Final Report

Economic impact assessment for Hort Frontiers: An evaluation of *SITplus: Raising Qfly sterile insect technique to world standard* (HG14033)

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Economic impact assessment for Hort Frontiers (HA20000)

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Contents

List of Tables

List of Figures

Public summary

Hort Frontiers invests funds from a wide range of co-investors including businesses, research agencies, government departments, education institutions, the Australian Government and horticulture levies. Economic impact assessment of these investments is required to meet Hort Innovation obligations under its Organisational Evaluation Framework, its Statutory Funding Agreement, and to demonstrate a return to a diverse set of co-investors and other stakeholders.

This economic impact assessment of the Hort Frontiers program addresses these requirements through the completion of a series of project-specific, ex-post, independent impact assessments of the program. The economic impact assessment was completed using guidelines prepared by the Council of Rural Research and Development Corporations (CRRDC, 2018).

The project assessed in this impact assessment *was HG14033: SITplus: Raising Qfly Sterile Insect Technique to World Standard*. Investment in project HG14033 represented a significant and complex RD&E program investment. The structure of HG14033 recognised the diverse processes involved in an effective SIT program and provided support for each. Given the diversity of needs, HG14033 operated under 10 thematic areas and contained 26 distinct projects, each with its own objectives, leadership, team, collaborations, and resources.

The primary outcome of the overall investment in project HG14033 was the development of essential knowledge and technology to support effective and efficient SIT and AWM through the SITPlus group. Information and data from the project already have been used as input to guide pilot SIT programs that have reported success of Qfly suppression in the field.

Technical summary

This report presents the results of an impact assessment of a Hort Frontiers Fruit Fly Fund project *HG14033: SITplus: Raising Qfly Sterile Insect Technique to World Standard*. The project was funded by Hort Innovation over the period June 2015 to June 2021.

The investment was first analysed qualitatively within a logical framework that included activities and outputs, outcomes, and impacts. Actual and/or potential impacts then were categorised into a triple bottom line framework. Principal impacts identified were then considered for valuation in monetary terms (quantitative assessment). Past and future cash flows were expressed in 2021/22-dollar terms and were discounted to the year 2021/22 using a discount rate of 5% to estimate the investment criteria and a 5% reinvestment rate to estimate the modified internal rate of return (MIRR).

HG14033 represented a significant and complex RD&E program investment. The structure of HG14033 recognised the diverse processes involved in an effective SIT program and provided support for each. Given the diversity of needs, HG14033 operated under 10 thematic areas and contained 26 distinct projects, each with its own objectives, leadership, team, collaborations, and resources.

The primary outcome of the overall investment in project HG14033 was the development of essential knowledge and technology to support effective and efficient SIT and AWM through the SITPlus group. Information and data from the project already have been used as input to guide pilot SIT programs that have reported success of Qfly suppression in the field.

Total funding from all sources for the project was $26.3 million (present value terms). The investment produced estimated total expected net benefits of $54.9 million (present value terms). This gave a net present value of $28.6 million, an estimated benefit-cost ratio of 2.1 to 1, an internal rate of return of 4.4% and a MIRR of 11.6%.

Sensitivity analyses demonstrated that the investment criteria remain positive even when key assumptions were set to more conservative values. This indicated that the positive results were credible and robust. Further, given that some impacts identified were not valued, the investment criteria reported may be an underestimate of the true performance of the investment in HG14033.

Keywords

Impact assessment, Cost-Benefit Analysis, Fruit Fly Fund, Hort Frontiers, Queensland Fruit Fly, Qfly, Sterile Insect Technique, SIT, SITplus

Introduction

The Hort Frontiers program facilitates collaborative cross-industry investments that are focused on high-risk, transformative research, development, and extension (RD&E) with the potential for significant impact. Investments are longer-term, complex, and focus on traditionally underinvested themes.

Hort Frontiers invests funds from a wide range of co-investors including businesses, research agencies, government departments, education institutions, the Australian Government and horticulture levies. Economic impact assessment of these investments is required to meet Hort Innovation obligations under its Organisational Evaluation Framework, its Statutory Funding Agreement, and to demonstrate a return to a diverse set of co-investors and other stakeholders.

This economic impact assessment of the Hort Frontiers program addresses these requirements through the completion of a series of project-specific, ex-post, independent impact assessments of the program. A total of eight (8) RD&E investments (projects) were selected through a stratified, random sampling process. The projects, and the total life-of-project (LOP) value of their Hort Innovation managed investment in nominal terms are described in Table 1.

Table 1: Hort Frontiers Project Sample for Impact Assessment

Hort Frontiers Fund	Project Code	Project Title	Total LOP Investment[(a)] (nominal $)
Advanced Production Systems	AS19005	Australian Protected Cropping RD&E Strategy 2030	140,322
Fruit Fly	HG14033	SITplus: Raising Qfly Sterile Insect Technique to World Standard	20,502,806
Green Cities	GC15002	Which plant where when and why database	10,573,638
Health, Nutrition & Food Safety	HN15000	Innovative Cold Plasma for Horticultural Industries	5,080,321
International Markets	AM15007	Market Development Program - Almonds	925,499
International Markets	AM17001	Developing a national systems approach for meeting bio-security requirements to access key Asian markets	4,830,614
Leadership	LP15001	Global Masterclass Horticulture	3,235,805
Pollination	PH16004	Securing pollination for productive agriculture: guidelines for effective pollinator management and stakeholder adoption	2,182,967

(a) Hort Innovation managed investment

The project population for each fund from which the random sample was selected included completed projects where a final deliverable had been submitted and accepted in the three-year period from 1 July 2019 to 30 June 2022.

The projects in the random sample were selected such that:

(1) The total LOP sample value (in nominal dollar terms) represented at least 10% of the total Hort Innovation managed investment in the overall Hort Frontiers project population, and
(2) The total Hort Innovation managed investment in each project was greater than, or equal to, $100,000 (to exclude 'trivial' projects).

Further, the random sample was stratified first by Hort Frontiers Fund, to ensure all relevant Funds were represented, and then by LOP value range.

The final stratified random sample shown in Table 1 included the required eight (8) projects. At least one project from each Hort Frontiers Fund was selected and at least one project from each LOP range (as defined by Hort Innovation). The final random sample had a total nominal LOP value of $47.47 million (Hort Managed investment) equivalent to approximately 51.6% of the overall total nominal LOP value in the population. Also, the final random sample included one project completed in 2019/20, two completed in 2020/21, and five completed in 2021/22 (all relevant years represented).

Project HG14033: *SITplus: Raising Qfly Sterile Insect Technique to World Standard* was one of the investments randomly selected and is analysed in this report.

Methodology

The impact assessments followed general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some universities. The approach includes both qualitative and quantitative assessment components that are in accord with the impact assessment guidelines of the Council of Rural Research and Development Corporations (CRRDC) (CRRDC, 2018).

The evaluation process followed an input to impact continuum and involved identifying and briefly describing project objectives, activities, outputs, actual and expected outcomes, and any actual and/or potential impacts associated with project outcomes. The principal economic, environmental, and social impacts then were summarised in a triple bottom line framework.

Once impacts were identified and described, a decision then was made whether to value any of the impacts in monetary terms. Where it was decided to value one or more of the impacts, some, but not necessarily all, of the impacts identified were then valued in monetary terms. The decision to value an impact identified was based on:

- Data availability and information necessary to form credible valuation assumptions,
- The complexity of the relevant valuation methods applicable given project resources,
- The likely magnitude of the impact and/or the expected relative value of the impact compared to other impacts identified, and
- The strength of the linkages between the RD&E investment and the impact identified.

Where impact valuation was exercised, the impact assessment used cost-benefit analysis (CBA) as a principal tool. The impacts valued are therefore deemed to represent the principal benefits delivered by the project. However, as not all impacts were valued, the investment criteria reported for the individual investment evaluated are likely to represent an underestimate of the true performance of the investment.

Background and Rationale

Background

Australia's horticultural production was forecast to be worth over $14 billion (gross value of production) in 2022/23 (Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), 2022). A large proportion of horticultural production is susceptible to attack by fruit flies. Fruit flies attack and damage most kinds of soft skinned fruits and some harder skinned commodities. Fruit fly numbers tend to increase, usually in spring, when temperatures are warm and there is continued availability of suitable host plants. Adult female flies lay eggs into maturing fruit that hatch inside the fruit. The larvae then feed within the fruit. Crops such as summerfruit, citrus, apples, pears, loquats, berries, grapes, olives, persimmons, tomatoes, capsicum, eggplant, and mangoes can all be attacked (Plant Health Australia (PHA), 2021).

There are two main species of fruit flies within Australia: originally native to Africa, Mediterranean fruit fly (Medfly; *Ceratitis capitata*) occurs only in Western Australia (WA), mostly in the south-western parts. Queensland fruit fly (Qfly; *Bactrocera tryon*i) occurs in the Northern Territory (NT), Queensland (QLD), New South Wales (NSW) and Victoria (VIC) and is an Australian native species. Qfly currently is only reported to be present in eastern Australia and New Caledonia (CABI, 2022) and is a pest of quarantine concern that can have major negative impacts on Australia's capacity to trade competitively in international markets (NSW Department of Primary Industries (NSW DPI), n.d.).

To mitigate the negative impacts of Qfly, commercial horticulture producers around Australia collectively spend hundred of millions of dollars each year on various control measures and also suffer production losses (PHA, 2021). Qfly has become more prevalent and persistent in southern regions of Australia. Compounding the problem, use of the organophosphate insecticides Dimethoate and Fenthion typically used to protect crops has been restricted so that they are no longer an effective solution for many producers.

The sterile insect technique (SIT) involves irradiation, such as with gamma rays and X-rays, to sterilise mass-reared pest insects so that, while they remain sexually competitive, they cannot produce offspring. SIT does not involve transgenic (genetic engineering) processes and the International Plant Protection Convention (IPPC) categorises sterile insects as beneficial organisms (International Atomic Energy Agency (IAEA), 2022). SIT also is a recognised phytosnanitary procedure for pest management under the Internaional Standards for Phytosanitary Measures (ISPMs) (Department of Agriculture, Fisheries and Forestry (DAFF), 2021). The SIT differs from classical biological control, which involves the introduction of non-native biological control agents, in several ways (IAEA, 2022):

- Sterile insects are not self-replicating and therefore cannot become established in the environment.
- Breaking the pest's reproductive cycle, also called autocidal control, is by definition species-specific.
- The SIT does not introduce non-native species into an ecosystem.

SIT is recognised as an effective and desirable option for the management and/or eradication of fruit flies. It is species-specific, environmentally friendly and has been proven effective in overseas programs such as Chile, Guatemala, Mexico, USA and Japan. SIT can contribute to (DAFF, 2021):

- Reduced pest damage and costs.
- Reduced chemical pest controls.
- Reduced insect and post-harvest treatment requirements and damage.
- Improved productivity.
- Improved product quality.
- Improved environmental outcomes.

Rationale

SIT is used around the world to control many pest fruit fly species. SIT has been previously used to control or eradicate Medfly and Qfly in NSW, VIC, South Australia (SA), and WA. The technique has previously been used for suppression activities in areas of low wild fruit fly populations, and also during outbreaks within established Pest Free Areas (PFAs). In regulated PFA, SIT flies currently are only used in response to an incursion/outbreak with the aim to eradicate the incursion. However, despite being recognised as an integral part of future area-wide management (AWM) strategies for fruit fly, Qfly SIT in Australia was relatively underdeveloped and not sufficiently effective for deployment as a mainstream control option.

Through the Hort Fronties Fruit Fly Fund, project HG14033: *SITplus: Raising Qfly Sterile Insect Technique to World Standard* (hereafter referred to as simply SITplus) was funded to increase capacity and efficiency in delivering SIT programs for Qfly. The collaborative SITplus consortium was established to lead and co-ordinate the development of Qfly SIT in Australia, and to support the development activities of a new Qfly SIT facility under construction in SA.

Project Details

Summary

Project Code: HG14033
Title: *SITplus: Raising Qfly Sterile Insect Technique to World Standard*
Lead Research Organisation: Macquarie University (MU)
Partner Organisations: CSIRO, NSW DPI, South Australian Research and Development Institute (SARDI), the New Zealand (NZ) Institute for Plant and Food Research Ltd (PFR)
Project Leader: Phillip Taylor, Associate Professor, MU
Period of Funding: June 2015 to June 2021 (final report date)

Objectives

Project HG14033 was developed in recognition of the need for significant research and investment to bring Qfly SIT up to the standards of overseas operations used to control other fruit fly species. The investment was to address a number of knowledge and technology gaps, and to close the gap between the RD&E underpinning Qfly SIT in Australia and overseas programs of other species.

HG14033 represented a significant and complex RD&E program investment. The structure of HG14033 recognised the diverse processes involved in an effective SIT program and provided support for each. Given the diversity of needs, HG14033 operated under 10 thematic areas and contained 26 distinct projects, each with its own objectives, leadership, team, collaborations, and resources.

