including coffee berries and green papaya/pawpaw (Oriental fruit fly, 2021).

Table 1. Hosts of OFF (Source: USDA, Fruit Fly Regulated Articles and Host Lists and Assessments; <https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/fruit-flies/host-lists>)

The berries, fruit, nuts and vegetables of the listed plant species are now considered host articles for *B. dorsalis*. Unless proven otherwise, all cultivars, varieties, and hybrids of the plant species listed herein are considered suitable hosts of *B. dorsalis*.

<u>Scientific Name</u>	<u>Common Name</u>
<i>Acca sellowiana</i> (O. Berg) Burret	Guavasteen, pineapple-guava
<i>Adenantha pavonina</i> L.	Red sandalwood
<i>Adenia cissampeloides</i> (Planch. Ex Hook.) Harms	Manila palm
<i>Adonidia merrillii</i> (Becc.) Becc.	Manila palm
<i>Aegle marmelos</i> (L.) Corrêa	Baeltree
<i>Afzelia xylocarpa</i> (Kurz) Craib	Doussie
<i>Alangium chinense</i> (Lour.) Harms	Begonialeaf alangium
<i>Alangium salviifolium</i> (L. f.) Wangerin	Sage-leaf alangium
<i>Alpinia mutica</i> Roxb.	Small shell ginger
<i>Anacardium occidentale</i> L.	Cashew nut
<i>Ananas comosus</i> (L.) Merr.	Pineapple ¹
<i>Annona xatemoya</i> Mabb.	Atemoya

<i>Annona cherimola</i> Mill.	Cherimoya
<i>Annona glabra</i> L.	Pond-apple
<i>Annona macrophyllata</i> Donn. Sm.	Llama
<i>Annona montana</i> Macfad.	Mountain soursop
<i>Annona mucosa</i> Jacq.	Wild sweetsop
<i>Annona muricata</i> L.	Soursop
<i>Annona reticulata</i> L.	Custard apple
<i>Annona senegalensis</i> Pers.	Wild custard-apple
<i>Annona squamosa</i> L.	Custard apple, sugar apple
<i>Antidesma ghaesembilla</i> Gaertn.	Black currant tree
<i>Aporosa villosa</i> (Lindl.) Baill.	Ye-mein
<i>Ardisia crenata</i> Sims	Hen's eye, coralberry
<i>Areca catechu</i> L.	Areca palm, betel nut
<i>Arenga engleri</i> Becc.	Formosan sugar palm
<i>Arenga pinnata</i> (Wurmb) Merr.	Sugar palm
<i>Arenga westerhoutii</i> Griff.	N/A
<i>Artabotrys monteiroae</i> Oliv.	N/A
<i>Artabotrys siamensis</i> Miq.	N/A
<i>Artocarpus altilis</i> (Parkinson) Fosberg	Breadfruit
<i>Artocarpus dadah</i> Miq.	N/A
<i>Artocarpus elasticus</i> Reinw. ex Blume	Terap

<i>Artocarpus heterophyllus</i> Lam.	Jack fruit
<i>Artocarpus integer</i> (Thunb.) Merr.	Chempedak
<i>Artocarpus lacucha</i> Buch.-Ham.	Monkeyfruit
<i>Artocarpus lanceifolius</i> Roxb.	Keledang
<i>Artocarpus lanceolatus</i> Trécul	N/A
<i>Artocarpus odoratissimus</i> Blanco	Marang
<i>Artocarpus rigidus</i> Blume	Monkey-jack
<i>Artocarpus sericarpus</i> F. M. Jarrett	N/A
<i>Averrhoa bilimbi</i> L.	Bilimbi
<i>Averrhoa carambola</i> L.	Carambola, starfruit
<i>Azadirachta excelsa</i> (Jack) M. Jacobs	N/A
<i>Baccaurea angulata</i> Merr.	Red angled tampoi
<i>Baccaurea motleyana</i> (Müll. Arg.)	Rambai
<i>Baccaurea racemosa</i> (Reinw.) Müll. Arg.	Menteng
<i>Baccaurea ramiflora</i> Lour.	Burmese grape
<i>Bactris gasipaes</i> Kunth	Peach palm
<i>Balakata baccata</i> (Roxb.) Esser	Jiang guo wu jiu
<i>Barringtonia edulis</i> Seem.	Cutnut
<i>Benincasa hispida</i> (Thunb.) Cogn.	Ash gourd, ash pumpkin
<i>Bischofia javanica</i> Blume	Java-cedar, needlebark
<i>Blighia sapida</i> K. D. Koenig	Akee

<i>Borassus flabellifer</i> L.	Toddy palm
<i>Bouea macrophylla</i> Griff.	Gandaria
<i>Bouea oppositifolia</i> (Roxb.) Meisn.	Plum mango
<i>Breynia reclinata</i> (Roxb.) Hook. f.	N/A
<i>Bridelia stipularis</i> (L.) Blume	Lulalub
<i>Callicarpa longifolia</i> Lam.	Chukin
<i>Calophyllum inophyllum</i> L.	Alexandrian laurel, kamani
<i>Cananga odorata</i> (Lam.) hook. f. & Thomson	Ylang-ylang
<i>Canarium album</i> (Lour.) Raeusch	Chinese olive
<i>Capparis sepiaria</i> L.	Hedge caper bush
<i>Capparis tomentosa</i> Lam.	African caper
<i>Capsicum annuum</i> L.	Chili Bell pepper, chili, nioii lei,
<i>Capsicum chinense</i> Jacq.	Bonnet pepper
<i>Capsicum frutescens</i> L.	Tabasco pepper
<i>Capsicum pubescens</i> Ruiz & Pav.	Apple chile
<i>Careya arborea</i> Roxb.	N/A
<i>Careya sphaerica</i> Roxb.	Kra doon
<i>Carica papaya</i> L.	Papaya
<i>Carissa carandas</i> L.	Carandas-plum
<i>Carissa spinarum</i> L.	Currentbush
<i>Caryota mitis</i> Lour.	Burmese fishtail palm

<i>Casimiroa edulis</i> La Llave & Lex.	White sapote
<i>Celtis tetrandra</i> Roxb.	Si rui po
<i>Chionanthus parkinsonii</i> (Hutch.) Bennet & Raizada	N/A
<i>Choerospondias axillaris</i> (Roxb.) B. L. Burtt & A. W. Hill	N/A
<i>Chrysobalanus icaco</i> L.	Coco plum
<i>Chrysophyllum albidum</i> G. Don	White star apple
<i>Chrysophyllum cainito</i> L.	Caimito, star apple
<i>Chrysophyllum roxburghii</i> G. Don	Athapala
<i>Chukrasia tabularis</i> A. Juss.	Burmese almondwood
<i>Cinnamomum yabunikkei</i> H. Ohba	Yabu-nikkei
<i>Cissus repens</i> Lam.	N/A
× <i>Citrofortunella floridana</i> J. W. Ingram & H. E. Moore	Limequat
× <i>Citrofortunella microcarpa</i> (Bunge) Wijnands	Calamandarin, calamondin
<i>Citrullus colocynthis</i> (L.) Schrad.	Bitter apple, wild gourd
<i>Citrullus lanatus</i> (Thunb.) Matsum. & Nakai	Watermelon
<i>Citrus aurantiifolia</i> (Christm. Swingle)	Sour lime, lime
<i>Citrus aurantium</i> L.	Sour orange
<i>Citrus clementina</i> Hort. ex Tanaka	Clementine
<i>Citrus deliciosa</i> Ten.	Italian tangerine, willow-leaf mandarin
<i>Citrus depressa</i> Hayata	N/A
<i>Citrus hystrix</i> DC.	Kaffir lime

<i>Citrus jambhiri</i> Lush.	Rough lemon
<i>Citrus keraji</i> Hort. ex Tanaka	Kabuchi, keraji
<i>Citrus latifolia</i> (Yu. Tanaka) Tanaka	Persian lime
<i>Citrus limetta</i> Risso	Sweet lime
<i>Citrus limettioides</i> Tanaka	Indian sweet lime
<i>Citrus limon</i> (L.) Burm. f.	Lemon
<i>Citrus limonia</i> Osbeck	Rangpur lime
<i>Citrus maxima</i> (Burm.) Merrill	Pummelo, shaddock
<i>Citrus natsudaidai</i> Hayata	Japanese summer grapefruit, natsu-daidai
<i>Citrus nobilis</i> Lour.	King orange
<i>Citrus oto</i> Hort. ex Yu. Tanaka	N/A
<i>Citrus paradisi</i> Macfady	Grapefruit
<i>Citrus reticulata</i> Blanco	Mandarin orange, tangerine
<i>Citrus sinensis</i> (L.) Osbeck	Common, Kona, or sweet orange
<i>Citrus</i> × <i>tangelo</i> J. W. Ingram & H. E. Moore	Tangelo
<i>Citrus unshiu</i> Marcow.	Satsuma orange, unshū-mikan
<i>Clausena lansium</i> (Lour.) Skeels	Wampi
<i>Clusia rosea</i> Jacq.	Copey
<i>Coccinia grandis</i> (L.) Voigt	Ivy gourd
<i>Coccoloba uvifera</i> (L.) L.	Sea grape
<i>Coffea arabica</i> L.	Arabian coffee, coffee

<i>Coffea canephora</i> Pierre ex A. Froehner	Robusta coffee
<i>Cordia dentata</i> Poir.	English clammy berry
<i>Cordyla pinnata</i> (A. Rich.) Milne-Redh.	N/A
<i>Crescentia cujete</i> L.	Calabash
<i>Crinum asiaticum</i> L.	Asiatic poisonbulb, spider lily
<i>Cucumis ficifolius</i> A. Rich.	Cucumis
<i>Cucumis melo</i> L.	Cantaloupe, melon
<i>Cucumis sativus</i> L.	Cucumber
<i>Cucurbita argyrosperma</i> C. Huber	Cushaw
<i>Cucurbita maxima</i> Duchesne	Squash
<i>Cucurbita moschata</i> Duchesne	Butternut pumpkin, butternut, squash
<i>Cucurbita pepo</i> L.	Pumpkin, zucchini squash
<i>Desmos chinensis</i> Lour.	Jia ying zhua
<i>Dillenia obovata</i> (Blume) Hoogland	Simpoh padang
<i>Dimocarpus longan</i> Lour.	Longan
<i>Diospyros abyssinica</i> (Hiern) F. White	Native persimmon
<i>Diospyros areolata</i> King & Gamble	N/A
<i>Diospyros blancoi</i> A. DC.	Mabolo, velvet apple
<i>Diospyros castanea</i> (Craib). H. R. Fletcher	N/A
<i>Diospyros dasyphylla</i> Kurz	N/A

<i>Diospyros diepenhorstii</i> Miq.	Kaya malam
<i>Diospyros digyna</i> Jacq.	Black persimmon, black sapote
<i>Diospyros glandulosa</i> Lace	Mai kua thoun
<i>Diospyros japonica</i> Siebold & Zucc.	Ryūkyū-mamegaki
<i>Diospyros kaki</i> Thunb.	Japanese persimmon, kaki, Oriental persimmon
<i>Diospyros malabarica</i> (Desr.) Kostel.	Indian persimmon
<i>Diospyros maritima</i> Blume	Sea ebony
<i>Diospyros mespiliformis</i> Hochst. Ex A. DC	Jackalberry, African ebony
<i>Diospyros mollis</i> Griff.	Ma kluea
<i>Diospyros montana</i> Roxb.	Mountain persimmon
<i>Diospyros sandwicensis</i> (A. DC.) Fosberg	Elama, lama
<i>Diospyros virginiana</i> L.	American persimmon
<i>Diplocyclos palmatus</i> (L.) C. Jeffrey	Striped-cucumber
<i>Dovyalis hebecarpa</i> (Gardner) Warb.	Ceylon gooseberry, kitebilla
<i>Dracaena steudneri</i> Schweinf. ex Engl.	Northern large leaf dragon tree
<i>Drypetes floribunda</i> (Mull. Arg.) Hutch.	N/A
<i>Ehretia microphylla</i> Lam.	Philippine tea
<i>Elaeocarpus hygrophilus</i> Kurz	Ma-kok-nam
<i>Elaeocarpus serratus</i> L.	Ceylon olive
<i>Eriobotrya japonica</i> (Thunb) Lindl.	Loquat
<i>Erycibe subspicata</i> Wall. ex G. Don	Zhui xu ding gong teng

<i>Eugenia brasiliensis</i> Lam.	Brazil cherry, Brazilian plum
<i>Eugenia megacarpa</i> Craib	N/A
<i>Eugenia palumbis</i> Merr.	N/A
<i>Eugenia uniflora</i> L.	Surinam cherry
<i>Excoecaria agallocha</i> L.	Blind-your-eye mangrove
<i>Fagraea berteriana</i> A. Gray ex Benth.	Pua kenikeni
<i>Fagraea ceilanica</i> Thunb.	Hui li
<i>Fibraurea tinctoria</i> Lour.	Sekunyit
<i>Ficus auriculata</i> Lour.	Roxburgh fig
<i>Ficus benjamina</i> L.	Benjamin fig
<i>Ficus carica</i> L.	Common fig, fig
<i>Ficus chartacea</i> (Wall. ex Kurz) Wall. ex King	Zhi ye rong
<i>Ficus erecta</i> Thunb.	Ai xiao tian xian guo
<i>Ficus fistulosa</i> Reinw. ex Blume	Yellow stem fig
<i>Ficus hirta</i> Vahl	Cu ye rong
<i>Ficus hispida</i> L. f.	Hairy fig
<i>Ficus lepicarpa</i> Blume	N/A
<i>Ficus microcarpa</i> L. f.	Chinese banyan
<i>Ficus obpyramidata</i>	N/A
<i>Ficus ottoniifolia</i> Miq.	N/A
<i>Ficus pumila</i> L.	Bi li, creeping mission fig

<i>Ficus racemosa</i> L.	Cluster fig
<i>Ficus religiosa</i> L.	Sacred fig
<i>Ficus septica</i> Burm. f.	Septic fig
<i>Ficus sycomorus</i> L.	Sycamore fig, mulberry fig, wild fig
<i>Ficus virgata</i> Reinw. ex Blume	Dao rong
<i>Flacourtia indica</i> (Burman f.) Merrill	Governor's plum, ramontehi, rukam
<i>Flacourtia rukam</i> Zoll. & Moritzi	Prunier café
<i>Flueggea virosa</i> (Roxb. ex Willd) Royle	Common bushweed
<i>Fortunella japonica</i> (Thunb.) Swingle	Calamondin orange, Chinese orange, kumquat
<i>Fortunella margarita</i> (Lour.) Swingle	Nagami kumquat
<i>Fortunella polyandra</i> (Ridl.) Tanaka	Malayan kumquat
<i>Garcinia atroviridis</i> Griff. ex T. Anderson	Gelugor
<i>Garcinia speciosa</i> Wall.	Ma pong
<i>Garcinia costata</i> Hemsl. ex King	N/A
<i>Garcinia cowa</i> Roxb. ex DC.	Cowa
<i>Garcinia dulcis</i> (Roxb.) Kurz	Eggtree
<i>Garcinia griffithii</i> T. Anderson	N/A
<i>Garcinia hombroniana</i> Pierre	N/A
<i>Garcinia intermedia</i> (Pittier) Hammel	N/A
<i>Garcinia mangostana</i> L.	Mangosteen
<i>Garcinia mannii</i> Oliv.	Kar

<i>Garcinia parvifolia</i> Miq.	Kandis
<i>Garcinia prainiana</i> King	Button mangosteen
<i>Garcinia subelliptica</i> Merr.	N/A
<i>Garcinia venulosa</i> (Blanco) Choisy	N/A
<i>Garcinia xanthochymus</i> Hook. f.	Gourka, gamboge tree
<i>Garuga floribunda</i> Decne.	Garuga, nemismis
<i>Glochidion littorale</i> Blume	Saka saka
<i>Glycosmis pentaphylla</i> (Retz.) DC.	Shan xiao ju
<i>Gmelina elliptica</i> Sm.	Badhara bush
<i>Gmelina philippensis</i> Cham.	N/A
<i>Gymnopetalum scabrum</i> (Lour.) W. J. de Wilde & Duyfjes	Feng gua
<i>Gynochthodes umbellata</i> (L.) Razafim. & B. Bremer	Common Indian mulberry
<i>Haematostaphis barteri</i> Hook. f.	N/A
<i>Hanguana malayana</i> (Jack) Merr.	N/A
<i>Hexalobus monopetalus</i> (A. Rich.) Engl. & Diels	N/A
<i>Heynea trijuga</i> Roxb. ex Sims	N/A
<i>Holigarna kurzii</i> King	N/A
<i>Horsfieldia subglobosa</i> Warb.	Penarahan
<i>Hylocereus undatus</i> (Haw.) Britton & Rose	Dragon fruit
<i>Icacina oliviformis</i> (Poir.) J. Raynal	False yam
<i>Inocarpus fagiferus</i> (Parkinson) Fosberg	Marrup, Tahitian chestnut

