Final Report

Pilot sterile codling moth releases for the apple industry

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Public summary

Codling moth (*Cydia pomonella*) (CM) is a key pest in most pome-fruit production regions worldwide, including Australia where it is considered one of the most economically damaging pests in many production regions. Current management strategies include chemical control, phenology modelling, regular monitoring, mating disruption and biological control, but chemicals used for CM control disrupt beneficial insects, substantially affecting integrated pest management (IPM) systems. The goals of this pilot project were to (1) review the current-status of CM in Australia; (2) examine the application of Sterile Insect Technique (SIT) as a tool for control of CM in Australian apple orchards; (3) establish release sites to determine the efficacy of sterile codling moths (SCM) in control of wild populations; and (4) determine the feasibility of integrating SIT into existing apple and pear management and production programs in Australia.

As a biological control method, SIT has numerous benefits over traditional pesticide control methods for management of CM. SIT is compatible with other biological IPM methods and is an ideal tool for organic or low-input orchards. It is also environmentally safe and species specific.

This pilot program has successfully investigated safe and secure biosecurity pathways for entry of SCM into Australia from Canada, developed and tested the logistics of transport and release, and examined the costs and feasibility of success. The project has demonstrated proof of concept for the use of SIT as a tool for control of CM with reduced fruit damage at two test sites.

An economic analysis was undertaken to compare the costs and economic benefits achievable between SIT, mating disruption, and agrichemical use, to inform grower and industry uptake of the technology. Findings from this analysis indicate that gross orchard gate income per hectare is expected to be higher under SIT relative to mating disruption (+$277) or pesticide use only (+$2295). These figures indicate SIT represents an approach that is economically beneficial for at least some growers if moths can be sourced and released locally, but that this quickly becomes unaffordable due to the increased freight costs and import charges if moths must be imported from Canada.

The limited mobility of codling moth means that effective management using SIT is achievable, even in smaller production areas, making it feasible for use at an individual orchard level. Area-wide management would offer increasing economies of scale in larger growing regions, but to be successful, consultation and collaboration between the pome fruit industry, regional councils, relevant State government departments and the wider public will be essential

While it is technically feasible to import SCM from Canada, it is too unreliable due to inconsistency of shipments throughout the season, and the long transport chain (60+ hours). However, if the sterile moths could be sourced from within Australia it would seem reasonable to expect that the levels of codling moth control achieved and economic returns to growers would be viable.

Keywords

Integrated Pest Management; biological control; pesticide resistance; area-wide integrated pest management; sterile insect technique; SIT; *Cydia pomonella*

Introduction

Codling moth (*Cydia pomonella*) is a key pest in most pome-fruit production regions worldwide, including Australia where it is considered one of the most economically damaging pests in many production regions. If unchecked, codling moth can damage 50% to 90% of fruit, resulting in decimation of the industry. Other industries affected by codling moth in Australia include cherry, summer fruit, nashi and walnut. Current management strategies include chemical control, phenology modelling, regular monitoring, mating disruption and biological control, but chemicals used as part of codling moth control programs disrupt beneficial insects, substantially affecting integrated pest management (IPM) systems. Codling moth has also developed some resistance to insecticides presently used, making it more difficult to control. Pheromone trapping, feeding attractants and mating disruption have a greater effect in large commercial blocks of trees. However, orchards are reinfested easily from neglected orchards, roadside and unmanaged backyard apple, pear, and stone fruit trees where no coding moth control is undertaken.

Australia's apple and pear production is valued at $647 million-dollars (Hort Innovation 2023). Nationwide, if 1% fruit losses occur due to codling moth in the Australian apple and pear industry based on 2022/23 estimates, this equals a loss of $6.5 million dollars in production. In addition to the value of crop loss, the cost of control measures (chemical sprays, monitoring and pheromone traps, biological control and mating disruption practices), discarding damaged fruit during harvesting and adhering to regulatory requirements for export need to be added. Conservative estimates place these additional costs at approximately $0.02 per kilogram based on data from Apple & Pear Australia Limited (APAL), the Australian Pip Industry "Orchard Business Analysis" and Model Future Orchard 2012 walk. Development of new technologies that can be integrated into existing IPM strategies will be of considerable benefit to Australian apple and pear growers, improving returns by an estimated $136 million.

Furthermore, export markets of China, Thailand and Taiwan require pest monitoring activities be carried out by registered crop monitoring services and future Australian apple market development may be based on how well Australia can control codling moth. Codling moth will substantially affect exporting apple and pear orchardists as well as stone fruit, cherries, nashi and walnuts.

<u>Sterile insect technology</u>

Sterile insect technique (SIT) is a relatively new strategy that is becoming more widely used for mobile pests. It is a recognised phytosanitary procedure for pest suppression and management under the International Standards for Phytosanitary Measures – IPSM03 (DAFF 2023).

Initiated in the 1930s, SIT was first used successfully to control the devastating cattle pest screwworm fly in 1953 on the island of Curacao (DPIRD 2018). The technique has since been developed to provide effective control of more than 20 insects. SIT programs work by flooding the wild population with large numbers of sterile males to substantially reduce the number of fertile eggs produced. When this is repeated over several seasons, the population crashes and infestations drop below damage threshold levels.

SIT is species-specific and environmentally friendly. Benefits of SIT include:

- reduced pest damage and costs
- reduced chemical pest controls
- improved productivity
- improved product quality
- improved environmental outcomes.

SIT is now recognised as an effective and desirable option for the management and/or eradication of fruit flies and has been proven effective in overseas programs in Chile, Guatemala, Mexico, USA, and Japan (DAFF 2023). The technology has been used in Australia for the control of Mediterranean fruit fly (*Ceratitis capitata* 'Medfly') and Queensland fruit fly (*Bactrocera tryoni* 'Qfly') in NSW, VIC, SA, and WA. It has been used successfully for suppression activities in areas of low wild fruit fly populations, and during outbreaks within established Pest Free Areas (PFAs).

More recently SIT has also been successfully trialled in Australia as part of an integrated pest management approach to prevent flystrike at a property level by sheep blowflies (*Lucilia cuprina*) (DPIRD 2022).

<u>Sterile insect technology for codling moth</u>

Canada has been successfully applying SIT for codling moth control within an area-wide approach in southern British Columbia for over 20 years (Nelson et al. 2021). Relative to pre-program levels, codling moth populations have been reduced by 94% and fruit damage to less than 0.2% in more than 90% of orchards in the release area. Nelson et al. (2021) have also reported a 96% reduction in pesticide use against codling moth in British Columbia. Walker (2022) reported a 90-95% reduction in moth densities following six years of an area-wide release pilot study in New Zealand. Trials in Michigan, USA found that sterile males mating with wild females can reduce egg hatch by more than 90 percent.

Introduction of a pilot SIT codling moth program to Australia will provide an opportunity for the apple and pear industry to attain substantial improvements in IPM practices, thus reducing reliance on chemical control methods and enabling a practical safe and socially acceptable method for management of codling moth infestations in neglected orchards and unmanaged roadside and backyard trees. This will provide a substantial benefit to all horticultural crops impacted by codling moth.

<u>Project aims</u>

The goals of this pilot project were to (1) review the current-status of codling moth in Australian apple and pear growing regions; (2) examine the application of SIT as a tool for control of codling moth in Australian apple orchards; (3) establish release sites to determine the efficacy of sterile codling moths (SCM) in control of wild populations; and (4) determine the feasibility of integrating SIT into existing apple and pear management and production programs in Australia. To achieve these goals, the project sought to:

- Investigate safe and secure biosecurity pathways for entry of sterile codling moth into Australia from Canada's Okanagan-Kootenay Sterile Insect Release (OKSIR) Program in British Columbia;
- Identify suitable test regions representative of Australian domestic and export apple production zones for the safe release and testing of sterile codling moth;
- Cooperate and work with industry grower participants and community stakeholders to determine the effectiveness of sterile codling moth within existing area-wide IPM programs;
- Conduct an economic assessment of the release program and an analysis of SIT for control of codling moth for the apple and pear industry;
- Make recommendations for the adoption and integration of sterile codling moth into IPM programs based on findings and the effectiveness of control of codling moth using SIT;
- Provide a highly accessible contact point for community and industry enquiries about this pilot program ensuring community and stakeholder engagement on its scientific progress and findings.

Project Team

This was a collaborative project with team members from multiple organisations:

Personnel	Organisation
Dr Sally Bound, Michele Buntain	Tasmanian Institute of Agriculture (TIA)
Dr Guy Westmore	Natural Resources and Environment (NRE)
Dr Peter Crisp	SA Research & Development Institute (SARDI)
Dr Michael Tarbath	Fruit Growers Tasmania (FGT)
Ian Cover	Cover-All Consulting (initially with FGT)
Paul James	Lenswood Co-op, SA
Dr Craig Hull	Department of Agriculture, Fisheries and Forestry (DAFF)

Methodology

The project was divided into two phases, with progression to Phase 2 based on the success of Phase 1.

Year 1: Phase 1 comprised the foundational activities, including development of program logic, importation facilitation and establishment of entry pathway protocols, and mapping of codling moth distribution within Australia.

- *Activity 1*: Develop Project Logic
- *Activity 2*: Review and map codling moth distribution in Australian apple production regions
- *Activity 3*: Establish importation requirements from the Canadian OKSIR facility
- *Activity 4*: Determine suitable regions for release
- *Activity 5*: Develop entry pathway process into Australia
- *Activity 6*: Independent review to inform STOP/GO decision.

Years 2-3. Phase 2 aimed to introduce and test area wide IPM systems for SCM based on pilot releases in regional areas, undertake an economic assessment of release programs, put in place a point of contact for SCM enquiries, and develop recommendations on the viability of SIT as a tool for codling moth control in Australia.

- *Activity 7: Expand DPIPWE (NRE) rear-out facility*
- *Activity 8: Pilot release of sterile codling moth and evaluation of impact*
- *Activity 9: Integration of sterile codling moth into area-wide IPM systems*
- *Activity 10: Industry enhancement and awareness benefits program*
- *Activity 11: Economic assessment of release programs*
- *Activity 12: Development of recommendations.*

Full details of the methodology for each activity is provided in Appendix 1

Results and discussion

Activity 1: Project logic, M&E, communication, stakeholder & risk management plans
The foundational workshop was held on 12th November 2019 with all team members. Activities undertaken during the workshop included development of the program logic, discussion of stakeholders, next users, targets and KPI's, key evaluation questions, and potential risks to the project. These plans are all provided in Appendix 2

Activity 2: Map codling moth distribution:
The project entomologist, Dr Guy Westmore has produced a codling moth distribution map based on 578 codling moth records. Projected distribution maps were also produced using Maxent (Maximum entropy model), a species distribution modelling tool for predicting the distribution of a species from a set of records and environmental predictors. The maximum entropy model was found to be the best in both predictive performance and model stability when compared with other similar niche models (Phillips et al. 2006, Phillips and Dudik 2008). (Full details are provided in Appendix 1).

Activity 3: Establish importation requirements from Canadian OKSIR program
To enable the approval of an import permit from the Canadian OKSIR facility, registration of the facility under DAFF's Offshore Irradiation Treatment Providers Scheme was required. To obtain registration under this scheme the normal practice is for a DAFF officer to visit the facility to undertake an audit. However, as this was not feasible under the COVID-19 travel restrictions, DAFF provided an alternative approach for permit approval, with the regulatory approval process for OKSIR relying on a signed manufacturer's declaration from the facility (desktop audit).

Activity 4: Determine suitable regions for release
The project initially allowed for two release areas of SCM, with the main sites in Tasmania and secondary sites in the Adelaide Hills of South Australia. The criteria used for site selection included presence of codling moth in the orchard, but not in overwhelming numbers, in addition to grower and close neighbours not exporting to avoid problems with market protocols. Release sites were selected for both Tasmania and South Australia in year 1 of the project. However, following the substantial increases in the cost of SCM production and airfreight charges, the South Australian sites were omitted, and the Tasmanian sites increased from the original two sites to three sites. All three release sites were located in the Huon Valley were matched with paired control sites. Site locations are provided in Appendix 1, Figure 2.

Activity 5: Develop entry pathway process into Australia

- **Submission of application for Import Permit:** An application for an Import Permit to import sterile codling moth from the Canadian OKSIR facility was submitted to the Department of Agriculture, Fisheries and Forestry (DAFF) on 19 December 2019. The application (import permit application no. 0003917272) was assessed in accordance with sections 178 and 179 of the Biosecurity Act 2015. Due to restrictions resulting from the COVID-19 pandemic outlined under Section 6 Project disruptions above, approval of the import permit was significantly delayed, taking 27 months from application to approval.
- **Finalised SCM secure importation process (DAFF):** The permit to import sterile codling moths was received on 7 April 2022 (see Appendix 4). This permit was valid for multiple consignments between 7 April 2022 and 7 April 2024.
  - The conditions of the permit allowed for the importation of *Cydia pomonella* which have been sterilised by gamma irradiation treatment at the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility, located in Canada. Imported material could only be used for direct release into the environment for biological control use and was limited to only apple orchard field sites in South Australia and Tasmania, as part of the sterile insect release research program.
  - It should be noted that this is the first approval for a direct field release (i.e. without going through quarantine) of any organism in Australia and represents a significant achievement for the project team.

- **Import logistics:** The supply pathway involved road transport, three commercial flights followed by customs and quarantine clearance and finally road transport to the release sites (Appendix 1, Figure 3). Only two viable supply pathways were available each week, departing Canada either Mondays or Wednesdays, and arriving into Hobart airport after approximately 40 hours. Following quarantine approval and clearance, moths were transported directly to the field release sites. Table 1 shows the total transit time from packing to site release, a total of 61 hours which is well in excess of the ideal transit time of less than 36 hours.

Table 1: Total transit time from packing of moths to site releases

Activity	Hours
Time from packing to arrival at Hobart Airport	41
Cool storage until quarantine inspection & shipment clearance	18
Pickup and transport to release sites	2
	61

Activity 6: Independent review to inform STOP/GO decision

The project reference group discussed the Stop/Go criterion scheduled for Milestone 104 (MS104) at its meeting on 21st April 2022. It was agreed that this criterion was too early in the project timeline, being only eight months from the commencement of the project (COVID hold adjusted) and that it would be more appropriate to move this criterion to the mid point of the project (MS105), by which time the import process would have been trialled and the first releases of moths in the designated release sites undertaken. Movement of this criterion from MS104 to MS105 was approved. Following successful importation of moths and field releases, the STOP/GO milestone was approved on 6th January 2023.

Activity 7: Expand DPIPWE rear-out capacity

This activity was discontinued when it was identified that the moths provided by OKSIR would be mature adults, and the funds that were originally allocated for this purpose were used to cover the additional costs of moths and freight.

Activity 8: Pilot release of sterile codling moth and evaluation of impact

- **Moth release densities and methodology:** A release rate of 3,000 male moths per hectare was determined following discussions between Dr Guy Westmore, the project biosecurity entomologist, and OKSIR technical staff. As shipments included a mix of both male and female moths with a ratio of approximately 50:50, the total release rate was determined at 6,000 moths per hectare.
- **Insect rearing and shipment:** Moths were mass reared at the OKSIR facility in Osoyoos, British Columbia (OKSIR 2024). The rearing process involved laying of eggs on wax paper lining special moth cages. Following egg laying, the waxed paper was then placed on a prepared diet containing a red dye that resulted in a permanent internal pink marker to enable differentiation of sterilised moths from wild moths following release (Appendix 1, Figure 4). Larvae were developed in rearing rooms with strictly controlled light, temperature and humidity (OKSIR 2024).
    - Irradiated moths were packed into sealable paper cups (Appendix 1, Figure 5) holding approximately 3,000 moths per cup. Sealed cups were placed into foam boxes containing ice packs to ensure temperature remained between 0-2°C during shipment.
- **SCM releases and monitoring of wild/sterile populations:**
    - Imported sterile codling moths were released over two growing seasons (2022/2023 and 2023/2024) at three treatment sites (Appendix 1, Figure 2) on a weekly basis from late October through to mid February.
    - Total release area was 15.5 ha spread over the three sites; this was reduced to 13.9 ha in season 2 with the removal of planted area from a section of the release site in pair #3. Total control area was 10.7 ha. Details of site area and number of pheromone traps for monitoring are provided in Table 2.

Table 2: Area of release and control sites and number of monitoring traps.

Pair #	Site area (ha)		Number of traps	
	Release	Control	Release	Control
1	4.6	4.1	5	4
2	3.9	4.6	4	5
3	7.0/5.4*	5.0	7/5*	5
	15.5/13.9*	10.7	16/14*	14

* site area reduced in season 2

    - On arrival at each release site, the required number of cups were removed from the insulated packaging and decanted into insulated flasks. The moths were released manually via an orchard walkthrough, starting at the second row in each block and then every third row. Moths were poured into 10 ml measuring cups to ensure a consistent release density before being distributed along each row at the rate of 10 ml for every 20 trees (Appendix 1, Figure 6).
    - Dates for the field releases over the two seasons are provided in Appendix 1, Table 3. Although a total of 17 releases were scheduled, two releases were missed each season as a result of severe weather in Canada causing a missed flight connection or closure of the OKSIR facility during public holidays.
    - Sticky traps with codling moth pheromone lures were installed at all release and control sites to monitor both sterile and wild population numbers (Appendix 1, Figure 7). Trapping density at each site was based on the standard export protocol of one trap per hectare. All traps were checked weekly the day prior to releases of the sterile moths, with the sticky bases removed and replaced at each check. During trap inspections, each of the codling moths adhering to each base were examined to determine whether they were wild or sterile, with the total number of wild and sterile moths recorded separately for each trap.
- **Trap monitoring results**
    - Weekly capture rates of sterile and wild moths at all the release and control sites over the two seasons can be found in Appendix 1, Figure 8. In both seasons, missed releases affected the sterile moth population, with the number of sterile moth captures decreasing several days after the missed release.

- Weather conditions also impacted on activity and survivability of the released sterile moths (Appendix 1, Figure 9). The low sterile:wild moth ratio on traps observed during season 1 in the critical period of Nov-Dec coincided with a two-month period of cold, wet weather, which may have reduced the survival and suppressed the activity of the released moths. During periods of regular moth releases, sterile catches varied directly with the average maximum temperature and inversely with the total rainfall in the week preceding each trap catch (Figure 9). The only period in which this relationship did not hold was in the first two weeks of January, reflecting the absence of sterile moth releases on 22 and 29 December.