Logical Framework

A detailed logical framework for Project HG14033 was developed as part of the qualitative stage of the impact assessment. The logical framework described the activities, outputs, and actual and expected outcomes of project HG14033. The investment was then evaluated qualitatively within this framework and the likely economic, environmental, and social impacts of the total investment were identified and reported. Considering the relative size of the SITplus RD&E program investment and the scope of the RD&E activities (10 Themes containing 26 individual projects), the full logical framework is presented in Appendix 1.

Project Investment

Nominal Investment

Table 2 shows the annual investment made in Project HG14033. In addition to funding through the Hort Frontiers Fruit Fly Fund and lead research organization, MU, additional support for the project was provided by project partners including CSIRO, NSW DPI, SARDI, and the NZ Institute for Plant and Food Research Ltd.

Table 2: Annual Investment in Project HG14033 (nominal $, cash and in-kind)

Year (ended 30 June)	HORT FRONTIERS FRUIT FLY FUND ($)	MU[(a)] ($)	TOTAL[(b)] – HORT MANAGED FUNDS ($)
2015	1,202,091	1,797,909	3,000,000
2016	1,402,633	2,097,849	3,500,482
2017	1,402,633	2,097,849	3,500,482
2018	1,402,633	2,097,849	3,500,482
2019	1,402,633	2,097,849	3,500,482
2020	701,312	1,048,929	1,750,241
2021	701,290	1,048,885	1,048,885
Total	**8,215,224**	**12,287,120**	**20,502,344**

Source: Hort Innovation HG14033 Project Agreement and subsequent Project Variation Agreements.
(a) MU funding reported as Hort Managed Funds from RD&E strategic co-investment.
(b) Any minor discrepancies in totals are due to minor rounding errors.

Program Management Costs

For the Hort Frontiers investment the cost of managing the Hort Innovation funding was added to the Hort Innovation contribution for the project via a management cost multiplier (1.162). This multiplier was estimated based on the share of 'payments to suppliers and employees' in total Hort Innovation expenditure (3-year average) reported in the Hort Innovation's Statement of Cash Flows (Hort Innovation Annual Report, various years). This multiplier was then applied to the nominal investment by Hort Innovation shown in Table 2.

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2021/22-dollar terms using the Implicit Price Deflator for Gross Domestic Product (ABS, 2022). Project HG14033 was a large and complex RD&E program made up of 26 individual projects. A wide range of scientific publications, industry articles, media releases, conferences and other presentations were completed throughout HG14033. Research outputs also were communicated directly to key stakeholders including other researchers (e.g., FF17001), Hort Innovation and other research funders. Therefore, no additional extension costs were incorporated in the quantitative analyses.

Impacts

Table 3 provides a summary of the principal types of impacts delivered by the project, based on the logical framework (Table 2). Impacts have been categorised into economic, environmental, and social impacts.

Table 3: Triple Bottom Line Categories of Principal Impacts from Project HG14033

Economic	• Increased efficiency and/or effectiveness of resource allocation for future Qfly SIT RD&E through the realisation of essential foundational scientific knowledge and increased coordination and collaboration for Qfly SIT RD&E in Australia (for example, research outputs used to inform FF17001 and related Qfly SIT RD&E).
	• Contribution to potentially reduced SIT production and implementation costs through the adoption of recommendations that improve mass-rearing processes and SIT program logistics.
	• Contribution to improved effectiveness and efficiency of future SIT programs to control or eradicate Qfly in Australia. This in turn is expected to lead to increased long-term productivity and/or profitability for Australian horticultural producers in Qfly affected regions through:
	  ◦ Reduced Qfly damage and control costs.
	  ◦ Increased value because of increased average product quality.
	  ◦ Maintained or increased market access (both domestic and international).
	• Reduced future Qfly eradication costs from Qfly incursions/spread to new regions (e.g., WA and other domestic Qfly PFAs).

Environmental	• Some contribution to improved environmental outcomes through reduced agricultural chemical use for Qfly and therefore potential for reduced chemical export off-farm.
Social	• Maintained returns to investment in RD&E because of increased scientific knowledge and research capacity achieved through the support and training of over 20 post-graduate students and research fellows.

Public versus Private Impacts

The impacts identified from the investment were both public and private in nature. Public impacts will be delivered through increased effectiveness/efficiency of public resource allocation for Qfly SIT RD&E, increase scientific knowledge and research capacity, and improved future environmental outcomes from more effective implementation of SIT programs for fruit fly control.

Private impacts will accrue to horticultural producers and other horticulture supply chain stakeholders. Private impacts are likely to include reduced production costs for SIT production and program implementation and increased efficacy of future Qfly SIT programs leading to long-term increased productivity/profitability.

Distribution of Private Impacts

Private impacts will initially be captured by the horticultural producers/businesses affected by improved future SIT programs to control or eradicate Qfly and/or benefiting from maintained/improved market access through improved control of Qfly. Over the longer-term, private impacts are expected to be shared along horticulture produce supply chains, including input supplied, trade partners, and domestic and international consumers according to relevant supply and demand elasticities.

Impacts on Other Australian Industries

The project had a broad focus across Australian horticultural industries and was not expected to have any direct impacts on other Australian sectors. However, SIT has the potential to be applied to insect pests across a range of agricultural industries. The foundational scientific knowledge and research capacity created by HG14033 may contribute indirectly to long-term benefits in other agricultural industries through knowledge spillovers.

Impacts Overseas

Project HG14033 included collaboration with the NZ Institute for Plant and Food Research Ltd and engaged with international experts through the International Atomic Energy Agency. World-leading research methods and outputs produced by HG14033 may contribute to improved SIT RD&E and outcomes in other countries.

Match with National Priorities

The Australian Government's National Science and Research Priorities and National Agricultural Innovation Priorities are reproduced in Table 4. The project outcomes and related impacts will contribute to National Science and Research Priority 1. Project HG14033 also contributed to National Agricultural Innovation Priority 3 with potential contribution to Priority 1.

Table 4: Australian Government Research Priorities

Australian Government Strategies and Priorities	
National Science and Research Priorities[1]	**National Agricultural Innovation Priorities**[2]
1. **Food** – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets. 2. **Soil and Water** – improving the use of soils and water resources, both terrestrial and marine. 3. **Transport** – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions. 4. **Cybersecurity** – improving cybersecurity for individuals, businesses, government, and national infrastructure. 5. **Energy and Resources** – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries. 6. **Manufacturing** – supporting the development of high value and innovative manufacturing industries in Australia. 7. **Environmental Change** – mitigating, managing or adapting to changes in the environment. 8. **Health** – improving the health outcomes for all Australians.	On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper. 1. Australia is a trusted exporter of premium food and agricultural products by 2030. 2. Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030. 3. Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030. 4. Australia is a mature adopter, developer and exporter of digital agriculture by 2030.

Alignment with the Hort Frontiers Fruit Fly Strategic Priorities

The Hort Frontiers Fruit Fly Fund had four key investment themes defined by the Hort Innovation's Co-Investment Strategic Intent: Fruit Fly Fund document (Hort Innovation, 2018):

1) AWM and SIT
2) Develop and maintain capacity
3) Trade and market access alignment
4) Novel control technologies

Project HG14033 directly delivered against investment Theme 1 (AWM and SIT) and also contributed to all three other Fruit Fly Fund Themes.

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[1] See: 2015 Australian Government Science and Research Priorities. https://www.industry.gov.au/data-and-publications/science-and-research-priorities

[2] See: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment

Case Study

The following section provides real world feedback on how the outputs of the investment have benefited growers through protection and maintenance of key PFAs to support and maintained international market access.

R&D CASE STUDY: MASTERING AUSTRALIAN HORTICULTURE

THE CHALLENGE

Practical application of SIT for Qfly is still in the pilot stage and sterile flies are not yet available for commercial purchase. However, pilot trials have been highly successful, and the South Australian viticulture industry has already seen the potential benefits when the research was used as part of a program to eradicate Qfly following an outbreak near Loxton (SA) in 2019 (Smart, 2020).

THE APPROACH

Adult Qfly in production (photo credit: Smart, 2020)

Following declaration of the Qfly outbreak in the Riverlands SA in 2019, millions of sterile flies were bred in the Port Augusta based National SIT facility before being released aerially by plane into the region. SIT releases, along with baiting and hygiene operations, comprised the eradication response undertaken by PIRSA.

"An eradication response involving SIT, hygiene and baiting operations is regarded as the best method to effectively eliminate fruit flies," said SA's chief plant health manager, Dr Ross Meffin.

Winegrapes are a non-preferred host for Qfy and Medfly and in most situations, field damage is minimal. However, winegrapes are often grown adjacent to other horticultural crops that are hosts for fruit fly and impacts on export markets are considerable. As a result, winegrapes are often part of quarantine measures to eradicate and limit spread of these flies. These quarantine measures can cause headaches for growers and wine companies, particularly during vintage (Smart, 2020).

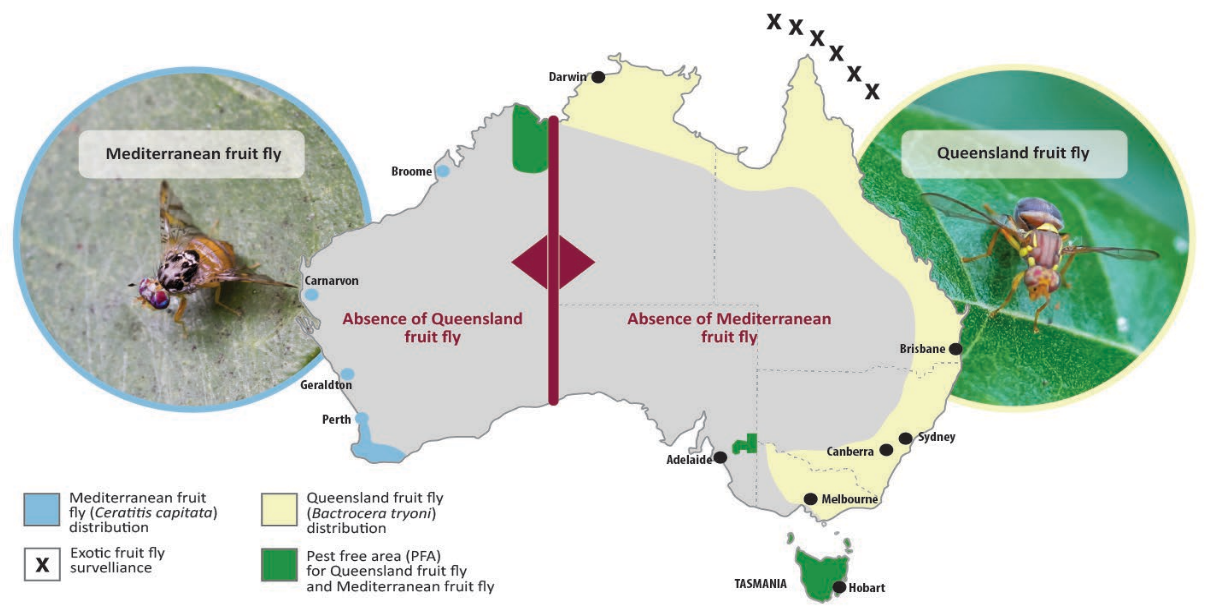
Damaged fruit from a Qfly outbreak in SA (photo credit: ABC News, 2019)

"SIT really is the ultimate in pest management." said Dr Meffin. "We've managed to breed really healthy flies for release here in Australia. Our flies are surviving for up to six months or more in the wild, which is quite unusual. This longevity is the outcome of significant research into diet, rearing conditions and release protocols, as well as strict hygiene in the factory."

THE IMPACT

The Riverland is one of only two, internationally recognised PFAs in Australia that support horticultural growers with a massive trade advantage when exporting. Minister for Primary Industries SA, Tim Whetstone, said early estimates of costs to government were $1.7 million, which included strategies to remove the flies. "It has been quite an extensive campaign, what I would say is that's it been very successful," he said.

Following the successful eradication campaign, SIT program director Dan Ryan said: "…we know from international experience that SIT can be used across a range of insects. The technology could easily be adapted to insects that pose a direct threat to the viticultural industries, such as brown marmorated stink bugs. We're well equipped."



Distribution of fruit fly in Australia (photo credit: DAFF, 2022)

As well as being used for eradication, SIT can be used for exclusion and suppression of pests. "Sterile insects can be released around the boundary of an area we want to protect or to create a buffer zone, for example, between the Sunraysia and Riverland areas," Ryan said.

Valuation of Impacts

Impacts Not Valued

Not all the impacts identified in Table 3 could be valued in the assessment. Those not valued included:

- Contribution to potentially reduced SIT production and implementation costs through the adoption of recommendations that improve mass-rearing processes and SIT program logistics. As Qfly SIT still is in the pilot phase, data for the total annual operational costs for future SIT programs to control Qfly (including production facility costs) were not available and uncertain.
- Some contribution to improved environmental outcomes through reduced agricultural chemical use for Qfly and therefore potential for reduced chemical export off-farm. The long-term environmental impacts associated with new and improved Qfly management and control through SIT have not yet been studied and therefore were uncertain. Further, the linkages between environmental impacts and the SITplus investment were considered weak relative to the other impacts assessed.