<i>Irvingia gabonensis</i> (Aubry-Lecomte ex O'Rorke) Baill.	Dikanut
<i>Irvingia malayana</i> Oliv. ex A. W. Benn.	Kabok
<i>Ixora javanica</i> (Blume) DC.	N/A
<i>Ixora macrothyrsa</i> (Teijsm. & Binn.) R. Br.	Santan-pula
<i>Juglans hindsii</i> (Jeps.) R. E. Sm.	California walnut, Hinds's walnut
<i>Juglans nigra</i> L.	Black walnut
<i>Juglans regia</i> L.	English walnut
<i>Kedrostis leloja</i> (Forssk.) C. Jeffrey	N/A
<i>Knema globularia</i> (Lam.) Warb.	Xiao ye hong guang shu
<i>Lagenaria siceraria</i> (Molina) Standl.	Bottle gourd
<i>Lansium domesticum</i> Corrêa	Langsat, lanzones
<i>Lansium parasiticum</i> (Osbeck) K. C. Sahni & Bennet	N/A
<i>Lepisanthes alata</i> (Blume) Leenh.	Sinpaju
<i>Lepisanthes fruticosa</i> (Roxb.) Leenh.	N/A
<i>Lepisanthes rubiginosa</i> (Roxb.) Leenh.	Kelatiayu
<i>Lepisanthes tetraphylla</i> (Vahl) Radlk.	N/A
<i>Litchi chinensis</i> Sonn.	Litchi, lychee
<i>Litsea glutinosa</i> (Lour.) C. B. Rob.	Bolly-beech
<i>Litsea salicifolia</i> (J. Roxb. ex Nees) Hook. f.	Hei mu jiang zi
<i>Luffa acutangula</i> (L.) Roxb.	Ribbed loofah

<i>Luffa aegyptiaca</i> Mill.	Loofah
<i>Lycianthes biflora</i> (Lour.) Bitter	Hong si xian
<i>Machilus thunbergii</i> Siebold & Zucc.	Tabu
<i>Maclura cochinchinensis</i> (Lour.) Corner	Cockspurthorn
<i>Maerua duchesnei</i> (De Wild.) F. White	N/A
<i>Malpighia emarginata</i> DC.	Barbados cherry, acerola,
<i>Malpighia glabra</i> L.	Acerola, Acerola cherry, Barbados cherry, west Indian, cherry
<i>Malus pumila</i> Mill.	Apple, domestic apple
<i>Malus sylvestris</i> (L.) Mill.	Apple, crab apple
<i>Mammea siamensis</i> T. Anderson	N/A
<i>Mangifera caesia</i> Jack	Wani
<i>Mangifera caloneura</i> Kurz	Mamuangpa
<i>Mangifera foetida</i> Lour.	Bachang mango
<i>Mangifera griffithii</i> Hook. f.	Rawa
<i>Mangifera indica</i> L.	Mango
<i>Mangifera laurina</i> Blume	Boa pow, mangga
<i>Mangifera longipetiolata</i> King	Asam damaran, asam kumbang
<i>Mangifera odorata</i> Griff.	Kuine, Saipan mango
<i>Mangifera pajang</i> Kosterm.	Bambangan
<i>Manilkara jaimiqui</i> (C. Wright) Dubard	Wild sapodilla
<i>Manilkara zapota</i> (L.) P. Royen	Sapote, chicle, chiku, sapodilla

<i>Merremia vitifolia</i> (Burm. f.) Hallier f.	Zhang ye yu huang cao
<i>Microcos tomentosa</i> Sm.	N/A
<i>Mimusops elengi</i> L.	Elengi, pogada, Spanish cherry
<i>Mitrephora maingayi</i> Hook. f. & Thomson	Thabut-net
<i>Momordica balsamina</i> L.	Balsam apple, bitter melon
<i>Momordica charantia</i> L.	Balsam pear, bitter melon
<i>Momordica cochinchinensis</i> (Lour.) Spreng.	Balsam apple
<i>Morella rubra</i> Lour.	Chinese-arbutus
<i>Morinda citrifolia</i> L.	Noni, Indian mulberry
<i>Morinda coreia</i> Buch.-Ham.	N/A
<i>Morus alba</i> L.	White mulberry
<i>Morus nigra</i> L.	Black mulberry
<i>Muntingia calabura</i> L.	Jamaica cherry
<i>Murraya exotica</i> L.	Chinese-boxwood
<i>Murraya paniculata</i> (L.) Jack	Mock orange, orange jasmine
<i>Musa acuminata</i> Colla	Chinese banana, dwarf banana ²
<i>Musa balbisiana</i> Colla	Plantain
<i>Musa basjoo</i> Siebold & Zucc. Ex Linuma	Japanese banana
<i>Musa ×paradisica</i> L.	Banana, common banana ²
<i>Musa troglodytarum</i> L.	Fe'i banana
<i>Myxopyrum smilacifolium</i> Blume	N/A

<i>Nauclea orientalis</i> (L.) L.	Canary wood
<i>Neolamarckia cadamba</i> (Roxb.) Bosser	Burflower tree
<i>Neolitsea sericea</i> (Blume) Koidz.	Shirodamo
<i>Nephelium cuspidatum</i> Blume	Panungaian
<i>Nephelium lappaceum</i> L.	Rambutan
<i>Nestegis sandwicensis</i> (A. Gray) O. Deg., I. Deg. & L. A. S. Johnson	Olopua
<i>Ochreinauclea maingayi</i> (Hook. f.) Ridsdale	N/A
<i>Ochrosia mariannensis</i> A. DC.	N/A
<i>Olax scandens</i> Roxb.	Dheniani
<i>Opilia amentacea</i> Roxb.	N/A
<i>Opuntia ficus-indica</i> (L.) Mill.	Cactus, prickly pear
<i>Palaquium maingayi</i> (C. B. Clarke) King & Gamble	Nyatoh
<i>Pandanus fragrans</i> Gaudich	Screw pine
<i>Pandanus odorifer</i> (Forssk.) Kuntze	Hala, pandanus, screw pine
<i>Parinari anamensis</i> Hance	N/A
<i>Parkia biglobosa</i> (Jacq.) R. Br. ex G. Don	African locust-bean
<i>Parkia speciosa</i> Hassk.	Petai
<i>Passiflora caerulea</i> L.	N/A
<i>Passiflora edulis</i> Sims	Lilikoi, passion fruit, purple, granadilla, yellow lilikoi

<i>Passiflora foetida</i> L.	Love-in-a-mist, pohapoha, stinking passion fruit
<i>Passiflora incarnata</i> L.	Maypop, wild passion fruit
<i>Passiflora laurifolia</i> L.	Bell apple, water lemon, yellow granadilla
<i>Passiflora ligularis</i> Juss.	Sweet granadilla
<i>Passiflora quadrangularis</i> L.	Giant granadilla
<i>Passiflora suberosa</i> L.	N/A
<i>Passiflora tripartita</i> (Juss.) Poir.	Banana passion fruit, soft leaf, passionflower
<i>Pereskia grandiflora</i> Pfeiff.	N/A
<i>Persea americana</i> Miller	Alligator pear, avocado
<i>Phoenix dactylifera</i> L.	Date palm
<i>Phyllanthus acidus</i> (L.) Skeels	Gooseberry tree
<i>Physalis minima</i> L.	Green gooseberry
<i>Physalis peruviana</i> L.	Ground cherry, poha
<i>Pimenta dioica</i> (L.) Merrill	Allspice
<i>Planchonella duclitan</i> (Blanco) Bakh. f.	N/A
<i>Polyalthia longifolia</i> (Sonn.) Thwaites	
<i>Polyalthia simiarum</i> (Buch.-Ham. ex Hook. f. & Thomson) Benth. ex Hook. f. & Thomson	N/A
<i>Pometia pinnata</i> J. R. Forst. & G. Forst.	Fijian longan
<i>Poncirus trifoliata</i> (L.) Raf.	Japanese bitter orange

<i>Pouteria alnifolia</i> (Baker) Roberty	N/A
<i>Pouteria caimito</i> (Ruiz & Pav.) Radlk.	Abiu
<i>Pouteria campechiana</i> (Kunth) Baehni	Canistel, egg fruit, egg fruit tree
<i>Pouteria sapota</i> (Jacq.) H. E. Moore & Stearn	Mamey sapote, marmalade fruit
<i>Pouteria viridis</i> (Pittier) Cronquist	Green sapote
<i>Premna serratifolia</i> L.	Coastal premna
<i>Prunus armeniaca</i> L.	Apricot
<i>Prunus avium</i> (L.) L.	Sweet cherry
<i>Prunus campanulata</i> Maxim.	Taiwan cherry
<i>Prunus cerasifera</i> Ehrh.	Cherry plum, methley plum
<i>Prunus cerasoides</i> D. Don	Sour cherry, wild Himalayan cherry
<i>Prunus cerasus</i> L.	Sour cherry, maraschino cherry
<i>Prunus domestica</i> L.	Common plum, European plum
<i>Prunus ilicifolia</i> (Nutt. ex Hook. & Arn.) D. Dietr.	Catalina cherry, hollyleaf cherry
<i>Prunus mume</i> Siebold & Zucc.	Japanese apricot
<i>Prunus persica</i> (L.) Batsch.	Peach. Nectarine
<i>Prunus salicina</i> Lindl.	Japanese plum
<i>Prunus salicina</i> Lindl. x <i>Prunus cerasifera</i> Ehrn.	Methley plum
<i>Psidium cattleyanum</i> Sabine	Purple, red and yellow strawberry guava, strawberry
<i>Psidium guajava</i> L.	Common guava, guava
<i>Punica granatum</i> L.	Pomegranate ³

<i>Pyrus communis</i> L.	Pear
<i>Pyrus pashia</i> Buch.-Ham. ex D. Don	N/A
<i>Pyrus pyrifolia</i> (Burm. f.) Nakai	Sand pear
<i>Rhodomyrtus tomentosa</i> (Aiton) Hassk.	Downy rose myrtle, myrtle
<i>Saba comorensis</i> (Bojer ex A. DC.) Pichon	N/A
<i>Saba senegalensis</i> (A. DC.) Pichon	Liane saba, mad, made
<i>Salacia verrucosa</i> Wight	N/A
<i>Sambucus javanica</i> Reinw. ex Blume	Chinese elder
<i>Sandoricum koetjape</i> (Burm. f.) Merrill	Santol
<i>Santalum paniculatum</i> Hook. & Arn.	sandalwood
<i>Sarcocephalus latifolius</i> (Sm.) Bruce	Country fig
<i>Sauropus androgynus</i> (L.) Merr.	Star gooseberry, katuk
<i>Schoepfia fragrans</i> Wall.	N/A
<i>Sclerocarya birrea</i> (A. Rich.) Hochst.	Maroola plum
<i>Shirakiopsis indica</i> (Willd.) Esser	N/A
<i>Simarouba glauca</i> DC.	Paradise tree
<i>Siphonodon celastrineus</i> Griff.	N/A
<i>Solanum aculeatissimum</i> Jacq.	Dutch eggplant
<i>Solanum aethiopicum</i> L.	Kumba
<i>Solanum americanum</i> Mill.	N/A
<i>Solanum anguivi</i> Lam.	African eggplant

<i>Solanum betaceum</i> Cav.	Tree tomato
<i>Solanum capsicoides</i> All.	N/A
<i>Solanum donianum</i> Walp.	Mullein, nightshade
<i>Solanum erianthum</i> D. Don	Big eggplant
<i>Solanum granulosoleprosum</i> Dunal	N/A
<i>Solanum incanum</i> L.	Bitter apple
<i>Solanum lasiocarpum</i> Dunal	Indian nightshade
<i>Solanum linnaeanum</i> Hepper & P.-M. L. Jaeger	Apple-of-sodom
<i>Solanum lycopersicum</i> L.	Tomato
<i>Solanum macrocarpon</i> L.	Gboma eggplant
<i>Solanum mammosum</i> L.	Macawbush
<i>Solanum mauritianum</i> Scop.	Bugtree
<i>Solanum melongena</i> L.	Eggplant
<i>Solanum muricatum</i> Aiton	Melon pear, pepino
<i>Solanum nigrescens</i> M. Martens & Galeotti	Divine nightshade
<i>Solanum nigrum</i> L.	Black nightshade
<i>Solanum pimpinellifolium</i> L.	Currant tomato
<i>Solanum pseudocapsicum</i> L.	Jerusalem cherry
<i>Solanum quitoense</i> Lam.	Quito orange
<i>Solanum seaforthianum</i> Andrews	Black nightshade

<i>Solanum sessiliflorum</i> Dunal	Cocona, peach tomato
<i>Solanum stramonifolium</i> Jacq.	N/A
<i>Solanum torvum</i> Sw.	Devil's fig, turkeyberry
<i>Solanum trilobatum</i> L.	N/A
<i>Sorindeia madagascariensis</i> DC.	Sondriry
<i>Spondias dulcis</i> Sol. ex Parkinson	Otaheite apple, Jew plum, wi apple
<i>Spondias mombin</i> L.	Jamaica plum, yellow mombin
<i>Spondias pinnata</i> L.	Common hog plum
<i>Spondias purpurea</i> L.	Purple mombin, red mombin, Spanish plum
<i>Streblus asper</i> Lour.	N/A
<i>Strychnos mellodora</i> S. Moore	N/A
<i>Strychnos nux-vomica</i> L.	N/A
<i>Syzygium aqueum</i> (Burm. f.) Alston	Water apple, watery rose apple
<i>Syzygium aromaticum</i> (L.) Merr. & L. M. Perry	Clove
<i>Syzygium borneense</i> (Miq.) Miq.	N/A
<i>Syzygium cumini</i> (L.) Skeels	Malay apple, Java plum
<i>Syzygium formosanum</i> (Hayata) Mori.	Tai wan pu tao
<i>Syzygium grande</i> (Wight) Walp.	N/A
<i>Syzygium jambos</i> (L.) Alston	Rose apple
<i>Syzygium lineatum</i> (DC.) Merr. & L. M. Perry	N/A
<i>Syzygium malaccense</i> (L.) Merrill & L. M. Perry	Mountain apple, Malay apple

<i>Syzygium nervosum</i> DC.	Daly River, satin-ash
<i>Syzygium samarangense</i> (Blume) Merr. & L. M. Perry	Java apple, water guava
<i>Terminalia bellirica</i> (Gaertn.) Roxb.	Belleric, beach almond
<i>Terminalia catappa</i> L.	False kamani, tropical almond
<i>Terminalia chebula</i> Retz.	Black myrobalan, chebula
<i>Terminalia citrina</i> (Gaertn.) Roxb. Ex Fleming	Black chuglam
<i>Theobroma cacao</i> L.	Cocoa
<i>Thevetia peruviana</i> (pers.) K. Schum.	Yellow oleander
<i>Toddalia asiatica</i> (L.) Lam.	N/A
<i>Trichosanthes costata</i> Blume	N/A
<i>Trichosanthes pilosa</i> Lour.	Snake gourd
<i>Triphasia trifolia</i> (Burm. f.) P. Wilson	Limeberry
<i>Turpinia ternata</i> Nakai	San ye shan xiang yuan
<i>Uvaria grandiflora</i> Roxb. ex Hornem.	N/A
<i>Uvaria littoralis</i> (Blume) Blume	N/A
<i>Vaccinium reticulatum</i> Sm.	Ohelo
<i>Viburnum japonicum</i> (Thunb.) Spreng.	Hakusan-boku
<i>Vitellaria paradoxa</i> C. F. Gaertn.	Shea-butter tree
<i>Vitis</i> spp.	Grapes
<i>Wikstroemia phillyreifolia</i> A. Gray	Akia, false ohelo
<i>Wikstroemia uva-ursi</i> A. Gray	Akia, false ohelo

<i>Willughbeia cochinchinensis</i> (Pierre) K. Schum.	N/A
<i>Willughbeia coriacea</i> Wall.	Borneo rubber
<i>Xanthophyllum flavescens</i> Roxb.	N/A
<i>Ximenia americana</i> L.	Yellow plum
<i>Zehneria mucronata</i> (Blume) Miq.	N/A
<i>Zehneria wallichii</i> (C. B. Clarke) C. Jeffrey	N/A
<i>Ziziphus jujuba</i> Mill.	Jujube
<i>Ziziphus mauritiana</i> Lam.	Chinese date, Jujube
<i>Ziziphus mucronata</i> Willd.	N/A
<i>Ziziphus nummularia</i> (Burm. f.) Wight & Arn.	N/A
<i>Ziziphus oenoplia</i> (L.) Mill.	N/A

Diagnostic information

An identification guide for Oriental Fruit Fly has been developed by PaDIL (<https://www.padil.gov.au/compare?pestIds=136199>).

- **Body Coloration:** The body of the Oriental fruit fly is predominantly black or dark fuscous, sometimes with a combination of black and yellow.
- **Face:** The face of the fly may have a transverse sulcus or distinct antennal grooves. Additionally, there may be dark spots present in the antennal furrows.
- **Thorax:** The thorax, specifically the scutum (the upper surface of the thorax), can be black with orange to red-brown areas or entirely black.
- **Lateral Stripes:** There are typically two pale whitish to yellow stripes located on the lateral sides of the thorax. These stripes may extend to the intra-alal bristles or even beyond.
- **Leg Coloration:** The femora (thigh segments) of the legs are all of one color and do not show variation.
- **Wing Characteristics:** The wings have an apical band in cell r4+5, and the ratio of the width of this band to the length of the r-m vein falls within the range of 0.25 to 0.33.
- **Abdomen:** The abdominal tergites (dorsal plates of the abdomen) exhibit a dark stripe along the midline of T3-T5. Additionally, there is a transverse dark line on T3.