- **Fruit damage assessments**
  - Field examination of fruit for codling moth damage was undertaken prior to harvest in late February of each season. Five panels of four trees were randomly selected per hectare (i.e. 20 trees per hectare) (Table 3). A full description of the methodology and results is provided in Appendix 1.

Table 3: Details of number of trees and fruit examined at each site for codling moth damage.

Pair	Site	Hectares	# traps	# panels	# trees	# fruit
1	Control	4.1	4	20	80	2,000
1	Release	4.6	5	25	100	2,500
2	Control	4.6	5	25	100	2,500
2	Release	3.9	4	20	80	2,000
3	Control	5	5	25	100	2,500
3	Release	5	5	25	100	2,500
			28	140	560	14,000

- **Larvae trap results**
  - The number of over-wintering larva in each trap varied between sites (Appendix 1, Figure 11), with numbers in the release and control sites in each pairing being similar with the exception of pair #3 in season 2 where the release site had higher numbers than the control site. This difference however is explained by the higher pest pressure at this site. Pair #2 had the lowest number of larvae trap numbers across both seasons, in keeping with the lower observed pest pressure and improved control at this site.

- **SCM quality control**
  - Quality assessments were undertaken on three separate consignments of sterile moths. Receival dates for the consignments tested were 28 Sep 2022, 8 Dec 2022 and 12 Jan 2023. All assessments were conducted on randomly selected moths from one randomly selected cup (out of 32 per consignment). All quality control tests were conducted at 22-25°C, 16:8 (L:D) photoperiod, 60% RH. Tests conducted included: sex ratio, insect weight, mating ability, moth longevity. All results are reported in Appendix 1, Section 5.8.7.
  - As a result of the high mortality rate of the moths under refrigeration for an extended period, a mini-mortality experiment was undertaken in January 2024 to determine the length of refrigeration that the moths were able to sustain following approximately 60 hours transit time. Mortality rate (Appendix 1, Figure 23) of the moths that were immediately released rather than being placed under additional refrigeration was 5-6% r for the first five days and then increased rapidly with 44% mortality at eight days and 98% mortality at 12 days. Moths placed under refrigeration for one day showed a similar trend but with 2-3% increased mortality for the first few days after release. For moths refrigerated for two extra days, mortality increased from 17% to 33% over the first five days after release. Initial mortality one day after release for moths refrigerated for three and four days was 40 and 65%, respectively, while mortality of moths refrigerated for an additional 5 or more days was 89% or higher. This data suggests that the sooner the moths are released following receipt of the shipment the greater their chance of survival, and a maximum of one day of additional refrigeration following a 60 hour transit time would be acceptable.

Activity 9: Integration of SCM into area-wide integrated pest management systems:
Sterile insect technique has been confirmed as an effective control tactic against lepidopteran pests, including codling moth, when applied in an area-wide integrated pest management (AW-IPM) program (Vreysen 2009; Blomefield et al. 2011; Cartier 2015; Nelson et al. 2021). According to Horner et al. (2016), SIT is an ideal tool for IPM strategies, providing both economic and environmental benefits. SIT and mating disruption (MD) are considered to be complementary tools in AW-IPM programs and many entomologists believe that combining SIT and MD provides more effective control than either SIT or MD alone (Cartier 2015).

Due to the relatively short duration of this Australian pilot project it was not feasible to integrate SIT into an AW-IPM program for codling moth control. However, the inclusion of SIT along with chemical, cultural and biological techniques for over 20 years in the southern region of British Columbia in Canada (Nelson et al. 2021) demonstrates that SIT can be successfully included as part of a sustainable AW-IPM program for codling moth control.

Activity 10: Industry enhancement and awareness benefits program

Multiple activities were undertaken to raise awareness of the pilot project and of the benefits of SIT, ranging from media releases, industry articles, YouTube videos, project and FAQ web pages, radio interviews, and seminar presentations (Appendix 4).

Activity 11: Economic assessment of release programs.

- **Import costs:** Costs for purchase of sterile moths from Canada, freight, quarantine and customs charges (including requirement to use a Customs Broker) are provided in Appendix 1, Table 6. The total season cost was based on a 17 week season, but this may be longer in warmer regions of Australia. The number of moths imported each week was sufficient to treat 14 ha of orchard.
  The season costs to treat 1 ha of orchard with sterile codling moths imported from the OKSIR facility in Canada are detailed below in Table 4. Approximately 30% of the cost is for the moths, and the remaining 70% is accounted for by packaging and freighting costs, import GST charge, Australian quarantine and border force fees.

Table 4. Seasonal costs per hectare to import sterile moths from Canada.

	2022-2023 season	2023-2024 season
Sterile moths	1,797	1,987
Packaging & freight (from Canada)	3,653	3,800
Australian quarantine & border force costs	813	922
Import charges	229	258
Total cost to treat 1 ha (for 17 weeks)	**6,492**	**6,967**

- An economic analysis of a potential sterile codling moth (SCM) release program was completed by Nic Finger, Horticultural Consultant, Fruit Help Pty Ltd. The analysis aimed to establish an approximate per hectare cost, potential release strategies and potential effect of a longer term timeframe in terms of aggregate costs, benefits and opportunities. The full report is available in Appendix 3.

Activity 12: Development of project recommendations

Recommendations arising from this pilot project are based on the data collected during the project, the economic analysis undertaken, discussions with OKSIR and New Zealand scientists and other information sourced from the literature. Recommendations are detailed on page 14 of this report.

Outputs

Table 5. Output summary

Output	Intended Audience	Description	Detail - Evidence
Foundational workshop Stakeholder engagement & communication plan Monitoring & Evaluation plan	Project team;	A foundational workshop was conducted to develop project plans including key roles and responsibilities, stakeholder engagement plan, M&E plan and risk register for the project	Whole project team participation; Plans produced and updated and made available on shared drive and through email to project team. • Appendix 2: M&E plan • Appendix 2: Stakeholder engagement plan • Appendix 2: Risk register
SCM reference group	Project team;	An external advisor was enlisted to provide guidance on the project. Biannual meetings held.	Dr Greg Chandler (Hort Innovation – Head of Biosecurity R&D) enlisted Meeting minutes recorded.
Agreements with Canadian OKSIR for import of SCM	Project team;	Video conference with OKSIR In principal agreement with	Collaboration culminated in 1. successful import of SCM from OKSIR;

		OKSIR to provide SCM to Australia (March 2022).	2. information exchange prior to and during a visit to the OKSIR facility in 2024 to improve outcome of moth releases
Importation pathway	Project team;	An application was made for import of sterile codling moths. A secure SCM importation process was established with the assistance of DAFF. International and local freight logistics were achieved with approx. 60 hrs from shipment to release.	Permit for import of SCM from OKSIR (April 2022) issued in April 2022. International and local freight logistics were achieved with approx. 60 hrs from shipment to release. Successful trial and research shipments over 2 years.
Distribution map of CM in Australia	Project team; Biosecurity Australia	The maps distribution maps of CM produced to show potential range of CM using environmental predictors	Codling moth distribution maps informed potential release sites for SCM in Australia. This will be a useful tool for future area wide management strategy development.
Requirements for releasing SCM	Project team;	This was established with Australian biosecurity which included approved release rates and locations of release sites. A SCM release protocol was developed for the project.	SCM release protocol including methodology, release rates and locations.
Rearing Facilities for SCM in Australia	Not applicable	This output was not pursued or deemed necessary due to the importation of live moths in preference to larvae.	Not required
Trial Results on release program for SCM	Project team; Australian apple industry – growers, service providers, researchers; Funding bodies	The trial results are reported in full in this Final Report. A summary of trial results was presented and discussed at an industry webinar and will be further made available through the industry journal, project research web page & webinar recording	Milestone reports Final report completed Webinar (June 17th 2024)
Economic analysis	Project team; Australian apple industry – growers, service providers, researchers; Funding bodies	The economic analysis is reported in full in this Final Report. The economic analysis was presented and discussed at an industry webinar & will be available through the industry journal & project research web page & webinar recording	Economic analysis reported Final Report completed Webinar attendance June 17, 2024 • 15 online SA, NSW, Vic, NZ and Tas • 8 in person from Tasmania.
Recommendations for integrating SCM into existing apple & pear programs	Project team; Australian apple industry – growers, service providers, researchers; Funding bodies	The recommendations from the project are reported in full in this Final report. They will be presented through the industry journal & project research web page.	Final report completed
Training programs for agronomists & consultants	Service providers to the Australian apple industry	The training program was considered not applicable due to no commercially economic SCM being available for Australian apple industry. Agr webinar with industry was conducted for industry representative including agronomists	Webinar attendance June 17, 2024 15 online attendees from SA, NSW, Vic, NZ and Tas with 8 local attendees from Tasmania including 3 agronomists.

Communication & Extension Outputs	Australian apple industry – growers, service providers, researchers. General public	Communications & extension outputs included: • Media: radio, newspaper • Social media: YouTube, Facebook, X • Internet – TIA project page; APAL website • Internet – National, international news stories • Industry E-news • Industry Journal articles • Events – Agfest, Industry conference, Industry webinar	Reported in Appendix 4.

Outcomes

The project aligns with the Apple and Pear SIP 2022-2026 Outcome 2: Industry supply, productivity and sustainability

Strategy 1: Develop management strategies to optimise productivity and profitability in apple & pear orchards including crop protection and environmental factors

Table 6. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Knowledge of codling moth distribution in Australia	*Outcome 2, Strategy 1* KPI: Distribution map of codling moth in Australia	This fundamental knowledge is essential to the future development of area wide management strategies for SCM. The Apple Industry hold this as a resource to guide future investment in this technology.	Milestone Report 103 Final report
Collaboration between Canada OKSIR and Australia for the release of SCM	*Outcome 2, Strategy 1* KPI: Agreements in place with Canada OKSIR		Milestone report 104 Final report
Knowledge of the economic feasibility of SCM system for Australia	*Outcome 2, Strategy 1* KPI: Report reviewed and accepted by key stakeholders (HI, TIA, Expert panel)	The impact of the economic analysis will be realised as a guide for future investment in SCM technology and application by the Australian apple industry. It underpins the recommendations made to industry in this Final report.	Economic analysis report Expert panel amendments included
Apple growers and with greater understanding of SCM management systems	*Outcome 2, Strategy 1* KPI: 50% of Australian apple growers have increased awareness of SCM as an IPM tool for codling moth 25% of Australian apple growers have increased knowledge of SCM management systems necessary to implement SCM in orchards	This end of project outcome will be evaluated by October 2024. As final extension activities rely on key components such as the economic analysis and recommendations to be completed, it was considered premature to assess this criteria.	A planned survey of growers is detailed in Appendix 5– M&E interim report
Specialist service providers with greater understanding of the requirements for SCM production and release	*Outcome 2, Strategy 1* 50% of targeted service providers have increased knowledge of SCM production	This end of project outcome will be evaluated by October 2024. As final extension activities rely on key components such as the	A planned survey of service providers is detailed in Appendix 5 – M&E interim report

	and release requirements	economic analysis and recommendations to be completed, it was considered premature to assess this criteria.	

Monitoring and evaluation

A detailed interim M&E report is provided in Appendix 5.

Table 7. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Project Effectiveness To what extent were the proposed activities and outputs delivered?	Distribution map of codling moth in Australia produced. Formal collaboration with Canada's OKSIR program established. An importation pathway for sterile codling moths to Australia was achieved. The requirements for releasing sterile codling moths in Australia were established and verified in the importation permit. The economic feasibility of sterile codling moth systems for Australia was determined.	The economic analysis and feasibility study initially proposed could have been expanded to include the opportunity for producing sterile codling moths in Australia, looking at potential scenarios around setting up a facility in Australia and potential markets including NZ for Australian produced sterile codling moths. The cost benefit of such a scenario would assist the apple industry in its decision making.
To what extent were the immediate project outcomes achieved?	The feasibility of sterile codling moth management systems in Australia are reported.	
Project Appropriateness, Relevance & Impact	To be reported in October 2024	This criterion will be conducted in the coming months.
Project Efficiency Did the project deliver on time and on budget with an efficient use of resources? What efforts were made to improve efficiency?	The key project research activities were completed on time and on budget with efficient use of resources. Major efficiencies were required due to impact of COVID-19 on freight charges. The team adapted the research project and achieved comparable outcomes despite this.	Future improvement would be to allow sufficient time after completion of field assessment activities for reporting and extension to occur within the project timeframe.

Recommendations

This pilot study has been successful in demonstrating proof of concept for the use of SIT as a tool for control of codling moth in Australia using sterilised moths imported from Canada.

Commercialisation and adoption of SIT for use in commercial production systems will be predicated on growers being able to access moths at an economically affordable quantity and price, as well as the ability to effectively and efficiently disseminate moths across their commercial production areas.

Grower access to moths

The most immediate barrier to SIT adoption for codling moth control is the lack of production and access to sterilised codling moth to support commercial releases.

Trial shipments imported in this study have demonstrated that the freight costs of moth imports are unlikely to be economically viable due to the additional freight and customs costs, and shown that the international supply chain is vulnerable to seasonal disruptions.

Commercial uptake of SIT for codling moth control will require domestic production to be developed. This will require further work to understand the feasibility and challenges associated with developing endemic capability and capacity to produce sterile codling moth production, including:

- The requirements and costs to develop mass rearing capability
- Options to spread infrastructure and development costs across multi-species facilities
- What a viable funding model for this development may look like
- The minimum release area required to produce a viable volume of sterile moths

Options should also be explored to partner with New Zealand to reduce development costs and achieve shared commercial economies of scale.

Effective moth dissemination

This trial undertook manual releases to ensure moths were released in sufficient uniformity and density. Whilst effective, the efficiency of this approach is unlikely to be cost effective within a commercial setting. Further research should evaluate approaches and technologies to improve the efficiency of moth releases. Progress on this issue has already been made in both Canada and New Zealand, including the development of ground-based and aerial technologies to aid in moth release.

Refereed scientific publications

None to report

References

Blomefield, T; Carpenter, JE; Vreysen, MJB (2011) Quality of mass-reared codling moth (Lepdioptera: Tortricidae) after long distance transportation: 1. Logistics of shipping procedures and quality parameters as measured in the laboratory. *Journal of Economic Entomology,* **104**(3):814-822. doi: 10.1603/EC10238

Cartier, L (2015) Economic benefits of using sterile insect technique and mating disruption to control codling moth. Journal of Agricultural Science, 7(9): 14-25. doi:10.5539/jas.v7n9p14

Department of Agriculture, Fisheries and Forestry (DAFF) (2023) Sterile Insect Technique use in Australia. Downloaded from https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/fruit-flies-australia/management/sterile-insect-technique

DuPont, T (2020) WA sterile insect release project – year two update. Washington State Tree Fruit Extension. Downloaded from https://treefruit.wsu.edu/article/wa-sir-project-y2-update/ on 17/05/2024.

Esch, ED; Horner, RM; Krompetz, DC; Moses-Gonzales, N; Tesche, M; Suckling, DM (2021) Operational parameters for the aerial release of sterile codling moths using an uncrewed aircraft system. *Insects*, **12**, 159. https://doi.org/10.3390/insects12020159

FAO/IAEA (2010) Rearing Codling Moth for the Sterile Insect Technique. https://www.iaea.org/sites/default/files/21/06/nafa-ipc-manual-ipc-codling-moth-sterile-insect-technique-2010.pdf

Horner, RM; Lo. PL; Rogers, DJ; Walker, JTS; Suckling, DM (2020) Combined effects of mating disruption, insecticides and the sterile insect technique on *Cydia Pomonella* in New Zealand. *Insects*, **11**: 837. doi: 10.3390/insects11120837

Horner, RM; Walker, JTS; Rogers, DJ; Lo, PL; Suckling, DM (2016) Use of the sterile insect technique in New Zealand: benefits and constraints. *New Zealand Plant Protection*, **69**: 296-304.

Hort Innovation (2023) Australian Horticulture Statistics Handbook for Fruit 2022/23. Downloaded from https://www.horticulture.com.au/contentassets/a36fdfa2427d4ad284c426663b06f15c/hort-stats-fruit-22-23.pdf

Milkovitch, M; Courtney, R (2021) Releasing research on sterile insect release. Good Fruit Grower, March 1st 2021 Issue

Nelson, C; Esch, E; Kimmie, S; Tesche, M; Philip, H; Arthur, S (2021) Putting the sterile insect technique into the modern integrated pest management toolbox to control the codling moth in Canada. Area-Wide Integrated Pest Management: Development and Field Application, pp. 111–127. J. Hendrichs, R. Pereira and M. J. B. Vreysen (eds.), CRC Press, Boca Raton, Florida, USA. doi: 10.1201/9781003169239-7

NSW Department of Primary Industries (NSW DPI) (2022) Innovative Sterile Insect Technique (SIT) for sheep blowfly. Downloaded from https://www.dpi.nsw.gov.au/dpi/about-us/research-and-development/projects/biosecurity/sit on 16/05/2024.

OKSIR (2024) Sterile insect release process. Downloaded from https://www.oksir.org/the-program/sterile-moth-release-process/ on 12/05/2024.

Phillips, SJ; Anderson, RP; Schapire, RE (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, **190**(3–4): 231–259. doi: 10.1016/j.ecolmodel.2005.03.026

Phillips, SJ; Dudik, M (2008) Modelling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, **31**: 161-175. doi: 10.1111/j.2007.0906-7590.05203.x

Vreysen, MJB; Carpenter, JE; Marec, F (2009) Improvement of the sterile insect technique for codling moth *Cydia Pomonella* (Linnaeus) (Lepidoptera Tortricidae) to facilitate expansion of field application. *Journal of Applied Entomology*, **134**: 165-181. doi: 10.1111/j.1439-0418.2009.01430.x

WA Department of Primary Industries and Regional Development (DPIRD) (2018) Sterile insect technique for fruit fly control. Downloaded from https://www.agric.wa.gov.au/medfly/sterile-insect-technique-fruit-fly-control?page=0%2C1 on 16/05/2024.

Walker, J (2022) Development of a pilot codling moth SIT program in New Zealand. Downloaded 17/05/2024 from https://www.youtube.com/watch?v=dJ9RHsqt9hc

Intellectual property

No project IP or commercialisation to report.