Impacts Valued

Analyses were undertaken for total benefits that included future expected benefits. A degree of conservatism was used when finalising assumptions, particularly when some uncertainty was involved. Sensitivity analyses were undertaken for those variables where there was greatest uncertainty or for those that were identified as key drivers of the investment criteria.

Four impacts were valued within the quantitative assessment:

1. Increased efficiency and/or effectiveness of resource allocation for future Qfly SIT RD&E
2. Increased long-term productivity and/or profitability for Australian horticultural producers in Qfly affected regions from HG14033 contributions to improved effectiveness and efficiency of future SIT programs to control or eradicate Qfly in Australia.
3. Reduced future Qfly eradication costs for Qfly incursions/spread to new regions.
4. Maintained returns to investment in RD&E because of increased scientific knowledge and research capacity.

Impact 1: Increased efficiency/effectiveness of Qfly SIT RD&E resource allocation

The key outcome of the investment in project HG14033 was the realisation of essential RD&E for the development of effective, economical and sustainable Qfly SIT in Australia. HG14033 focused on the underlying knowledge and technology to support development of SIT and AWM through the SITPlus group Australia (for example, research outputs used to inform FF17001 and related Qfly SIT RD&E). Also, the SITplus program was developed through a weaving together of diverse projects carried out by member organisations to give greater impact through coordinated and collaborative RD&E that created research process and output efficiencies, knowledge sharing, reduced duplication of effort, and improved prioritisation of current and future Qfly SIT investment.

<u>Valuation of Impact 1</u>

Though the ongoing total annual investment in Qfly SIT related RD&E across Australia was uncertain, it was assumed that the average annual investment in project HG14033 was indicative of the level of investment sought for new and continuing RD&E over the next 10 years. The investment in HG14033 then was assumed to have created an efficiency dividend for Qfly SIT research for that next 10-year RD&E investment period. That is, without the project HG14033 investment, future Qfly SIT RD&E would have cost relatively more to produce the same outputs.

Specific assumptions used in the valuation of Impact 1 are described in Table 5.

Impact 2: Increased long-term productivity and/or profitability for Australian horticultural producers

The research carried out through investment in HG14033 has resulted in relevant and useful knowledge that has been used to inform Qfly SIT pilot program (e.g., FF17001) and will contribute to more effective and efficient future Qfly SIT control programs. The improved future efficacy of Qfly control achieved with SIT programs will, in turn, contribute to increased productivity and/or profitability for horticultural producers in Qfly affected regions in Australia.

Increased productivity and/or profitability is expected to be driven by:

a. Reduced Qfly damage and control costs.
b. Increased value because of increased average product quality.
c. Maintained or increased market access (both domestic and international).

Valuation of Impact 2

Several previous studies have investigated the economic impacts (costs) of fruit flies in Australia. A comprehensive CBA of the National Fruit Fly Strategy Action Plan completed by ABARES in 2012 estimated the value of a number of key potential benefits associated with fruit fly species. Benefits estimated included (Abdalla, Millist, Buetre, & Bowen, 2012):

- The average annual value of exports of fruit fly susceptible horticulture products between 2006 and 2009 was estimated at $406.9 million (2012-dollar terms) with around 20% of this value estimated to be from fruit exported to international markets with fruit fly phytosanitary requirements.
- Total annual costs of maintaining domestic fruit fly free areas were estimated at $14.22 million (2012-dollar terms) across the fruit fly exclusions zone, area freedom in Tasmania, area freedom in WA, and area freedom in SA.
- On average, $2.6 billion (2012-dollar terms) of fruit fly susceptible produce was grown in endemic regions between 2006 and 2009 and medium expectations for annual production losses in those regions were estimated to range from 0.5 to 3% depending on the commodity and severity of the fruit fly effects.

In 2016, it was estimated that the total cost of fruit fly species in Australia had increased to approximately $300 million from control measures and international trade restrictions (PHA, 2022).

Specific assumptions used in the valuation of Impact 2 are described in Table 5.

Impact 3 Reduced future Qfly eradication costs from Qfly incursions/spread to new regions

The work carried out through project HG14033 has contributed to improved effectiveness and efficiency of future Qfly SIT programs used to eradicate and control Qfly. This was demonstrated in 2019 in SA where the pilot SIT programs contributed to the eradication of a Qfly outbreak near Loxton (see Case Study). SIT program director, Dan Ryan, noted that as well as being used for eradication, SIT can be used for exclusion and suppression of pests creating a buffer zone between endemic regions and PFAs, for example, between the Sunraysia and Riverland areas. Implementation of Qfly SIT therefore is likely to contribute to reduced or avoided future eradication costs for Qfly outbreaks by increasing the effectiveness and efficiency of emergency responses and/or reducing the risk of incursion and/or spread of Qfly.

Valuation of Impact 3

The 2012 ABARES study on the costs and benefits of the National Fruit Fly Strategy Action Plan estimated that the total average annual cost of eradicating efforts for fruit flies from PFAs was $8.64 million (2012-dollar terms). A specific CBA on Qfly management in VIC estimated that Qfly eradications costs ranged from $61,000 to $267,000 per outbreak depending on the size of the outbreak (small, medium, or large). A recent example from WA estimated that the state government had expended more than $13.5 million over two years to eradicate Qfly, including use of pilot Qfly SIT programs (MacTiernan, 2021).

Specific assumptions used in the valuation of Impact 3 are described in Table 5.

Impact 4: Maintained returns to investment in RD&E because of increased scientific knowledge and research capacity

HG14033 made significant contributions to research capability and capacity through funding support and training of over 20 post-graduate students and research fellows. The research capability and capacity of the students is expected to contribute to maintaining or increasing the value of future RD&E investments for Australian agriculture, and specifically horticulture.

Valuation of Impact 4

Increased scientific knowledge and research capacity are likely to underpin maintained returns to future RD&E investments. The total average annual investment in RD&E funded through Hort Innovation was estimated at $98.9 million including industry levy, Frontiers Fund, and non-levy RD&E (five-year average, 2017/18 to 2021/22, nominal dollar terms) (Hort Innovation, Annual Reports, 2018 to 2022). However, other horticultural RD&E is funded by state and territory governments and privately by industry. Thus, a figure of $98.9 million per annum for Australia expenditure on horticultural RD&E is likely an underestimate of total expenditure on pork RD&E.

Aggregate analyses of the performance of Australian RD&E investments funded by the 15 rural research and development corporations found that the weighted average benefit-cost ratio (BCR) for rural research was approximately 4.5 to 5.5 to 1 over 30 years at a 5% discount rate (Agtrans Research; AgEconPlus; EconSearch, 2016; Agtrans Research, 2019).

It was assumed that the HG14033 SITplus investment and resulting capacity building has contributed to the maintenance of the return on investment for horticultural RD&E. For example, with the HG14033 investment, the return on future horticultural RD&E investment would return a maintained average BCR of 5.0 to 1, indicating net benefits of approximately $5.00 for every $1.00 invested over 30 years (using a 5% discount rate). Whereas without the HG14033 investment and associated scientific knowledge and research capacity, it was assumed that future horticulture RD&E investments would generate lower overall average returns 2% less than with the investment indicative of a BCR of 4.9 to 1, indicating net benefits of $4.90 for every $1 invested over 30 years (at a 5% discount rate).

Specific assumptions for the valuation of Impact 4 are provided in Table 5.

Counterfactual

Defining the counterfactual, or without investment scenario, is critical to the outcome of the analysis, and usually entails more than simply projecting current industry trends indefinitely into the future. In ex-post analyses, the counterfactual is a hypothetical scenario and determining the characteristics of this counterfactual requires judgements about the course of events that would have transpired in the absence of the research outputs produced by the investment under consideration. This counterfactual scenario obviously did not, and will not occur, and can only be inferred from knowledge of the industry and its markets and through consultation/expert opinion (CRRDC, 2018).

For the analysis of the investment in project HG14033, it was assumed that the impacts as estimated would not have occurred without the investment.

CSIRO Adopt Model Insights

The primary outcome of project HG14033 was the creation of foundational RD&E for the development of effective, economical and sustainable Qfly SIT research and implementation in Australia. The project focused on the underlying development of knowledge and technology to support SIT and AWM through the SITPlus group. More specifically, information from HG14033 experimental trials provided the foundations for operational SIT practices adopted in the trial operational releases under project FF17001 (Post-factory pilot of SITplus fly production). Thus, as broader industry adoption of SIT was not a direct outcome of the project, the CSIRO Adopt Tool was not utilised for the quantitative analysis.

Summary of Assumptions

Table 5 contains a summary of other assumptions required for estimation of quantified impacts.

Table 5: Summary of Additional Assumptions for Impact Valuation

Variable	Assumption/Value	Source/Comment
Impact 1: Increased efficiency of resource allocation for Qfly SIT RD&E		
Without project HG14033		
Total average annual expenditure on Qfly SIT RD&E	$3.32 million	Based on the total average annual investment (cash and in-kind) in project HG14033 in real dollar terms and accounting for project administration and management costs.
With project HG14033		
Efficiency dividend for resource allocation for future RD&E	20.0%	Analyst assumption
Total annual expenditure saving	$664,114 per annum	20.0% x $3.32 million

First year of impact	2019/20	Based on successful completion of project HG14033 in mid-2021 and commencement of related Qfly RD&E (e.g., FF17001) using HG14033 outputs during the life of the HG14033 project
Period of stable maximum impact	10 years (2019/20 to 2028/29	Based on a conservative estimate of at least two subsequent rounds of Qfly SIT RD&E investments nationally of similar length to HG14033 (~6 years)
Last year of impact	2030/31	Analyst assumption - assumes disadoption/reduced relevance of project outputs and/or new/improved Qfly SIT information produced over time.
Impact 2: Increased long-term productivity and/or profitability for Australian horticultural producers		
Without project HG14033		
Estimated annual impact costs associated with fruit fly in Australia	$358 million	Based on a total cost of fruit fly species in Australia estimated at $300 million in 2016 from control measures and international trade restrictions (PHA, 2022) Updated to 2021/22-dollar terms using the Implicit Price Deflator for Gross Domestic Product (GDP) (ABS, 2022)
Proportion of costs associated specifically with Qfly	80%	Analyst estimate – based on the distribution of Qfly and spatial characteristics of the Australian horticultural industry relative to the other major endemic fruit fly species, Medfly.
With project HG14033		
Proportion of industry affected by Qfly adopting SIT as part of commercial management and/or AWM of pests	60%	Based on data used and presented by CSIRO evaluating the costs and benefits of AWM using SIT for Qfly (Schellhorn, 2017)
Reduction in future Qfly impact costs from adoption/ implementation of effective/ efficient Qfly SIT programs	20%	Analyst estimate – conservative estimate based on the benefit scenario estimates used and reported by ABARES for the CBA of the National Fruit Fly Strategy Action Plan (Abdalla, et al., 2012)
First year of impact	2024/25	Based on the duration of current RD&E investments conducting pilot trials of Qfly SIT (e.g., FF17001)
Year of maximum impact	2028/29	Five years after first year of impact allowing time for localised benefits to be demonstrated and findings from pilot programs extended to industry stakeholders. Impact then continues at this level until the last year of benefits estimated (30-years from the last year of investment).
Impact 3: Reduced future Qfly eradication costs from Qfly incursions/spread to new regions		
Without project HG14033		
Estimated annual eradication costs for fruit fly in domestic PFAs	$10.3 million	Based on reported annual cost of fruit fly eradication activities of $8.64 million (2012-dollar terms) (Abdalla, et al., 2012) Updated to 2021/22-dollar terms using the Implicit Price Deflator for GDP (ABS, 2022)

Proportion of costs associated specifically with Qfly	80%	Analyst estimate – based on the distribution of Qfly and spatial characteristics of the Australian horticultural industry relative to the other major endemic fruit fly species, Medfly (consistent with Impact 2)
With project HG14033		
Reduction in Qfly eradication costs from adoption/ implementation of effective/ efficient Qfly SIT programs	20%	Analyst estimate – conservative estimate based on the benefit scenario estimates used and reported by ABARES for the CBA of the National Fruit Fly Strategy Action Plan (Abdalla, et al., 2012) (consistent with Impact 2)
First year of impact	2019/20	Based on successful completion of project HG14033 in mid-2021 and commencement of related Qfly RD&E (e.g., FF17001) using HG14033 outputs during the life of the HG14033 project
Year of maximum impact	2023/24	Five years after first year of impact allowing time for localised benefits to be demonstrated and findings from pilot programs extended to industry stakeholders. Impact then continues at this level until the last year of benefits estimated (30-years from the last year of investment).
Impact 4: Increased scientific knowledge and research capacity		
Estimated total average annual investment in RD&E	$98.9 million	5-year average, based on average Hort Innovation RD&E project expenditure (Hort Innovation, Annual Reports, 2018 to 2022)
Proportion of Hort Innovation annual RD&E benefitting from maintained returns	3.5%	Based on average annual RD&E costs for the SITplus program of $3.32 million as a proportion of total annual Hort RD&E expenditure $3.32 million / $98.9 million
Average BCR for Australian agricultural RD&E **with** the HG14033 investment	5.0 to 1 (over 30 years at a 5% discount rate)	Average return based on estimated average BCR of 4.5 to 5.5 to 1 for the aggregate investment in the rural RDCs (Agtrans Research; AgEconPlus; EconSearch, 2016; Agtrans Research, 2019).
Average BCR for Australian agricultural RD&E **without** the HG14033 investment	4.9 to 1 (over 30 years at a 5% discount rate)	Analyst assumption – conservative estimate assuming a 2% reduction in average returns to RD&E
First year of RD&E investment that will benefit from the increased knowledge and research capacity	2021/22	Based on successful completion of project HG14033 in mid-2021, conferral of at least 17 PhDs during the life of the project, and a total of more than 20 post-graduate students and research fellows engaged throughout the project
First year of maintained returns to pork RD&E investments	2022/23	Analyst assumption: one year after the first year of RD&E investment benefitting from the capacity built by the HG14033 investment.