- Female Terminalia: In females, the terminalia (reproductive structures) display a ratio between the syntergosternite 7 and abdominal tergite 5, ranging from 0.7 to 0.75.
- Aculeus Length: The aculeus, which is a needle-like structure at the posterior end of the abdomen, typically measures between 1.4 and 1.6 mm.

Whole body



Fore wing



Head front



Head side



Head top



Lateral



Posterior



Thorax above



Thorax side



Control measures

3.1 International Standards (IAEA)

Several coordinated research projects to assess the application of Sterile Insect Technology for Bactrocera fruit fly management are being run through the IAEA.

- Simultaneous Application of SIT and MAT to Enhance Pest Bactrocera Management D41027
- Irradiated Fruit Flies: the Secret to Protecting Thailand's Premium Fruit Exports
- Isolation of Gene Markers Leads to More Effective, Efficient Insect Pest Control
- Update of the technical leaflet released in six languages on the discrimination between two invasive Bactrocera fruit fly pests
- Identification of the Male Determining Factor Reduces the Cost of SIT Application Against Insect Pests

In addition to this the IAEA provide:

- Trapping guidelines for area-wide fruit fly programmes
- Fruit Sampling Guidelines for Area-Wide Fruit Fly Programmes
- Guideline for packing, shipping, holding and release of sterile flies in area-wide fruit fly control programmes
- Guidelines for the use of mathematics in operational area-wide integrated pest management programmes using the sterile insect technique with a special focus on Tephritid fruit flies

3.2 Regions

Gutierrez et al (2021), established the likelihood of incursions of tropical fruit flies into areas that may be affected by several factors including overharvesting, mismanagement or climate change. Several regions already engage in control of several species of fruit flies especially in areas with more favourable climate

conditions (tropical preferred over temperate regions). How Oriental fruit fly is managed in these regions is dependent on a number of factors, including environment, established programs, resources, affected industries and IAEA support.

3.2.1 Asia

Oriental fruit fly is endemic to much of tropical Asia. Countries with established infestations include (CABI 2020; Vargas et al. 2007): Bangladesh, Bhutan, Cambodia, China (southern), Hong Kong, India, Indonesia, Japan (Ryukyu Islands), Laos, Malaysia, Myanmar, Nepal, Ogasawara Islands, Pakistan, Philippines, Sri Lanka, Taiwan, Thailand, Vietnam.

Management has often been in collaboration with IAEA and has resulted in implementing an area-wide integrated fruit fly management programme in many of the affected countries. This includes preharvest orchard management, baiting, trapping, sterile insect technique (SIT) components, Male Annihilation and general surveillance. Table (1) illustrates current methods employed by the countries listed above.

Table 1: Current control methods used by Asian countries against *B.dorsalis*.

COUNTRY	EARLY DETECTION	WIDE RESPONSE PLANS	GROWER MANAGED PROTOCOLS	REGULATORY CONTROL	CULTURAL CONTROL	CHEMICAL CONTROL	STERILE INSECT TECHNIQUE)	MALE SUPPRESSION	FIELD MONITORING	EARLY WARNING (PATHWAYS FROM OTHER COUNTRIES)
BANGLADESH	Endemic	x	✓	x	Bagging	✓	x	x	✓	✓
BHUTAN	Endemic	x	✓	x	Baiting hygiene	✓	x	x	✓	x
CAMBODIA	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
CHINA	Endemic	✓	✓	✓	Bagging orchard hygiene	✓	✓	✓	✓	✓
HONG KONG	Endemic	x	✓	x	Bagging orchard hygiene	✓	x	x	✓	x
INDIA	Endemic	✓	✓	✓	Bagging orchard hygiene	✓	x	✓	✓	x
INDONESIA	Endemic	x	✓	x	Orchard hygiene	✓	✓	✓	✓	x
JAPAN (ISLANDS)	Invasive	✓	✓	✓	Orchard hygiene	✓	✓	✓	✓	✓
LAOS	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
MALAYSIA	Endemic	x	✓	x	Bagging orchard hygiene	✓	x	x	✓	x
MYNAMAR	Endemic	x	✓	x	Bagging orchard hygiene	✓	x (part)	x	✓	x
NEPAL	Endemic	x	✓	✓	Bagging orchard hygiene	✓	x	x	✓	x
PAKISTAN	Endemic	x	✓	✓	Orchard hygiene	✓	x	x	✓	✓

PHILIPPINES	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
SRI LANKA	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	x
TAIWAN	Endemic	✓	✓	x	Orchard hygiene	✓	✓	✓	✓	✓
THAILAND	Endemic	✓	✓	x	Orchard hygiene	✓	✓	x	✓	x
VIETNAM	Endemic	x	✓	x	Orchard hygiene	✓	x	x	✓	✓

3.2.2. Africa

B. dorsalis is not endemic to Africa. However, more than forty-five countries of sub-Saharan Africa have become infested since the first appearance of oriental fruit fly (as *Bactrocera invadens*) in Kenya in 2003 (see Goergen et al. 2011). The fly's appearance in Africa is suspected to have occurred around the same time it also occurred in Sri Lanka (Mutamiswa et al 2021). The presence of this invasive pest fruit fly has added to the list of pest and disease that hamper the potential growth of African horticulture. Bans on fruit and vegetable export have added to many African countries' financial losses.

The response by many African nations was initially through monitoring and surveillance programs. However, longer term management was needed after this initial emergency response. Research and integrated pest management plans were developed to ensure continued fruit production and marketing. The World Bank funded research into *B.dorsalis* management (World Bank, 2007) including area wide management and early warning pathway surveillance in order to improve quarantine both nationally and internationally. Research into management protocols has developed in a number of countries within the continent. South Africa is considered one of the worlds top twenty fruit producing countries and work on *B. dorsalis* by South African researchers, Manrakhan et al (2012, 2013, 2017, 2018), has focused on providing practical tools for growers in different regions. Attempts at eradication using bait sprays and MAT have been successful in South Africa (Manrakhan, 2011) in some regional areas but risks of reinfestation remains high.

In addition to individual country management protocols, the IAEA has encouraged cross country collaboration in order to maintain markets for valuable crops and ensure that exported fruits and vegetables fall within importing counties phytosanitary requirements.

Management protocols employed across the African continent are summarised in Table 3.2.

Table 3.2: Summary of management protocols used across Africa against *B.dorsalis*.

EARLY DETECTION	Monitoring and surveillance occurs in some African countries/areas where <i>B.dorsalis</i> is absent (Manarakhan et al, 2015) however a widespread monitoring system as part of an extended management plan including areas where the fly is present <u>and</u> absent in some geographic areas has yet to be developed (Mutamiswa, 2021).
WIDE RESPONSE PLANS	Surveillance, monitoring and development of buffering zones has occurred in parts of Africa (Manrakhan, 2015). Different countries utilize different strategies with some countries particularly in sub-Saharan Africa preferring certain control methods (chemical, cultural or biological control) over widespread response plans.
GROWER MANAGED PROTOCOLS	The majority of fruit growing farmers initiate some form of grower management for fruit fly (and other pests). Some areas within African countries maintain pest free areas of production for production and exportation of fruits to Europe under EPPO guidelines.
REGULATORY CONTROL	Under export conditions exporting African countries are required to follow guidelines of the EPPO and destination importing country regulations (EPPO 2018, 2019).
CULTURAL CONTROL	Orchard hygiene acts as a phytosanitary measure and can suppress populations of <i>B. dorsalis</i> with studies suggesting that populations can be high in fallen fruits such as Mangoes (Rwomushana et al 2008). Bagging remains a popular control of a variety of invasive pests like <i>B.dorsalis</i> .
CHEMICAL CONTROL	Both insecticides are widely used to suppress <i>B. dorsalis</i> with an increase over the past decade (Akotsen-Mensah, 2017). Biopesticides/natural substance use has also increased against fruit flies (Ekesi et al., 2007; Piñero et al., 2009) and is an attractive option for subsistence farming.
STERILE INSECT TECHNIQUE	SIT has not been developed as an area wide management tool for <i>B.dorsalis</i> as yet by any African countries. However, facilities exist for rearing and eradication of other exotic fruit fly species.
MALE SUPPRESSION	MAT has been pivotal in eradication for some South African regions and was successful in Mauritius (Sookar et al., 2014). Ghana and Cameroon have successfully used MAT for managing (but not eradicating) <i>B.dorsalis</i> (Kwasi, 2008; Hanna et al., 2008).
FIELD MONITORING	Pheromone traps with male lures are used across Africa (Karsten et al., 2018). Many of these traps use methyl eugenol to which <i>B.dorsalis</i> is highly attracted (Manrakhan et al., 2014).

INTEGRATED PEST MANAGEMENT

Integrated Pest Management techniques are widely encouraged throughout the regions but is limited with smaller farming enterprises (Muriithi et al., 2020). IPM programs have been used against *B. dorsalis* in Tanzania and West Africa (Vayssières et al., 2015).

POSTHARVEST PHYTOSANITARY MEASURES

Heat and cold treatments remain the most used postharvest treatments. Postharvest hot water dipping is used in green mangoes in Mozambique (Dohino et al., 2016) and further research (Ndlela et al., 2017) endorsed this as a control for *B. dorsalis*. Cold treatments are standard export treatments for a wide variety of commodities to export destinations and have been part of ongoing bilateral agreements between African nations and export destinations.

EARLY WARNING (PATHWAYS FROM OTHER COUNTRIES)

South Africa developed an early warning system and contingency plans to ensure early detection and rapid response to reduce and eradicate populations of *B. dorsalis* (Ndivhuho et al, 2021). The main benefit to Ndivhuho's study was the identification that an ongoing systems approach through area wide management was needed in order to prevent further incursions

3.2.3 North America

3.2.3.1 Mainland USA

Florida and California

In several regions of the United States, USDA APHIS PPQ and state cooperators engage in year-round or seasonal detection trapping for exotic fruit flies. If an infestation is detected in the State, the California Department of Food and Agriculture conducts eradication projects to prevent environmental and economic damage that would be caused by Oriental fruit fly (CDFA, 2018). Male attractant technique is used for eradication, where bait stations with methyl eugenol are placed around chosen sites (utility poles and street trees) (CDFA, 2018).

Florida has a long history of invasive fruit fly detections with four programs prior to 2016 focussing on *B.dorsalis*. One of those detections triggered an emergency response as it occurred within one of southern Florida’s main agricultural areas. Guidelines and triggers for response to *B.dorsalis* across mainland USA can be seen in Table 3.3 with recommendations that regional fruit fly action plans for species- and region-specific operational requirements should be consulted before action is taken.

Table 3.3 USDA Cooperative Fruit Fly Emergency Response Triggers & Guidelines*

	Emergency Response Triggers			
	Delimitation	Duration of Delimitation (# generations for single fly detections)	Eradication	Quarantine
<i>Bactrocera dorsalis</i> (Oriental FF) Other <i>Bactrocera</i> species responding to methyl eugenol (ME): <i>B. zonata</i> (Peach FF), <i>B. correcta</i> (Guava FF), etc	1 fly	F2	2 flies within a 3 mile (4.8 km) radius during 1 life cycle	<p>If ALL finds are >4.5 miles (7.2 km) from commercial host production area: 8 flies (either sex) within a 3mile (4.8 km) radius during 1 life cycle.</p> <p>If any find is <4.5 miles (7.2 km) from commercial host production area: 6 flies within a 3-mile (4.8 km) radius during 1 life cycle.</p>

*APHIS response USDA (2020).

Patterns for response to invasive fruit flies within the mainland USA involves:

- Fruit Fly Detection Trapping
 - Monitored year round
 - High risk areas ports of entry
 - Core and buffer areas
 - Delimitation surveys
- Eradication Measures

- ME feeding lure and bait spray (MAT)
- Soil drenches
- Foliar bait sprays
- Orchard sanitation
- Ariel bait sprays
- Regulatory Measures
 - Monitoring of host plants
 - Grower monitoring for phytosanitary treatments

3.2.3.2 Hawaii

B.dorsalis is an established invasive species in Hawaii. There is existing general information for farmers about how they can control fruit fly, including Oriental fruit fly, on their farms—see full list below. This information may be implemented to help manage Oriental fruit fly populations which differs in its response to mainland USA. Suggested management methods include: exclosure, sanitation, monitoring population levels, identifying host plants and fruit fly life cycles, rotate crops, harvesting fruits when under-ripe, and placing traps and other similar control methods (Messing, 1999). SIT is often employed in conjunction with other means of eradication.

Key steps in managing fruit flies in Hawaii (Messing, 1999)

- Prevention-practice sanitation techniques.
- Monitor the levels of pests; determine if you have economic injury; evaluate and use the best strategies.
- Identify the fruit fly species and become familiar with its life cycle and host plants.
- Determine which other plants in the area are fruit fly hosts, and determine when these plants are fruiting.
- If possible, rotate your crops so they do not fruit when other hosts are fruiting and pest populations are peaking.
- Harvest fruits under-ripe when possible (e.g., papayas are usually fruit fly-free if picked when less than 1/4 ripe).
- If fruit flies cause economic injury, apply appropriate controls.
- Divert pests with poisoned border plants, baits, or lures.
- Monitor pests again and reevaluate your strategies

The control of *B.dorsalis* in Hawaii had relied heavily on chemical control. However, this approach is changing to incorporate a more systems approach through area wide management through research and extension (Mau et al 2007; Vargas et al, 2016)

3.2.4 Central and South America

Throughout central and south America invasive fruit fly species have taken their toll on the regions fruit and vegetable industry. Mediterranean fruit fly in particular has been an issue and through the IAEA a three year project was launched to assess the pest status of invasive fruit fly and encourage the use of SIT along with other control methods. The project succeeded in making five areas either fruit fly free or 'low prevalence'. *B dorsalis* is not currently invasive in the region.

3.2.4.1 Central America

The United States of America has had an ongoing concern about the potential of certain species of tropical fruit flies to invade US agriculture. A result of this is that the USDA has run fruit fly emergence and release facilities within several central American countries. This cooperative agreement for the prevention, detection, suppression and eradication of economically important fruit flies has been an important strategy for mitigating incursions into mainland USA and to provide participating countries technical assistance to conduct fruit fly programs. This includes Mexico, Guatemala and Belize as well as countries within the Caribbean region.

The targeted species for these programs is focussed on Mediterranean fruit fly and the Mexican fruit fly (*Anastrepha ludens* Loew) but recent out breaks of oriental fruit fly into the USA (Florida and California) have necessitated renewed interest in management strategies for regions outside the USA. However, updates to action plans for oriental fruit fly from these regions have not been made since 1989 (USDA, 1989).

3.2.4.2 South America

Brazil: a case study country

Fruit flies are the major cause of fruit drop and currently Brazil employs SIT against Mediterranean Fruit Fly in the north east of the country, (Mello Garcia et al, 2024) with pest free areas allowing for exporting of fruit to the USA and China. Other pest species are handled through a systems approach with pest risk mitigation carried out by farmers at the ground level (sprays, sanitation, cultural control, baiting) and phytosanitary measures at the greater production level. Early detection and pest risk assessments occur in large production areas to ensure Brazil's status as one of the main world fruit and vegetable producers and exporters. Currently no specific plans are in place specifically for *B. dorsalis* as other species are considered more of an economic threat.

3.2.5 Oceania

Tahiti and Papua New Guinea

B. dorsalis is widespread within Tahiti having arrived in 1996 around the same time an outbreak had occurred in Queensland. Eradication programs were conducted from 1997 to 2001 but ultimately failed. Host range on the islands was from around 25 different host plants with *B. dorsalis* displacing two other species of invasive fruit flies. Control measures include the deployment of large numbers of traps baited with highly attractive male-specific lures (methyl eugenol) and general preharvest management, baiting, trapping, chemical and cultural control as well as biological control with a *Fopius arisanus* and *Diachasmimorpha longicaudata* (Hymenoptera: Braconidae). *B. dorsalis* is also now widespread throughout French Polynesia.

Studies suggested that *B. dorsalis* outcompeted *Bactrocera tryoni* another exotic in Tahiti, (LeBlanc et al, 2012, 2013). However further investigation regarding the possibility of it outcompeting *B. tryoni* in Australia (Dominiak, 2024) identified some inconsistencies in reports from the 1996 Queensland incursion and some fundamental differences between the two species that could slow an invasion of *B. dorsalis* and in some instances could be used advantageously as a potential early warning against exotic fly incursions.

fly surveillance, better-targeted eradication programs and risk assessments for imports/exports. *B. dorsalis* is established in Papua New Guinea and is Australia's closest neighbour. As a consequence of PNGs closeness and the risk of being a source for potential *B. dorsalis* incursions into Australia, researchers from the Australian Commonwealth Department of Agriculture Fisheries and Forestry,

continue to deliver extension materials and training to remote parts of PNG. The program trains farmers and agricultural officers to monitor and manage pest fruit flies including *B. dorsalis*. Providing improved biosecurity to the region provides farmers with tools to reduce populations but also provides a source for monitoring of the spread of *B.dorsalis* into mainland Australia and New Zealand.