Acknowledgements

Special thanks are due to our grower partners in this project for their willingness to be part of our pilot study and allowing us full access to their orchards over two seasons:

Scott Price and Andrew Smith from R&R Smith
Aaron and Nathan Bowden, Bowden Bros Organics
Mark Duggan, Duggan Brand

Appendices

Appendix 1: AP18001_full project report
Appendix 2: M&E_Stakeholder engagement_Risk management
Appendix 3: Report_Economic assessment of release program
Appendix 4: SCM communication & Extension outputs_June 2024
Appendix 5: SCM Interim M&E Report_June 2024
Appendix 6: AusTreeCrop_Bound 2023.pdf

AP18001

Pilot Sterile Codling Moth Releases for the Apple Industry

Final Report

Sally Bound (TIA)
Guy Westmore (NRE)
Michele Buntain (TIA)

June 2024

Contents

Project Summary

As a biological control method, Sterile Insect Technology (SIT) has numerous benefits over traditional pesticide control methods for management of codling moth (*Cydia pomonella*). SIT is an ideal tool for integrated pest management (IPM) programs as it is compatible with other biological IPM management methods including mating disruption, granulosis virus, and releases of beneficial insects including *Trichogramma* and *Mastrus* species, and is an ideal tool for organic or low-input orchards. Additional benefits to the use of SIT in codling moth control programs:

- it is environmentally safe
- species specific hence there is no effect on non-target organisms, i.e. protection of beneficial insects
- product quality and productivity are improved
- provides for residue-free pest management
- avoids problem of pesticide resistance
- no/reduced spray drift to nearby properties.

This pilot program has successfully investigated safe and secure biosecurity pathways for entry of sterile codling moth into Australia; developed and tested the logistics of transport and release, and examined the costs and feasibility of success, as well as identifying key components of future success.

The project has demonstrated proof of concept for the use of SIT as a tool for control of codling moth in Tasmania. Data collected over the first two release seasons in Tasmania's Huon Valley found that SIT was effective at reducing levels of codling moth damage at two of the three sites tests, with efficacy at the third site likely constrained by the very high abundance of wild moths.

An analysis of the costs and economic benefits of SIT use was undertaken as part of this project to compare the costs and economic benefits achievable between SIT, mating disruption, and agrichemical use, to inform grower and industry uptake of the technology. Findings from this analysis indicate that gross orchard gate income per hectare is expected to be higher under SIT relative to mating disruption (+$277) or pesticide use only (+$2295).

These figures indicate SIT represents an approach that is economically beneficial for at least some growers if moths can be sourced and released locally, but that this quickly becomes unaffordable due to the increased freight costs and import charges if moths must be imported from Canada.

Conclusions

While it is technically feasible to import SCM from Canada, practical testing of this supply chain showed that it is highly constrained and vulnerable to disruption. Causes of disruption included seasonal weather events, seasonal shutdowns, as well as delays and other hold-ups at national/state biosecurity barriers. The effect of these disruptions was to prevent the dispatch and/or arrival of shipments for releases during periods of key moth activity in Australia, and to extend the transport chain to 60+ hours which limit the longevity of imported moths. This vulnerability to disruption is likely compromises the reliability and overall efficacy of SIT release programs which rely on access to imported codling moths. On this basis, it would seem reasonable to expect that the levels of codling moth control achieved and economic returns to growers would be similar or improved if the sterile moths could be sourced from within Australia.

The economic analysis was limited in that it did not consider the level of codling moth damage to be a variable for consideration, and instead used the values provided by Gill (2014) from British Columbia, Canada as the basis for estimating the reduced damage to be between 0.37% - 3.06% (i.e. the difference between SIT and the other control options). These estimates assume a high degree of codling moth control within the orchard (3.1%), and therefore a constrained capacity for SIT to further reduce crop losses below this point. Fruit damage levels in many Australian growing regions are considerably higher than the 3.1% noted for Canada, often ranging from 5 – 25%, and sites with higher incidences of codling moth damage are likely to receive higher financial benefits from reducing that damage through the adoption of SIT.

The limited mobility of codling moth means that effective management using SIT is achievable even in smaller production areas, making it feasible for use at an individual business level. Hence, whilst area-wide management would offer increasing economies of scale (where it might be able to be implemented), this is a “nice to have”, not a “need to have”. For an area-wide codling moth SIT program to be successful, lasting agreement and support between the pome fruit industry, regional councils, relevant State government departments and the wider public will be essential, which may not be achievable in all areas.

Recommendations – where to from here?

This pilot study has been successful in demonstrating proof of concept for the use of SIT as a tool for control of codling moth in Australia using sterilised moths imported from Canada.

Commercialisation and adoption of SIT for use in commercial production systems will be predicated on growers being able to access moths at an economically affordable quantity and price, as well as the ability to effectively and efficiently disseminate moths across their commercial production areas.

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The most immediate barrier to SIT adoption for codling moth control is the lack of production and access to sterilised codling moth to support commercial releases.

Trial shipments imported in this study have demonstrated that the freight costs of moth imports are unlikely to be economically viable due to the additional freight and customs costs, and shown that the international supply chain is vulnerable to seasonal disruptions.

Commercial uptake of SIT for codling moth control will require domestic production to be developed. This will require further work to understand the feasibility and challenges associated with developing endemic capability and capacity to produce sterile codling moth production, including

- The requirements and costs to develop mass rearing capability
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- What a viable funding model for this development may look like
- The minimum release area required to produce a viable volume of sterile moths

Options should also be explored to partner with New Zealand to reduce development costs and achieve shared commercial economies of scale.

Effective moth dissemination

This trial undertook manual releases to ensure moths were released in sufficient uniformity and density. Whilst effective, the efficiency of this approach is unlikely to be cost effective within a commercial setting. Further research should evaluate approaches and technologies to improve the efficiency of moth releases. Progress on this issue has already been made in both Canada and New Zealand, including the development of ground-based and aerial technologies to aid in moth release.

1. Background

Codling moth (*Cydia pomonella*) is a key pest in most pome-fruit production regions worldwide, including Australia where it is considered one of the most economically damaging pests in many production regions. If unchecked, codling moth can damage 50% to 90% of fruit, resulting in decimation of the industry. Other industries affected by codling moth in Australia include cherry, summer fruit, nashi and walnut. Current management strategies include chemical control, phenology modelling, regular monitoring, mating disruption and biological control, but chemicals used as part of codling moth control programs disrupt beneficial insects, substantially affecting integrated pest management (IPM) systems. Codling moth has also developed some resistance to insecticides presently used, making it more difficult to control. Pheromone trapping, feeding attractants and mating disruption have a greater effect in large commercial blocks of trees. However, orchards are reinfested easily from neglected orchards, roadside and unmanaged backyard apple, pear, and stone fruit trees where no coding moth control is undertaken.

Australia's apple and pear production is valued at $647 million-dollars (Hort Innovation 2023). Nationwide, if 1% fruit losses occur due to codling moth in the Australian apple and pear industry based on 2022/23 estimates, this equals a loss of $6.5 million dollars in production. In addition to the value of crop loss, the cost of control measures (chemical sprays, monitoring and pheromone traps, biological control and mating disruption practices), discarding damaged fruit during harvesting and adhering to regulatory requirements for export need to be added. Conservative estimates place these additional costs at approximately $0.02 per kilogram based on data from Apple & Pear Australia Limited (APAL), the Australian Pip Industry "Orchard Business Analysis" and Model Future Orchard 2012 walk. Development of new technologies that can be integrated into existing IPM strategies will be of considerable benefit to Australian apple and pear growers, improving returns by an estimated $136 million.

Furthermore, export markets of China, Thailand and Taiwan require pest monitoring activities be carried out by registered crop monitoring services and future Australian apple market development may be based on how well Australia can control codling moth. Codling moth will substantially affect exporting apple and pear orchardists as well as stone fruit, cherries, nashi and walnuts.

Sterile insect technique

Sterile insect technique (SIT) is a relatively new strategy that is becoming more widely used for mobile pests. It is a recognised phytosanitary procedure for pest suppression and management under the International Standards for Phytosanitary Measures – IPSM03 (DAFF 2023).

Initiated in the 1930s, SIT was first used successfully to control the devastating cattle pest screwworm fly in 1953 on the island of Curacao (DPIRD 2018). The technique has since been developed to provide effective control of more than 20 insects. SIT programs work by flooding the wild population with large numbers of sterile males to substantially reduce the number of fertile eggs produced. When this is repeated over several seasons, the population crashes and infestations drop below damage threshold levels.

SIT is species-specific and environmentally friendly. Benefits of SIT include:

- reduced pest damage and costs
- reduced chemical pest controls
- improved productivity
- improved product quality
- improved environmental outcomes.

SIT is now recognised as an effective and desirable option for the management and/or eradication of fruit flies and has been proven effective in overseas programs in Chile, Guatemala, Mexico, USA, and Japan (DAFF 2023). The technology has been used in Australia for the control of Mediterranean fruit fly (*Ceratitis capitata* 'Medfly') and Queensland fruit fly (*Bactrocera tryoni* 'Qfly') in NSW, VIC, SA, and WA. It has been used successfully for suppression activities in areas of low wild fruit fly populations, and during outbreaks within established Pest Free Areas (PFAs).

More recently SIT has also been successfully trialled in Australia as part of an integrated pest management approach to prevent flystrike at a property level by sheep blowflies (*Lucilia cuprina*) (DPIRD 2022).

Sterile insect technique for codling moth

Canada has been successfully applying SIT for codling moth control within an area-wide approach in southern British Columbia for over 20 years (Nelson et al. 2021). Relative to pre-program levels, codling moth populations have been reduced by 94% and fruit damage to less than 0.2% in more than 90% of orchards in the release area. Nelson et al. (2021) have also reported a 96% reduction in pesticide use against codling moth in British Columbia. Walker (2022) reported a 90-95% reduction in moth densities following six years of an area-wide release pilot study in New Zealand. Trials in Michigan, USA found that sterile males mating with wild females can reduce egg hatch by more than 90 percent.

Introduction of a pilot SIT codling moth program to Australia will provide an opportunity for the apple and pear industry to attain substantial improvements in IPM practices, thus reducing reliance on chemical control methods and enabling a practical safe and socially acceptable method for management of codling moth infestations in neglected orchards and unmanaged roadside and backyard trees. This will provide a substantial benefit to all horticultural crops impacted by codling moth.

2. Project aims

The goals of this pilot project were to (1) review the current-status of codling moth in Australian apple and pear growing regions; (2) examine the application of SIT as a tool for control of codling moth in Australian apple orchards; (3) establish release sites to determine the efficacy of sterile codling moths (SCM) in control of wild populations; and (4) determine the feasibility of integrating SIT into existing apple and pear management and production programs in Australia. To achieve these goals, the project sought to:

- Investigate safe and secure biosecurity pathways for entry of sterile codling moth into Australia from Canada's Okanagan-Kootenay Sterile Insect Release (OKSIR) Program in British Columbia;
- Identify suitable test regions representative of Australian domestic and export apple production zones for the safe release and testing of sterile codling moth;
- Cooperate and work with industry grower participants and community stakeholders to determine the effectiveness of sterile codling moth within existing area-wide IPM programs;
- Conduct an economic assessment of the release program and an analysis of SIT for control of codling moth for the apple and pear industry;
- Make recommendations for the adoption and integration of sterile codling moth into IPM programs based on findings and the effectiveness of control of codling moth using SIT;
- Provide a highly accessible contact point for community and industry enquiries about this pilot program ensuring community and stakeholder engagement on its scientific progress and findings.

3. Project Team

This was a collaborative project with team members from multiple organisations:

Personnel	Organisation
Dr Sally Bound, Michele Buntain	Tasmanian Institute of Agriculture (TIA)
Dr Guy Westmore	Natural Resources and Environment (NRE)
Dr Peter Crisp	SA Research & Development Institute (SARDI)
Dr Michael Tarbath	Fruit Growers Tasmania (FGT)
Ian Cover	Cover-All Consulting (initially with FGT)
Paul James	Lenswood Co-op, SA
Dr Craig Hull	Department of Agriculture, Fisheries and Forestry (DAFF)

4. Project logic phases

The project was divided into two phases, with progression to Phase 2 based on the success of Phase 1.

Year 1: Phase 1 comprised the foundational activities, including development of program logic, importation facilitation and establishment of entry pathway protocols, and mapping of codling moth distribution within Australia.

- *Activity 1*: Develop Project Logic
- *Activity 2*: Review and map codling moth distribution in Australian apple production regions
- *Activity 3*: Establish importation requirements from the Canadian OKSIR facility
- *Activity 4*: Determine suitable regions for release
- *Activity 5*: Develop entry pathway process into Australia
- *Activity 6*: Independent review to inform STOP/GO decision.

Years 2-3. Phase 2 aimed to introduce and test area wide IPM systems for SCM based on pilot releases in regional areas, undertake an economic assessment of release programs, put in place a point of contact for SCM enquiries, and develop recommendations on the viability of SIT as a tool for codling moth control in Australia.

- *Activity 7: Expand DPIPWE (NRE) rear-out facility*
- *Activity 8: Pilot release of sterile codling moth and evaluation of impact*
- *Activity 9: Integration of sterile codling moth into area-wide IPM systems*
- *Activity 10: Industry enhancement and awareness benefits program*
- *Activity 11: Economic assessment of release programs*
- *Activity 12: Development of recommendations.*

5. Methodology and Results

5.1. Activity 1: Project logic, M&E, communication, stakeholder & risk management plans

A one day workshop was held in Hobart on 12th November 2019. Workshop participants were: Michele Buntain (facilitator, TIA), Sally Bound (project leader, TIA), Guy Westmore (NRE), Peter Crisp (SARDI), Paul James (Lenswood Coop), Ian Cover (FGT), Michael Tarbath (FGT), Steve Paterson (TIA).

The workshop provided a valuable opportunity for team members to meet face-to-face. Activities undertaken during the workshop included development of the program logic, discussion of stakeholders, next users, targets and KPI's, key evaluation questions, and potential risks to the project.

A further meeting was held on 26th November to develop the Stakeholders communication plan. Participants at this meeting were Michele Buntain and Sally Bound (TIA) and Ian Cover and Michael Tarbath (FGT).

5.2. Activity 2: Map codling moth distribution.

The project entomologist, Dr Guy Westmore has produced a codling moth distribution map based on 578 codling moth records (Figure 1). The source of the 578 records is broken down as follows:

- Australian Plant Pest Database: 125
- Global Biodiversity Information Facility: 131
- Tasmanian Plant Pest Database: 258
- Industry reports/published papers/other reliable records: 54

Projected distribution maps were also produced using Maxent (Maximum entropy model), a species distribution modelling tool for predicting the distribution of a species from a set of records and environmental predictors. The maximum entropy model was found to be the best in both predictive performance and model stability when compared with other similar niche models (Phillips et al. 2006, Phillips and Dudik 2008).

Prior to running the Maxent analysis, 422 records were removed (leaving 156) so that there was only one record used from each locality. The Maxent maps and model outputs can be found in Appendix 1.

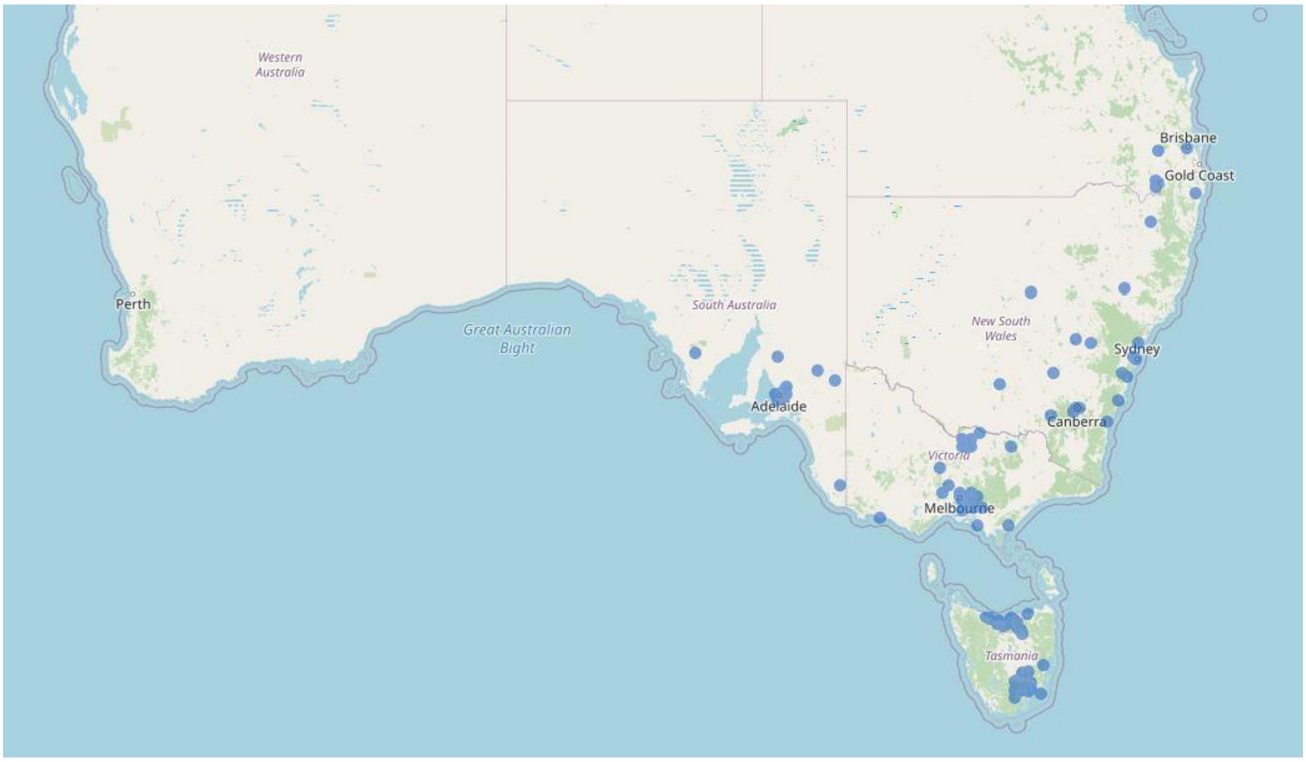


Figure 1: Distribution of codling moth (*Cydia pomonella*) in Australia, based on 578 records.