Period/duration of impact - the number of years of future RD&E investment that will benefit from the improved knowledge and capacity	10 years	Analyst assumption – allows for researchers exiting the sector or moving to non-related fields
Risk Factors (all Impacts)		
Probability of output (probability that the SITplus project successfully produced outputs required to deliver impact)	100%	Based on successful completion of project HG14033 in mid-2021 and commencement of related Qfly RD&E using HG14033 outputs during the life of the HG14033 project (e.g., FF17001)
Probability of outcome (probability that outputs will be used/adopted at levels assumed to achieve impact)	80%	
Probability of impact (probability that, given outcomes, the assumed impact will be realised as estimated)	80%	Allows for exogenous factors that may affect realisation of impacts and that the benefits estimated may not persist into the future as assumed.
Other Factors		
Additional adoption/ implementation costs required to deliver impacts	The assumptions used in the valuation of impacts are assumed to be NET of any additional adoption/ implementation costs required to deliver the impacts.	
Attribution to the HG14033 RD&E investment	Project HG14033 built on a wide range of previous and ongoing fruit fly RD&E (see logical framework presented in Appendix 1). Further, a range of new and future investments are required to facilitate the ultimate impacts of the project, including funding for pilot SIT programs and other RD&E to fill knowledge gaps. Therefore, an attribution factor of 40% was applied to reflect the benefits directly attributable to the HG14033 investment	

Results

All costs and benefits were discounted to 2021/22 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the project investment period plus 30 years from the last year of investment (2020/21) as per the CRRDC Impact Assessment Guidelines (CRRDC, 2018).

Investment Criteria

Table 7 and Table 8 show the investment criteria estimated for different periods of benefits for the total investment and the Hort Frontiers only investment. Hort Frontiers present value of benefits (Table 8) was estimated by multiplying the total present value of benefits by the Hort Frontiers proportion of total undiscounted costs expressed in 2021/22-dollar terms (40.1%).

Table 6: Investment Criteria for Total Investment in Project HG14033

Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	0.58	4.84	19.19	31.60	41.33	48.95	54.92
Present Value of Costs ($m)	26.27	26.27	26.27	26.27	26.27	26.27	26.27
Net Present Value ($m)	-25.69	-21.43	-7.08	5.33	15.05	22.67	28.64
Benefit-Cost Ratio	0.02	0.18	0.73	1.20	1.57	1.86	2.09
Internal Rate of Return (%)	n.s.	negative	negative	1.5	3.2	4.0	4.4
MIRR (%)	negative	1.6	12.5	13.4	12.9	12.2	11.6

n.s.: no unique solution

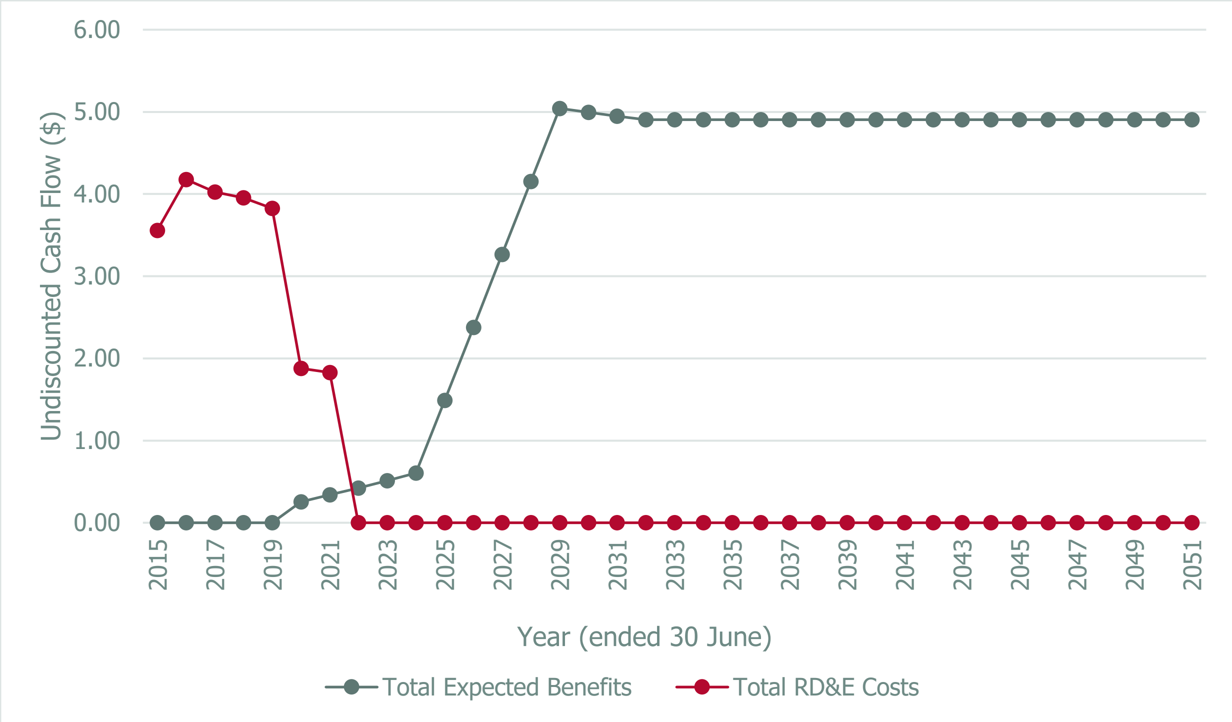
Table 7: Investment Criteria for Hort Frontiers Only Investment in Project HG14033

Investment Criteria	Years after Last Year of Investment						
	0	5	10	15	20	25	30
Present Value of Benefits ($m)	0.23	1.94	7.69	12.66	16.56	19.61	22.00
Present Value of Costs ($m)	10.53	10.53	10.53	10.53	10.53	10.53	10.53
Net Present Value ($m)	-10.30	-8.59	-2.84	2.14	6.03	9.09	11.48
Benefit-Cost Ratio	0.02	0.18	0.73	1.20	1.57	1.86	2.09
Internal Rate of Return (%)	n.s.	negative	negative	1.5	3.2	4.0	4.4
MIRR (%)	negative	1.6	12.5	13.4	12.9	12.2	11.6

n.s.: no unique solution

The annual undiscounted benefit and cost cash flows for the total investment for the duration of the HG14033 investment plus 30 years from the last year of investment are shown in Figure 1.

Figure 1: Annual Cash Flow of Undiscounted Total Expected Benefits and Total Real Investment Costs



Source of benefits

Table 8 shows the contribution to total benefits from each of the two benefits valued. The benefits from improved market access (increased proportion of total production going to export markets) at maintained premium export prices was the highest impact valued in terms of the contribution to total benefits.

Table 8: Source of Total Benefits
(Total investment, 30 years)

Impact	Contribution to PVB ($m)	Share of Total Benefits (%)
Impact 1: Increased efficiency/effectiveness of Qfly SIT RD&E resource allocation	1.48	2.7
Impact 2: Increased long-term productivity and/or profitability for Australian horticultural producers	46.43	84.5
Impact 3 Reduced future Qfly eradication costs from Qfly incursions/spread to new regions	6.20	11.3
Impact 4: Maintained returns to investment in RD&E because of increased scientific knowledge and research capacity	0.80	1.5
Total	**54.92**	**100.0**

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 9 presents the results. The results showed a moderate sensitivity to the discount rate. This was largely because the benefit cash flows extended well into the future (30 years from the last year of investment) and therefore were subject to relatively more significant discounting.

Table 9: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount Rate		
	0%	5% (base)	10%
Present Value of Benefits ($m)	126.48	54.92	28.02
Present Value of Costs ($m)	23.24	26.27	29.73
Net Present Value ($m)	103.23	28.64	-1.71
Benefit-cost ratio	5.44	2.09	0.94

A sensitivity analysis was then undertaken on assumed attribution of benefits to the investment in HG14033 as this was considered a key driver of the investment criteria and was uncertain. Results are provided in Table 10. When the attribution of benefits to HG14033 was set to 19.1% with all other factors unchanged, the project is approximately at "break-even" with a benefit-cost ratio (BCR) of 1 to 1.

Table 10: Sensitivity to Attribution of Benefits to HG14033
(Total investment, 30 years)

Investment Criteria	Attribution of Benefits to HG14033		
	25%	40% (base)	50%
Present Value of Benefits ($m)	34.32	54.92	68.64
Present Value of Costs ($m)	26.27	26.27	26.27
Net Present Value ($m)	8.05	28.64	42.37
Benefit-cost ratio	1.31	2.09	2.61

A final sensitivity analysis then was used to investigate changes to the investment criteria from a change to the assumed reduction in future Qfly impact costs from implementation of improved Qfly SIT programs. This variable was selected because Impact 3 (increased long-term productivity/profitability) contributed the majority of the total benefits (84.5%, present value terms). The results (Table 11) showed a moderate to high sensitivity to reduction in future Qfly impact costs. The project would 'break-even' with future impact Qfly impact costs reduced by 3.8%, with all other variables unchanged.

Table 11: Sensitivity to Assumed Reduction in Future Qfly Impact Costs
(Total investment, 30 years)

Investment Criteria	Reduction in Future Qfly Impact Costs		
	5%	10% (base)	20%
Present Value of Benefits ($m)	31.70	54.92	101.35
Present Value of Costs ($m)	26.27	26.27	26.27
Net Present Value ($m)	5.43	28.64	75.08
Benefit-cost ratio	1.21	2.09	3.86

Confidence Rating

The results produced are highly dependent on the assumptions made, some of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes.

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 12 The rating categories used are High, Medium, and Low, where:

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made

Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made

Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 12: Confidence in Analysis of Project

Coverage of Benefits	Confidence in Assumptions
High	Medium-Low

Coverage of benefits valued was assessed as High, two of six impacts identified were valued. Also, the two impacts valued were assessed as minor and indirect relative to the impacts valued. Confidence in assumptions was rated as Medium-Low, most of the data and assumptions used were underpinned by credible, published data and/or expert consultation. However, where no data/evidence was available within the scope of the assessment, a number of key assumptions were estimated by the analyst.

Conclusions

HG14033 represented a significant and complex RD&E program investment. The structure of HG14033 recognised the diverse processes involved in an effective SIT program and provided support for each. Given the diversity of needs, HG14033 operated under 10 thematic areas and contained 26 distinct projects, each with its own objectives, leadership, team, collaborations, and resources.

The primary outcome of the overall investment in project HG14033 was the development of essential knowledge and technology to support effective and efficient SIT and AWM through the SITPlus group. Information and data from the project already have been used as input to guide pilot SIT programs that have reported success of Qfly suppression in the field.

Total funding from all sources for the project was $26.3 million (present value terms). The investment produced estimated total expected net benefits of $54.9 million (present value terms). This gave a net present value of $28.6 million, an estimated benefit-cost ratio of 2.1 to 1, an internal rate of return of 4.4% and a MIRR of 11.6%.

Sensitivity analyses demonstrated that the investment criteria remain positive even when key assumptions were set to more conservative values. This indicated that the positive results were credible and robust. Further, given that some impacts identified were not valued, the investment criteria reported may be an underestimate of the true performance of the investment in HG14033.

Recommendations

Impact assessment is now a mature process within Hort Innovation. No recommendations are made for further refinement.