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Biosecurity Preparedness Simulation Exercises
Testing Oriental Fruit Fly Preparedness

Sydney, 18-19 July 2024

Cairns, 8-9 August 2024

EXERCISE REPORT

ABOUT THE REPORT

The Exercise Motus Report was authored by Plant Health Australia (PHA) in consultation with the Exercise Planning Team which includes representatives from Industry and Government. The purpose of this report is to provide a summary of activities and a critical analysis of the outcomes and learnings of Exercise Motus. The information presented was informed by exercise evaluation and the observations of the Exercise Planning Team and Exercise Evaluators.

Any feedback or questions in relation to the report can be directed to PHA as follows:

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Version Control

VERSION	DATE	COMMENTS
0.A	17/04/2025	Draft provided by PHA to Project Committee and Macquarie University
	30/04/2025	Final version submitted to Macquarie University

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Abbreviations

AgVic	Agriculture Victoria
BAU	Business as usual
BISOP	Biosecurity Incident Standard Operating Procedure
CCEPP	Consultative Committee on Emergency Plant Pests
CEO	Chief Executive Officer
CA	Control Area
DAFF	Department of Agriculture, Fisheries and Forestry
DCP	Dangerous contact premises
EPP	Emergency Plant Pest
EPPRD	Emergency Plant Pest Response Deed
FASTA	Fresh and Secure Trade Alliance
HPP	High priority pest
IAEA	International Atomic Energy Agency
ILC	Industry Liaison Coordinator
ILO	Industry Liaison Officer
NMG	National Management Group
NSW DPIRD	New South Wales Department of Primary Industries and Regional Development
PBPWG	Plant Biosecurity Preparedness Working Group
PIB	Peak Industry Body
PIF	Plant Industry Forum
PIRSA	Department of Primary Industries and Regions, South Australia
PFA	Pest Free Area
PHA	Plant Health Australia
QDPI	Queensland Department of Primary Industries
RA	Restricted Area
SARDI	South Australian Research and Development Institute
TFE	Technical Feasibility of Eradication

EXECUTIVE SUMMARY

Bactrocera dorsalis (oriental fruit fly, OFF) is a significant horticultural biosecurity threat to Australia, with the potential to cause large scale economic impacts should it establish in Australia. Oriental fruit fly has an extensive host list and causes damage to a crop when female flies pierce the fruit or vegetable's skin to lay their eggs beneath the surface. This process introduces bacteria which causes rotting, which the maggots will then feed on. If OFF were to establish in Australia it could cause significant damage to Australia's \$9 billion horticulture industry.

To enhance biosecurity preparedness for OFF, Exercise Motus, led by Plant Health Australia conducted multiple simulation exercises across Sydney and Cairns to test current and potential requirements for managing an OFF incursion. The exercise involved extensive collaboration between industry and government representatives and examined the response by government and industry to a detection in Sydney, New South Wales (NSW) and in Mareeba, Queensland (QLD).

Discussions and activities during the exercises focused on the following objectives:

- Understanding the immediate actions that would need to be undertaken by both government and industry in the early phase of a response to maintain business continuity.
- Examining the impacts on business continuity through identifying the effects on production and movements at a regional and state level.
- Testing recommended fruit fly commodity movement protocols (from an infested area for treatment prior to going to market) that have been developed under the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project.
- Identifying potential issues or critical gaps in the recommended movement protocols and solutions that could be considered by the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project team.

Each of these objectives were tested in the scenarios, except for objective 3, which did not occur as the draft protocols contained insufficient level detail to enable participants to provide constructive feedback. As a result, the scenarios were modified to instead ask participants to capture what information would be required to support the development of functional movement protocols in the future.

Key findings from the exercises included the importance of clear and consistent communication, the need for pre-agreed movement protocols, and the significance of engaging all stakeholders, including local councils and community leaders. This report emphasises the value of a unified approach between government and industry to ensure a common understanding and acceptance of response actions.

Several recommendations have been made to improve biosecurity preparedness that require input from state and territory governments, Department of Agriculture, Fisheries and Forestry (DAFF), affected industries, researchers, the National Fruit fly Council (NFFC) and Plant Health Australia (PHA), exemplifying how OFF requires a national approach.

Overall, the Exercise Motus Report demonstrates the commitment of PHA and its partners to safeguarding Australia's horticultural sector from the threat of exotic fruit flies. The collaborative efforts and insights gained from this exercise will undoubtedly strengthen the nation's biosecurity framework and ensure a swift and effective response to future biosecurity threats. It is important to note the importance of reporting early to reduce the impact of the exotic plant pest and prevent spread. The Emergency Plant Pest Response Deed (EPPRD) is a formal, legally binding agreement between Plant Health Australia (PHA), the Australian Government, all state and territory governments and plant industry signatories, covering the management and funding of responses to Emergency Plant Pest (EPP) Incidents. *Bactrocera dorsalis* is an exotic plant pest, and if detected, parties are obligated to respond to eradicate the pest as required under the EPPRD.

RECOMMENDATIONS

	RECOMMENDATION	POTENTIAL LEAD
1	Develop an industry engagement campaign, engaging with affected PIBs, on the impacts of <i>B. dorsalis</i> , to reduce apathy regarding fruit fly surveillance.	NFFC
2	In consultation with industry, provide specific information on the signs and symptoms of <i>B. dorsalis</i> damage in the forms of fact sheets or webpages. As well as the importance of early reporting and all suspect pests can be reported to the Exotic Plant Pest Hotline (1800 084 881).	NFFC
3	Work with fruit fly impacted industries to inform them of prevention and preparedness activities growers can undertake that may support business continuity during a response.	PHA
4	Work with fruit fly impacted industries to promote the PHA industry resource toolkit to help growers understand response processes and actions.	PHA
5	States and territories to consider how they could best circulate up to date and easily accessible information on movement controls, in the event of an oriental fruit fly outbreak.	All states and territories
6	Ensure funding and investment is sufficient to support the development of nationally agreed host and non-host lists for <i>B. dorsalis</i> .	FASTA
7	Develop a communication checklist that Industry Liaison Officers (ILOs) can reference during a fruit fly response, in collaboration with industry.	PHA
8	Inform industry and jurisdictions of their obligations to report the detection of exotic plant pests i.e. <i>B. dorsalis</i> as required under the Emergency Plant Pest Response Deed (EPPRD).	PHA
9	Raise awareness of the Australian Emergency Plant Pest Response Plan (PLANTPLAN) as the nationally endorsed guidelines for implementing a response under the EPPRD.	PHA
10	Undertake engagement with key growers (through affected peak industry bodies) of affected hosts in national growing regions to understand the requirements of their supply chain and identify required movement pathways.	NSW DPIRD
11	Submit a paper to the Subcommittee on Market Access, Risk and Trade to prepare pre-determined secure state and interstate transport routes to support the movement of fruit fly affected crops to approved treatment facilities or destruction sites.	NSW DPIRD
12	Explore accepted control options for <i>B. dorsalis</i> including existing Interstate	FASTA

	Certification Assurance (ICAs) for QFLY and or Medfly and determine if they can be adapted for <i>B. dorsalis</i> .	
13	Considering the outcome of Recommendation 11, review and update the draft movement protocols developed under the Biosecurity preparedness for Oriental Fruit Fly project (FF18001), in consultation with state and territory governments and affected industries.	NSW DPIRD
14	Support discussions through the Subcommittee on Plant Health Diagnostics to develop a National Diagnostic Protocol for <i>B. dorsalis</i> and other exotic fruit flies.	DAFF

OVERVIEW OF THE EXERCISE

Background

Extensive work by both government and industry, principally through the National Fruit Fly Council (NFFC), has been completed on the prevention and management of exotic fruit fly in Australia. This is summarised in the publicly available [National Fruit Fly Strategy 2020-2025](#). The proposal was for a simulation exercise to test current and potential requirements required, in the event of an incursion, to allow the safe movement of product out of a 'Suspension Area' to support business continuity and market access.

Bactrocera dorsalis (oriental fruit fly) is a significant horticultural biosecurity threat to Australia, with the potential to cause large scale economic impacts should it establish in Australia. It is number four on the National Priority Plant Pest list¹ together with other high priority exotic fruit fly species. Oriental fruit fly has been recognised as a pest of concern to crops represented by the following signatories to the Emergency Plant Pest Response Deed (EPPRD):

- Apple and Pear Australia Ltd.
- Avocados Australia Ltd.
- Australian Banana Growers' Council Inc.
- Canned Fruit Industry Council of Australia Ltd.
- Cherry Growers Australia Inc.
- Citrus Australia Ltd.
- Dried Fruits Australia Inc.
- Grain Producers Australia Ltd.
- Queensland Fruit and Vegetable Growers Ltd. (Growcom)
- Australian Lychee Growers' Association
- Australian Mango Industry Association
- Australian Melon Association
- Passionfruit Australia Inc.
- Raspberries and Blackberries Australia Inc.
- Summerfruit Australia Ltd.
- Strawberries Australia Inc. Australian Processing Tomato Research Council Inc.
- Australian Table Grape Association Inc.
- Australian Grape and Wine Inc.
- AUSVEG

Additionally, the following crops not represented by parties to the EPPRD are also considered hosts:

- Coffee
- Papaya
- Fresh tomatoes
- Tropical exotic fruit (e.g. rambutans, mangosteens, longans)

Additionally, oriental fruit fly is established in Australia's near neighbours, specifically Papua New Guinea and Timor-Leste, which increases the risk of incursion into Australia. Oriental fruit fly moves into the Torres Strait, in far North Queensland, seasonally and the National Exotic Fruit Flies in Torres Strait Eradication Program works to eradicate them. This Response Plan is managed under the EPPRD and is Cost Shared by the Commonwealth, State and Territory Governments and Affected Industry Parties.

The extensive host range, establishment in Australia's near neighbours and market access implications of oriental fruit fly makes it a considerable biosecurity concern. A nationally agreed system for surveillance and quarantine zones in Australia for Queensland fruit fly (Qfly) and Mediterranean fruit fly (Medfly) is in place in the event of an incursion in a pest free area. There is no equivalent agreed system for exotic fruit fly. The guidelines for endemic fruit fly incursions and the historical eradication of Papaya fruit fly (part of the oriental fruit fly complex) in 1998 provided a starting point for the discussions in this exercise. These examples have/had movement restriction guidelines that will be used to pose challenges to participants regarding product movement and business continuity.

¹ <https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/plant/national-priority-plant-pests>

The outcomes of this exercise were to assist with informing industry and government about the potential impacts of an exotic fruit fly incursion, and the domestic regulators on potential movement protocols that could be developed to meet their legislated entry requirements. This sub project was developed as part of Hort Frontiers project FF18001 Biosecurity preparedness for Oriental Fruit Fly and was managed by Plant Health Australia.

This exercise forms part of a larger project funded through Hort Innovation titled *Biosecurity preparedness for Oriental Fruit Fly* (FF18001) led Macquarie University and in collaboration with New South Wales Department of Primary Industries and Regional Development (NSW DPIRD) and South Australian Research and Development Institute (SARDI). Funding for the exercise is through the above project, as well as contributions received through the National Fruit Fly Council (NFFC).

Aim

To improve the resilience of horticulture sectors through informing the development of movement protocols that minimise the impact on industry during an emergency response to an incursion of oriental fruit fly.

Objectives

1. Understanding the immediate actions that would need to be undertaken by both government and industry in the early phase of a response to maintain business continuity.
2. Examining the impacts on business continuity through identifying the effects on production and movements at a regional and state level.
3. Testing recommended fruit fly commodity movement protocols (from an infested area for treatment prior to going to market) that have been developed under the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project.
4. Identifying potential issues or critical gaps in the recommended movement protocols and solutions that could be considered by the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project team.

Scenarios

The fictional scenarios presented in this exercise were the detection of *B. dorsalis* in Sydney, New South Wales (NSW) and in Mareeba, Queensland, QLD.

The Sydney scenario began with a detection at a residential property in Mascot which later escalated to a detection at a commercial property in Kemps Creek. The Mareeba scenario involved a detection on a commercial property at Mareeba.

Both scenarios explored the suggested activities NSW and QLD would take under the specific circumstances and these are further outlined in this report.

Planning and delivery

Exercise planning

Planning was undertaken in a manner aligned with the principles outlined in the Australian Disaster Resilience Handbook 3: Managing Exercises, 2012, Australian Institute for Disaster Resilience CC BY-NC². An Exercise Planning Team comprised of representatives the following organisations provided guidance on the development and implementation of the exercise:

- Plant Health Australia (PHA)
- NSW Department of Primary Industries and Regional Development
- Queensland Department of Primary Industries

² <https://knowledge.aidr.org.au/collections/handbook-collection/>

- Department of Agriculture, Fisheries and Forestry
- Australian Table Grapes Association
- Australian Mango Industry Association
- Citrus Australia
- AUSVEG

Exercise delivery

Exercise Motus was delivered in two locations as a desktop exercise over two days, encompassing several short activities. Each exercise varied in the scenarios presented on Day 1 and had shared scenarios on Day 2. Both scenarios were designed to simulate an incursion of OFF in a production area. This was chosen as it allowed participants to work through the exercise objectives and questions under what would be a realistic scenario, if a real incursion were to occur. The following tables capture the scenarios and activities for both the Sydney and Cairns sessions on Day 1 and the shared scenarios on Day 2.

Table 1. Overview of key activities delivered during Day 1 of the Sydney exercise, delivered 18 July 2024.

SYDNEY DAY 1 – SCENARIO AND ACTIVITIES	
Session 1	
Scenario	Suspect flies are found in a surveillance trap at Mascot near Sydney Airport. Both morphological and molecular test results confirm the samples as <i>B. dorsalis</i> which were confirmed by a second lab. The NSW Chief Plant Protection Officer (NSW CPPO) notified the Australian Chief Plant Protection Officer (ACPPPO) within 24 hours of the first detection. Potentially Affected Industry Parties were identified by PHA under the EPPRD requirements and notified of the detection and a meeting of the Consultative Committee on Emergency Plant Pests (CCEPP) was convened.
Activity	Government participants were asked what movement restrictions would be applied to each of the affected areas and what immediate biosecurity emergency response actions they would take at this point in the response.
Session 2	
Scenario	Following the International Atomic Energy Agency (IAEA) Trapping Guidelines for Area-wide fruit fly Programs, supplementary trapping was deployed which showed the presence of additional suspect <i>B. dorsalis</i> . Diagnostics confirmed the presence of several males and one gravid female <i>B. dorsalis</i> . NSW DPIRD issues an <i>Individual Biosecurity Direction</i> to the owner of Infected Premises 1 (IP1) which places movement restrictions on the premises. A member of the community called the Exotic Plant Pest Hotline (1800 084 881) to report maggot infested fruit they purchased from a roadside stall of a working farm in the Kemps Creek area. NSW DPIRD biosecurity officers collected infested fruit samples from the Kemps Creek farm with confirmation of larvae to be <i>B. dorsalis</i> . The Kemps Creek farm becomes Infected Premises 2 (IP2), and a second set of movement restrictions and controlled movement zones are put in place around IP2. Movement restrictions and controlled movement zones have impacted multiple growers, packing sheds, transport infrastructure, transport routes and wholesale suppliers.
Activity	With the escalation of the scenario with restrictions in each of the affected areas, government participants are again asked what their immediate biosecurity emergency response actions would be.
Session 3	
Scenario	Continued supplementary trapping on the Kemps Creek farm showed the presence of an additional suspect <i>B. dorsalis</i> . Samples from stripped fruit and traps confirmed the presence of several males and one gravid female <i>B. dorsalis</i> . These detections exceed the response threshold set in the Mediterranean fruit fly NSW outbreak eradication plan (this plan aligns with the National Fruit Fly Protocols). With three male flies and one gravid female oriental fruit fly identified an outbreak is now declared and eradication procedures commence.

Activity	<p>Movement restrictions are now in place with a direct impact on growers. Participants were asked the following questions.</p> <ol style="list-style-type: none"> 1. What the immediate impacts on industry would be. 2. What would be industries' and governments' initial actions to maintain business continuity with respect to: <ul style="list-style-type: none"> • How movement restrictions are communicated to industry by both government and peak industry bodies. • What role a grower, local/State industry association, or national peak body would play in maintaining business continuity. • What treatments can/would industry accept. • How would governments engage with unaffected industries in the affected area who had been impacted. 3. How would government and industry ensure effective engagement with each other regarding the response actions to ensure a common understanding, including: <ul style="list-style-type: none"> • Communicating current restrictions to industry (both growers and downstream operators) and communities. • Communicating movement access requirements to government.
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Table 2. Overview of key activities delivered during Day 1 of the Cairns exercise, delivered 8 August 2024.