5.3. Activity 3: Establish importation requirements from Canadian OKSIR program

To enable the approval of an import permit from the Canadian OKSIR facility, registration of the facility under DAFF's *Offshore Irradiation Treatment Providers Scheme* was required. To obtain registration under this scheme the normal practice is for a DAFF officer to visit the facility to undertake an audit. However, as this was not feasible under the COVID-19 travel restrictions, DAFF provided an alternative approach for permit approval, with the regulatory approval process for OKSIR relying on a signed manufacturer's declaration from the facility (desktop audit).

5.4. Activity 4: Determine suitable regions for release

The project initially allowed for two release areas of SCM, with the main sites in Tasmania and secondary sites in the Adelaide Hills of South Australia. The criteria used for site selection included presence of codling moth in the orchard, but not in overwhelming numbers, in addition to grower and close neighbours not exporting to avoid problems with market protocols.

Release sites were selected for both Tasmania and South Australia in year 1 of the project. However, following the substantial increases in the cost of SCM production and airfreight charges as noted in Section 6 Project disruptions, the South Australian sites were omitted, and the Tasmanian sites increased from the original two sites to three sites. All three release sites were located in the Huon Valley within a 10 km radius of Huonville and were matched with paired control sites. Site locations are provided in Figure 2. The release and control sites for pairs 1 and 2 were on the same orchard, however for pair 3 the release and control sites were on different orchards with different management practices.

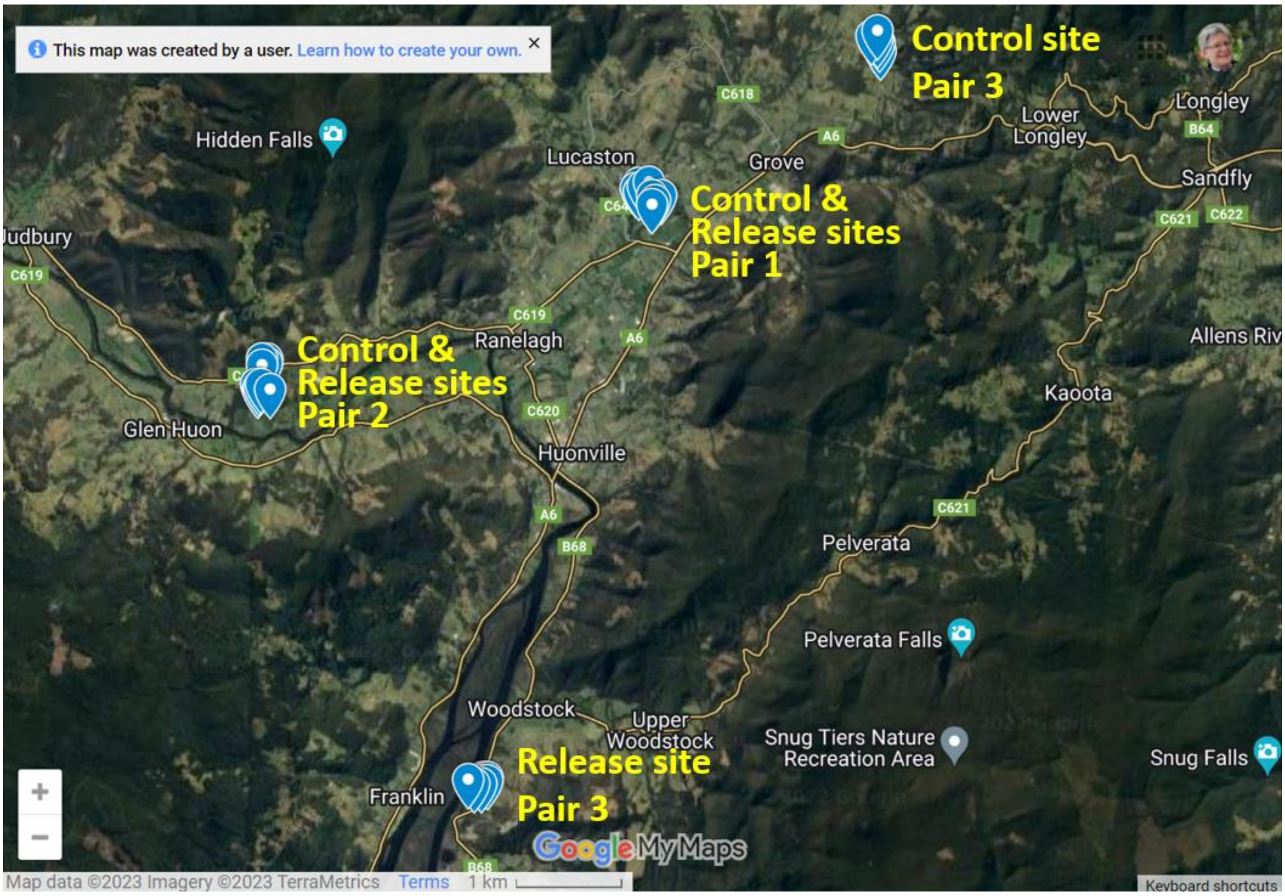


Figure 2: Sterile codling moth release and control sites in Tasmania.

5.5. Activity 5: Develop entry pathway process into Australia

5.5.1. Submission of application for Import Permit

An application for an Import Permit to import sterile codling moth from the Canadian OKSIR facility was submitted to the Department of Agriculture, Fisheries and Forestry (DAFF) on 19 December 2019. The application (import permit application no. 0003917272) was assessed in accordance with sections 178 and 179 of the Biosecurity Act 2015. Additional information was requested on two occasions and this was provided promptly. Due to restrictions resulting from the COVID-19 pandemic outlined under Section 6 Project disruptions above, approval of the import permit was significantly delayed, taking 27 months from application to approval.

5.5.2. Finalised SCM secure importation process (DAFF)

The permit to import sterile codling moths was received on 7 April 2022 (see Appendix 4). This permit was valid for multiple consignments between 7 April 2022 and 7 April 2024.

The conditions of the permit allowed for the importation of *Cydia pomonella* (Codling moth) which have been sterilised by gamma irradiation treatment at the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility, located in Canada. Imported material could only be used for direct release into the environment for biological control use and was limited to only apple orchard field sites in South Australia and Tasmania, as part of the sterile insect release research program.

It should be noted that this is the first approval for a direct field release (i.e. without going through quarantine) of any organism in Australia and represents a significant achievement for the project team.

5.5.3. Import logistics

Prior to the scheduled field releases, a trial shipment of SCM was organised with OKSIR in late

September 2022 to ensure that freight logistics and biosecurity control at both national and state borders were sorted prior to the field releases. The supply pathway involved road transport, three commercial flights followed by customs and quarantine clearance and finally road transport to the release sites.

Only two viable supply pathways were available each week, departing Canada either Mondays or Wednesdays, and arriving into Hobart airport after approximately 40 hours. Regional airline embargos of live animals due to competing space over the Canadian winter period forced a change of airports and airlines twice.

During the release season, sterile moths were shipped from the OKSIR facility on Mondays, arriving in Hobart mid-afternoon on Wednesdays. Sterile moths were packed at the OKSIR facility commencing at 6am on the day of shipment before being transported to Penticton Regional Airport (YYF), a one hour drive from the OKSIR facility.

The supply chain involved two legs of road transport plus three flights (Figure 3):

1. OKSIR facility to Penticton (road transport)
2. Penticton to Vancouver (flight 1)
3. Vancouver to Sydney (flight 2)
4. Sydney to Hobart (flight 3)
5. Hobart to Huon Valley release sites (road transport)

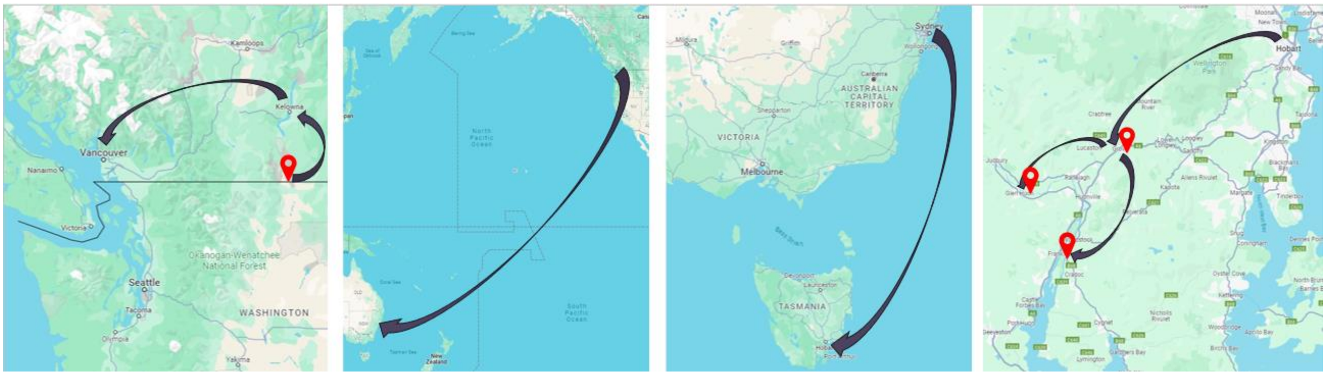


Figure 3: Transit details, from left OKSIR facility to Vancouver, Vancouver to Sydney, Sydney to Hobart, Hobart to Huon Valley release sites.

Ideally a transit time of less than 36 hours is desirable, with quality of the moths dropping off after 72 hours. Transit time from packing to arrival at Hobart airport was approximately 41 hours. This is already longer than the ideal transit time of less than 36 hours.

Moths were placed straight into refrigeration by Qantas Freight on arrival into Hobart until quarantine inspection. Following quarantine approval and clearance, moths were transported directly to the field release sites. Table 1 shows the total transit time from packing to site release, a total of 61 hours which is well in excess of the ideal transit time of less than 36 hours.

Table 1: Total transit time from packing of moths to site releases

Activity	Hours
Time from packing to arrival at Hobart Airport	41
Cool storage until quarantine inspection & shipment clearance	18
Pickup and transport to release sites	2
	61

5.6. Activity 6: Independent review to inform STOP/GO decision

The project reference group discussed the Stop/Go criterion scheduled for Milestone 104 (MS104) at its meeting on 21st April 2022. It was agreed that this criterion was too early in the project timeline, being only eight months from the commencement of the project (COVID hold adjusted) and that it would be more appropriate to move this criterion to the mid point of the project (MS105), by which time the import process would have been trialled and the first releases of moths in the designated release sites undertaken.

Movement of this criterion from MS104 to MS105 was approved. Following successful importation of moths and field releases, the STOP/GO milestone was approved on 6th January 2023.

5.7. Activity 7: Expand DPIPWE rear-out capacity

This criterion was included as it was initially expected that moths would be imported as larvae and suitable facilities would be required to rear to adult stage. This activity was discontinued when it was identified that the moths provided by OKSIR would be mature adults, and the funds that were originally allocated for this purpose were used to cover the additional costs of moths and freight as noted below in Section 6. Project Disruptions.

5.8. Activity 8: Pilot release of sterile codling moth and evaluation of impact

5.8.1. Moth release densities and methodology

A release rate of 3,000 male moths per hectare was determined following discussions between Dr Guy Westmore, the project biosecurity entomologist, and OKSIR technical staff. As shipments included a mix of both male and female moths with a ratio of approximately 50:50, the total release rate was determined at 6,000 moths per hectare.

5.8.2. Insect rearing and shipment

Rearing

Moths were mass reared at the OKSIR facility in Osoyoos, British Columbia (OKSIR 2024). The rearing process involved laying of eggs on wax paper lining special moth cages. Following egg laying, the waxed paper was then placed on a prepared diet containing a red dye that resulted in a permanent internal pink marker to enable differentiation of sterilised moths from wild moths following release (Figure 4). Larvae were developed in rearing rooms with strictly controlled light, temperature and humidity (OKSIR 2024).

Figure 4: Sterilised moth with abdominal scales removed to show pink body resulting from the specialised diet.

The larvae were moved to a room designed to collect adult moths after 21 days of development. After emerging from their cocoons, the adult moths made their way to black lights in the room and were pulled through a vacuum collection system to the collection room which was kept at a low temperature to force the moths to become dormant. Moths were then irradiated with gamma radiation, receiving 150 Gy from a cobalt60 source (Gammacell 220, Nordion, Kanata, ON, Canada; dose rate of 6.4 - 6.5 kGy/h).

Packaging

Irradiated moths were packed into sealable dixie style cups (Figure 5) holding approximately 3,000 moths per cup. Sealed cups were placed into foam boxes containing ice packs to ensure temperature remained between 0-2°C during shipment.

(a)  (b) 

Figure 5: Packaging of moths for transport (a) cups containing approximately 3,000 dormant moths; (b) boxed foam crates ready for shipment.

5.8.3. SCM releases and monitoring of wild/sterile populations

Imported sterile codling moths were released over two growing seasons (2022/2023 and 2023/2024) at three treatment sites (see Figure 2) in the Huon Valley in southern Tasmania on a weekly basis from late October through to mid February. None of the treatment blocks were registered for export, nor were the treatment blocks adjacent to export blocks.

Total release area was 15.5 ha spread over the three sites; this was reduced to 13.9 ha in season 2 with the removal of planted area from a section of the release site in pair #3. Total control area was 10.7 ha. Details of site area and number of pheromone traps for monitoring are provided in Table 2.

Table 2: Area of release and control sites and number of monitoring traps.

Pair #	Site area (ha)		Number of traps	
	Release	Control	Release	Control
1	4.6	4.1	5	4
2	3.9	4.6	4	5
3	7.0/5.4*	5.0	7/5*	5
	15.5/13.9*	10.7	16/14*	14

* site area reduced in season 2

On arrival at each release site, the required number of cups were removed from the insulated packaging and decanted into insulated flasks. The moths were released manually via an orchard walkthrough, starting at the second row in each block and then every third row. Moths were poured into 10 ml measuring cups to ensure a consistent release density before being distributed along each row at the rate of 10 ml for every 20 trees (Figure 6).

Figure 6: Left to right: decanting cup of moths into insulated flask; pouring moths from flask into measuring cup: distributing moths along the tree row**.**

Dates for the field releases over the two seasons are provided in Table 3. Although a total of 17 releases were scheduled, two releases were missed each season as a result of severe weather in Canada causing a missed flight connection or closure of the OKSIR facility during public holidays (see Table 3 for details).

Table 3: Details of sterile codling moth releases at treatment sites across the two release seasons.

Week	SCM releases 2023/24	Comments	SCM releases 2023/24	Comments
1	26 Oct 2022	Monitoring traps installed 25 October 2022	25 Oct 2023	Monitoring traps installed 23 Oct 2023
2	03 Nov 2022		02 Nov 2023	
3	10 Nov 2022		09 Nov 2023	Double shipment due to Canadian public Holiday Mon 13 Nov; half of shipment released, other half kept in coolroom for release on 16 Nov
4	17 Nov 2022		16 Nov 2023 – no release	14 Nov quality testing of cool stored moths showed 50% mortality of batch Decision made not to release on 16 Nov
5	24 Nov 2022		23 Nov 2023	
6	01 Dec 2022		30 Nov 2023	
7	08 Dec 2022		07 Dec 2023	
8	15 Dec 2022		14 Dec 2023	
9	22 Dec 2022 - No shipment	Shipment cancelled due to severe winter weather in Canada resulting in missed connecting flight	21 Dec 2023	Double shipment – all moths released
10	29 Dec 2022 - No shipment	OKSIR facility closed over Christmas break	28 Dec 2022 - No shipment	OKSIR facility closed over Christmas break
11	7 Jan 2022	Late shipment due to New Year closure of OKSIR facility	08 Jan 2024	Late shipment due to New Year closure of OKSIR facility
12	12 Jan 2022		11 Jan 2024	1 cup retained for storage mortality experiment
13	19 Jan 2023		18 Jan 2024	
14	26 Jan 2023		25 Jan 2024	
15	02 Feb 2023		01 Feb 20243	
16	09 Feb 2023		08 Feb 2024	
17	16 Feb 2023	Final release for the 2022-23 season	15 Feb 2023	Final release for the 2023-24 season
18	-		-	
19	-		-	
20	-	Final trap check for the 2022-23 season	-	Final trap check for the 2023-24 season

Sticky traps with codling moth pheromone lures were installed at all release and control sites to monitor both sterile and wild population numbers (Figure 7). Trapping density at each site was based on the standard export protocol of one trap per hectare. All traps were checked weekly the day prior to releases of the sterile moths, with the sticky bases removed and replaced at each check. During trap inspections, each of the codling moths adhering to each base were examined to determine whether they were wild or sterile, with the total number of wild and sterile moths recorded separately for each trap. Trap checks were continued for three weeks beyond the final SCM release.

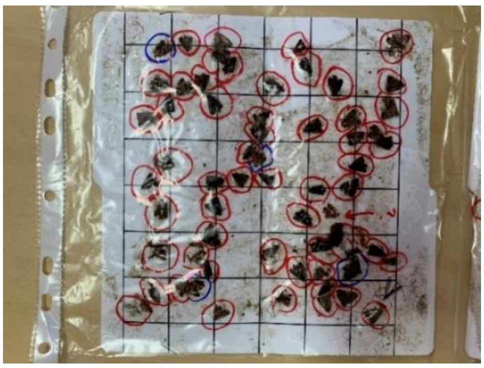
(a).  (b) 

Figure 7. (a) Codling moth pheromone trap in the orchard; (b) Sticky base after collection – sterile moths are circled in red, wild moths in blue

5.8.4. Trap monitoring results

Figure 9 shows the weekly capture rates of sterile and wild moths at all the release and control sites over the two seasons.

The ratio of sterile:wild moths in trap catches varied greatly between weeks. In Season 1 (2022/23), low numbers of sterile moths were recaptured between October and December with a ratio at all three sites remaining below 5:1 in most weeks (Figure 8a,c,e). The number of sterile moths captured in traps increased rapidly from mid-January, at the same time as the catch of wild moths began to decrease, with the sterile:wild ratio on traps lifting consistently above 10:1 and over 150:1 in some weeks.