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Abbreviations and Acronyms

AWM	Area-wide Management
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
BCR	Benefit-Cost Ratio
CRISPR	Clustered Regularly Interspaced Short Palindromic Repeats
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CBA	Cost-Benefit Analysis
CRRDC	Council of Rural Research and Development Corporations
DAFF	Department of Agriculture, Fisheries and Forestry (Commonwealth)
GSS	Genetic Sexing Strain
GVP	Gross Value of Production
Hort Innovation	Horticulture Innovation Australia Ltd
PFR	Institute for Plant and Food Research Ltd (New Zealand)
IRR	Internal Rate of Return
IAEA	International Atomic Energy Agency
IPPC	International Plan Protection Convention
ISPM	International Standards for Phystosanitary Measures
IRA	Isotope Ratio Analysis
LOP	Life of Project
MU	Macquarie University
Medfly	Mediterranean Fruit Fly
MIRR	Modified Internal Rate of Return
NPV	Net Present Value
NSW	New South Wales
NSW DPI	New South Wales Department of Primary Industries
NZ	New Zealand
NGS	Next Generation Sequencing
n.d.	No Date
NT	Northern Territory
PFA	Pest Free Area
PHA	Plant Health Australia
PVB	Present Value of Benefits
PVC	Present Value of Costs
QC	Quality Control
QLD	Queensland
Qfly	Queensland Fruit Fly

RK	Raspberry Ketone
RD&E	Research, Development, and Extension
SA	South Australia
SARDI	South Australian Research and Development Institute
SOP	Standard Operating Procedure
SIT	Sterile Insect Technique
VIC	Victoria
WA	Western Australia

Glossary of Economic Terms

Cost-benefit analysis:	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Benefit-cost ratio:	The ratio of the present value of investment benefits to the present value of investment costs.
Discounting:	The process of relating the costs and benefits of an investment to a base year using a stated discount rate.
Internal rate of return:	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Investment criteria:	Measures of the economic worth of an investment such as Net Present Value, Benefit-Cost Ratio, and Internal Rate of Return.
Modified internal rate of return:	The internal rate of return of an investment that is modified so that the cash inflows from an investment are re-invested at the rate of the cost of capital (the re-investment rate).
Net present value:	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Present value of benefits:	The discounted value of benefits.
Present value of costs:	The discounted value of investment costs.

Appendices

Appendix 1: Detailed Logical Framework Describing Project HG14033

Table 15 provides a detailed description of project HG14033 in a logical framework.

Table 13: Logical Framework for Project HG14033

Activities	***Project Management*** • To aid management of the overall program, leaders of each project within the program were established and these project leaders assisted in planning, management and reporting. • An independent review of the overall program was solicited from Professor Boaz Yuval (Israel, a major provider of medfly SIT R&D and frequent adviser to IAEA). • A comprehensive monitoring and evaluation framework was developed utilising an online 'SmartSheet'. • Research fellows and PhD candidates were recruited. ***Theme 1: Preserving genetic quality in domestication and mass-rearing*** <u>Project 1: Characterise the 'domestication' process (CSIRO/MU)</u> • It was known that there were significant changes in behaviour, physiology and morphology of fruit flies through domestication, but little was known about the associated biological processes or how to manage them. • One of the greatest concerns for the viability of SIT was from the potential for the domestication process to affect the ecological or sexual competence of the flies, which would be evident in field releases as poor survivorship, poor distribution, and lower than expected levels of mating with wild type flies. • The project was undertaken in two phases: (1) characterising change, and (2) amelioration. • Phase 1 experiments reviewed and assessed the 'standard' domestication process to understand what changes were expressed under existing protocols. • The study investigated the effects (combined) of genetic drift, that reduces variation randomly, and genetic selection, that reduces genetic variation in more uniformly. • Multiple experimental Qfly colonies were established at MU and CSIRO to maximise replication. • Physiological assays were developed at MU and applied at both locations. • Molecular assays were applied at CSIRO to samples generated from colonies at both locations. • Phase 2 focused on learnings from Phase 1 whereby elements of existing protocols found to be the likely cause of detrimental effects on domestication of Qfly. • Procedures to ameliorate the negative effects then were developed to facilitate the preservation of wild type genetic material in mass reared flies. • Each group (MU/CSIRO) also supported a PhD student. • Activities and outputs from the overall project provided input to Theme 5 Project 1 and Theme 2 Project 5. ***Theme 2: Production and delivery processes*** Several Qfly production processes had already been investigated in previous or ongoing projects (e.g., Hort Innovation projects MT13040 and HG13045). This enabled Theme 2 to build on the previous investments and target specific knowledge gaps. <u>Project 1: Defining Quality Control (QC) protocols (NSW DPI/MU/SARDI)</u> • Standard QC procedures are outlined in the IAEA manual for use with SIT programs globally, with many of the procedures developed principally for Medfly.

	• Some of the key QC parameters include % egg hatch, pupal weight, % adult emergence, flight ability, mortality under stress, sex ratio, sterility and mating compatibility. Accurate measures of these parameters provide product quality information for SIT facility managers. • The required level of each parameter for Qfly that should be set as the accepted standard in production was unresolved. • The project investigated QC parameters for Qfly that were potentially deficient and re-evaluated existing parameters to provide input to the IAEA QC protocols for Qfly. • The project also evaluated and provided parameters for processes where impacts on Qfly quality occur but are not covered by the current IAEA standards. • In addition to the investigation of existing standard IAEA QC protocols, new QC measures were identified, investigated and assessed as potential supplementary QC tests. <u>Project 2: Sterility induction and its consequences (SARDI/MU/PFR)</u> • The existing Qfly SIT program relied on gamma irradiation for sterility induction, using optimal doses developed through a previous HIA project at MU (HG06040) and later confirmed as effective under factory conditions by NSW DPI. • However, gamma radiation was not going to be available for the new SA SIT facility, which meant that alternative methods for sterility induction needed to be investigated as a fallback for if suitable RNAi (ribonucleic acid interference, also known as post-transcriptional gene silencing) technology was not available. • Based on evidence from previous studies, x-rays were investigated as an alternative source of sterilising radiation. • The optimal dose for sterility induction by x-ray was evaluated. • Pathological effects of x-rays used for sterility induction at a range of doses also were examined. This included how x-ray irradiation affected gene expression, antennal structure and olfaction, behaviour, morphology, physiology, and nervous system development. • A PhD student also was supported by the project. <u>Project 3: Maintaining fly quality during transport (MU/NSW DPI)</u> • Several past studies had shown that transportation of SIT pupae from production site to release sites negatively affected fly quality. • This was a concern for the new SA SIT facility that planned to produce, pack, and transport flies as pupae to distant locations for release in SIT programs. • The project used the results from Theme 2 Project 1 to investigate and identify the key aspects of transportation that contributed to negative effects on Qfly quality. • The findings of the first part of the study (key aspects) then were used to evaluate which transportation systems maintained the highest quality of Qfly pupae at the point of delivery. <u>Project 4: Logistics of production and delivery (CSIRO/NSW DPI/MU)</u> • At a strategic level, supply chain decisions need to be made to optimise SIT production and delivery. Further, in an outbreak situation, operational decisions need to be made on which locations to release the flies, how many sterile flies to release, and how frequently. • The goal of the project was to develop a strategic model to maximise the effectiveness of releases, where the effectiveness of each release (or sequence of releases in a given location) needed to be estimated by ecological and biological functions. • Prototype strategic models were set up using an SA Riverlands case study in the event of an incursion mid- to late- season.

	• Members of the project team met with commercial partners and stakeholder in SA and other experts to gain a detailed understanding of current trapping practices and any additional practical considerations for optimising release strategies. • Data were gathered on past incursions across the SA region. • The spatial layout of commercial fruit production and backyard production, urban areas, and recreation areas across the region was mapped. • The strategic and operational model were defined for a SIT Qfly release for the SA Riverland region, including factory, supply, and transport constraints. • Forecasting functions were developed to represent the benefits or response from a sterile male release strategy. • The operational model was designed so that it could be run regularly based on ongoing trapping data and included processes to optimise model parameters within a reasonable timeframe. • Optimal release strategies were developed using the operational model by simulating outbreak scenarios using historical outbreak and trapping data for the Riverland region. • The strategic model then was used to develop scenarios of optimal rearing our facility locations under different budget constraints to validate the practical suitability of the locations with commercial partners. <u>Project 5: Microbial gut symbionts (NSW DPI/MU)</u> • Microbial gut symbionts were recognised as important insect partners that contribute to nutrition, health, and reproductive success. • Related Hort Innovation projects (MT13040 and MT13045) were testing and developing new larval diets for Qfly and each of these projects included some exploration of the potential value offered by microbial gut symbionts. • The project team collaborated with projects MT13040 and MT13045 to pool resources to further investigate Qfly gut symbionts. • The collaborative project investigated gut symbionts as probiotics for larval and adult Qfly. • A molecular approach was used to assess the gut microflora at different life stages of domesticated and wild Qfly. • Gut microorganisms that are vertically transmitted via eggs or larvae were identified to understand how mass-rearing affects Qfly gut microflora at each life stage. • Results of the initial gut microflora assessment then were used to select probiotic candidates for assessment. • Each probiotic candidate was assessed on its ability to improve the sterile fly and their suitability as a commercial produce for use in a mass-rearing facility. • Protocols for incorporating probiotic consortiums into both solid and liquid larval diets (large-scale_ were investigated. • Probiotic candidates were tested to assess the efficacy on fitness and competitiveness of Qflies in different rearing environments and at different production levels. • The benefits and costs of adding probiotics into the larval diet also were investigated. • Protocols for incorporating probiotic consortiums into the adult Qfly diet then were assessed. • This involved determining the optimal times to add specific probiotic consortiums and suitable concentrations. • The required concentration of yeast included in adult diets when probiotics were used also was evaluated to determine whether the amount of yeast could be reduced (production cost saving). • An adult probiotic diet also was tested as a pre-release treatment that was considered in Theme 3 Project 1. ***Theme 3: Pre-release treatments and release methods***

	<u>Project 1: Pre-release treatments (MU/NSW DPI)</u> • In Australia, MU had previously published research on the value of yeast hydrolysate as a pre-release supplement that was shown to increase reproductive development and mating success, increase male ability to inseminate females, increase the male ability to prevent females from remating, and enhance longevity. These patterns were demonstrated in prior field releases led by NSW DPI. • There were many additional pre-release supplements that could be considered to enhance the post-release performance of Qflies and enhance the efficiency of SIT. • The project investigated several alternative pre-release treatments. • Methoprene (a juvenile hormone analogue). Methoprene had been found to accelerate maturation and improve mating performance in Qfly. However, the methods used in previous studies were not practical for SIT application because of the use of toxic and flammable hormone carriers. MU developed a new approach that avoided both these issues. The MU method was used to further evaluate the effects of Methoprene as a pre-release treatment for SIT Qflies. • Raspberry ketone (RK) was assessed to understand the potential merits as a pre-release treatment. • Additional pre-treatments considered included the use of stimulates (caffeine and aromatherapy). <u>Project 2: Release methods (MU/NSW DPI)</u> • Existing practices for SIT Qfly release relied on bins containing emerged adult flies that were taken to the field for release. This method is effective but cumbersome, costly and labour intensive, requiring specialised rearing out facilities close to release sites. • There had been some previous research on alternative release methods, but no definitive conclusions about optimal release methods. • The costs and potential benefits of a range of alternative release methods were explored. Alternative methods considered included the use of blowers to release emerged adult flies, pupal releases, aerial releases by piloted aircraft, drone, or airship. • Testing also was conducted for stationary (pupal and adult) and roving (aerial, adult) release methods including automated delivery and release tracking. ***Theme 4: Post-release identification*** Where SIT flies are released, it is important that the released sterile flies can be easily and cost-effectively differentiated from the wild Qfly population. Sterile flies misidentified as wild can lead to false outbreak alerts and wild flies misidentified as sterile can lead to delays in response to actual outbreaks. Differentiation also is important so that changes in pest populations can be continuously monitored during an SIT release to facilitate adaptive management. <u>Project 1: Visible markers (NSW DPI/MU)</u> • Traditional SIT identification was based on a ‘self-marking technique’ whereby pupae were coated with fluorescent powder that is transferred externally to emerging adults. Unfortunately, the external dyes had been found to significantly reduce survival and quality of sterile Qflies. • The effects of a catalogue of fluorescent dyes used as SIT markers on SIT fly performance were assessed under a range of scenarios. • The use of internal visible markers also was assessed as an alternative to externally applied dyes. <u>Project 2: Identification through biomarkers (SARDI/MU)</u> • New and existing (known) biomarkers of irradiation exposure were investigated in terms of their application in post-release SIT identification. • Part of the study followed on from previous Hort Innovation project VG09160 that identified a persistent biomarker of irradiation-damage in Qfly (known as yH2Av).