CAIRNS DAY 1 – SCENARIO AND ACTIVITIES	
Session 1	
Scenario	<p>A mango grower contacted the Exotic Plant Pest Hotline (1800 084 881) to report they had seen oviposition marks on mature green mangoes at their farm near Mareeba, Queensland. A Queensland Department of Primary Industries (QDPI) biosecurity officer investigated and collected stung fruit samples, which were sent for larval identification. Steiner traps containing methyl eugenol were deployed with further specimens also sent for identification. Morphological and molecular diagnostic confirmed one male <i>B. dorsalis</i>.</p> <p>The Queensland Chief Plant Health Manager (QCPHM) formally notified the Australian Chief Plant Protection Officer (ACPPPO) of the detection within 24 hours of becoming aware of the incident. Potentially Affected Industry Parties were identified by PHA under the EPPRD requirements and notified of the detection and a meeting of the Consultative Committee on Emergency Plant Pests (CCEPP) was convened.</p>
Activity	<p>Government participants were asked what movement restrictions would be applied to each of the affected areas and what immediate biosecurity emergency response actions they would take at this point in the response.</p>
Session 2	
Scenario	<p>Following PLANTPLAN guidelines³ delimiting surveillance was started and data from these surveys was used to identify the Restricted Area, which comprises all properties where <i>B. dorsalis</i> had been confirmed (Infected Premises), properties that have come into direct or indirect contact with an Infected Premise or infested plants (Contact Premises) and properties which may have been exposed to oriental fruit fly (Suspect Premises). A Control Area was established around the Restricted Area to control the movement of susceptible hosts and other regulated materials until the extent of the incursion was determined.</p> <p>QDPI issued a Biosecurity Emergency Order under the <i>Biosecurity Act 2014</i>, which placed movement restrictions on the Restricted Area and Control Area.</p>
Activity	<p>Movement restrictions are now in place with a direct impact on growers. Participants were asked the following questions.</p> <ol style="list-style-type: none"> 1. What the immediate impacts on industry would be. 2. What would be industries' and governments' initial actions to maintain business continuity with respect to: <ul style="list-style-type: none"> • How movement restrictions are communicated to industry by both government and peak industry bodies. • What role a grower, local/State industry association, or national peak body would play in maintaining business continuity. • What treatments can/would industry accept.

³ <https://www.planthealthaustralia.com.au/response-arrangements/plantplan/>

	<ul style="list-style-type: none"> • How would governments engage with unaffected industries in the affected area who had been impacted. <p>3. How would government and industry ensure effective engagement with each other regarding the response actions to ensure a common understanding, including:</p> <ul style="list-style-type: none"> • Communicating current restrictions to industry (both growers and downstream operators) and communities. • Communicating movement access requirements to government.
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Table 3. Overview of key activities delivered during day 2 of the exercise, delivered 19 July 2024 in Sydney and 9 August 2024 in Cairns.

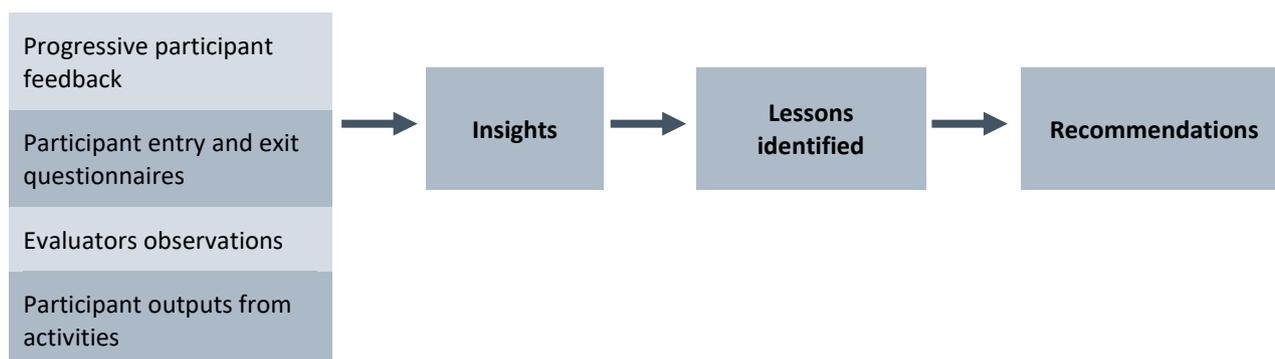
DAY 2 – SCENARIO AND ACTIVITIES	
Session 1	
Scenario	The response has moved forward two months and delimiting surveillance in the Export Assurance Zone has confirmed <i>B. dorsalis</i> is absent and therefore supports business continuity from this zone. <i>B. dorsalis</i> has been contained within the Corrective Action Zone.
Activity	<p>Participants were shown a mock map of their jurisdiction’s outbreak zone and asked what the impact on market access and business continuity would be depending on which zones a business was located.</p> <p>Following this discussion, it was anticipated attendees would discuss how the movement protocols, provided by Macquarie University, would be applied to each scenario. However, these movement protocols proved to not have sufficient detail to allow participants to discuss their implementation. Participants were instead asked several questions that aimed to capture what information was needed to generate functional movement protocols:</p> <ol style="list-style-type: none"> 1. What considerations were needed when developing movement protocols including: <ul style="list-style-type: none"> ○ What will be the impacts of additional transport costs? How do these relate to seasonal timing? ○ Would additional transport movements affect crop quality? ○ How would the protocols fit into the national fruit fly management system? 2. Do current systems and processes support the implementation of movement protocols? <ul style="list-style-type: none"> ○ Who will enforce permitting systems, compliance checks and border checks? ○ How will this be communicated? ○ Can existing resources (transport, treatment facilities) meet demand across all affected industries and/or during peak production? ○ What additional resources would be needed? Are these currently widely available? Is there enough to meet demand during peak production?
Session 2	
Scenario	Having explored the scenario and identified challenges, participants are asked to summarise key issues and critical gaps.
Activity	<p>All the participants discussed the challenges of implementing movement protocols and what evidence would be needed to have agreement across all parties.</p> <p>Having noted the challenges participants then discussed solutions to the issues raised.</p>

EVALUATION

The aim of the Evaluation was to gather, analyse and report on the Exercise Conduct and the Exercise Aim and Objectives. The desired outcome of the Evaluation was to provide a set of recommendations, drawn from the lessons identified and data collected during the Exercise, to assist participants and their respective organisations to identify priorities to further enhance their preparedness for a biosecurity emergency response.

The Evaluation methodology adopted was an OIL (Observations, Insights, Lessons) process – gathering observations relevant to the evaluation questions from a variety of sources, analysing that data to identify key insights and themes which can translate into lessons identified and formed into recommendations for future action.

Observations



Participants were surveyed prior to and following the completion of the exercise to gauge the impact the exercise event had on their level of preparedness and to inform learnings. Evaluation results from participants are captured in Appendix 2.

Observations and Insights were analysed through the application of a P2OST2E capability framework as described below. The analysis identified common themes, positive aspects to sustain and gaps to address, relating to each element with an emphasis on the ‘People’, ‘Process’ and ‘Organisation’ elements in addition to considering the ‘Exercise Management’ element more generally. These themes formed the Lessons Identified that were developed into Recommendations. The analysis was undertaken by the Evaluator(s) during both exercises.

ELEMENT	DESCRIPTION
People	Roles, responsibilities, accountabilities and skills
Process	Policy, procedures or processes
Organisation	Structures or jurisdictions
Support	Infrastructure, facilities, maintenance
Technology	Technology, equipment, systems, standards, security, interoperability
Training	Capability qualifications/skill levels, identification of required training and development
Exercise	Exercise development, structure, management, conduct

Source: AIDR Handbook Collection, “Managing Exercises Handbook 3”

PARTICIPANTS

Participants included members of plant industry organisations that represent crops that may be impacted by *B. dorsalis*, government biosecurity/agricultural agencies including New South Wales, South Australia, Victoria, Western Australia and Queensland state governments, DAFF, Kiwi Vine Health (New Zealand) and members from the exercise planning team. A full list of participants is included in Appendix 1.



Figure 1 Exercise Motus participants during Sydney component of the exercise.



Figure 2 Exercise Motus participants and facilitators at Cairns component of the exercise.

EXERCISE OUTCOMES AND FINDINGS

Opening session

A representative from NSW DPIRD opened both exercises with a background presentation on *Bactrocera dorsalis*. The presentation included key information on the taxonomic history, identification, and associated diagnostic challenges, host range, geographic distribution, and dispersal of this destructive fruit fly. The complexities faced when differentiating fruit flies, particularly with several cryptic species within the *B. dorsalis* complex, were highlighted.

Diagnosticians use specific morphological traits as the quickest and most reliable form of identification of adult flies. However, this can be challenging for the untrained eye, such as growers and agronomists. The visual traits used to identify *B. dorsalis* can vary greatly within the species and, in some cases, closely resemble *Bactrocera cacuminata* (Wild Tobacco fruit fly). This high level of variability between individuals could lead to misdiagnosis by growers who might mistake *B. dorsalis* for the native *B. cacuminata* or *B. musae*.

It is well understood and documented that *B. dorsalis* is highly polyphagous, has a large host range and can establish in new areas over a season. However, there is limited published information on what triggers *B. dorsalis* to move beyond an emergence site or how far they can travel, whether assisted or unassisted.

During the QLD exercise, an overview of the National Exotic Fruit Flies in Torres Strait Eradication Program was provided, detailing its role in preventing the spread of exotic fruit flies into mainland Australia. The trapping network consists of methyl eugenol and cue-lure traps on all inhabited islands and some uninhabited islands with fruit trees in the Torres Strait, as well as the Northern Peninsula Area of Cape York. When the number of target flies reaches agreed thresholds, Northern Australia Quarantine Strategy (NAQS) staff and contractors conduct bait-spraying, while QLD Department of Primary Industries (QDPI) staff and The Torres Strait Island Regional Council (TSIRC) and local contractors provide male annihilation technique (MAT) blocking to eradicate the population. Only male flies are attracted to the lures in the traps; however, so in seasons where female flies have established populations in fruit trees, it leads to larger numbers of detections and a more prolonged eradication effort.

The presentation generated good discussion, leading to a greater awareness of the unknowns regarding *B. dorsalis* and why it is a pest of significance to Australia's plant industries

Immediate impacts on industry

Objective 1 – To understand the immediate actions that would need to be undertaken by both government and industry in the early phase of a response to maintain business continuity.

Governments immediate response actions

As the impacted states in the exercise, NSW and QLD both indicated they would initiate a response under the EPPRD. Both the NSW and QLD Chief Plant Health Manager (CPHM) notified Australian Chief Plant Protection Officer (ACPPO) within 24 hours of a diagnosis. Additionally, potentially Affected Industry Parties were identified by PHA under the EPPRD requirements, ACPPO would initiate Consultative Committee on Emergency Plant Pests (CCEPP) proceedings with notifications sent to jurisdictions, the Commonwealth and AIPs.

Once the OFF diagnosis was confirmed movement controls would be put in place by both NSW and QLD, and movement of produce from the affected area would be restricted. It is likely that other states and territories as well as international trading partners would implement their own movement restrictions once the outbreak has been confirmed.

Both jurisdictions also indicated they would work with AIPs and the DAFF from the onset of the response to develop appropriate communications to both growers and international trading partners. It was also noted that communication would support unaffected states' continued access to international markets and provide confidence that the incursion was restricted to a single state and that determining its extent was ongoing. In both exercise scenarios, government and industry were clear on the communication methods to be used, many of which were existing processes implemented during biosecurity emergency responses such as national talking points.

In the Sydney exercise, due to the peri-urban location of the outbreak, participants noted that messaging would be tailored to the urban setting to engage people on the impact *B. dorsalis* would have on hosts and crop production.

Scenario escalation

In both exercise scenarios *B. dorsalis* has been detected in production areas and participants were again asked what government's immediate biosecurity response actions would be, given movement restrictions are in place within the impacted zones. Governments indicated they would implement a range of actions that were in-line with general biosecurity response actions including involving industry at this early stage with a request for industry liaison officers (ILOs).

Treatment options would be identified to make sure businesses can continue to operate. There would also be engagement with local governments and community leaders to help support and spread messaging to growers and the general public. To support government efforts Plant Industry Forum (PIF) members indicated they would consider meeting to assist in the deployment of suitable ILOs given the large number of affected industries.

The government's overview of their immediate actions raised questions for industry participants regarding the longer-term impacts of the response. These issues have been captured later in this report, however, the discussion at this point in the exercise highlighted the need for industries to have detailed information on response actions especially those that affect business continuity and for it to be available during the early stages of the response. Many of the concerns raised by industry were not about the immediate actions such as surveillance or crop destruction but looked further ahead to what was needed to treat affected crops so they could be moved to markets and for growers to continue to trade.

Industry asked:

- What crop movement would be allowed in or out of the areas placed under a biosecurity order?
- What would be the impact on production outside the affected area?
- Would proof of freedom be affected at this stage?
- What would be the impacts on international export?
- Is there a discrepancy between the information communicated locally and what is conveyed to international trading partners - are the messages given to growers consistent with those shared with trade partners?
- When should Owner Reimbursement Costs (ORC) be discussed with affected growers?

This level of questioning emphasised the importance plant industries place on business continuity with a focus on the long-term impacts of a response. Being impacted by a response was noted but knowing what was needed to continue to trade was more of a concern based on the questions raised.

Immediate impact to industry

In both exercise scenarios, it was quickly identified that for industry, there would be a high level of concern and uncertainty, and the level of impact would vary depending on seasonal variations and which industries were affected. However, for all impacted industries movement restrictions would have economic implications including loss of access to markets leading to income losses and reduced confidence from investors, lenders and consumers.

Industry noted that the fear associated with response impacts could result in grower’s reluctance to report any unusual insect damage on their crops. While growers represented under the EPPRD would be eligible for ORCs, it was noted that to support growers’ willingness to report, they would need a greater understanding that there were reimbursements available for specific costs and losses incurred during a response under the EPPRD. Industry participants highlighted that growers may find it difficult to understand the importance of *B. dorsalis* especially in areas or states where other fruit fly species are present. Educating growers on the importance of reporting all unusual symptoms including green fruit that has been stung and still appeared marketable was needed.

Industry participants identified several recommendations to improve communication and help alleviate grower concerns of aspects of a response process during an incursion. There may also be a need to develop additional industry-specific information on prevention and preparedness activities that growers can undertake to support business continuity, including record-keeping requirements for ORC claims.

Recommendation 1	Develop an industry engagement campaign on the impacts of <i>B. dorsalis</i> , to reduce apathy regarding fruit fly surveillance.
Recommendation 2	Provide industry with specific information on the signs and symptoms of <i>B. dorsalis</i> damage in the forms of fact sheets or webpages.
Recommendation 3	Work with fruit fly impacted industries to inform them of prevention and preparedness activities growers can undertake that may support business continuity during a response.
Recommendation 4	Work with fruit fly impacted industries to promote the PHA industry resource toolkit to help growers understand response processes and actions.

Industries identified the immediate impacts of an OFF incursion on business continuity but noted uncertainty around solutions to these impacts. This uncertainty could lead to panic, loss of social license towards response activities, or distrust in the evidence-based approach to pest eradication efforts. Greater acceptance of response activities and disruption to business continuity may occur if longer-term solutions are known and communicated to affected growers.

While the flow-on effects of trade restrictions on downstream businesses such as transport companies, supermarkets, or commercial nurseries were out of scope for the exercise, it is worth noting they would also be impacted and incur economic losses. Engaging these businesses similarly to affected plant industries would support their understanding of response actions and the implications for their businesses. It is vital these downstream industries support compliance outlined in movement protocols to ensure a response has the best chance of successful eradication.

Maintaining business continuity

With barriers to business continuity identified, participants were asked how they would engage with Affected and non-Affected Industry Parties to maintain operations.

Participants indicated that an ILO would be requested and provided to support response planning and public information functions in control centres. There would be a high level of communication with Affected industries and growers, and all participants agreed it was important to provide consistent messaging to all Affected Parties.

Referring to past responses, participants indicated there was a need for improved communication on how affected growers accessed or were provided information regarding certification and compliance to allow the movement of crops. It was also noted that greater harmonisation was needed between jurisdictions to support the movement of commodities. A centralised location where this agreed information could be found would remove uncertainty and difficulty in meeting response requirements was supported.

Recommendation 5	States and Territories to consider how they could best circulate up to date and easily accessible information on movement controls, in the event of an oriental fruit fly outbreak.
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Participants agreed that having an agreed host list to identify AIPs and a non-host list to reassure non-affected industries as participants initially questioned which crops would be considered hosts and, consequently, which industries would be affected during both exercise scenarios.

Participants acknowledged there was significant time and money required to commission the development of nationally agreed host and non-host lists for *B. dorsalis* and a lack of resources from both government and industry. At the time of the exercise the Plant Health Committee (PHC) Plant Biosecurity Preparedness Working Group (PBPWG) was also looking into identifying gaps and that the development of an agreed host list for priority plant pests was on their radar.