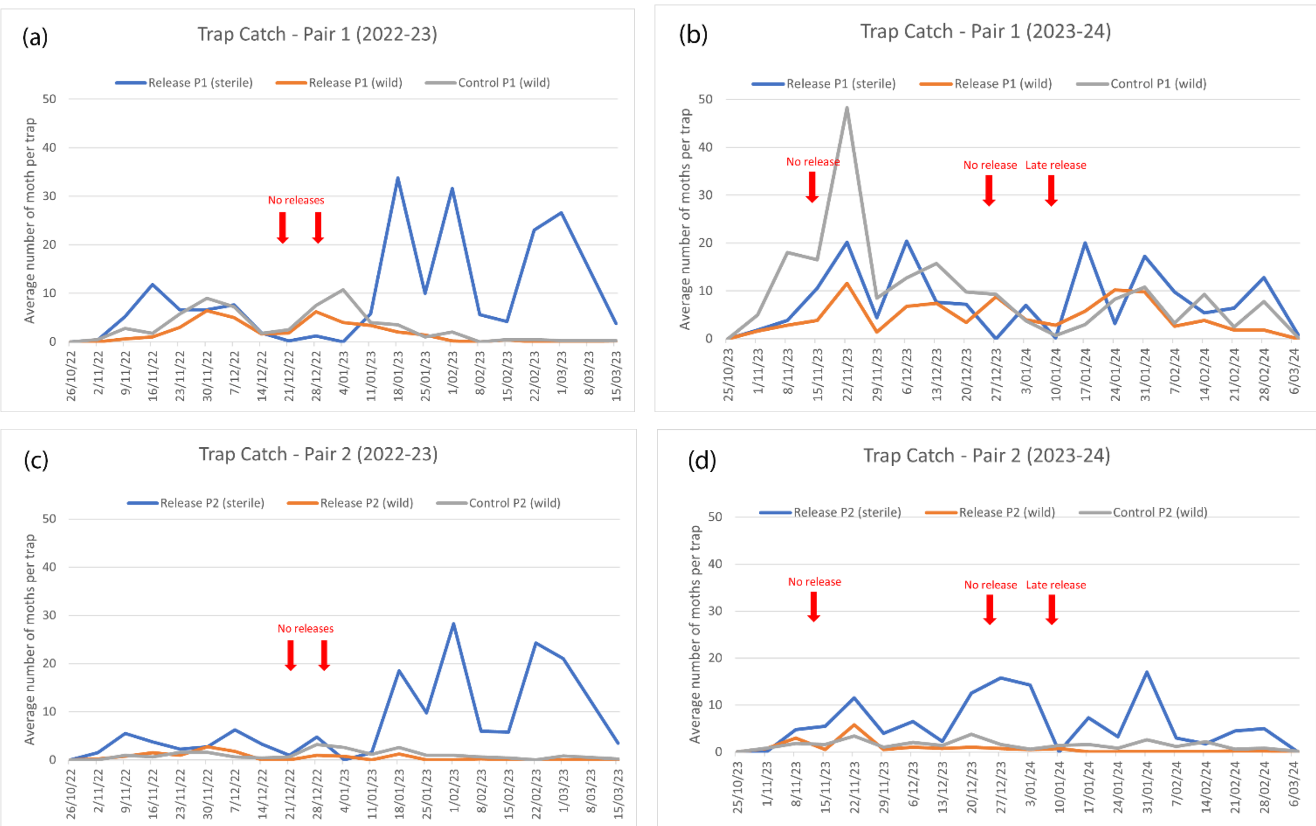
In the second season (Figure 8b,d,f), the ratio of sterile:wild moths in weekly trap catches again varied between sites. Sterile moth captures in the pair #1 release site remained relatively consistent until mid-December with a ratio of less than 2:1. Although wild moth numbers peaked in the pair #1 control site in mid-late November, the number of wild moths in the matched pair release site were reduced by a factor of four, indicating that the sterile moths were successfully mating with the wild population early in the season.

Sterile moth captures at the pair #2 release site were consistently higher than wild moth captures each week, with the number of sterile moths captured in traps increased from mid-December, at the same time as the catch of wild moths began to decrease, with the sterile:wild ratio on traps lifting to 28:1 at the latest trap check.

The ratio of sterile:wild moth captures at the pair #3 release site was below 1 on eight trap monitoring dates.

In both seasons, missed releases affected the sterile moth population, with the number of sterile moth captures decreasing several days after the missed release.

Weather conditions also impacted on activity and survivability of the released sterile moths (Figure 9). The low sterile:wild moth ratio on traps observed during season 1 in the critical period of Nov-Dec coincided with a two-month period of cold, wet weather, which may have reduced the survival and suppressed the activity of the released moths. During periods of regular moth releases, sterile catches varied directly with the average maximum temperature and inversely with the total rainfall in the week preceding each trap catch (Figure 9). The only period in which this relationship did not hold was in the first two weeks of January, reflecting the absence of sterile moth releases on 22 and 29 December.



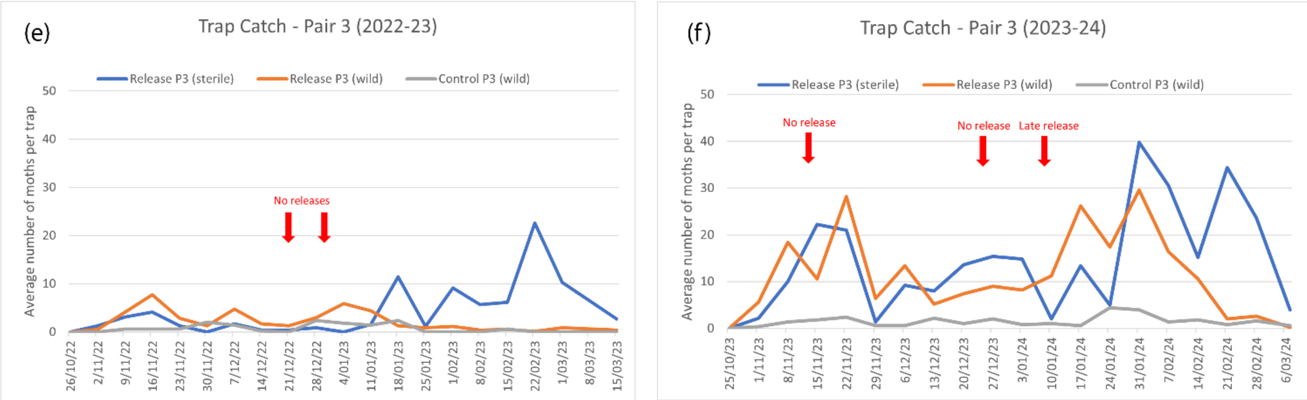


Figure 8. Average number of sterile and wild moths per trap between late October and mid March in two consecutive release seasons. In season 1 (2022-23) no sterile moth release occurred on 22 or 29 Dec 202nd and the final release date was 16 Feb 2023; in season 2 (2023-24) no sterile moth release occurred on 16 Nov or 28 Dec 2023 and the final release date was 15 Feb 2024.

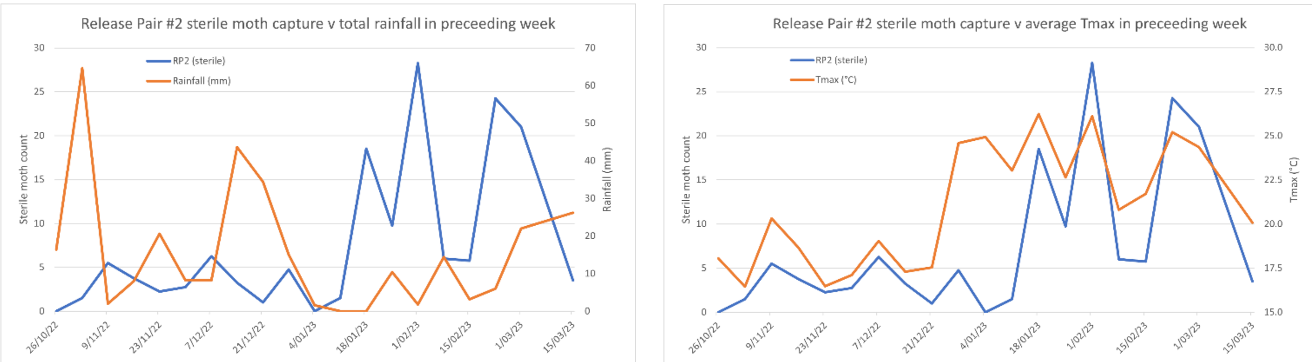


Figure 9. Impact of rainfall (left) and maximum daily temperature (right) on recapture numbers of sterile moths for the Pair #2 release site in season 1.

5.8.5. Fruit damage assessments

Field examination of fruit for codling moth damage was undertaken prior to harvest in late February of each season.

Five panels of four trees were randomly selected per hectare (i.e. 20 trees per hectare) (Table 4). A total of 25 fruit were examined from each tree, beginning with the branch closest to head height on the northernmost side of the trunk and examining all fruit on the branch, working down branches until 25 fruit had been assessed. Assessment was visual examination of fruit including observation of the calyx for any exuding frass, and recording the number of fruit with CM stings for each tree.

Table 4: Details of number of trees and fruit examined at each site for codling moth damage.

Pair	Site	Hectares	# traps	# panels	# trees	# fruit
1	Control	4.1	4	20	80	2,000
1	Release	4.6	5	25	100	2,500
2	Control	4.6	5	25	100	2,500
2	Release	3.9	4	20	80	2,000
3	Control	5	5	25	100	2,500
3	Release	5	5	25	100	2,500
			28	140	560	14,000

For pair #1, fruit damage observed in the control site in season 1 was 5.6% compared to 2.1% in the release site, while in season 2 the damage in the control site was 18.1% compared to 5.6% in the release site (Figure

10). For pair #2 the damage was marginally higher in the control site than in the release site across both seasons (1.4% vs 0.9% in season 1 and 0.7% vs 0.6% in season 2). Although fruit damage was not reduced to the level (0.04%) reported by Gill (2014) in orchards under the Canadian OKSIR program, the damage observed in pair #1 was reduced by 62% in season 1 and 69% in season 2 compared to the control site, and a reduction of 32% and 14% was observed for Pair #2 in seasons 1 and 2, respectively.

However, in pair #3 fruit damage was considerably higher in the release site than the control across both seasons (18.8 vs 0.4 in season 1, and 27.4 vs 1.9% in season 2). Unlike other sites used in the trial, these sites were spatially separated and maintained under different management systems. Results indicate that the number of wild moths in the release site were initially too high for SIT to effectively disrupt reproductive success at this site, whilst the grower program in the pair #3 control site was extremely effective in managing codling moth population density at this site.

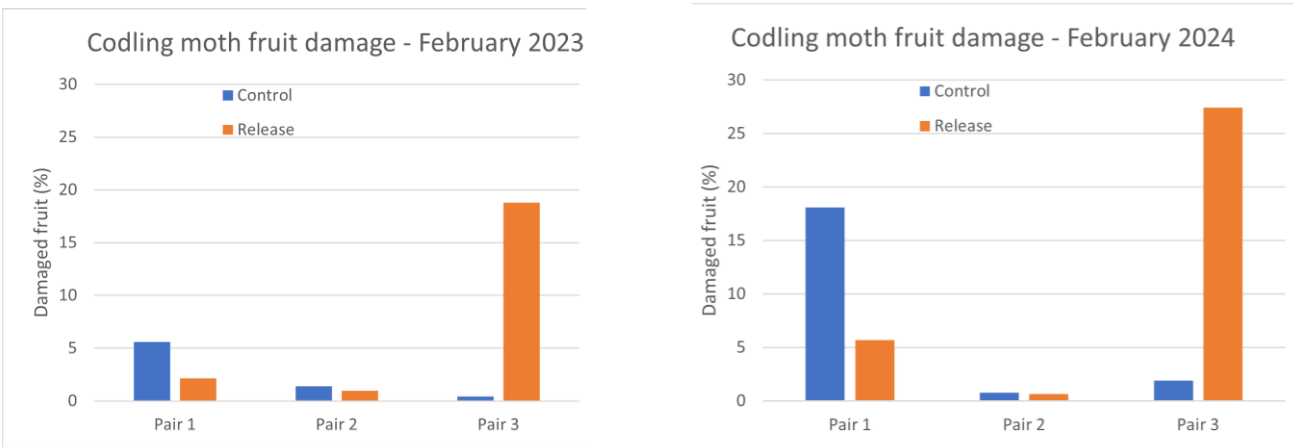


Figure 10. Codling moth damage to fruit at all release and control sites for season 1 (left) and season 2 (right).

5.8.6. Larvae trap results

The number of over-wintering larva in each trap varied between sites (Figure 11), with numbers in the release and control sites in each pairing being similar with the exception of pair #3 in season 2 where the release site had higher numbers than the control site. This difference however is explained by the higher pest pressure at this site. Pair #2 had the lowest number of larvae trap numbers across both seasons, in keeping with the lower observed pest pressure and improved control at this site.

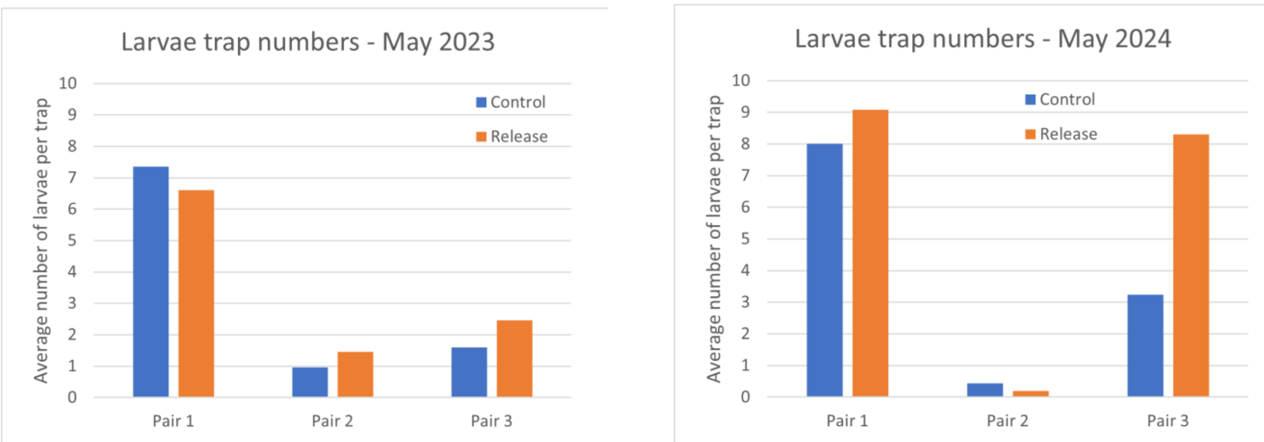


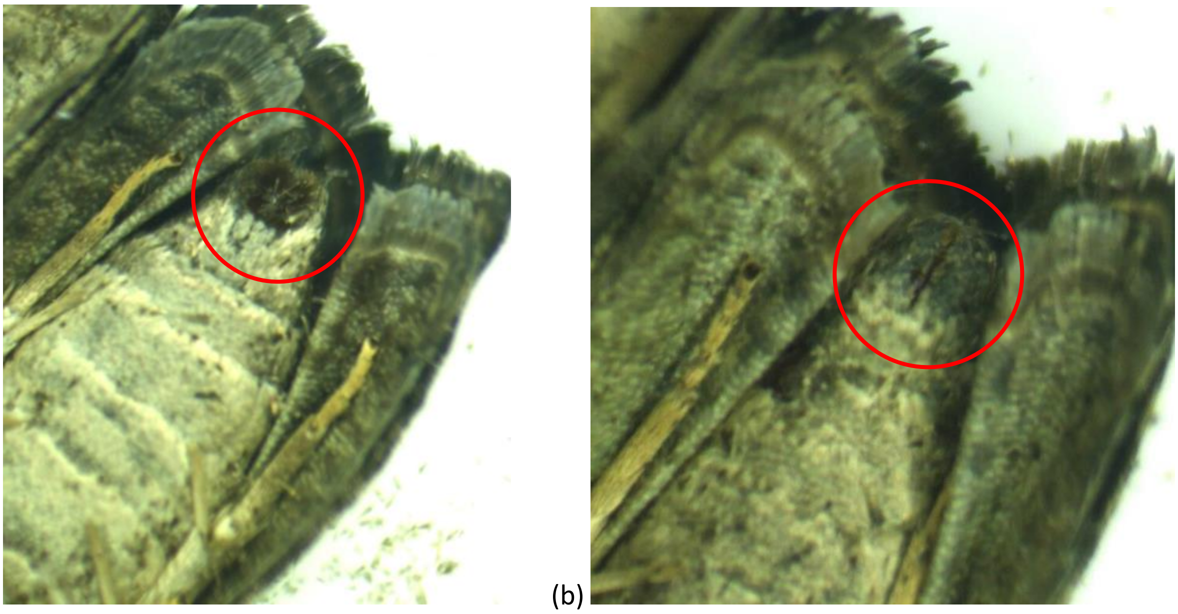
Figure 11. Number of over-wintering larvae in larvae traps around trunk for season 1 (left) and season 2 (right).

5.8.7. SCM quality control

Quality assessments were undertaken on three separate consignments of sterile moths. Receival dates for the consignments tested were 28 Sep 2022, 8 Dec 2022 and 12 Jan 2023. All assessments were conducted on randomly selected moths from one randomly selected cup (out of 32 per consignment). All quality control tests were conducted at 22-25°C, 16:8 (L:D) photoperiod, 60% RH.

Sex ratio

The sex ratio of males to females was calculated by separating and counting male and female moths from 5 randomly selected lots of 100 moths (consignment 1), 6 lots of 100 moths (consignment 2) and 6 lots of 200 moths (consignment 3). Sex was determined by examination of visible external genitalia (Figure 12) under a dissecting microscope. On the resting female, the external genitalia consist of a large anal papilla, which is a circular brown spot the width of the terminal segments and the dark opening to the bursa copulatrix in the front of the anal papilla. The visible external genitalia of the male are a pair of scaled claspers at the tip of the abdomen.



(a) (b)

Figure 12. External genitalia of codling moth (a) female showing concave pad, and (b) male showing black claspers on abdomen tip.

Male moths made up an average of 46.96 percent across all consignments (Figure 13). The sex ratio approached 50:50 as sample size increased.