	• The yH2Av protein market was further examined to determine whether this protein marker could be used to confirm the sterility status of unmarked flies caught in monitoring traps. • Molecular assays measuring DNA fragmentation were evaluated for the potential to discriminate released irradiated flies from the wild Qfly population. • Requirements for sample capture conditions, retrieval time, and sample processing were established. • The study also explored whether work could be undertaken to assess the metabolic profiling or irradiated versus non-irradiated male flies. <u>Project 3: Isotope ratio analysis (MU/NSW DPI)</u> • Methods based on Isotope Ratio Analysis (IRA) had recently been developed for Medfly and malaria mosquitoes at the IAEA. These methods provided an opportunity to improve the cost effectiveness, speed and reliability of SIT identification processes that underpin Qfly outbreak declarations and pest management responses. • The project aimed to develop cheap, fast, and reliable IRA protocols for identifying sterile flies as an alternative to relatively expensive microsatellite DNA methods likely to become increasingly unreliable if wild genetic material is able to be increased in domesticated Qflies. • The study tested IRA procedures to identify the carbon isotope signature from cane sugar used in the mass-rearing diet of sterile flies. For example, the cane sugar signature is distinctly different from the signature found in fruit. • Small samples from Qfly bodies were analysed using an Isotope Ratio Mass Spectrometer and to reveal the bodies' carbon composition to identify SIT flies. <u>Project 4: Genetic biomarkers (CSIRO/SARDI)</u> • For the SITplus RD&E program, it was considered difficult to develop a genetic biomarker technology that would be shared by all released sterile flies, while at the same time implementing research to retain genetic diversity during mass-rearing. • One solution considered by the program would arise if the Adelaide-based SITplus project was successful in developing a genetic sexing strain (GSS) based on gene editing technology (CRISPR[3]). • If successful, this technology would generate a unique mutation in the DNA of release flies. • The frequency of the mutation then could be measured in recollected flies with high efficiency and accuracy using next generation sequencing (NGS)- based amplicon genotyping method. • Regardless of the success of the primary GSS work, the same technology could be used to generate sterile flies with a unique biomarker for use in mark-recapture programs. • The project team engaged with the University of Adelaide project to facilitate information sharing and prioritisation of further RD&E associated with the genetic editing research. • While the Adelaide-based research was ongoing, a second approach was investigated by the project team. • Novel, benign microbial symbionts were introduced into the gut of released flies. • The persistence of the different bacterial species introduced in the Qfly gut post-release was evaluated to identify a bacterial species that persisted but has no deleterious effects on the released flies. • Where identified, a biomarker then was developed to detect and quantify the presence of the bacterium in recaptured flies. ***Theme 5: Ecological competence*** The mass-rearing environment is very different from the conditions that flies encounter following release. The ability of sterile flies to tolerate adverse environmental conditions in the period following release is

[3] CRISPR: Clustered Regularly Interspaced Short Palindromic Repeats

	critical for the success of SIT. Previous data have shown that recapture rates, reflecting survivorship and maturation, have typically been lower in SA than in NSW when using NSW SIT flies. The projects under Theme 5 investigated the traits that confer ecological performance post-release (e.g., survival, dispersal) as well as suitability for different climate zones. <u>Project 1: Genetics/Genomics of Qfly ecological fitness (CSIRO/MU)</u> • Genes (or genetic markers linked to genes) underlying genetic traits that were expected to have a strong influence on performance on Qflies post-release were identified. • Performance characteristics considered important were those that were expected to change following mass-rearing and/or sterility treatments. • Characteristics investigated included climate tolerance, changes to rates of development or maturation, predator evasion, and dispersal ability. • Bioassays best suited to quantify performance traits of interest were developed at MU while molecular and genetic techniques to identify the genetic basis for the traits were developed at CSIRO. • Replicated, reciprocal conspecific or hybrid crosses were performed between field-collected genetic material and a laboratory culture. • The offspring from each cross were maintained separately for two generations and a reduced representation full genome sequencing approach then was used to generate sufficient markers for mine scale mapping. • Once identified, the genetic information was to understand and monitor negative changes in the key performance traits during the rearing and release process so that management strategies could be developed to prevent negative changes and make SIT more efficient and effective. <u>Project 2: Regional variation in Qfly fitness genetics/genomics (CSIRO/MU)</u> • Genetic variation found in nature can be harnessed for the production of flies of prescribed attributes and studies of such variation allow for exploration of the 'invasive potential' of flies from different populations. • The extent of regional genetic variation of Qfly populations was studied and characterised. • The genetic basis for variation in target characteristics then was identified and recorded. • Testing strategies were developed to retain the target characteristics during domestication. ***Theme 6: Applied landscape ecology*** <u>Project 1: Dispersal, maturation and survival of sterile and fertile flies (MU/CSIRO/NSW DPI)</u> • The purpose of this project was to better understand the ecology and behaviour of sterile flies after release as part of an SIT program. This information can be used to optimise release parameters such as where, when, and how many to release to maximise the effectiveness of SIT. • The performance of new lines of SIT flies established in related SITplus projects, along with wild flies, was assessed through simulated releases and tracking of flies. • The wild type flies were used to provide a benchmark for comparison with mass-reared fertile and sterile flies enabling assessment of the effects of domestication and steralisation in an ecology setting. • Information generated also were used to better understand how new outbreaks of flies spread in the environment. • Further, the data were used to determine quarantine distances around outbreaks. <u>Project 2: Host-related temperature phenology (NSW DPI/MU)</u> • Where significant numbers of host fruit trees of different species are present in a location, maturing dates of fruit of individual host species are a good indication of the timing when significant recruitment events to the local fly population occur.

	• Such population recruitment events are expected to be registered later in the seasonal patterns of trap catches as 'spikes' after a time lag. • To estimate the timing of Qfly population spikes, the project first examined the relative abundance of host plants across the study location (an QLD orchard with two or more host plants and where Qfly were present with an existing trapping grid). • Phenology of fruit development in host plants was studied and the development durations of fruit fly eggs and larvae inside the fruit of host plants were analysed. • Finally, the development durations of pupae in the soil at the study location were investigated. • Existing data also were collated with additional data generated through a series of temperature-controlled experiments and in-field observations of Qfly population dynamics. • Following data collection activities, temperature-dependent phenology models were developed to simulate phenology processes. • The models then were integrated to describe the local fruit fly population dynamics and provide a guide to the timing of population spikes that can be used to time management interventions. • The project linked with Theme 6 Project 2 (another phenology project) for cross-regional model validation. <u>Project 3: Adaptive potential of Qfly to geographic distribution and climate change (MU/CSIRO/NSW DPI)</u> • This project considered the current and likely future vulnerability of southern growing regions to Qfly, informed by the understanding of environmental tolerance that was developed over the course of the overall SITplus RD&E program. • Information gathered in Theme 5 (e.g., Project 1 and 2) were used to explore the potential for Qfly to adapt to new climate regimes. For example, geographic and climate clines in fly characteristics, within population physiology changes over the past few decades, and physiological and genetic differences between leading edge and core populations were used to explore likely responses to climate change. • Tolerance to abiotic factors, such as heat and desiccation, were compared to scenarios of future climate to assess the likelihood of Qfly shifting its distribution over coming decades. • Distribution models that incorporate the climate niche of Qfly, dispersal ability, and horticultural land-use were developed to identify potential hotspots of future Qfly outbreaks. • Likely responses of Qfly to climate change also were determined by modelling the effectiveness of quarantine measures in previously limiting the spread of Qfly, and the effects of extreme weather events on Qfly distribution. <u>Project 4: Local drivers of fruit fly behaviour (MU/NSW DPI)</u> • This project was designed to better understand the movement and spread of Qfly through the environment and whether the environment can be manipulated to constrain the movements of populations. • Dispersal patterns at a landscape-level were investigated and the behaviour of flies relative to resources at a local-level were characterised. • A range of environmental drivers were assessed in terms of their effect on Qfly behaviour. Drivers included physical barriers, light, local condition variations such as ambient temperature, humidity, and wind. <u>Project 5: Assessing reinstatement periods (NSW DPI)</u> • Detection of Qfly outbreaks is relatively straightforward conceptually, as the presence of flies in traps confirms presence of flies in the field. However, it was not sufficiently understood whether the absence of flies in traps indicated the absence of flies in-field.

	• Operationally, outbreak thresholds were well understood, but the trade reinstatement thresholds were not as clear. Traditional reinstatement tables in trade Codes of Practice have been used but had limited scope and were outdated. • Scenario tree analysis was explored and developed as a method to analyse zero detections for fruit flies. ***Theme 7: Mating ability of sterile flies*** Where flies are successfully domesticated, reared, and released, and survive and mature in the field, but then fail to perform sexually, then SIT will be severely compromised or fail altogether. Studies of overseas SIT programs had highlighted sexual deficiencies caused by mass-rearing and irradiation of fruit flies. Theme 7 aimed to understand where failures may occur or where there was potential for improvements by understanding the Qfly mating system and what male traits confer high mating success. Project 1: Variation and functions of pheromones (MU/PFR) • Qflies have five major components in their pheromone blend, and pheromone composition was considered a likely important component of species recognition and mate assessment. • Pheromone variation among male Qflies from multiple sources was investigated. • Pheromones were collected directly from pheromone glands and from the air above 'calling' flies. • Gas chromatography then was used to quantify the abundance of each component molecule and ascertain the overall pheromone molecule blend. • Bioassays were conducted to assess female preference for different blends and for males producing particular blends. • Differences between pheromone composition in males then was correlated with the attractiveness of those males to females. • Once the importance of each pheromone component and blend characteristics were understood, various management strategies were considered. • Understanding of preferred pheromone blends was used to provide guidance for breeding more attractive SIT males. • The effect of production practices on pheromone composition and male attractiveness then was explored to understand whether mass-rearing related changes renders the release of SIT flies less attractive to wild females. The effect of mass-rearing on pheromone blend was jointly investigated with Theme 1 Project 1. • Regional differences in pheromone composition in males and preferences of females were investigated with Theme 8 Project 2. Project 3: Genetics/Genomics of Qfly reproductive fitness (CSIRO/MU) • The purpose of this research was to identify the genetic basis of reproductive characteristics that are likely to drive mating performance of released sterile flies. • The genes (or genetic markers linked to genes) underlying reproductive traits of interest, such as pheromone composition, calling behaviour, and reproductive effort, were identified. • As for Theme 5 Project 1, the level of variation in each target trait identified was quantified and the genetic basis for this variation was identified. • Information and data generated by the project then were used to understand and monitor changes in target reproductive traits during the rearing and release process. • The change characteristics and associated data then were used to provide guidance on strategies or processes to minimise or eliminate negative changes in target traits. ***Theme 8: Protecting sterile matings*** If a wild female Qfly mates with a released sterile male but then later remates with a fertile wild male then she will be able to produce viable offspring and SIT will be compromised. This is a particular issue with

	Qflies, as the irradiation process curtails sperm production such that females that mate with a sterile and then a fertile male are likely to fully recover fertility and reproductive capacity. <u>Project 1: Prevalence and predictors of multiple mating (MU/CSIRO)</u> • To study the prevalence of remating in wild populations, data on remating prevalence was collected in the field. These data were used to provide a baseline estimate of the rate of natural remating that mass-reared processes could be compared too. • Data on factors associated with and mediating female remating tendency also were collected and analysed. • Laboratory studies also were carried out to investigate specific male traits for their relationship with female remating tendency. • Wild type females were collected from the field and allowed to ovipost in the laboratory. • Larvae then were assessed for multiple paternity by microsatellite DNA. • The proportion of females with multiple paternity was assessed. • The second study was designed to assess male traits associated with paternity. • Large numbers of females were allowed to mate with a male Qfly and then allowed to remate. • Twice-mated females were set up with oviposition substrates and paternity of offspring was assessed also using microsatellite DNA. • All mating males were collected and measured and copula duration for each pair was recorded. This enabled the project team to test for relationships among male traits (e.g., size, age, pre-release treatment, larval diet), copula duration and paternity patterns. <u>Project 2: Mechanism of sexual inhibition (CSIRO/MU)</u> • A combination of genetics/genomics, biochemistry, and metabolic approaches to identify the factors controlling the suppression of remating in Qfly females after copulation. • Data from the project were analysed to provide a deeper understanding of the mechanisms involved in the suppression of remating. ***Theme 9: Compatible control technologies*** SIT is best implemented as one pillar of AWM. Thus, there was a need for development of compatible methods for Qfly control programs. <u>Project 1: Predators as control agents (MU/NSW DPI)</u> • Very little was known about sources of mortality of released Qflies, and in particular the role of predators. • MU had collected some pilot laboratory data on how the processes of domestication and irradiation influenced the vulnerability of Qflies to diurnal and nocturnal spider predators. • Both the domestication process and irradiation increased the vulnerability of Qflies to predators, and this appeared to be because of reduced responsiveness to contact. • The predation pressure on mass-reared and wild type Qflies was quantified through field surveys and laboratory experiments. • Field surveys along transects were used to monitor the frequency of Qflies predated on by a range of invertebrate predators including spiders and predacious insects (e.g., mantids, assassin bugs). • Natural local densities of predators were utilised for the study and the distance and density of released flies was factored in. • The data generated were used to estimate predator densities and the likelihood of fly loss to predators relative to release density, time, and distance to the release point. • Controlled laboratory experiments were designed and completed to understand how predators and Qflies interact.