It was also observed that pre-agreed host lists developed for Emergency Plant Pests (EPPs) were not recognised by the CCEPP in previous responses. As *B. dorsalis* is listed as a Category 2 EPP in Schedule 13 of the EPPRD, the development of agreed lists for both host and non-host crops would provide a pathway forward and certainty for Affected Parties during a response. Development of lists should be in collaboration with government and peak industry bodies (PIB) to provide certainty to Affected Parties decision-making and pre-agreement commitment that the lists will be accepted during a response.

Recommendation 6	Ensure funding and investment is sufficient to support the development of nationally agreed host and non-host lists for <i>B. dorsalis</i> .
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Effective engagement to ensure a common understanding

Exercise participants acknowledged the importance of effective engagement between government and industry to ensure a common understanding and acceptance of response actions. During the exercise, various engagement processes and opportunities for improvement were identified to help support collaboration and increase responsiveness.

Feedback indicated that existing processes as part of an EPPRD response such as Affected Party representation on the CCEPP and National Management Group (NMG), and an ILO within the incident control centre would facilitate engagement and information exchange during the response. These processes also allow Affected Parties to raise questions and address concerns to improve their understanding.

Additionally, tasks performed by the Public Information function within the Incident Management Team (IMT) would be implemented. These include developing National Talking Points, industry advice updates, website updates, and face-to-face meetings with affected growers and communities.

Reflecting on past experiences, participants noted that engagement would be more successful if it was clear and free of bureaucratic language. It should provide information to manage expectations of response activities and timeframes, including those that growers may be unaware of, such as diagnostics and surveillance, and have clear expectations of their roles and responsibilities. Delivering this information to industries before a response, rather than during, would allow growers to plan ahead and understand what is expected of them. Additionally, communications should outline the compliance requirements of each biosecurity zone, with clear instructions on what can and cannot be done, and what documentation is required to meet the compliance requirements for each zone

The discussion around both scenarios highlighted the need to extend communication and engagement activities beyond signatories to the EPPRD or Affected Parties. Including urban and peri-urban communities, local councils and

community leaders and downstream businesses were some options that could be considered. In the Sydney exercise scenario, non-agricultural communities, such as backyard growers, were impacted by the response, and it was agreed that their understanding of compliance with response activities was critical. The discussions highlighted the importance of compliance across all sectors of the community, not just those directly impacted.

Participants agreed that successful response communication needed to be regular, ongoing throughout the response, repeated, delivered in multiple ways, and be a unified approach between government and industry. This consistent and unified messaging (i.e. national talking points) would allow affected growers and communities to see that responding to biosecurity incidents is a shared responsibility requiring a united effort.

Recommendation 7

Develop a communication checklist that Industry Liaison Officers (ILOs) can reference during a fruit fly response, in collaboration with industry.

Impact to market access

Objective 2 – Examine the impacts on business continuity through identifying the effects on production and movements at a regional and state level.

Consistency in restriction zone terminology

To understand what situations would require movement protocols to be developed for moving a crop or crop product, participants were presented with several scenarios where impacted growers needed to move their crops with the goal of accessing existing markets. Participants were also asked how business continuity changes, depending on where each grower was located within the zones, and how that would impact their market access.

To support discussion, participants were provided an overview of what restrictions would be put in place for each of the following zones.

Table 1: Descriptions of zone used during in each exercise. The terms used are not equivalent between Sydney and Cairns.

SYDNEY	EXPLANATION	CAIRNS	EXPLANATION
Delimitation zone	A radius around all properties where <i>B. dorsalis</i> has been confirmed	Dangerous contact premises	Properties that have come into direct or indirect contact with an infected premise or infested plants or exposed to <i>B. dorsalis</i> .
Corrective action zone	A radius extending from the discovery point, including the delimitation zone, where no host can move without CPPO approval	Restricted Area	A relatively small area (compared to a Control Area) around an Infected Premises that is subject to intense surveillance and movement controls.
Export assurance zone	A radius beyond the corrective action zone where the movement of host crops is prohibited without treatment or processing to be free from fruit fly	Control Area	An area around the restricted area where movement is controlled but not restricted. The area is intended to reduce likelihood of <i>B. dorsalis</i> spreading beyond the Restricted Area.
Control movement zone	All areas within the circle surrounding the epicentre and including all other zones, in which area freedom is suspended.	Pest Free Area (PFA)	An area where <i>B. dorsalis</i> is known not to occur as demonstrated by scientific evidence and in which, where appropriate, this condition is being officially maintained.

In the Sydney exercise scenario, participants were confused why NSW would use the zone terminology outlined in the National Fruit Fly Protocol, rather than PLANTPLAN, which is used for responding to established fruit fly outbreaks. Additionally, participants felt the terminology used in the National Fruit Fly Protocol was complicated and the names of each zone did not clearly indicate the restrictions in place or what affected growers could expect. Participants questioned why, if the response was under the EPPRD, the terminology outlined in PLANTPLAN was not used.

In the Cairns exercise scenario, terminology as defined in PLANTPLAN was used, but there was still confusion among participants about the movement restrictions that would be implemented in each zone during a response.

Participants highlighted a desire for consistent terminology to be applied across jurisdictions and understand where the terminology was sourced from.

Recommendation 8

Inform industry and jurisdictions of their obligations to report the detection of exotic plant pests i.e. *B. dorsalis* as required under the Emergency Plant Pest Response Deed (EPPRD).

Recommendation 9	Raise awareness of the Australian Emergency Plant Pest Response Plan (PLANTPLAN) as the nationally endorsed guidelines for implementing a response under the EPPRD.
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Participants discussed the necessary support for crop movement in the absence of movement protocols. They agreed that business continuity depended on the permissions within each zone and the type of crop grown. For zones immediately surrounding the detection point, jurisdictions indicated that no crops would be moved to market or treatment facilities until surveillance confirmed the area was free from *B. dorsalis*. For other zones, participants extensively discussed the requirements to support business continuity for growers. A summary of these discussions is provided at Table 2.

Table 2: Summary of participant's discussion of requirements to allow movements for each scenario. Sydney and Cairns terms have been grouped together for ease of reference, noting they are not exact equivalents to one another.

TERM	SUMMARY
Delimitation zone and Infected Premises	No movement of affected crops to market. Only movement of affected crops to destruction or disposal sites
Corrective action zone	<ul style="list-style-type: none"> As with the Delimitation Zone and Infected Premises, it is unlikely that jurisdictions would allow the movement of crops outside the Corrective Action Zone/Restricted Area due to the severity of <i>B. dorsalis</i> impacts. Destruction of host crops and surveillance to ensure the pest hadn't spread would occur in these zones. Depending on the scale of the response and at which point during the season it occurred, large volumes of host material may need to be disposed of. If there is limited capacity within the zone for disposal, movement protocols may be required to transport host material to destruction sites outside of the zone. A delay in implementing response actions would place added pressure on Affected parties and delay a return to business for growers.
Restricted Area	
Export assurance zone	<ul style="list-style-type: none"> While host movement can occur, it would be unlikely that the treatment needed to meet market access requirements was within an impacted zone and a movement protocol would be required for transportation to a treatment facility. Secure transport would need to comply with a control order, biosecurity direction or permit, or Plant Health Certificate, which would need to be monitored to ensure compliance. For some crops the time and cost to transport would be economically unviable especially if crops needed to travel long distances. For example, Mareeba to Brisbane or Sydney to Melbourne to be treated at an irradiation facility. There are currently no agreed treatment options for <i>B. dorsalis</i> therefore it would take time to establish accepted methods agreed upon by industries and governments. If existing treatment facilities are available, they may not have the capacity to treat the volume of affected crops and provide treatment options suitable for all potentially affected plant material.
Control Area	
Control movement zone	<ul style="list-style-type: none"> It was assumed that: <ul style="list-style-type: none"> If a crop was secured and compliant it could move through the control movement zone and Pest Free Area zones to treatment. Crops that had been treated at an approved facility could move however continued monitoring/testing may be required by movement protocols. It was discussed whether consumers would need to show proof of purchase to ensure the product was from an unaffected area or identify where in the supply chain it was purchased. How hitchhiker <i>B. dorsalis</i> could be managed was also discussed. This again raised the issue of host and non-host crops, noting that in past responses non-host crops were subject to response actions as they can provide a movement pathway out of the response area.
Pest Free Area (PFA)	

Following discussion, it was identified that movement pathways needed to support business continuity for Affected industries during a response need to be identified. Additionally, it was suggested that control measures or protocols that would enable acceptance of produce into other jurisdictions and how the affected crops would be transported to approved treatment facilities should be investigated. As part of this work, consideration could be given to matters such as:

- Allowed movements agreed upon by all jurisdictions
- Required certification to ensure compliance
- Risk assessment of possible movements and methods, with definitions outlining compliance requirements
- Development of commodity and movement-specific protocols rather than a single protocol for all industries
- Likelihood of affected crops in various production areas having access to suitable treatment options
- Feasibility of implementing draft protocols, including how compliance will be resourced and facilitated during a response.

Recommendation 10	Undertake engagement with key growers of affected hosts in national growing regions to understand the requirements of their supply chain and identify required movement pathways.
Recommendation 11	Submit a paper to the Subcommittee on Market Access, Risk and Trade to prepare pre-determined secure state and interstate transport routes to support the movement of fruit fly affected crops to approved treatment facilities or destruction sites.

Industry business continuity plans

Industry participants were asked if they had established business continuity plans and if these plans had been communicated with industry members.

Industries represented at the Sydney component of the exercise indicated they did not have business continuity plans, nor did they see it as a viable priority given the limited resources available to most PIBs. Citrus Australia is exploring business continuity as part of a response strategy being developed for the citrus industries high priority pests (HPP). Both DAFF and AgVic indicated they are also doing some work to support continuity including the development of strategies for pests that are consistently detected (such as BMSB) and are looking to simplify and expand the process.

Due to the time, cost and collaboration needed to develop business continuity plans it was suggested that pooling resources across multiple industries would be beneficial. It was also noted that HPPs such as *B. dorsalis* should be prioritised.

Implementing movement protocols

Objective 3 – Test the recommended fruit fly commodity movement protocols (from an infested area for treatment prior to going to market) that have been developed under the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project

Objective 4 – Identify potential issues or critical gaps in the recommended movement protocols and solutions that could be considered by the Biosecurity preparedness for Oriental Fruit Fly (FF18001) project team.

Testing the proposed movement protocols

While objective 3 of the simulation exercise originally sought to test recommended fruit fly commodity movement controls with participants, it was determined they did not have sufficient information to test them in the scenario. Unfortunately, this means objective 3 was unable to be met. To support future efforts to develop the movement controls participants were instead asked several questions that aimed to capture what information was needed to generate functional movement protocols:

1. What considerations were needed when developing movement protocols including:
 - What will be the impacts of additional transport costs? How do these relate to seasonal timing?
 - Would additional transport movements affect crop quality?
 - How would the protocols fit into the national fruit fly management system?
2. Do current systems and processes support the implementation of movement protocols?
 - Who will enforce permitting systems, compliance checks and border checks?
 - How will this be communicated?
 - Can existing resources (transport, treatment facilities) meet demand across all affected industries and/or during peak production?

Many of the questions raised at this point in the exercise scenarios had also been considered and discussed during previous sections of the exercise.

How movement protocols could be implemented

While considering the impacts and challenges of the possible movements a clear theme emerged from participants; that without efficient access to affordable treatment options, the ability to move host crops would be limited.

Whilst considering treatment options was out of scope for this exercise, a greater understanding of what treatments were available was needed to support decision-making by all Affected Parties during a response including the feasibility of eradication.

It was discussed that currently there was no approved treatment for *B. dorsalis* in affected produce to allow for market access from an Export assurance zone/Control Area. Approved treatments currently used for other fruit fly species to support market access was not a feasible option for all potentially affected crops, were not geographically available in all growing areas and may not be approved by other jurisdictions if applied during a *B. dorsalis* response.

Additionally, if treatment options were approved it was discussed that additional costs would be incurred to meet movement protocol requirements, transport crops to treatment facilities, implement treatment protocols and transport to market. Based on the shelf life of crops post-harvest, these requirements would not be feasible for all affected crops and for many would not be cost-effective. Crops would either perish during transport, treatment would affect crop quality, or the cost of transport and treatment could not be recovered at the point of sale.

Participants also noted that if current approved treatment facilities did meet the requirements to support efforts to allow for market access during eradication, they may not have the capacity to meet demand during a response. Industry raised concerns regarding how priority would be given when a wide host list and host range are impacted. Would export or high-value crops be given priority over lower-value state-based crops?

While this exercise was being developed the Fresh and Secure Trade Alliance (FASTA) was launched and had been

exploring current treatments that were available (i.e. cold storage, heat treatment, irradiation and chemical options) and what they can be used for in various circumstances in overseas countries where *B. dorsalis* is also a horticultural pest. This is a step in the right direction, but further research is needed to ensure there is agreement from all jurisdictions, our trade partners and the Australian Pesticides and Veterinary Medicines Authority (APVMA).

Recommendation 12	Explore accepted control options for <i>B. dorsalis</i> including existing Interstate Certification Assurance (ICAs) for QFLY and or Medfly and determine if they can be adapted for <i>B. dorsalis</i> .
Recommendation 13	Considering the outcome of Recommendation 11, review and update the draft movement protocols developed under the Biosecurity preparedness for Oriental Fruit Fly project (FF18001), in consultation with state and territory governments and affected industries.

Secure transport pathways need to be identified to allow the movement of impacted crops from affected areas to treatment facilities or unaffected crops through affected areas to market. These activities also need to be supported by inspection protocols that are agreed to by industry and resources allocated to enforce compliance activities (e.g. staff).

The general public and consumers were also identified as barriers to implementing movement protocols. It was noted that during other responses, gaining the approval of those outside horticultural industries and ensuring their compliance when following response activities was essential to effective eradication. Communication is needed to ensure the general public understand the importance of complying with biosecurity orders during a response. Communication strategies need to educate and target those not directly involved in horticultural industries to ensure compliance across all sectors.

Participant feedback and exercise discussions noted that the National Diagnostic Protocol (NDP) for *B. dorsalis* as well as other exotic fruit flies needed to be developed and maintained. For states such as QLD where *B. dorsalis* closely resembles native fruit flies and there is a high volume of insects collected in traps, a quick, reliant NDP is needed to provide rapid diagnostics during an incursion and to meet proof of freedom for our trading partners. This diagnostic work is currently being undertaken by the FASTA.

Recommendation 14	Support discussions through the Subcommittee on Plant Health Diagnostics to develop a National Diagnostic Protocol for <i>B. dorsalis</i> and other exotic fruit flies.
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FEEDBACK ON EXERCISE MOTUS

To evaluate the success of the simulation exercises, participants were asked to fill out both pre and post workshop questionnaires. Part of this evaluation included post workshop feedback on the following questions:

1. What actions or processes would improve the movement restrictions?
2. What are the greatest impacts movement restrictions will have on business continuity?
3. What actions or processes would improve the likelihood of the industry meeting the movement protocol requirements?
4. What information or resources do you feel would assist industry to be better prepared? E.g. guidelines, background information, reference materials or on-farm processes
5. What challenges do you see?
6. What solutions do you see to these challenges?

While this feedback was not mandatory, and was open ended several general themes were presented from participants.

- The lag time in implementing the protocols would impact crops getting to market therefore impacting quality and marketability. This would cause greater economic stress to affected industries as well as impact the supply chain and consumer confidence.
- Ability to access freight options when needed.
- Unclear treatment conditions and bottlenecks in accessing possible current treatment facilities due to limited capacity and volume of affected crops.
- Cross-jurisdictional agreement of movement protocols during a response.
- An increase in processes, forms permits and associated costs that industry and growers will need to absorb to comply with these requirements.
- The ability of business to survive the loss of contracts and income associated with prolonged responses.
- Unclear movement pathways for growers during a response.