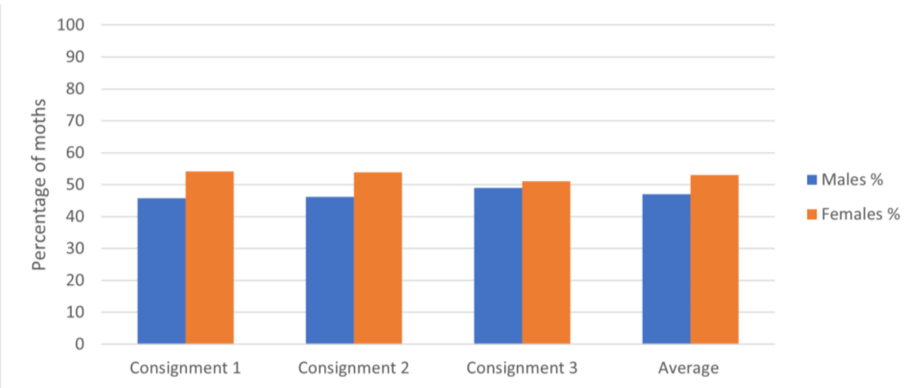


Figure 13. Sex ratio of male to female sterile codling moths in each of three consignments (28/09/22, 8/12/22, 12/01/23) and average sex ratio across all consignments.

Adult weight

The adult female is both larger and heavier than the male. Target quality parameters are male adults > 18-20 mg and female adults > 28-30 mg or heavier (FAO/IAEA, 2010). The average weight of males across the three assessed consignments ranged from 16.79 mg to 18.77 mg, with an average of 17.64 mg. The average weight of females across the three assessed consignments ranged from 26.50 mg to 32.60 mg, with an average of 30.13 mg (Figure 14).

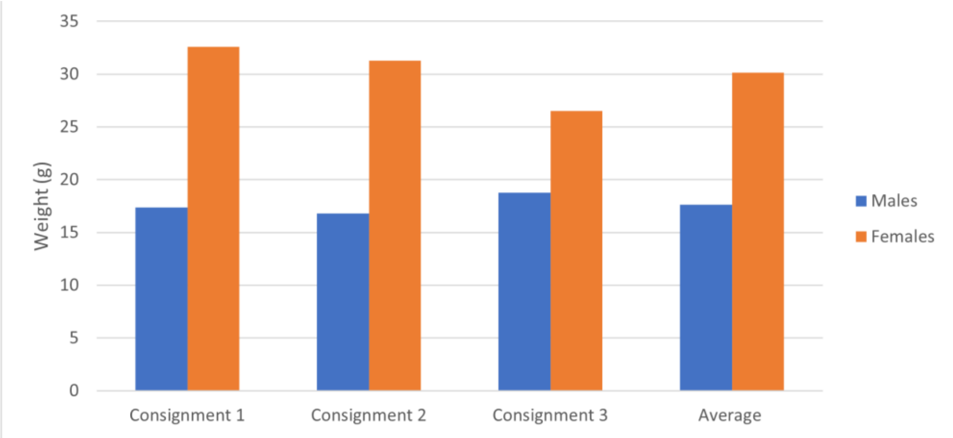


Figure 14. Average weight of sterile codling moths from three consignments (28/09/22, 8/12/22, 12/01/23).

<u>Mating ability</u>

Mating ability is ideally measured pairing sterile males with wild females. With no access to non-sterilised females, this experiment tested mating ability using sterile males and sterile females. Ten moth pairs (male + female) were placed in each of five 20 x 15 x 15 cm ventilated cages (Sistema Klip-it, 3L) (Figure 15) and assessed for successful mating after 48 h.

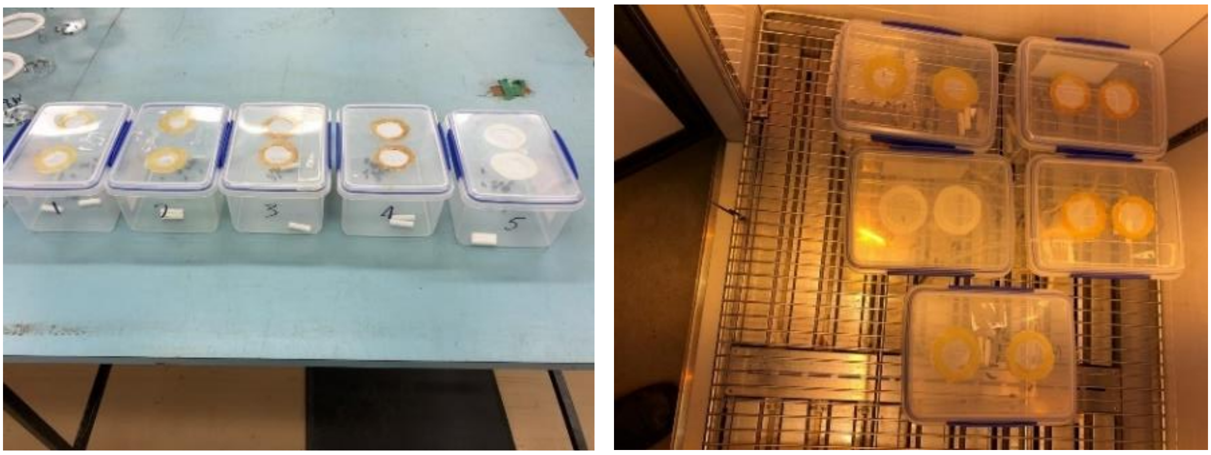


Figure 15. Mating experiment setup.

Mating success was determined by the percentage of females with spermatophores in the bursa copulatrix after 48 h (Figure 16).

Figure 16. Codling moth bursa copulatrix.

Mating success across the three assessed consignments ranged from 64 % to 80 %, with an average of 73.3 % (Figure 17).

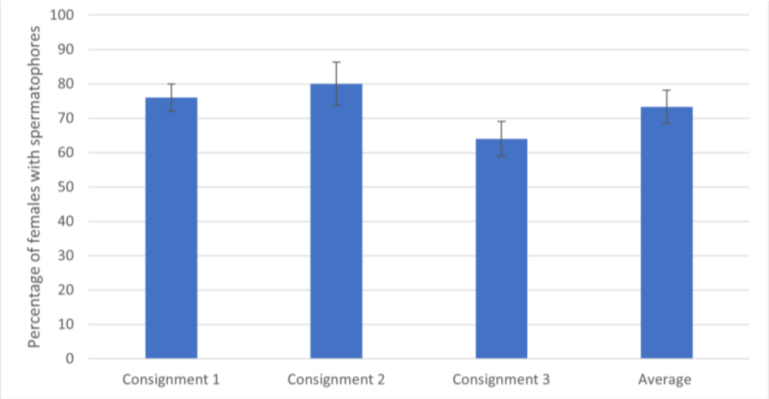


Figure 17. Mating ability of sterile codling moths - percentage of female codling moths with spermatophores in the bursa copulatrix after 48 h from three consignments (28/09/22, 8/12/22, 12/01/23).

Moth longevity

Adult longevity is directly correlated with the nutritional status of the larval and pupal stages. The mortality test measures the percentage of adults that survive for a set time without food and is indicative of the amount of nutritional reserves present when adults emerge. Larvae and pupae that acquired high nutrient reserves during development produce adults that live longer. Radiation dose can directly affect adult longevity.

Fifty male moths and fifty female moths were each placed in five ventilated containers (10 moths per container) (Pint-sized BugDorm, AUSENTOSUPPLIES), without food or water at 22°C (Figure 18). The same experiment was replicated concurrently with moths given initial access to water from moistened dental rolls.

Figure 18. Longevity (mortality) experiment in progress.

Initial mortality after 24 h (Figure 19) was high (11-24 %), but not unexpected, and is likely attributed to a percentage of moths dying or being damaged during packing and shipping. The remaining moths exhibited low mortality during the first five days, with mortality increasing significantly from day six. More than half of all moths in all treatments had died after seven days. Male moths exhibited similar levels of mortality to female moths over the first five days, but from day six, mortality of male moths increased at a much faster rate than that of female moths.

For the first 7-8 days, male and female moths with access to water exhibited significantly lower mortality than moths without access to water (Figure 19). After day eight, this difference was not observed, which may be due to the dental wicks drying out such that no moths had access to water after this point.

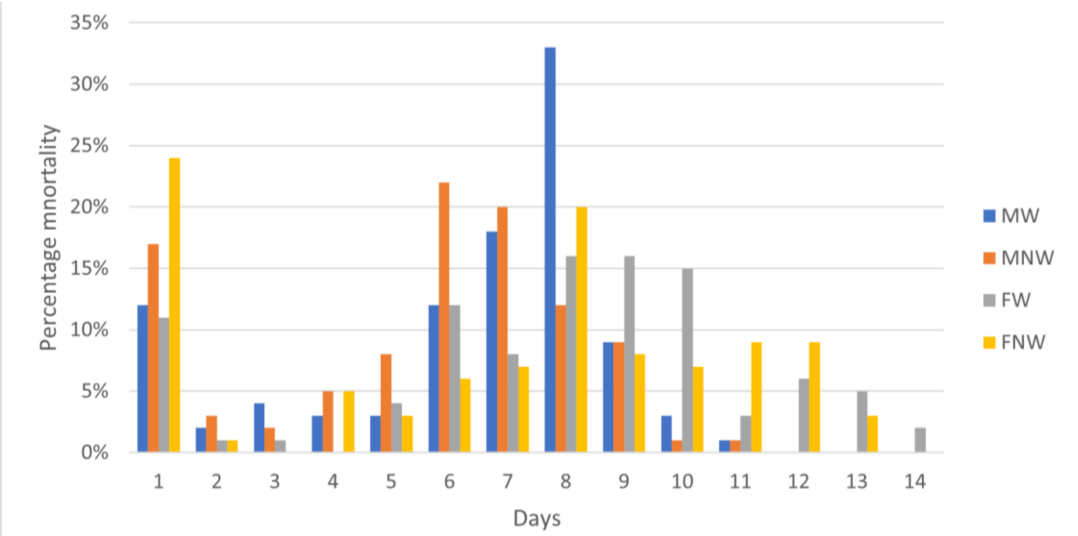


Figure 19. Average daily mortality of male codling moths with access to water (MW) and without access to water (MNW) and female codling moths with access to water (FW) and without access to water (FNW), across three consignments (28/09/22, 8/12/22, 12/01/23).

Cumulative mortality rate (Figure 20) remained below 20% until day 5 in males and day 6 in females; there was an increase in mortality in moths with lack of access to water. Male moths reached 100% mortality by day 11, while female mortality only reached around 92% by day 12.

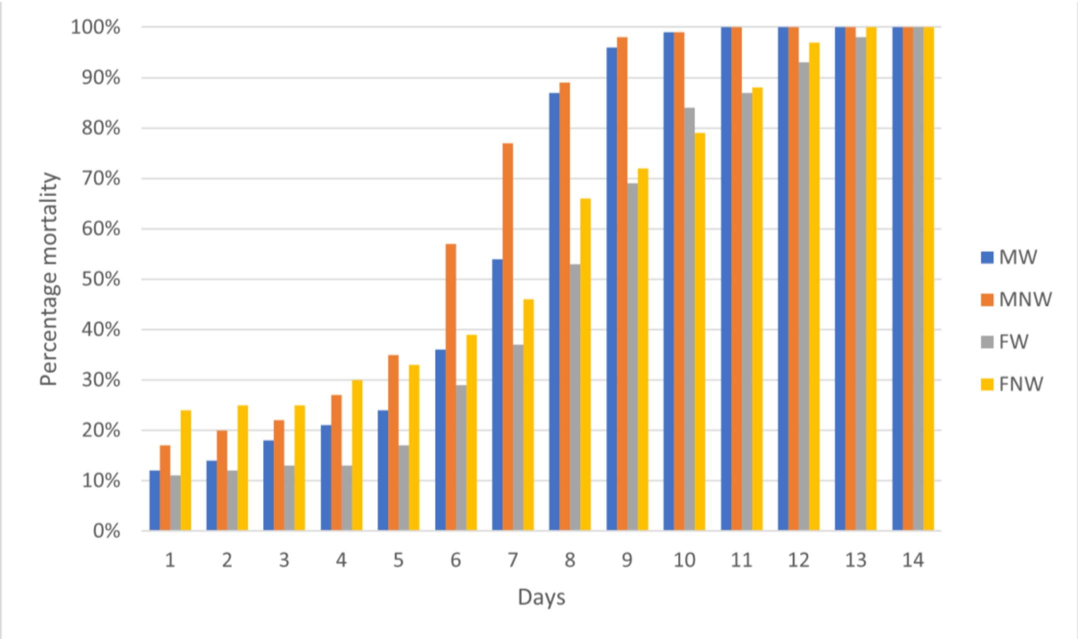


Figure 20. Average total mortality of male codling moths with access to water (MW) and without access to water (MNW) and female codling moths with access to water (FW) and without access to water (FNW), across three consignments (28/09/22, 8/12/22, 12/01/23).

5.8.8. The impact of length of storage time on moth longevity following release

As a result of the high mortality rate of the moths under refrigeration for an extended period (as noted in Section 6. Project disruptions), a mini-mortality experiment was undertaken in January 2024 to determine the length of refrigeration that the moths were able to sustain following approximately 60 hours transit time.

One cup of moths was selected at random from the consignment received on 11 January 2024 and placed under refrigeration at approximately 3°C in the TIA entomology laboratory. A total of 70 pint-sized BugDorms (720ml #EMDP24, Australian Entomological Supplies) were labelled to provide 10 replications for each of 7 days (Day 0 to Day 6), with Day O being no storage, Day 1 = one day storage, Day 2 = two days storage etc.

For each day, 10 dental rolls were covered with distilled water in a clean container and the bugdorms for the relevant day were set out. Approximately 200 moths were gently decanted from the cup onto damp paper towel and the cup immediately returned to the fridge. The moths were gently rolled on the paper towel to remove excess loose scales (Figure 21).

(a) (b)

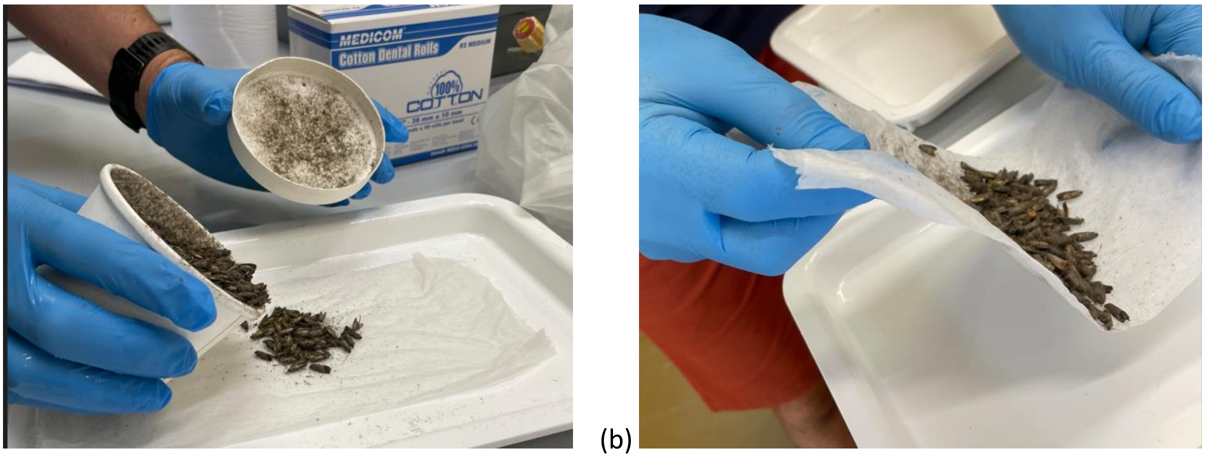


Figure 21. (a) Decanting of moth sample from transport cup onto damp paper towel; and (b) gently rolling on damp paper towel to remove loose scales.

Moths were then placed onto the centre of an A5 tray containing a paper strip (Figure 22a) and the tray placed onto the stage of a stereo microscope to enable the sorting of males from females (Figure 22b) – the males were gently swept onto the paper strip and at the completion of sorting were decanted into a clean container. The females were discarded into a ziplock bag and destroyed.

(a) (b) (c)

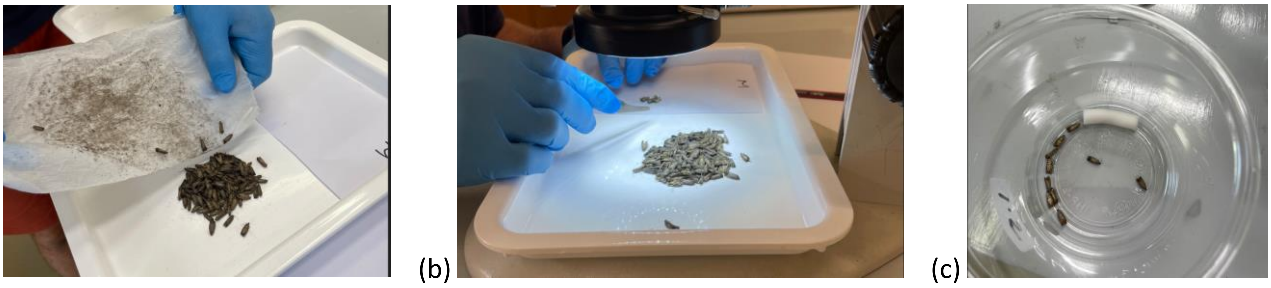


Figure 22. (a) preparing moths for sorting; (b) gender identification under a stereo microscope; and (c) moths in bugdorm.

The dental rolls were drained and one roll placed in each bugdorm. Ten moths were gently scooped into each bugdorm (Figure 22c) and the lid secured. The bugdorms were placed into the insect rearing room at 23°C with a 16:8 (L:D) photoperiod.

This process was repeated daily for each storage time. Bugdorms were inspected individually every 24 hours for 14 days for each storage time, and the number of dead moths recorded.

Mortality rate (Figure 23) of the moths that were immediately released rather than being placed under additional refrigeration was 5-6% r for the first five days and then increased rapidly with 44% mortality at eight days and 98% mortality at 12 days. Moths placed under refrigeration for one day showed a similar trend but with 2-3% increased mortality for the first few days after release. For moths refrigerated for two extra days, mortality increased from 17% to 33% over the first five days after release. Initial mortality one day after release for moths refrigerated for three and four days was 40 and 65%, respectively, while mortality of moths refrigerated for an additional 5 or more days was 89% or higher. This data suggests that the sooner the moths are released following receipt of the shipment the greater their chance of survival, and a maximum of one day of additional refrigeration following a 60 hour transit time would be acceptable.