	• Fine-scale predator-prey interactions were observed and used to better understand what prey behaviour and environmental conditions contributed to the likelihood of predation. Project 2: Parasitoids as control agents (NSW DPI/MU) • Three species of parasitoid wasps, *Fopius arisanus*, *Diachasmimorpha tryoni* and *D. kraussi* have been identified as parasitising Qflies, the latter two persisting in the dry, hot inland areas of Australia. • Building upon existing knowledge, the project addressed key areas of parasitoid biology and ecology to assist with the implementation of an augmentative biological control program to complement SIT. • A mass-rearing system for key Qfly parasitoids was developed. This involved the development of pre-release feeding as different diets affect longevity, fecundity, and other important life parameters. • The spatial ecology of Qfly parasitoids was studied including responses to landscape composition and connectivity, and the effects of host distribution (including non-Qfly hosts). Project 3: The importance of crop hygiene (MU/NSW DPI) • In a previous successful Hawaii AWM program, poor crop hygiene was found to be a major source of pest fruit flies. For example, not allowing fallen fruit to remain long enough for larvae to exit and pupate in the soil. • Basic field studies were carried out to establish the extent to which fallen infested fruit exacerbate Qfly problems. • The costs associated with crop hygiene practices required to reduce this internal source of Qfly were identified and reported. ***Theme 10: Combining and implementing control technologies*** Project 1: Enclosure testing of SIT and AWM practices (MU/NSW DPI) • There was a need for greater confidence in tool selection for AWM of Qfly in Australian settings. • Extensive experimentation in simulated field conditions was carried out to explore optimal combinations of compatible control tools. • Very large field enclosures were used to simulate various operational contexts to assess the merits of several SIT and AWM practices in isolation and in combination. • Known populations of flies were released each enclosure and various combinations of control options were deployed to assess the net effects. Project 2: Field-testing of SIT and AWM practices; Trial implementations (NSW DPI/MU) • Early on, HG14033 identified a need to bring practises developed during the SITplus program into operational settings through trial AWM and SIT programs. • At the commencement of HG14033 there were no operational programs. Accordingly, while highlighting the need for field testing and adoption this was excluded from the scope of required work for HG14033 which focused on the underlying development of knowledge and technology to support SIT and AWM through the SITPlus group. • However, throughout HG14033 it was possible to run small-scale experimental releases in Somersby and Menagle (both NSW) to test a variety of SIT practices, such as age of release (Theme 6 Project 1), pre-release RK and methoprene treatments (Theme 3 Project 1), post-release identification (Theme 4 Project 3), to assess dispersal of sterile flies and to compare the landscape-scale distribution of sterile and wild flies (Theme 3 Project 1, Theme 6 Project 1). • Large amounts of data were collected on fly movement and survival, and information about how these practises impact on field performance of released sterile flies was gathered. • Information from HG14033 experimental trials provided the foundations for operational SIT practices adopted in the trial operational releases of FF17001.
Key	***Theme 1: Preserving genetic quality in domestication and mass-rearing***

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<td>Outputs</td>
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<u>Project 1: Characterise the ‘domestication’ process (CSIRO)</u>

This project investigated aspects of Qfly biology that are affected by domestication, explored genetic underpinnings of such effects, and recommended approaches to ameliorate negative impacts of domestication.
Resistance to heat and desiccation decreased rapidly with domestication in some but not all populations.
This suggested that genetic changes that reduce abiotic resistance could occur in a few generations of mass-rearing and that amelioration measures need to be implemented early in the mass-rearing process to minimise the rate of loss.
Source populations for Qfly strain were found to vary substantially in ecologically important traits and how these traits respond to domestication.
It was therefore recommended that multiple source populations and rearing conditions be evaluated to minimise deterioration of these wild type characters during domestication.
In addition to studies of desiccation resistance, the project also found domestication-related changes in thermal preferences of Qfly with more domesticated lines preferring cooler locations.
Beyond affecting survivorship in the field, such changes in thermal preference can affect dispersal and distribution of the flies following release, potentially resulting in some mis-match of locations of sterile and wild flies at local scales.
Domestication effects were also found in dietary needs of the flies, modifying the protein:carbohydrate ratios that maximise flight performance and mating propensity.
Domestication had some positive effects on mating performance, likely as a consequence of the extreme selection on sexual performance in cages containing many thousands of flies.
Domesticated flies were found to have increased mating propensity and to transfer more sperm, as well as undiminished ability to mate with previously mated females and to induce sexual inhibition in their mates.
Further, in other project areas domesticated flies were found to release more pheromones owing to elevated calling performance (rapid wing beating that produces a calling ‘song’) (Theme 7 Project 1).
In addition to the studies presented under Theme 1 Project 1, very significant effects of domestication were found in other project areas and are reported under Theme 2 Project 1 (Quality control parameters), Theme 2 Project 5 (Microbiome and immunity), Theme 6 Project 4 (Microhabitat preferences & Sexual calling behaviour), and Theme 8 Project 2 (Mating propensity).

Theme 2: Production and delivery processes
<u>Project 1: Defining Quality Control (QC) protocols (NSW DPI)</u>

This project explored factors that can affect quality and provided a test of QC protocols. The project also provided training on QC procedures for staff in mass rearing and rear-out facilities under FF17001 and FF18003.
The findings of the project included:

Some QC parameters change reliably with domestication, others were characteristic of colonies.
QC parameters of colonies from multiple sources should be screened for stable desirable performance metrics.
Larval diet and rearing density affect pupal size, which is closely linked to performance traits.
Pupal size can be included as an easily measured and informative routine QC metric.
Field cage mating competitiveness and compatibility assays, should be conducted at least annually.

The project team recommended that:

The potential practical application of partial sex sorting on the basis of pupal size be considered.
QC manual procedures be strictly adhered to at all factory and rear-out facilities.
QC operations should be regularly audited to ascertain compliance.

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- QC retraining should be implemented when non-compliance is identified.

Project 2: Sterility induction and its consequences (SARDI)

- This project assessed the dose response of pupal Qfly in terms of sterility and quality, and developed an assay to quantify absorbance of irradiation.
- Project 2 found that:
  - Sterilization by x-rays is comparable in dose response to sterilization by gamma rays
  - Doses of 60 – 70 Gy provide a high level of sterility and retain high quality
  - γH2AX assays provide a reliable marker for biodosimetry
  - γH2AX signal is persistent, and can serve as a molecular marker to identify sterile flies post-release
  - Irradiation reduces motility of flies and ability to tolerate starvation, and these changes should be taken into account when considering dispersal and survival of flies especially in challenging environments.

Project 3: Maintaining fly quality during transport (MU)

- This project investigated aspects of handling at the factory and during transportation that may impact on the quality of flies available for release.
- Key findings of the project included:
  - Hypoxia is required for irradiation and transportation, but more than two days is detrimental.
  - Periods of hypoxia required for irradiation and transportation should be minimised to preserve fly quality.
  - Where longer periods of hypoxia are required, quality is better retained at 18°C than higher temperatures.
  - Consideration should be given to use of insulated boxes and chilling for transporting pupae.
  - Pupae are very vulnerable to damage from handling and vibrations, especially after the sixth day of pupation.
  - Exposure of pupae to vibrations should be minimised wherever practical.

Project 4: Logistics of production and delivery (NSW DPI)

- This project modelled a range of scenarios to assess economic merits of production and delivery options, and also produced a 'dashboard' that can be used to track changes in fly quality between batches both before and after transportation.
- A model for logistics planning is continuing to be developed.
- Data that can be integrated with the available logistics model needs to be continually updated to improve value.
- Available services and costs should be periodically reviewed in order to adopt faster, cheaper and more quality-preserving options when they become available.

Project 5: Microbial gut symbionts

- This project explored the role of microbes in the biology of Qfly and considered potential applied significance in rearing and protection from immune challenges.
- The microbial symbionts project results and recommendations included:
  - Qfly have a rich bacterial and fungal microbiome, which varies with host or larval diet.
  - Elements of bacterial microbiome are passed from mother to offspring.
  - The microbiome changes substantially during domestication and through development.
  - The microbiome is important for development and for offspring performance.
  - Production processes should facilitate the exposure of early larval stages to appropriate microbiota.

- The microbiome is important for adult nutrition.
- The microbiome remains stable after release; pre-release probiotics hold little promise of improving fly quality.
- Some heterogeneity in larval diets is acceptable, as the larvae are very capable of selective foraging and of tolerating variable diet.
- Larval crowding has some negative impacts on adult quality; care must be taken when considering expansion of production above the usual levels.
- Immune function is linked to microbiome and diet.
- Immune priming is not supported as a means of enhancing post-release protection from pathogens.

Theme 3: Pre-release treatments and release methods

<u>Project 1: Pre-release treatments (MU and NSW DPI)</u>

- Qfly have historically been released when just 2- 3 days of age and suffer high mortality such that few survive to maturity. This project sought solutions to this serious constraint through pre-release treatments.
- The project reported the following results:
    - RK, methoprene and caffeine are all effective at accelerating development of Q-flies and could be applied in operational SIT programs under the historical conditions of 2 – 3 day pre-release holding period.
    - Releasing flies at five days of age (See Theme 3 Project 2) yields such massive improvements in field performance of sterile Qflies that additional supplements provide no incremental benefit to development.
    - Males treated with RK and methoprene are fully capable of inducing sexual inhibition in their mates, even when mating at unusually young ages.
    - Mosquito larvicides can provide a cheap source of methoprene.
    - RK is incorporated in pheromone, and increases amount of pheromone produced.
    - RK feeding reduces cuelure response, potentially enabling simultaneous SIT and MAT that would vastly increase the efficacy of SIT.
    - RK treatment provides some protection from predators by aversion.
    - Males treated with RK or methoprene have increased vulnerability to nutritional stress and so these treatments should be avoided when releasing flies in dry environments.
    - Plant-based proteins do not provide an alternative to yeast hydrolysate for pre-release nutrition.

<u>Project 2: Release methods (MU/NSW DPI)</u>

- Aerial release is intended as a primary operational approach to Qfly SIT. This project trialled and refined aerial release protocols for use in operations and pilot release programs (FF17001).
- The project showed that:
    - Aerial release systems developed for the SITplus program are effective.
    - Releases should be carried out as soon as practicable after chilling and packing of adult flies to minimise deleterious effects.
    - To support alternative small-scale and local implementations of Qfly SIT, consideration should be given to the development and testing of pupal release methods.

Theme 4: Post-release identification

<u>Project 1: Visible markers (NSW DPI/MU)</u>

- This project assessed available dyes and reviewed potential alternative marking methods for SIT Qflies.
- The project found that all of the tested dyes except for Stella green were similar in all assessed metrics of fly performance and are recommended for use in SIT programs.

	• 2g dye/L of pupae is optimal in terms of visibility and fly performance. Project 2: Identification through biomarkers (SARDI/MU) • This project considered the possibility of using irradiation-induced molecular signatures as a means of distinguishing released sterile (irradiated) flies. • Results indicated that γH2AX provides a reliable marker of irradiation that can be used to distinguish sterile and wild flies if visible markings prove ambiguous. • Based on this finding, a tool could be developed based on γH2AX for routine use in SIT programs for Qfly, and potentially other insects. Project 3: Isotope ratio analysis (MU/NSW DPI) • Qflies in nature have access to C3 sugars, mass-reared flies are fed C4 sugars which leave a signature in their body composition. This project investigated the viability of persistent isotopic signatures as a supplementary means of distinguishing sterile and wild flies. • The project showed that intrinsic $\delta^{13}C$ analysis offers a precise tool to discriminate between sterile and wild Q flies in SIT programs. • Also, $\delta^{15}N$ values, that can be analysed together with $\delta^{13}C$, do not provide a stand-alone method of discriminating between sterile and wild flies but give other insights into diet. • ^{13}C isotope enrichment of diets can be used to increase signal strength, although it is an expensive approach. Project 4: Genetic biomarkers (CSIRO/SARDI) • Natural hybridisation occurs in some fruit flies. This project explored the genetic structure of natural hybridisation to potential create of Qfly-compatible hybrids for SIT. The distinct genetics of such hybrids could be readily detected by routine molecular assays. • *B. tryoni* vs *B. neohumeralis* diagnostic markers can be developed using informative X-linked polymorphisms. • *B. tryoni* vs *B. jarvisi* diagnostic markers can be developed chromosomal inversion polymorphisms. • Hybridisation can yield genetically distinct and readily identifiable types, and if sexually compatible with Qfly could be used in SIT releases. ***Theme 5: Ecological competence*** Project 1: Genetics/Genomics of Qfly ecological fitness (CSIRO/MU) • To advance toward ameliorating the negative impacts of domestication, this project investigated the genetics underpinning desiccation resistance. • Desiccation stress tolerance is variable across individuals and is heritable. • Genes conferring desiccation resistance have been mapped, and can be used as markers in breeding programs. • Variation in desiccation resistance is linked to lipids involved in membrane structure. Project 2: Regional variation in Qfly fitness genetics/genomics (CSIRO/MU) • One approach to addressing the negative impacts of domestication on desiccation resistance is to source mass rearing populations from regions that naturally express high levels of desiccation resistance. • To identify populations that might serve as sources of desiccation resistant lines for SIT, this project assessed variation in desiccation resistance from across the Qfly range. • The approaches taken here also enabled understanding of the changes in fly characteristics that have taken place over the past 100 years during their southward range expansion, which had ancillary value

in understanding likely effects of future climate change or likely ability of exotic tropical species to adapt should they establish in Australia.
- The regional variation study showed that Qfly populations vary significantly in desiccation stress resistance, although there is no north-south cline.
- Population variation in desiccation resistance is stable across years.
- Select source populations for SIT strains which have relatively high climatic stress resistance.
- Use of the reference genetic database of Qfly populations generated in this project for source detection of future incursions or outbreaks, to inform risk management with interstate trading of horticultural commodities.