APPENDIX 1. PARTICIPANTS

LOCATION	NAME	ORGANISATION
Sydney	Jeff Scott	Australian Table Grape Association
	Jenny Treeby	Australian Table Grape Association
	Lana Russell	Agriculture Victoria
	Jessica Lye	Citrus Australia
	Nathan Hancock	Citrus Australia
	Matthew Calverley	DAFF
	Aphrika Gregson	DPIRD NSW
	Bev Zurbo	DPIRD NSW
	David Britton	DPIRD NSW
	Leonie Martin	DPIRD NSW
	Rachel Taylor-Hukins	DPIRD NSW
	Mark King	Dried Fruit Australia
	Matt Dyck	Kiwifruit Vine Health
	Joanna Embry	Melons Australia
	Con Poulos	PIRSA
	Lorissa McCosh	PHA
	Naomi Wynn	PHA
	Chris O'Connor	PHA
	Lily McDonald	PHA
	Linda Baker	QDPI
	Nancy Cunningham	SARDI
	Ben Reilly	Steritech
	Trevor Ranford	Summerfruit Australia Ltd
Warren Birchmore	Vinehealth Australia	
Cairns	Marine Empson	Australian Mangoes
	Trevor Dunmall	Australian Mangoes
	Rosalie Daniel	AUSVEG
	Isarena Schneider	DAFF
	Stefanie Oberprieler	DAFF
	Bev Zurbo	DPIRD NSW
	Leonie Martin	DPIRD NSW
	Jessica Bikaun	DPIRD WA
	Touhidur Rahman	DPIRD WA
	Jason Size	PIRSA
	Katharina Merkel	PIRSA
	Lorissa McCosh	PHA
	Naomi Wynn	PHA
	Brendan Missenden	QDPI

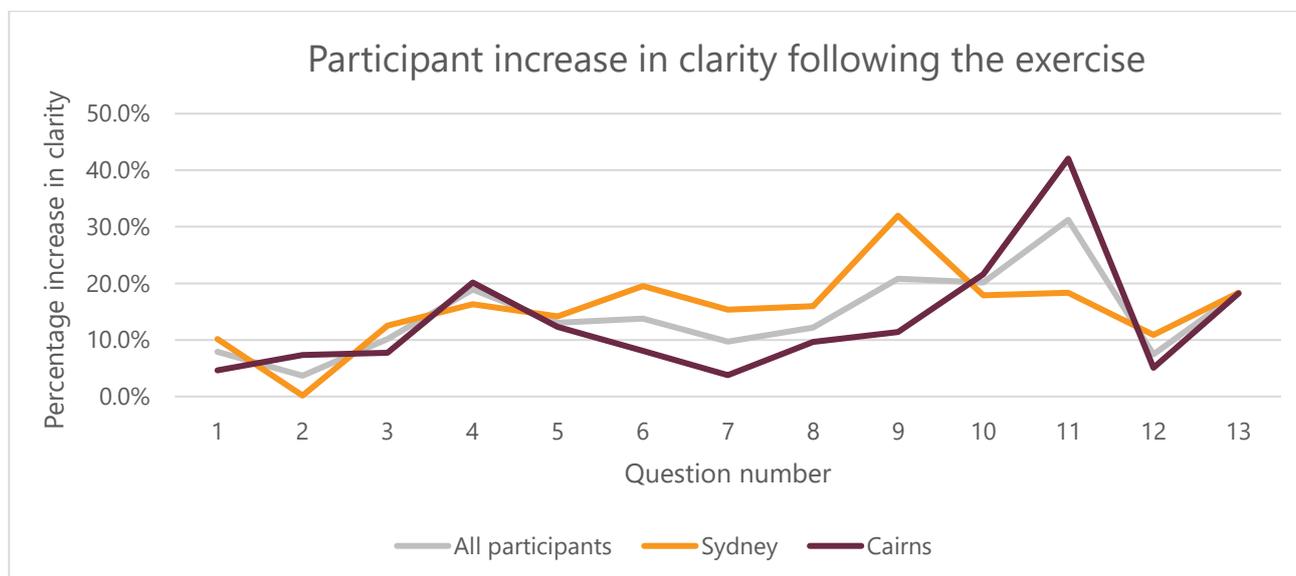
Brett Jackson	QDPI
Claire Hollis	DAFF
Hellen Agnew	QDPI
Linda Baker	QDPI
Melissa Starkie	QDPI
Peter Leach	QDPI
Rebecca Breaden	QDPI
Pauline Wyatt	QDPI
Emma Davis	QDPI
Jason Haffenden	QDPI
Kent Hutchinson	QDPI

APPENDIX 2. PARTICIPANT FEEDBACK

Participants were asked to give a rating of very clear, clear, unsure, unclear or very unclear to the following questions before and after the workshops. The percentage increase in understanding between the first and second survey is shown in Table 3.

Questions:

1. Objectives of the exercise
2. Immediate biosecurity emergency response actions by governments
3. Impacts on industry during a biosecurity emergency
4. Initial actions by government and industry to maintain business continuity
5. Engagement process between government and industry stakeholders
6. Terminology used to determine the various zones during a response
7. Business continuity in different zones (containment, buffer, surveillance)
8. Impacts on market access during a biosecurity emergency
9. Established business continuity plans within the industry
10. How the movement protocols would be implemented
11. Current systems and processes would support the movement protocols
12. Challenges government and industry face during a biosecurity emergency
13. Potential solutions to implement during a biosecurity emergency



Overall, there was an increase in participant's knowledge in all areas however questions 9 and 11 showed the greatest increase. At the other end of the scale understanding of the exercises objectives, knowledge of government's immediate biosecurity response actions and challenges government and industry face during a response showed the lowest improvement in clarity.

Below are additional comments made by participants reflecting on their involvement in the exercise.

Having worked through the scenario, what actions or processes would improve the movement restrictions?

- Having a clear understanding of treatments available and where those treatment facilities are.
- Develop protocols that are O-fly specific from national protocols.
- What movements could be permitted?
- Chemicals accepted. APVMA permits.
- Movement ICA's in place - transit treatment.
- Communication needs greater industry involvement on the ground and in control centres.
- Movement controls need further work to define consensus across stakeholders or movement protocols.
- Interstate agreements negotiated in place prior to potential outbreak.
- Secure pathways to access treatment options and capacity.

- Established templates and databases for comms and stakeholder groups.
- Government staff resourcing to assist industry with advice
- Clear instructions, communications about what growers can and cannot do, from government to industry.

What actions or processes would improve the likelihood of the industry meeting the movement protocol requirements?

- Having prior understanding of what those protocols will be.
- Availability of suitable treatment options that are cost effective.
- Clear access pathways to treatment facilities.
- Very quick advice on movement protocols being communicated to industry and constantly reinforcement of the protocols.
- Treatments need to be practical and committed in advance so that industry have ability to plan for them.
- Information, incentives, easy-to-fill-out applications for movement (and easy to find, too!)
- Conditions that don't change and certainty on what the future conditions might look like under an evolving (expanding) response.
- Risk based approach to movement of produce.
- Data sharing for decision making.

What information or resources do you feel would assist industry to be better prepare? (EG guidelines, background information, reference material or on-farm processes).

- Clear guidelines on acceptable treatments and movement protocols prepared in advance.
- APVMA permits ready.
- Reference fact sheets on pest prepared and out now.
- Information on what an oriental fruit fly outbreak would mean for individual growers.
- Understanding specific costs for alternative pathways.
- Create situational awareness. Many growers live with Queensland fruit fly so what makes oriental fruit fly special?
- Updated and maintained NDPs and standardised and centralised reference material.
- Accurate and up-to-date host and non-host list.
- A response plan that already exists and includes communication information that is updated every three to five years.

What challenges do you see?

- In the heat of battle, it's a challenge to get information to those who need it. Need to build awareness in peace times.
- Compliance of the public and growers ignoring their responsibilities.
- Transport logistics, understanding of movement protocols and their role.
- Inconsistency between states, detections likely to be in urban rather than production areas and disconnect with urban communities.
- Challenge to finding efficacious treatment if current fruit fly treatments are less than 99.99% effective.
- Complexity of stakeholders.
- Lack of technical understanding and scientific review of treatment options.
- Prioritisation of treatment facilities if large amounts of host material are caught within control zones and treatment facilities can't meet demand, will market forces determine prioritisation or government intervene?
- Big holes in preparedness. No firm position on dispersal, no clear host list, affected parties or treatments.
- Speed of the response, Government not working together, Industry not working together.
- What happens if *B. dorsalis* gets into World Heritage rainforest?

What solutions do you see to these challenges?

- Simulation exercises in regions with large number of affected industries.
- Start, discussions with others in community/supply chain, not just industry and growers.
- Engagement and participation in the IMT.

- Making preparedness activities a priority.
- CPHOs to all endorse a consistent approach.
- Pre outbreak agreements between stakeholders to ensure continuity and uniformity.
- Research on chemicals or literature review on efficacious treatments.
- Research on host lists.
- Prioritisation may need to consider more than just product value but also options available. For example, some high value products may have multiple treatment options available and therefore might not warrant prioritisation over lower value products.
- Investment in research.
- Collaboration between jurisdictions on issues related to preparedness
- Bringing more industry bodies to the table. Survey to growers for feedback on ways forward. Best ways to engage for compliance.
- Keep funding the Torres Strait program.
- FASTA research, cross-jurisdictional projects, data and information sharing,
- Agreed strategies/national plans.

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Oriental Fruit Fly

Surveillance

The use of routine surveillance outside of exotic pest species incursions is one of the main methods for detecting pathways of oriental fruit fly into Australia.

Surveillance at many levels is needed to ensure exotic fruit flies don't make their way into Australia and affect our valuable agriculture sector.

For importers infested fruit is the easiest way for flies to arrive, sanitation and observation are important means of detecting oriental fruit fly.

For horticultural growers maintaining sanitation and surveillance of not only rotting fruit but healthy undamaged fruit exhibiting unusual symptoms is important. Keep an eye out for:

- Larvae – maggots.
- Pin prick holes on the fruit surface.

Trapping

Regular checks in fruit fly prone areas (domestic) ensures that no exotic fruit flies have made their way into our agricultural systems. Oriental fruit fly, among other *Bactrocera* species, are strongly attracted to methyl eugenol (ME) which can be placed in traps alongside insecticide.

A trap with a strong attractant lure often has an insecticide added – killing and allowing retention of the fly for later identification purposes.

Traps can be hung from trees near horticultural crops with traps for catching a variety of exotic fruit fly species in use in several countries for many years. There are many trap types available but consist mainly of two types:

- Male attractant traps
- Protein/host scent

Studies show that oriental fruit flies prefer host odour traps over protein traps.

Integration of trapping into area wide management programs has been a successful means to monitor eradication programs.

Contact person name (optional – delete if not required)

Email:

Phone:

Website:

OFFICIAL

Male Attractant Traps

Lynfield and Steiner traps are used with male attractants (methyl eugenol). Dry cone traps, a newer type of trap, can also be used, but where the previous traps impregnate a soft cotton 'dental wick' with lure and insecticide, the cone trap uses a male lure sachet and the trap's inside is coated with insecticide.

Lynfield trap

The trap is designed to attract and capture fruit flies using a combination of visual and olfactory cues.

The trap consists of a cylindrical container, typically made from clear or translucent plastic, with several holes or slots near the top to allow fruit flies to enter. Inside the trap, an attractant, such as a pheromone lure or a food-based bait, is placed to draw the flies in. Common attractants include methyl eugenol—highly effective for species like *Bactrocera dorsalis*. The trap's design minimizes the risk to non-target insects.

Steiner trap

The trap is designed to attract and capture male fruit flies using specific chemical lures.

The trap consists of a rectangular or cylindrical container, usually made from plastic or metal. It has multiple entry points for fruit flies to enter. Inside the trap, a wick or a sponge soaked in a liquid attractant, such as a pheromone or a food lure, is suspended. The most common attractants used are trimmed lure for the Mediterranean Fruit Fly and cuelure for the Queensland Fruit Fly. These lures are highly effective in attracting male flies from a significant distance. Once the flies enter the Steiner trap, they are either killed by an insecticide applied to the wick or trapped and unable to escape. Some versions of the trap may also use a sticky substance on the interior walls. The trap can target specific fruit fly species with minimal impact on non-target organisms.

Cone trap

A cone trap is designed to lure and capture fruit flies using a combination of visual and olfactory attractants.

A cone trap consists of a plastic or paper cone suspended over a collection container. The cone is inverted, with its wide opening facing downward. The trap's design capitalises on the natural behavior of fruit flies, which tend to fly upwards after entering an enclosure. The flies are attracted to the trap by a lure placed inside, usually a pheromone or a food-based attractant like protein hydrolysate, drawing them into the cone through the wide opening at the bottom. Once inside, the flies move upwards and get trapped in the collection container, unable to escape due to the narrow apex of the cone. The collection container, which can contain an insecticide or a sticky surface, ensures that the captured flies are immobilized and eventually killed. The cone trap targets both male and female flies.

Protein/Host Scent Traps

Olfaction plays a strong role in food sourcing and ovipositioning for tephritid fruit flies and these types of traps attract both male and female fruit flies. They come in both in a wet type trap with liquidised lures or as a dry type trap with dry sachets (no sex specific), or a protein gel strip. Sticky traps are also often

used with a dry attractant. Regular inspection of traps allows for workers to empty the traps and replenish the bait.

WET TRAPS

McPhail trap

The trap consists of a container of plastic or glass, with a funnel-shaped lid. The container is translucent or transparent. At the bottom of the container, a liquid bait attracts fruit flies. The bait is a mixture of substances that emit odors similar to ripe or fermenting fruits. Common ingredients include apple cider vinegar, yeast, sugar, and water. The lid of the trap is designed with a funnel-shaped entrance that allows fruit flies to enter the trap but makes it difficult for them to escape. The narrow opening of the funnel prevents the flies from finding their way out. McPhail traps are typically hung from trees or other structures in the vicinity of fruit trees or crops. They may be suspended using wires, strings, or hooks.

Cera trap

The Cera trap is a cylindrical container made of transparent or semi-transparent durable plastic. Sturdy and weather-resistant it's similar to the McPhail trap and uses an attractive bait. The bait is a liquid mixture containing substances that emit odors resembling ripe or fermenting fruits. Ingredients such as hydrolyzed protein, yeast hydrolysate, sugar, and water are common. Inside the cylindrical container, there may be multiple chambers. These chambers maximise trapping efficiency by providing more surface area for the bait and likelihood of fruit flies entering the trap. The lid prevents rainwater from diluting the bait and minimises evaporation. The lid may also have vents to allow fruit flies to enter while preventing other insects from access. Like the McPhail trap, the Cera trap is hung from trees or other structures in near fruit trees or crops. It may feature a hook or attachment point for easy hanging.

DRY TRAPS

Cone trap (see previous)

Bio trap

A bio trap for fruit flies is a type of trap that utilises biological attractants or agents to lure and capture fruit flies. Unlike traditional traps that rely solely on chemical baits, bio traps leverage natural compounds or organisms that are attractive to fruit flies. The design of a bio trap can vary depending on the specific attractant being used and the target fruit fly species. It may consist of a container or chamber that houses the attractant, along with entry points or openings that allow fruit flies access.

STICKY TRAPS

Jackson trap

A Jackson sticky trap is usually a flat, rectangular or square-shaped piece of colored plastic or cardboard. Jackson traps are made of durable, poly-coated paperboard, these traps are designed to be used with a replaceable sticky-surfaced insert. The inserts slide out easily and should be replaced when they are full of insects and/or are covered in debris. Some Jackson sticky traps may also include a lure or attractant to increase their effectiveness.

Lures

Male Lures

There are two types of male lures

- Anthropogenic
- Plantborne

These male lures have previously been easy to synthesize as the chemistry of the compounds are relatively simple in structure. Although these lures vary in effectiveness depending on species and mated status, these lures remain incredibly potent as an attractant.

- Methyl eugenol (ME) is considered one of the most powerful male lures and its use is widespread in area wide management programs and surveillance traps. Oriental fruit fly is especially responsive to methyl eugenol.
- Raspberry Ketone, Raspberry Ketone Formate, and Cue Lure are effective attractants but for *B.dorsalis* less so than ME. They are generally the most widespread used lure for trapping.
- Fluorinated analogs of ME (eg isoeugenol) are becoming widespread due to the negative reports of chemical toxicity (carcinogen). However contradictory studies show that due to the extremely low doses used of ME the risk is significantly reduced. Analogs have been known to attract species that may not respond to other lures.
- Plant Phenylpropanoids, Dimethoxycinnamyl Analogs, although almost effective as ME as a feeding stimulant for *Bactrocera* species, the low volatility and attractancy is lower than ME.

Host/Protein Lures

These are weaker at attracting males but are often useful for trapping both male and female flies as female flies often seek protein after mating.

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Oriental Fruit Fly

Management Protocols

In Australia, states have specific plans in place to address the potential incursion of *Bactrocera dorsalis*.

General Information:

The Oriental fruit fly *Bactrocera dorsalis* is a serious pest of fruit crops, capable of infesting over 400 different fruits and vegetables. The wide range of host plants is one reason for *B.dorsalis* success in many parts of the world. Originating from Asia, it has spread to several countries worldwide, including incursions into Australia in 1996.

Further infestations of Oriental fruit fly could lead to significant economic losses in Australia's horticultural industry. It poses a threat to fruit production and trade due to quarantine restrictions imposed by importing countries and threatens Australia's \$16.3 billion horticultural market (HIA, 2023) alongside its export market worth of \$2.78 billion (Rural Bank, 2024).

Risk Factors include suitable climate conditions in many parts of Australia. This potentially could facilitate the establishment and spread of *B.dorsalis* throughout the country. The presence of susceptible host plants, which include much of Australia's commercial fruit and vegetable sectors, further increases the risk of infestation.

Management Strategies:

Australia employs a range of management strategies to prevent, detect, and respond to potential Oriental fruit fly incursions. Many of these strategies have a strong foundation in Australia's National Biosecurity Strategy Implementation Plan (2024).

These strategies include surveillance, monitoring, quarantine measures, and community engagement.

References to National and State-Based Management Plans for Potential Incursions:

1. National Management Plans:

National Fruit Fly Strategy

The National Fruit Fly Strategy provides a framework for coordinated action against fruit fly species, including species currently present, Mediterranean fruit fly (*Ceratitidis capitata*) and Queensland Fruit Fly (*Bactrocera tryoni*), as well as ensuring exotic species, including Oriental fruit fly (*Bactrocera dorsalis*).