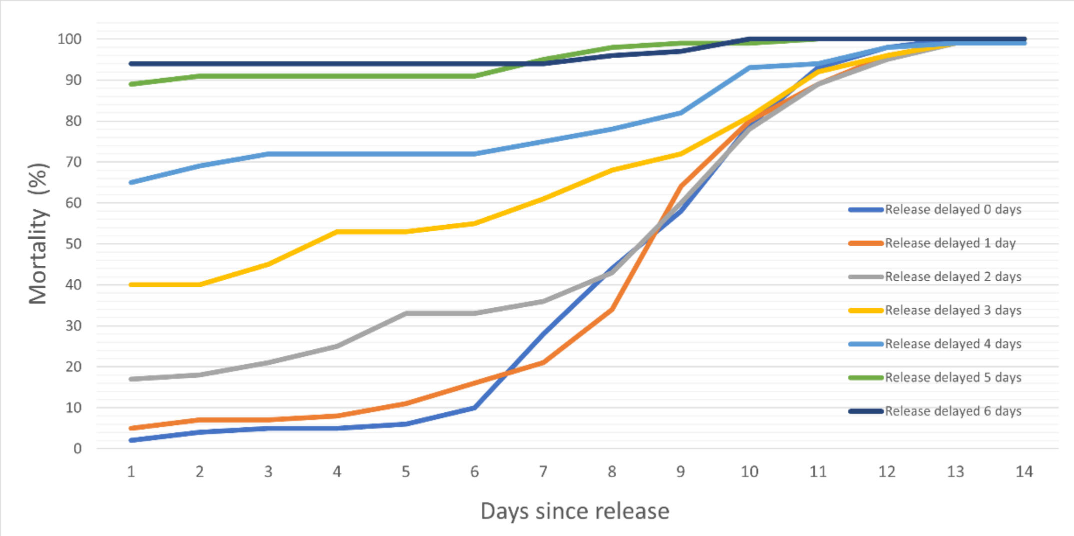


Figure 23. Mortality rate of male sterile codling moths following delayed release and continued cold storage after shipment arrival in Tasmania.

5.9. Activity 9: Integration of SCM into area-wide integrated pest management systems

Sterile insect technique has been confirmed as an effective control tactic against lepidopteran pests, including codling moth, when applied in an area-wide integrated pest management (AW-IPM) program (Vreysen 2009; Blomefield et al. 2011; Cartier 2015; Nelson et al. 2021). According to Horner et al. (2016), SIT is an ideal tool for IPM strategies, providing both economic and environmental benefits. SIT and mating disruption (MD) are considered to be complementary tools in AW-IPM programs and many entomologists believe that combining SIT and MD provides more effective control than either SIT or MD alone (Cartier 2015).

Due to the relatively short duration of this Australian pilot project it was not feasible to integrate SIT into an AW-IPM program for codling moth control. However, the inclusion of SIT along with chemical, cultural and biological techniques for over 20 years in the southern region of British Columbia in Canada (Nelson et al. 2021) demonstrates that SIT can be successfully included as part of a sustainable AW-IPM program for codling moth control.

5.10. Activity 10: Industry enhancement and awareness benefits program.

Multiple activities were undertaken to raise awareness of the pilot project and of the benefits of SIT, ranging from media releases, industry articles, YouTube videos, project and FAQ web pages, radio interviews, and seminar presentations (Table 5).

Table 5: Summary of project communication and engagement activities.

Date	What	Where	Topic
7 Oct 2019	Industry presentation	FGT Apple & Pear Industry Day	Introduction to the project
1 Mar 2023	Media Release	Key media outlet	Project overview
1 Mar 2023	Research Web Page	TIA	Project overview
1 Mar 2023	Project web Page	TIA	Project overview
10 Mar 2023	FAQ Web Page	TIA	Frequently asked questions
1 Mar 2023	YouTube	TIA	Interview with Sally - project description
1 Mar 2023	Facebook	TIA	Project overview
1 Mar 2023	Twitter	TIA	Project overview
3 Mar 2023	E-News	FGT Fruit E News	Project overview
3 Mar 2023	Internet news	HortiDaily	Project overview

2 Mar 2023	Radio Interview (national)	ABC Radio & ABC Country Hour	Project overview – interview with Sally Bound
6 Mar 2023	Internet story	National Tribune AgNews	Project overview
10 Mar 2023	Rural Newspaper	Tasmanian Country	Project overview
11 Mar 2023	Local Newspaper	The Hobart Mercury - Weekend	Codling moth management
26 Apr 2023	Internet resource	APAL website	Project update
28 Apr 2023	Internet story	Smart Company	IPM Internet news story
May 2023	Industry Journal (National)	Australian Fruit Grower - APAL	Project update
15-16 Jun 2023	FGT Conference	Launceston	Display of codling moth project
Oct 2023	Industry Journal (National)	Australian Tree Crop	Project Update
2-4 May 2024	Field Day	Agfest	Interactive display with project lead talking to growers and general public about the project
2 May 2024	Radio interview (National)	ABC Radio & ABC Country Hour	Project update - interview with Sally Bound
17 Jun 2024	National Webinar	Hybrid event - Zoom & face-to-face – FGT office	Discussion on the project results and potential for commercial use of sterile codling moth in Australia
Jul 2024	Industry Journal (National)	Australian Fruit Grower - APAL	

Conduct of formal training programs for agronomists and service providers is premature as the issue of ready availability of sterile codling moths in Australia will need to be addressed. However, the National webinar scheduled for 17 June had over 60 grower, agronomist and service provider registrations from New South Wales, Queensland, South Australia, Tasmania, Victoria and Western Australia, as well as from New Zealand.

5.11. Activity 11: Economic assessment of release programs.

Import costs

Costs for purchase of sterile moths from Canada, freight, quarantine and customs charges (including requirement to use a Customs Broker) are provided in Table 6. The total season cost was based on a 17 week season, but this may be longer in warmer regions of Australia. The number of moths imported each week was sufficient to treat 14 ha of orchard.

Table 6. Import costs of sterile codling moths from the OKSIR facility in Canada.

	Weekly cost	
	2022-2023	2023-2024
Purchase of SCM from OKSIR, Canada		
Sterile moths*	1,490	1,647
Packaging/labour/transport	746	775
Freight	2,284	2,376
Quarantine & import charges		
Import GST charges	188	212
Quarantine processing charge	38	43
Border force charges	243	248
Biosecurity charges	143	222
Customs Broker charges	108	108
Qantas Freight charges	137	138
Total weekly costs	**5,377**	**5,768**
Total season costs (17 weeks)	**91,409**	**98,056**

* 32 cups in season 1; 34 cups in season 2

The season costs to treat 1 ha of orchard with sterile codling moths imported from the OKSIR facility in Canada are detailed in Table 7. Approximately 30% of the cost is for the moths, and the remaining 70% is accounted for by packaging and freighting costs, import GST charge, Australian quarantine and border force fees.

Table 7. Seasonal costs per hectare to import sterile moths from Canada.

	2022-2023 season	2023-2024 season
Sterile moths	1,797	1,987
Packaging & freight (from Canada)	3,653	3,800
Australian quarantine & border force costs	813	922
Import charges	229	258
Total cost to treat 1 ha (for 17 weeks)	**6,492**	**6,967**

An economic analysis of a potential sterile codling moth (SCM) release program was completed by Nic Finger, Horticultural Consultant, Fruit Help Pty Ltd. The analysis aimed to establish an approximate per hectare cost, potential release strategies and potential effect of a longer term timeframe in terms of aggregate costs, benefits and opportunities. The conclusions and recommendations from this report are detailed below, the full report is available in Appendix 5.

Economic analysis conclusions

An economic analysis and consideration of broader potential costs and benefits of the program has demonstrated the following:

- Damage from codling moth to apples varies between control techniques
  - SIT is reported to have the lowest damage rates (Appendix 5, Table 1) relative to mating disruption and pesticide use only
    - Gains in gross orchard gate income are expected to be higher under SIT relative to mating disruption (+$277.5) or pesticide use only (+$2295)
- Implementation cost benefit is largely dependent on actual cost of release which requires significant levels of assumptions
  - Modelling of NPV over 20 years (considered life of orchard) for different codling moth control techniques demonstrated benefit over pesticide/mating disruption (Appendix 5, Table 5) where cost was less than $1491.19/ha
    - As such, cost to growers for application of SIT for codling moth would need to be $1191.19/ha or less to achieve a positive cost:benefit relationship (assuming a $350/ha spray control requirement for threshold exceedance)
      - Any business case for sterile codling moth import or local production would require that these costs are feasible for the size of the Australia industry
      - Without regulatory framework to collect mandatory payments to fund this initiative it is highly unlikely to be possible
        - State and federal barriers would likely be encountered
    - Cost of implementation in Canada is currently ~AUD$1430/ha
- Additional benefits would be (or potentially be) gained from:
  - Reduced pesticide use and associated social benefits
  - Reduced pesticide use and beneficial insect population improvements
  - Potential to negotiate area-wide approaches to export program phytosanitary requirements
  - Shifts in climate resulting in increased codling moth pressure
  - Changes in agrochemical resistance profiles of codling moth or significant price changes

Recommendations based on these findings:

- All growers should have the benefits of utilising mating disruption clearly communicated to ensure they are following best practise
- Sterile codling moth releases may be viable in Australia with clear target use cases and longer term vision for implementation (including potential subsidy in initial years for establishment)
- An analysis of requirements to allow SIT of codling moth in Australian facilities is completed and the

minimum area required under control to produce viable volumes is necessary
    - Low property density growing regions are unlikely to be suitable for area wide management in a cost-effective manner

- If sterile codling moth application was to be implemented, a clear funding model would need to be regulated to allow area wide management and funding
    - This would likely require some level of land tax input which would be incredibly difficult to regulate consistently in all regions and would be likely to face significant opposition from both industry and other potential co-funders (eg. residential)
    - Consideration to aerial release method should also be strongly considered as per findings of *Lo et al, 2021)*

- Consult export partners and experts regarding likelihood of improved market access or phytosanitary requirements for implementation of SIT for codling moth

- Given the geographical spread of the Australian apple and pear industry, considerations of potential other co-beneficiaries should be considered (residential properties, quince and walnut producers and to a lesser extent due to pest preference, stone fruit producers).

5.12. Activity 12: Development of project recommendations

Recommendations arising from this pilot project are based on the data collected during the project, the economic analysis undertaken, discussions with OKSIR and New Zealand scientists and other information sourced from the literature. Recommendations can be found in Section 7 below.

6. Project disruptions

During the course of this project the following issues arose which had a significant impact on the final project timeline and forced some changes to the original project protocol.

6.1. Issues caused by the COVID-19 pandemic

The project commenced in late October 2019 and while Activities 1,2 and 4 were able to be completed on schedule, restrictions and uncertainties caused by the COVID-19 pandemic resulted in requests to Hort Innovation in May 2020 and again in June2021 for deferral of the remainder of the project milestones based on the following reasoning:

1. the auditing of the OKSIR facility, which was not registered under the *Offshore Irradiation Treatment Providers Scheme*, was unable to be undertaken as the normal practice for auditing of a facility is for a Department of Agriculture, Fisheries and the Forestry (DAFF) officer to visit the facility. Advice was that an alternative means of auditing would take several additional months, leading to delays in the approval of the import permit.

2. Airfreight uncertainties meant that the shipping of live insects would be extremely challenging and delays in transit would reduce the viability of the sterile moths. Hence it was not feasible to undertake the planned releases in the 2020/2021 season (year 2) of the project.

After a two-year hiatus, the project recommenced in April 2022 following the granting of the import permit. With international flight timetables becoming more reliable in mid-2022 releases were planned for the 2022/2023 growing season.

6.2. Air-freight cost increases post COVID-19

Advice was received from OKSIR (Canada) in mid-August 2022 that since the provision of the original quote prior to COVID19 there had been an increase in production costs in addition to a tripling of freight costs as a result of COVID19 related increases. Due to this substantial increase in costs it was no longer feasible to undertake releases for two seasons in both Tasmania and South Australia as originally planned. A meeting of the Project Reference Group on 24th August 2022 concluded that, as at least two seasons of data were required to determine the feasibility of SCM as a control measure for codling moth, the only solution was to undertake the releases in Tasmania and omit the South Australian sites as this would still provide proof of concept. Reallocation of funds for modification of the DPIPWE rearing facilities that was no longer required due to the importation of adult moths rather than larvae, combined with removal of the South Australian shipments, meant that sufficient funds were available within the project budget to cover the substantial cost increase while still being able to provide proof of concept for the use of SCM as a control measure for codling moth in Australian orchards.

6.3. Supply chain disruptions

In Australia, the period of activity for codling moth extends from late October through to February. In Tasmania, a second peak in the wild moth population is normally observed between late December and mid-January, hence a break in weekly releases during this period is not ideal.

In the first release season (October 2022 to February 2023), severe winter weather in Canada resulting in disruption to all flights meant that the shipment scheduled for 22 December 2022 (week 9) did not arrive. This was further exacerbated by temporary closure of the OKSIR facility for seasonal public holidays and no shipment for week 10 (29 December 2022).

In season 2 (October 2023 to February 2024), the OKSIR facility was closed for public holidays in weeks 4 (16 November 2023) and 10 (29 December 2023). During the second release season it was investigated whether these disruptions could be managed by importing double the quantity of sterile moths in the week prior to a public holiday in Canada, with the view to releasing or cold storing the additional moths for release the following week.

Quality testing of the first double shipment was commenced on Monday 13 November 2023, with the testing entomologist Dr Guy Westmore finding that the extended period under refrigeration was associated with a high mortality rate of the stored moths. The decision was made not to release these moths, resulting in a 14-day gap in releases between 9 to 23 November 2023. As a result of the high mortality rate of the moths under refrigeration for an extended period (as noted above), a storage mortality experiment was undertaken in January 2024 to determine the length of refrigeration that the moths were able to sustain.

For the week 11 release, all moths in the double shipment that arrived in week 10 were released at the scheduled week 10 release, with no release occurring in week 11. This delay was exacerbated by further delays for the next scheduled shipment (3 Jan 2024) until 8 Jan 2024, resulting in an unforeseen 18-day gap in releases.

6.4. Delays with quarantine inspection and clearance

Shipments arrived into Hobart at 3.20 pm on Wednesday of each week. Quarantine staff were rarely available at Hobart airport to inspect the shipments until the following day, hence the shipments were not cleared for pickup until mid-late morning on Thursday of each week. This meant that by the time the shipments were picked up, transported to the release sites and the moth releases completed there was an additional delay of 20+ hours on top of the transit time from Canada to Hobart.

7. Conclusions and recommendations arising from this pilot study

As a biological control method, Sterile Insect Technology (SIT) has numerous benefits over traditional pesticide control methods for management of codling moth (*Cydia pomonella*). SIT is an ideal tool for integrated pest management (IPM) programs as it is compatible with other biological IPM management methods including mating disruption, granulosis virus, and releases of beneficial insects including *Trichogramma* and *Mastrus* species, and is an ideal tool for organic or low-input orchards. The use of SIT in codling moth control programs also includes the following additional benefits:

- it is environmentally safe
- species specific hence there is no effect on non-target organisms, i.e. protection of beneficial insects
- product quality and productivity are improved

- provides for residue-free pest management
- avoids problem of pesticide resistance
- no/reduced spray drift to nearby properties.

This pilot project has successfully investigated safe and secure biosecurity pathways for entry of sterile codling moth into Australia; developed and tested the logistics of transport and release, examined the costs and feasibility of SIT for codling moth control in Australia, and identified key components for future success.

The project has demonstrated proof of concept for the use of SIT as a tool for control of codling moth in Tasmania. Data collected over the two release seasons in Tasmania's Huon Valley found that SIT was effective at reducing codling moth at two of the three sites, with efficacy at the third site likely constrained by the very high abundance of wild moths. These constraints with the third site did however confirm the assertion by Vreysen et al. (2009) that for SIT to be effective the target population needs to be reduced by other control means to such levels where the release of sterile males becomes economic and effective.

According to Horner et al. (2016), SIT exhibits increased efficiency with decreasing pest population density. These authors suggest that SIT is the only environmentally-friendly technology that can eradicate insect pests if applied area-wide.

Vreysen et al. (2009) have also demonstrated the potential for codling moth SIT in Africa, Asia and South America, while the use of SIT in British Columbia for over 20 years and the recent 6-year pilot AW program in New Zealand (Horner et al. 2020; Walker 2022) have seen significant drops (90–99%) in populations of wild codling moth, clearly demonstrating that area-wide integration of SIT can successfully manage codling moth populations in an environmentally sound way (Nelson et al. 2021).

There is also considerable evidence in the literature that SIT can easily be integrated with other biological control methods such as pheromone-mediated mating disruption and granulosis virus (Vreysen et al. 2009; Cartier 2015; Horner 2016; Nelson et al. 2021). SIT and MD have been described as complimentary tools for an AW-IPM program (Cartier 2015). The conclusion by Hornet et al. (2016) that integration of SIT into an AW-IPM program enables the application of totally biological systems for managing insect pests is supported by the assertion by Nelson et al. (2021) that SIT can replace control products that are no longer environmentally or economically viable, and hence provide a biologically sustainable solution for controlling insect pests.

The economic analysis undertaken as part of this project concluded that SIT has the lowest fruit damage rates relative to mating disruption and pesticide use, however this analysis relied upon Canadian data from Gill (2014). Fruit damage levels in many Australian growing regions are considerably higher than the 3.1% noted by Gill (2014), often ranging from 5 – 25%. The outcome of this is that gains in gross orchard gate income per hectare are expected to be higher under SIT relative to mating disruption (+$277) or pesticide use only (+$2295). This would make the economics for the use of SIT for codling moth control even more viable.

As a biological control method, SIT has numerous benefits over traditional pesticide control methods. SIT is an ideal tool for IPM programs as it is compatible with other biological IPM management methods including mating disruption, granulosis virus and *Mastrus* releases, and is an ideal tool for organic or low-input orchards.

There are multiple additional benefits to the use of SIT in codling moth control programs:

- it is environmentally safe
- species specific hence there is no effect on non-target organisms, i.e. protection of beneficial insects
- product quality and productivity are improved
- provides for residue-free pest management
- avoids problem of pesticide resistance
- no/reduced spray drift to nearby properties.