Theme 6: Applied landscape ecology

Project 1: Dispersal, maturation and survival of sterile and fertile flies (MU/CSIRO/NSW DPI)

- This project assessed factors affecting the movement and survival of released flies, and whether released sterile flies tend to co-locate with wild flies.
- The project also discovered a 6-8 fold increase in the field abundance of mature sterile males when released at 5 days of age rather than the usual 2-3 days of age.
- In conjunction with Theme 3 Project 1, the project found that while methoprene and RK supplements improve maturation or survival of flies released at two days of age, they no longer provide benefits when flies are released at five days of age.
- This was because the substantial positive effects of extending the holding period to five days ensured that the flies were already in an advanced state of maturity when released such that additional pre-release treatments of methoprene and RK provided no further improvement.
- Accordingly, the project team recommend release of flies at five days of age following feeding on sugar and yeast hydrolysate without either RK or methoprene supplements.
- The effects then were assessed in field releases through project FF17001.
- Also, pre-release provisioning with yeast hydrolysate is important, greatly increasing survival and maturation after release in the field.
- Released sterile flies co-locate with wild flies at landscape scale, demonstrating broadly similar habitat preferences despite some differences in environmental tolerance.

Project 2: Host-related temperature phenology (NSW DPI/MU)

- This project assessed potential protocols for cool storage of Qfly eggs and pupae that could provide a means of regulating the flow from production to delivery.
- Eggs can be stored at 16°C to prolong development by up to 6.5 days without reducing egg hatching or development.
- Pupae can be stored at 23°C to prolong development by 2 days with minimal impact on quality.

Project 3: Adaptive potential of Qfly to geographic distribution and climate change (MU/CSIRO/NSW DPI)

- This project used the latest modelling tools to predict likely changes in distribution of Qfly and other endemic fruit flies over the coming decades, as well as the potential geographic range in Australia of major exotic threats.
- The project results indicated that:
    - Regions currently affected by Qfly will continue to be affected to at least 2070.
    - Some additional regions not currently occupied by Qfly are already suitable.
    - Additional regions are likely to become suitable for Qfly as climate changes.
    - Large regions of Australia are suitable for major exotic fruit fly pests, and will remain suitable to at least 2070.

Project 4: Local drivers of fruit fly behaviour (MU/NSW DPI)

	• This project explored the ways in which the movement and activity of sterile and wild flies is affected by local conditions.
	• Mass-reared (both fertile and sterile) males exhibit mating behaviours that differed spatially and temporally from wild conspecifics, which could lead to assortative mating.
	• Although wild flies initiate agonistic interactions at greater distances, mass-reared flies are similarly likely to initiate and win overall.
	• Sterilization by irradiation at the pupal stage reduces Qfly locomotor activity and starvation tolerance.
	
	<u>Project 5: Assessing reinstatement periods (NSW DPI)</u>
	• This project was coordinated with PFR NZ and the SITplus project drew of the NZ work to gain efficiencies within the broader program.
	
	Theme 7: Mating ability of sterile flies
	<u>Project 1: Variation and functions of pheromones (MU/PFR)</u>
	• This project described the pheromones produced, emitted and deposited by male and female Qfly, and assessed the effects of domestication on pheromone emission and sexual calling behaviour.
	• Findings of the project included:
	    • Both male and female pheromones are important in the Qfly mating system.
	    • Previous studies have greatly underestimated the complexity of pheromonal communication.
	    • Domestication increases pheromone emission, potentially improving sexual success.
	    • Domestication increases sexual calling effort, potentially improving sexual success.
	    • Cuticular chemistry is revealed as an important form of pheromonal communication.
	
	<u>Project 3: Genetics/Genomics of Qfly reproductive fitness (CSIRO/MU)</u>
	• This project ascertained the variation and heritability of pheromone profiles in Qfly.
	• Pheromone composition varies between individual males and is heritable.
	• Multiple genes are indicated in defining individual pheromone blend.
	• Many pheromone components increase in abundance through domestication.
	• Use a marker assisted breeding strategy to select colonies for mass rearing and to retain the desired specific pheromonal compounds or blends.
	
	Theme 8: Protecting sterile matings
	<u>Project 1: Prevalence and predictors of multiple mating (MU/CSIRO)</u>
	• This project documented sperm storage and usage by Qfly, and also estimated the prevalence of multiple mating in field populations.
	• The project showed that:
	    • Remating by female Qflies is common in the field.
	    • A high abundance of sterile flies in the field is important not only to increase sterile matings of virgin females but to ensure that a large proportion of rematings are also with sterile males.
	    • Females commonly store sperm from more than one male.
	    • Paternity of first and second mates changes as females age, with increasing use of first mate sperm.
	
	<u>Project 2: Mechanism of sexual inhibition (CSIRO/MU)</u>
	• This project explored in detail the molecular mechanisms that mediate induced sexual inhibition in Qfly.
	• Conclusions and recommendations of the project were as follows:
	    • There is substantial regional variation in female remating tendency.
	    • Regional variation is heritable.

	- Include male ability to induce sexual inhibition in mates as a criterion for choice of mass-reared colony.
	- Females become increasingly prone to remate through domestication.
	- Increased female remating tendency through domestication could impede SIT by absorbing a disproportionate amount of sterile male mating effort.
	- Domestication-induced changes in female remating should be considered in decision of when to replace domesticated colonies.
	- Female responsiveness to male pheromones is an important behavioural mechanisms of sexual inhibition.
	- Seminal fluid proteins potentially involved in induction of sexual inhibition of females are identified.
	
	Theme 9: Compatible control technologies
	Project 1: Predators as control agents (MU/NSW DPI)
	- This project explored the responses and vulnerability of Qfly to predators.
	- Sterile Qflies have diminished ability to evade predators, likely owing to reduced motility.
	- It was recommended that testing of anti-predator performance be included in periodic QC assays.
	- Predators' odours can induce avoidance or stasis, depending on predator species.
	- Odours from diverse predators inhibit foraging, mating and oviposition in Qfly.
	- A PCR assay is developed to monitor and quantify predation of Qfly .
	
	Project 2: Parasitoids as control agents (NSW DPI/MU)
	- Early on in the project, funds from Theme 9 Project 2 were redirected to Theme 2 Project 4 to facilitate expanded logistics research and to bridge projects dealing with demand and supply so that a single platform was developed.
	
	Project 3: The importance of crop hygiene (MU/NSW DPI)
	- This project investigated the number of wild flies that can be produced by untended fruit trees, providing a pest reservoir.
	- The project demonstrated that:
	  - Untended hosts and unharvested fruit can be a serious source of Qflies.
	  - Fallen and infested fruits should be removed wherever possible and economical.
	  - Untended fruit trees should be removed where possible as a long-term solution.
	
	Theme 10: Combining and implementing control technologies
	Project 1: Enclosure testing of SIT and AWM practices (MU/NSW DPI)
	- It is difficult and expensive to test efficacy of SIT in full scale trial operations such as in FF17001, but much can be learned from trials conducted in enclosures with wild and sterile flies. Such trials provide a more realistic assessment than laboratory trials of survival, development and mating as they investigate the 'net' effect under conditions that are much closer to the field.
	- This project tested the ability of sterile males to induce sterility in wild females in a replicated outdoor simulation.
	- Through simulated SIT operation under field cage conditions, the project supported SIT viability, reducing populations of wild flies.
	- Field cage SIT simulations could be developed as a periodic QC assay, going a step beyond the single generation FRIED test.
	
	Project 2: Field-testing of SIT and AWM practices; Trial implementations (NSW DPI/MU)
	- Full field testing of SIT and AWM practices were conducted through Project FF17001.

	• This project identified those practices and procedures developed in the course of HG14033 that provided the foundations for FF17001.
	
	Overall, the primary outputs of HG14033 clearly defined technical procedures for the establishment, maintenance and implementation of Qfly SIT to international standards. For example, through HG14033, detailed guidelines were developed for:
	1. The maintenance of desirable traits in mass-reared flies,
	2. The definition and assessment of quality,
	3. Sterility induction with minimal compromise to quality,
	4. Transport and delivery,
	5. Decisions of how many flies to produce and where to deploy,
	6. Maintenance of healthy fly colonies,
	7. Pre-release treatments to improve field performance,
	8. Release of flies to the field,
	9. Post-release identification of sterile flies,
	10. Breeding of flies of high ecological competence,
	11. Breeding of flies of high reproductive competence, and
	12. Combinations of methods compatible with SIT.
	• The guidelines were developed specifically to guide management of the new SA SIT facility, and will contribute significantly to the development of Standard Operating Procedures (SOPs).
	• In addition to the research/scientific outputs, a total of 21 PhD candidates were supported and trained.
	• Nineteen (19) of the 21 PhD students engaged in HG14033 already had submitted their theses by the end of the project funding period.
	• An online archive of all HG14033 outputs was created on the SITplus Research Site of the PHA Biosecurity Portal including:
	    • Peer-reviewed publications (also available from primary publication sources, and ResearchGate) – over 90 peer-reviewed publications were expected to arise from the HG14033 work,
	    • Master of Research and PhD theses (also available by free online access to MU thesis repository, https://www.researchonline.mq.edu.au/vital/access/manager/Index),
	    • A large number of oral and poster presentations delivered at external and internal meetings, and presentation abstracts**.**
	    • Other extension materials such as articles in industry newsletters and magazines and media releases,
	    • Covid-19 had some impact on SITplus project progress, mostly in the form of delays in finalising and publishing several elements. However, only a small number of projects still required data collection or fieldwork when the pandemic began and so impacts were generally quite minor in the context of overall program delivery.

Outcomes	• The primary outcome of HG14033 has been the realisation of essential RD&E for the development of effective, economical and sustainable Qfly SIT in Australia. • HG14033 focused on the underlying development of knowledge and technology to support SIT and AWM through the SITPlus group. • The SITplus program was developed through a weaving together of diverse projects carried out by member organisations to give greater impact. • More specifically, information from HG14033 experimental trials provided the foundations for operational SIT practices adopted in the trial operational releases under project FF17001 (*Post-factory pilot of SITplus fly production*). • For example, based on the findings of HG14033, for the first time an extended pre-release holding period has been adopted in SIT releases. • Pre-release yeast hydrolysate has been confirmed as highly effective and is adopted in FF17001.

	• Transportation of pupae from factory to rear-out facilities is based on HG14033 assessment of quality and development of logistics models. • Quality control assessment if flies at factory and rear-out are based on protocols delineated in HG14033. • Also, the fluorescent markers tested in HG14033 (Theme 4, Project 1) are used to reliably identify released flies in FF17001. • As FF17001 continues and other, related fruit fly RD&E projects progress there will be ongoing transfer to technology and support from HG14033, which has provided a substantial knowledge base to use in troubleshooting of issues and for medium to longer term improvement of mass-reared Qflies and SIT practises. • The effectiveness and impact of HG14033 has been demonstrated through the success of Qfly suppression reported to date in FF17001. • HG14033 also made significant contributions to research capability and capacity with the next generation of insect biosecurity researchers by integrating a large number of Master of Research, PhD students, and research fellows, as participants in most projects.

Potential Impacts	Impacts of project HG14033 are likely to include:
	• Increased efficiency and/or effectiveness of resource allocation for future Qfly SIT RD&E through the realisation of essential foundational scientific knowledge and increased coordination and collaboration for Qfly SIT RD&E in Australia (for example, research outputs used to inform FF17001 and related Qfly SIT RD&E).
	• Maintained returns to investment in RD&E because of increased scientific knowledge and research capacity achieved through the support and training of over 20 post-graduate students and research fellows.
	• Contribution to potentially reduced SIT production and implementation costs through the adoption of recommendations that improve mass-rearing processes and SIT program logistics.
	• Contribution to improved effectiveness and efficiency of future SIT programs to control or eradicate Qfly in Australia. This in turn is expected to lead to increased long-term productivity and/or profitability for Australian horticultural producers in Qfly affected regions through:
	    • Reduced Qfly damage and control costs.
	    • Increased value because of increased average product quality.
	    • Maintained or increased market access (both domestic and international).
	• Reduced future Qfly eradication costs from Qfly incursions/spread to new regions (e.g., WA and other domestic Qfly PFAs).
	• Some contribution to improved environmental outcomes through reduced agricultural chemical use for Qfly and therefore potential for reduced chemical export off-farm.

Source: HG14033 project documentation and consultation with project personnel and other expert stakeholders