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The strategy aims to have adequate preparedness in place and response strategies to manage potential incursions. In addition, an extensive seasonal eradication in the Torres Strait in order to prevent potential incursions onto the Australian mainland.

Reference: National Fruit Fly Council (2020). National Fruit Fly Strategy, Plant Health Australia. Plant Health Australia 2020. <https://www.preventfruitfly.com.au/wp-content/uploads/2023/04/National-Fruit-Fly-Strategy-2020-25.pdf>

Reference: Department of Agriculture, Fisheries and Forestry. (2023). Managing Fruit Flies in Australia. <https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/fruit-flies-australia/management>

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Reference: Commonwealth of Australia. (2021). Torres Strait Exotic Fruit Fly Eradication Program. <https://www.outbreak.gov.au/current-outbreaks/torres-strait-exotic-fruit-fly>

2. Specific State-Based Management Plans:

Queensland

Queensland's Department of Agriculture and Fisheries (DAF) coordinates state-specific management plans for potential Oriental fruit fly incursions.

These plans involve surveillance networks, response protocols, and public awareness campaigns to enhance early detection and rapid response capabilities.

Reference: Department of Agriculture and Fisheries, Queensland Government. (2017). Exotic fruit fly surveillance. <https://www.daf.qld.gov.au/business-priorities/biosecurity/plant/eradication-surveillance-control/exotic-fruit-fly-surveillance>

New South Wales (NSW):

The New South Wales Department of Primary Industries (NSW DPI) implements state-based management plans to safeguard the horticultural industry against Oriental fruit fly incursions.

These plans incorporate surveillance activities, regulatory measures, and industry partnerships to mitigate the risk of establishment and spread.

Reference: NSW Department of Primary Industries. (2022). Oriental Fruit Fly. <https://www.dpi.nsw.gov.au/biosecurity/plant/insect-pests-and-plant-diseases/orientalfly>

Additional Resources:

Plant Health Australia (PHA):

<https://www.fruitflyidentification.org.au/species/bactrocera-dorsalis/>

<https://www.farmbiosecurity.com.au/wp-content/uploads/2019/03/Oriental-fruit-fly-complex-FS-Avocado.pdf>

Business Queensland: <https://www.business.qld.gov.au/industries/farms-fishing-forestry/agriculture/biosecurity/plants/priority-pest-disease/oriental-fruit-fly>

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Oriental Fruit Fly

Control

The Oriental Fruit Fly (*Bactrocera dorsalis*) is a highly invasive pest that affects a wide variety of fruit and vegetable crops. Effective control is essential to prevent significant agricultural losses and to comply with quarantine regulations within your state or territory.

Controlling the Oriental Fruit Fly involves a multifaceted approach that integrates cultural, chemical, biological, and mechanical measures.

Initial response – Eradication will focus on chemical control and either Male Annihilation Technique (MAT) or Sterile Insect Technique (SIT).

Supporting treatments – Cultural control, classical biological control and Integrated Pest Management (IPM).

Ongoing management – Quarantine and regulatory measures.

Supporting treatments and ongoing management should begin at eradication/initial response to ensure that eradication procedures are strengthened.

Chemical Control

1. Insecticide treatments

Foliar Sprays: Apply contact insecticides to the foliage to kill adult flies. Insecticides like Spinosad, malathion, and pyrethroids can be effective.

Bait Sprays: Use a mixture of protein bait and insecticide to attract and kill adult flies. Bait sprays can target flies more effectively and reduce the amount of insecticide needed.

Combination treatment (Male Annihilation Technique MAT): Deploy traps baited with methyl eugenol and insecticides to attract and kill male flies. This reduces the mating potential of the population.

Soil Drenches: Apply insecticides to the soil to target pupae. This can be effective in areas where larvae drop to pupate.

There is a range of products available to commercial growers consult the [Australian and Veterinary Medicines Authority \(APVMA\) public chemical registration system \(PubCRIS\)](#).

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Withholding periods

Depending on type of spray insecticides will have a withholding period. Please refer to manufacturers recommendation (label) as these will be based on regulatory controls as outlined by the APVMA. Consider water courses and nearby livestock when spraying in commercial orchards/fields and in areas where the general public frequent. Exceptions to withholding periods may apply for organic sprays used in home gardens.

Insecticide spray effectiveness

Spray effectiveness may be influenced by a number of factors:

- Type of Spray
- Timing
- Coverage
- Management of off target impacts eg injury or damage to plants, animals or environment
- Flies resistance to chemical (usually built over a period of time)

Male Annihilation Technique

The Male Annihilation Technique has proven to be one the most effective means for control of *B.dorsalis* since it was first used in 1965 (Steiner et al, 1965). Subsequent use in eradication programs has followed successfully in the Okinawa Islands (Koyama, 1984).

The technique relies heavily on the attractiveness of a powerful male lure such as methyl eugenol (ME) and that lower densities of flies are more conducive to overall effectiveness (Jang et al, 2017; Manoukis et al, 2017).

Sterile Insect Technique (SIT)

The Sterile Insect Technique is an environmentally friendly means of insect control that has been highly successful for a number of invasive fruit fly species. It is usually used as a means of 'mopping up' after a the wild fruit fly population has been reduced using monitoring and other control measures. SIT against *B.dorsalis* has been shown to have positive economic benefits (Sutantawong et al, 2004).

1. Sterilization and Release

Mass Rearing: Sterilize large numbers of male flies using radiation.

Release Programs: Release sterilized males into the wild to mate with females, leading to non-viable eggs. This reduces the population over time.

2. Area-Wide Management:

SIT is most effective when implemented on a large scale, covering entire regions to ensure comprehensive population suppression.

Cultural Control

1. Sanitation

Field Hygiene: Regularly collect and destroy all fallen and infested fruits to reduce breeding sites. This should be done at least once a week to break the fly's lifecycle.

Pruning and Thinning: Remove excess foliage and thin out fruit clusters to improve air circulation and reduce the habitat for the flies.

2. Harvest Timing

Early Harvesting: Harvest fruits before they fully ripen when they are less attractive to the flies. This helps reduce the period fruits are exposed to the flies.

3. Mechanical Control

Mass Trapping: Use a large number of traps to capture both males and females, thereby reducing the overall population.

Physical Barriers: Netting over fruits and around trees to prevent flies from reaching the fruits.

Screen Houses: Grow high-value crops in screen houses to physically exclude the flies

Bagging Fruits: Cover developing fruits with paper, plastic, or cloth bags to protect them from oviposition by female flies. This method is very labor-intensive but effective for high-value crops.

Classical Biological Control

Parasitoids: Introduction of Natural Enemies: Release parasitoid wasps such as *Fopius arisanus*, which lay their eggs in fruit fly larvae, effectively controlling the population.

Conservation of Natural Enemies: Preserve and encourage natural predators and parasitoids by minimizing broad-spectrum insecticide use.

Predators: Generalist Predators: Encourage populations of generalist predators like ants, spiders, and predatory beetles that feed on fruit fly eggs and larvae.

Entomopathogenic fungi and nematodes

Integrated Pest Management (IPM)

Monitoring and Record-Keeping: Regularly monitor fly populations using traps and visual inspections. Keep detailed records of trap catches and infestation levels to inform management decisions.

Threshold-Based Control: Implement control measures based on population thresholds. This ensures interventions are timely and effective, reducing unnecessary chemical use.

Community Collaboration: Coordinate with neighboring farms and local authorities for area-wide management programs. Shared efforts increase the effectiveness of control measures and reduce the risk of reinfestation.

Quarantine and Regulatory Measures

1. Quarantine Protocols:

Follow strict quarantine measures to prevent the spread of the fly to new areas. This includes regulating the movement of host fruits and vegetables and ensuring compliance with international and local guidelines.

2. Inspection and Certification:

Regularly inspect crops and produce for signs of infestation. Obtain certification for pest-free status before shipping produce to non-infested areas.

Conclusion

Effective control of the Oriental Fruit Fly requires a comprehensive, integrated approach combining multiple control strategies. Regular monitoring, cultural practices, targeted chemical applications, biological controls, and area-wide management programs are essential components of a successful control strategy. Collaboration among farmers, communities, and regulatory bodies enhances the effectiveness and sustainability of these measures.

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Oriental Fruit Fly

Biology

Oriental fruit fly, *Bactrocera dorsalis* (Hendel, 1912) is considered a high pest risk species due to several characteristics.

These characteristics include:

- Highly invasive; native to Asia it's now found in parts of America, Oceania, most of sub-Saharan Africa and more recently Europe.
- High reproductive potential with short life cycle and several generations per year that produce many offspring per female.
- Rapid dispersal ability and very mobile.
- Broad host range with the potential to impact several industries in the horticultural sector.

Species Complex

The current scientific name of Oriental fruit fly is *Bactrocera dorsalis* (Hendel, 1912) (Manrakhan, 2020). However, *B. dorsalis* is part of the Oriental fruit fly species complex, which forms a group within the subgenus *Bactrocera* (Manrakhan, 2020).

Many synonyms of *B. dorsalis* have been identified, including:

- *Bactrocera invadens* (Drew, Tsura & White, 2005),
- *Bactrocera papayae* (Drew & Hancock, 1994),
- *Bactrocera philippinensis*
- *Dacus dorsalis* (Hendel, 1912) (Manrakhan, 2020).

The taxonomic tree for Oriental fruit fly is as follows:

CLASS: INSECTA

ORDER: DIPTERA

FAMILY: TEPHRITIDAE

GENUS: *BACTROCERA*

SPECIES: *BACTROCERA DORSALIS*

Contact person name (optional – delete if not required)

Email:

Phone:

Website:

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Description

Oriental fruit fly has four life stages: egg, larva, pupa and adult. *B. dorsalis* eggs are white, of a long elliptical shape and 1.2 mm long. The larvae are creamy white and length varies from 5-15 mm, with younger stages being smaller in size.

The pupae are white to yellow-brown, are roughly cylindrical and are approximately 5 mm long. Adult *B. dorsalis* have a wasp-like appearance and are approximately 7 mm long. They have clear wings and



have a black back with a paler abdomen. A black T-shaped marking is located on the abdomen.

Figure 1: Adult male Oriental fruit fly on leaf

Life Cycle

After approximately 7 days (at 23-30°C) and once the third instar larvae have completed their development, the larvae leave the fruit, disperse briefly and bury into the soil to pupate. Pupation has been found to occur over a few hours (at 23-30°C). The pupa then develops within the puparium. After approximately 10 days (at 23-30°C), once the pupation period is complete, the adult flies emerge from the puparium and surface the soil.

The emergence of flies has been found to occur between 8:00-10:00 AM. The newly emerged flies are inactive for approximately one hour before becoming active and feeding (at 23-30°C). At 25°C, the pre-oviposition period is 6.6 days. Most eggs may be laid within the first 3 weeks following emergence, though females can produce eggs for 2 months. Adult *B. dorsalis* can live for 2-3 months.

Insert graphic of lifecycle here.

Distribution

A 2018 review of the Global distribution and invasion pattern of oriental fruit fly showed that *Bactrocera dorsalis* had increased from five countries in 2010 to 75 countries within Asia, Africa, North America, South America and Oceania (Zeng et al, 2018). Current distribution can be seen in figure 3.

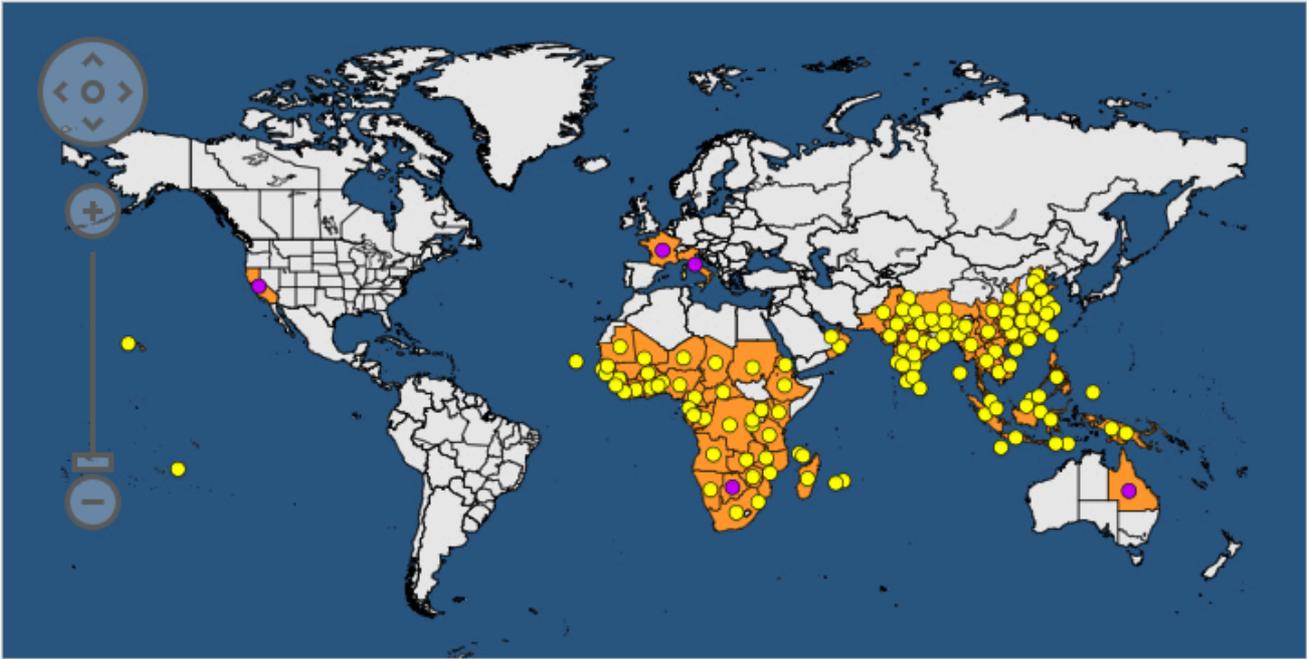


Figure 3: World distribution of *Bactrocera dorsalis*. (Also includes past records of synonyms *B. invadens*, *B. papayae* and *B. philippinensis* Source: EPPO Global Database, 2022)

Host Information

Many host species exist for *B. dorsalis* and the fly has been recorded on over 490 plant species in 81 families, with official host species lists only differing country to country. Hosts include both commercial and non-commercial plants. Oriental fruit fly infests both fruiting plants as well as fruit and vegetable produce (post-harvest).

An infestation in fruit can be identified by possible small discoloured (brown or black) or water-soaked patches on the fruit skin (necrosis) around the point of oviposition and/or decomposition of the fruit with the fruit dropping from the host plant prematurely. During an outbreak in Queensland, Australia in the 1990's, *B. dorsalis* was found to breed in 35 host plants, resulting in damage to many different types of fruit including coffee berries and green papaya/pawpaw.

In the 1996 outbreak of Papaya Fruit Fly in Queensland the following cultivated fruits were found to have been hosts, they include: Abiu, Banana, Beach cherry, Brazil cherry, Bush lemon, Canistel, Capsicum, Carambola, Cashew, apple, Chilli, Coffee, Cumquat, Guava, Grapefruit, Jaboticaba, Malay apple, Mango, Meyer lemon, Papaya, Passionfruit, Peach mango, Pummelo, Santol, Soursop, Star apple, *Terminalia catappa*, Tomato, White sapote.

Competition between species

The competition between *Bactrocera dorsalis* and other fruit fly species is characterised by its aggressive colonization behavior (Moquet et al, 2021) and highly adaptative nature. *B. dorsalis* has demonstrated a remarkable ability to exploit a broad range of host plants, often out competing indigenous species such as the Mediterranean Fruit Fly (*Ceratitis capitata*) and the Queensland Fruit Fly (*Bactrocera tryoni*) who have a more limited range of host plants in comparison. Its high reproductive rate and rapid life cycle allow it to establish large populations quickly and out-compete other species. *B. dorsalis* has shown adaptability to various environmental conditions, including different climatic zones, enhancing its invasive potential in both agricultural and natural ecosystems .

Australian researchers have embarked on climate risk studies for biosecurity threats, including oriental fruit fly (DPI NSW, 2024a, 2024b). Even with no currently established population future possible incursions of *B. dorsalis* could benefit under climate change. Even with minimal climate change, the ecological impact of *B. dorsalis* on other fruit fly species can be profound, leading to the displacement of native species. This displacement occurs through several mechanisms, including direct competition for food resources, oviposition sites, and breeding grounds.

Seasonality

B. dorsalis exhibits seasonality in diverse agricultural systems. This is an important factor in management and dependent on dry and cold stress with risk where irrigation is used year round vs risk within natural rainfall areas.

Oriental fruit fly breed in optimal (warm) temperatures and dispersal influenced by host availability. Sanitation, pesticide application, trap deployment and all other methods of cultural and chemical control (including removing infested fruit) will reduce population numbers. Consulting temperature dependent models and awareness of the ecology of the fly will help optimize control efforts early in any incursion. The addition of Sterile Insect Technology and Male Annihilation Technology should also further reduce populations to address issues that arise.

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