Conclusions

While it is technically feasible to import sterile codling moths from Canada, it is too unreliable due to inconsistency of shipment throughout the season and hold-ups at national/state biosecurity barriers. This vulnerability to disruption compromises the efficacy of the release program during periods of key moth activity. The 60+ hour transport chain also limits moth longevity. On this basis, it would seem reasonable to expect that the levels of codling moth control achieved and economic returns to growers would be similar or improved if the sterile moths could be sourced from within Australia.

The economic analysis was limited in that it did not consider the level of codling moth damage to be a variable for consideration, and instead used the values provided by Gill (2014) from British Columbia, Canada as the basis for estimating the reduced damage to be between 0.37% - 3.06% (i.e. the difference between SIT and the other control options). This assumes a level of codling moth control certainly not supported by the Tasmanian pilot study (see figure 12). Sites with higher incidences of codling moth damage are likely to receive higher financial benefits from reducing that damage through the adoption of SIT.

For businesses struggling to limit fruit damage from codling moth below ~5%, SIT may represent a potentially cost effective approach to reduce codling moth populations and fruit damage if a reliable and cost-effective source of sterile moths can be sourced (this assumes a return of $3.4k from reduced fruit losses). For those businesses or sites already able to maintain a high level of pest suppression, the financial returns from the improved control may not be economically rewarding in the long term.

The limited mobility of codling moth means that effective management using SIT is achievable, even in smaller production areas, making it feasible for use at an individual business level. This means that whilst area-wide management would offer increasing economies of scale (where it might be able to be implemented), this is a "nice to have", not a "need to have". For an area-wide codling moth SIT program to be successful, consultation and collaboration between the pome fruit industry, regional councils, State governments and the wider public will be essential, and this is likely to be a lengthy process.

Recommendations – where to from here?

As this pilot study has been successful in demonstrating proof of concept for the use of SIT as a tool for control of codling moth, further work should be undertaken to determine:

- The feasibility of production and sterilisation of codling moth either in Australia or in New Zealand , with consideration of the following:
    - Options to partner with New Zealand
    - Multi-species facilities
    - Mass rearing capability
    - The minimum release area required to produce a viable volume of sterile moths
- Consultation with international market access experts in DAFF regarding likelihood of improved market access or phytosanitary requirements for implementation of SIT for codling moth
- Consideration of area-wide management
    - Quantification of the benefits of area-wide management as opposed to individual orchards
    - What is the minimum area suitable for area-wide management
    - Consultation and collaboration between the pome fruit industry, regional councils, relevant State government departments and the wider public
- Consideration of release method
    - Ground versus aerial
    - Scale required for optimal efficiency of each method
- Development of a clear funding model

- Given the geographical spread of the Australian apple and pear industry, other potential co-beneficiaries should be considered (residential properties, quince, walnut and stone fruit producers)
-

8. Acknowledgments

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9. References

Hort Innovation (2023) Australian Horticulture Statistics Handbook for Fruit 2022/23. Downloaded from https://www.horticulture.com.au/contentassets/a36fdfa2427d4ad284c426663b06f15c/hort-stats-fruit-22-23.pdf

Blomefield, T; Carpenter, JE; Vreysen, MJB (2011) Quality of mass-reared codling moth (Lepdioptera: Tortricidae) after long distance transportation: 1. Logistics of shipping procedures and quality parameters as measured in the laboratory. *Journal of Economic Entomology,* **104**(3):814-822. doi: 10.1603/EC10238

Cartier, L (2015) Economic benefits of using sterile insect technique and mating disruption to control codling moth. Journal of Agricultural Science, 7(9): 14-25. doi:10.5539/jas.v7n9p14

Department of Agriculture, Fisheries and Forestry (DAFF) (2023) Sterile Insect Technique use in Australia. Downloaded from https://www.agriculture.gov.au/biosecurity-trade/pests-diseases-weeds/fruit-flies-australia/management/sterile-insect-technique

DuPont, T (2020) WA sterile insect release project – year two update. Washington State Tree Fruit Extension. Downloaded from https://treefruit.wsu.edu/article/wa-sir-project-y2-update/ on 17/05/2024.

Esch, ED; Horner, RM; Krompetz, DC; Moses-Gonzales, N; Tesche, M; Suckling, DM (2021) Operational parameters for the aerial release of sterile codling moths using an uncrewed aircraft system. *Insects*, **12**, 159. https://doi.org/10.3390/insects12020159

FAO/IAEA (2010) Rearing Codling Moth for the Sterile Insect Technique. https://www.iaea.org/sites/default/files/21/06/nafa-ipc-manual-ipc-codling-moth-sterile-insect-technique-2010.pdf

Horner, RM; Lo. PL; Rogers, DJ; Walker, JTS; Suckling, DM (2020) Combined effects of mating disruption, insecticides and the sterile insect technique on *Cydia Pomonella* in New Zealand. *Insects*, **11**: 837. doi: 10.3390/insects11120837

Horner, RM; Walker, JTS; Rogers, DJ; Lo, PL; Suckling, DM (2016) Use of the sterile insect technique in New Zealand: benefits and constraints. *New Zealand Plant Protection*, **69**: 296-304.

Milkovitch, M; Courtney, R (2021) Releasing research on sterile insect release. Good Fruit Grower, March 1st 2021 Issue

Nelson, C; Esch, E; Kimmie, S; Tesche, M; Philip, H; Arthur, S (2021) Putting the sterile insect technique into the modern integrated pest management toolbox to control the codling moth in Canada. Area-Wide Integrated Pest Management: Development and Field Application, pp. 111–127. J. Hendrichs, R. Pereira and M. J. B. Vreysen (eds.), CRC Press, Boca Raton, Florida, USA. doi: 10.1201/9781003169239-7

NSW Department of Primary Industries (NSW DPI) (2022) Innovative Sterile Insect Technique (SIT) for sheep blowfly. Downloaded from https://www.dpi.nsw.gov.au/dpi/about-us/research-and-development/projects/biosecurity/sit on 16/05/2024.

OKSIR (2024) Sterile insect release process. Downloaded from https://www.oksir.org/the-program/sterile-moth-release-process/ on 12/05/2024.

Phillips, SJ; Anderson, RP; Schapire, RE (2006) Maximum entropy modeling of species geographic distributions. *Ecological Modelling*, **190**(3–4): 231–259. doi: 10.1016/j.ecolmodel.2005.03.026

Phillips, SJ; Dudik, M (2008) Modelling of species distributions with Maxent: new extensions and a comprehensive evaluation. *Ecography*, **31**: 161-175. doi: 10.1111/j.2007.0906-7590.05203.x

Vreysen, MJB; Carpenter, JE; Marec, F (2009) Improvement of the sterile insect technique for codling moth *Cydia Pomonella* (Linnaeus) (Lepidoptera Tortricidae) to facilitate expansion of field application. *Journal of Applied Entomology*, **134**: 165-181. doi: 10.1111/j.1439-0418.2009.01430.x

WA Department of Primary Industries and Regional Development (DPIRD) (2018) Sterile insect technique for fruit fly control. Downloaded from https://www.agric.wa.gov.au/medfly/sterile-insect-technique-fruit-fly-control?page=0%2C1 on 16/05/2024.

Walker, J (2022) Development of a pilot codling moth SIT program in New Zealand. Downloaded 17/05/2024 from https://www.youtube.com/watch?v=dJ9RHsqt9hc

Appendices

1. Codling moth mapping distribution; Maxtent maps and model outputs
2. Import permit for sterile codling moth
3. Economic analysis report

Appendix 1: Codling moth distribution mapping - Maxtent maps and model outputs

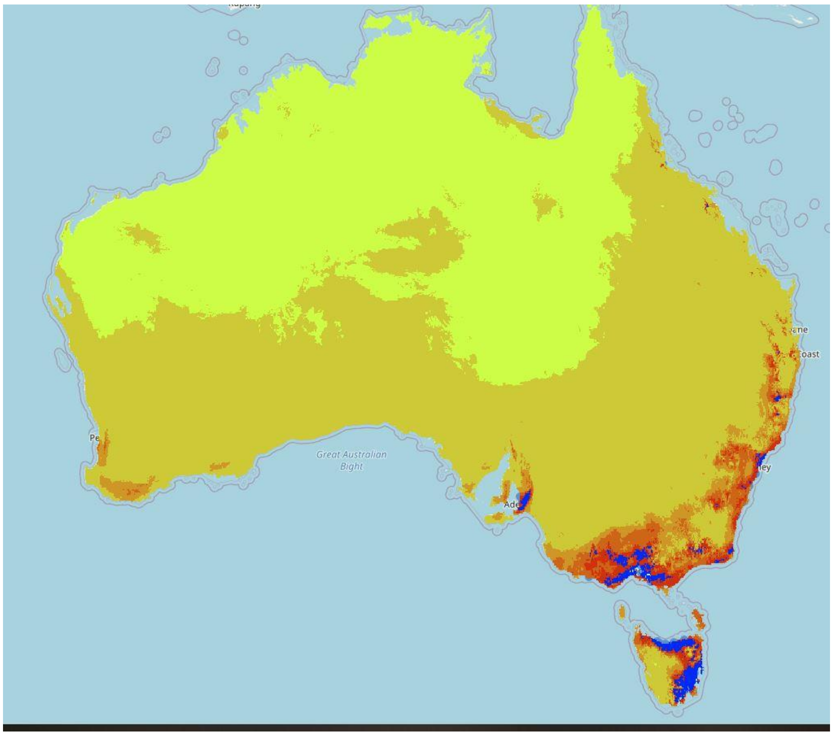


Figure A1: Projected distribution of codling moth within Australia

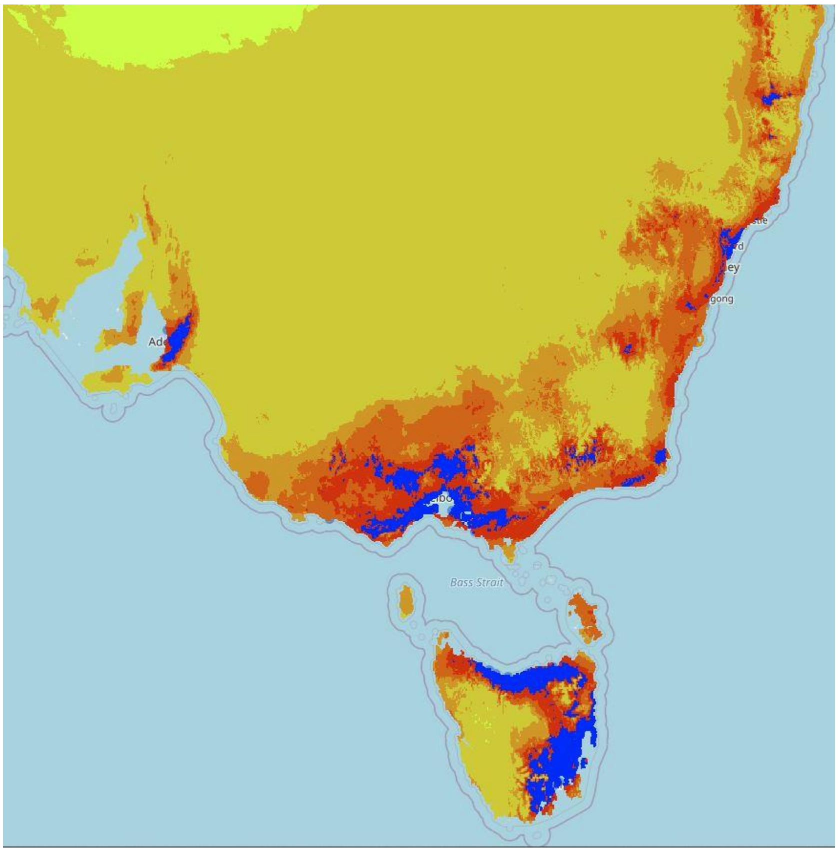


Figure A2: Projected distribution of codling moth within the southeast of Australia

Maxent model for Australian codling moth records

This page contains some analysis of the Maxent model for Australian codling moth records, created Mon Apr 27 16:29:34 AEST 2020 using Maxent version 3.4.1. Links at the bottom of this page to the raw data may be used for further analysis.

Model reference number: 710470

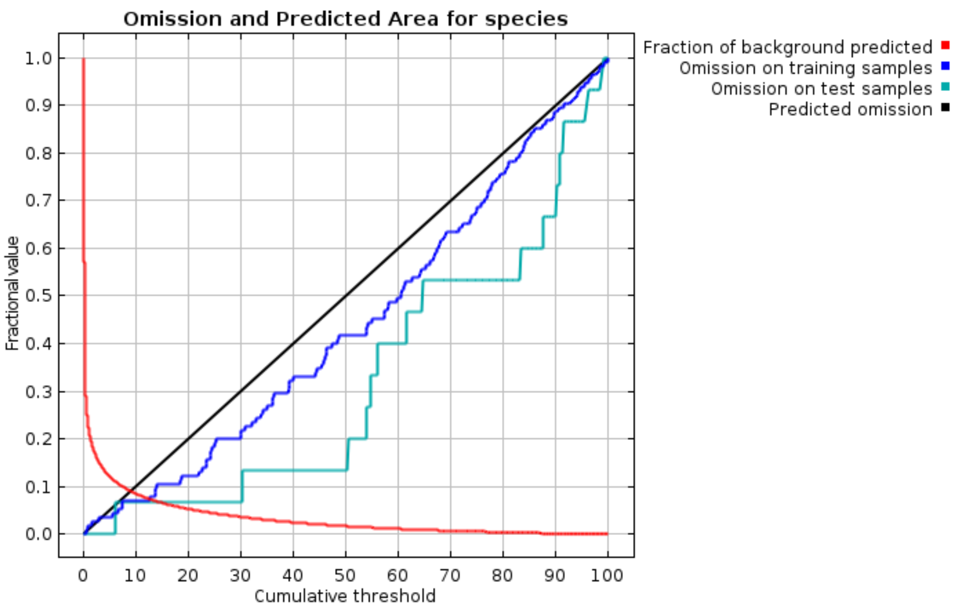
Species: *Cydia pomonella*

Layers:

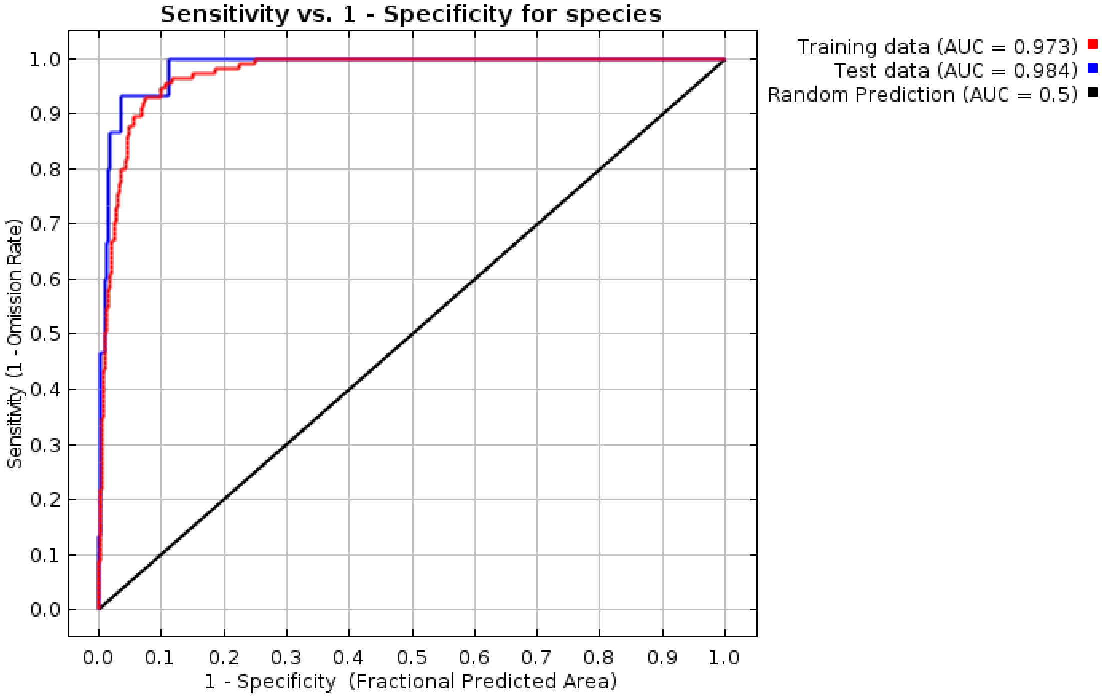
Precipitation - annual (Bio12) (el893)
Precipitation - coldest quarter (Bio19) (el863)
Precipitation - driest period (Bio14) (el872)
Precipitation - driest quarter (Bio17) (el889)
Precipitation - seasonality (Bio15) (el882)
Precipitation - warmest quarter (Bio18) (el878)
Precipitation - wettest period (Bio13) (el866)
Precipitation - wettest quarter (Bio16) (el886)
Temperature - annual mean (Bio01) (el874)
Temperature - annual range (Bio07) (el862)
Temperature - coldest period min (Bio06) (el867)
Temperature - coldest quarter mean (Bio11) (el876)
Temperature - diurnal range mean (Bio02) (el888)
Temperature - driest quarter mean (Bio09) (el875)
Temperature - isothermality (Bio03) (el883)
Temperature - seasonality (Bio04) (el892)
Temperature - warmest quarter (Bio10) (el890)
Temperature - warmest period max (Bio05) (el879)
Temperature - wettest quarter mean (Bio08) (el870)

<u>Analysis of omission/commission</u>

The following picture shows the omission rate and predicted area as a function of the cumulative threshold. The omission rate is calculated both on the training presence records, and (if test data are used) on the test records. The omission rate should be close to the predicted omission, because of the definition of the cumulative threshold.



The next picture is the receiver operating characteristic (ROC) curve for the same data. Note that the specificity is defined using predicted area, rather than true commission (see the paper by Phillips, Anderson and Schapire cited on the help page for discussion of what this means). This implies that the maximum achievable AUC is less than 1. If test data is drawn from the Maxent distribution itself, then the maximum possible test AUC would be 0.966 rather than 1; in practice the test AUC may exceed this bound.

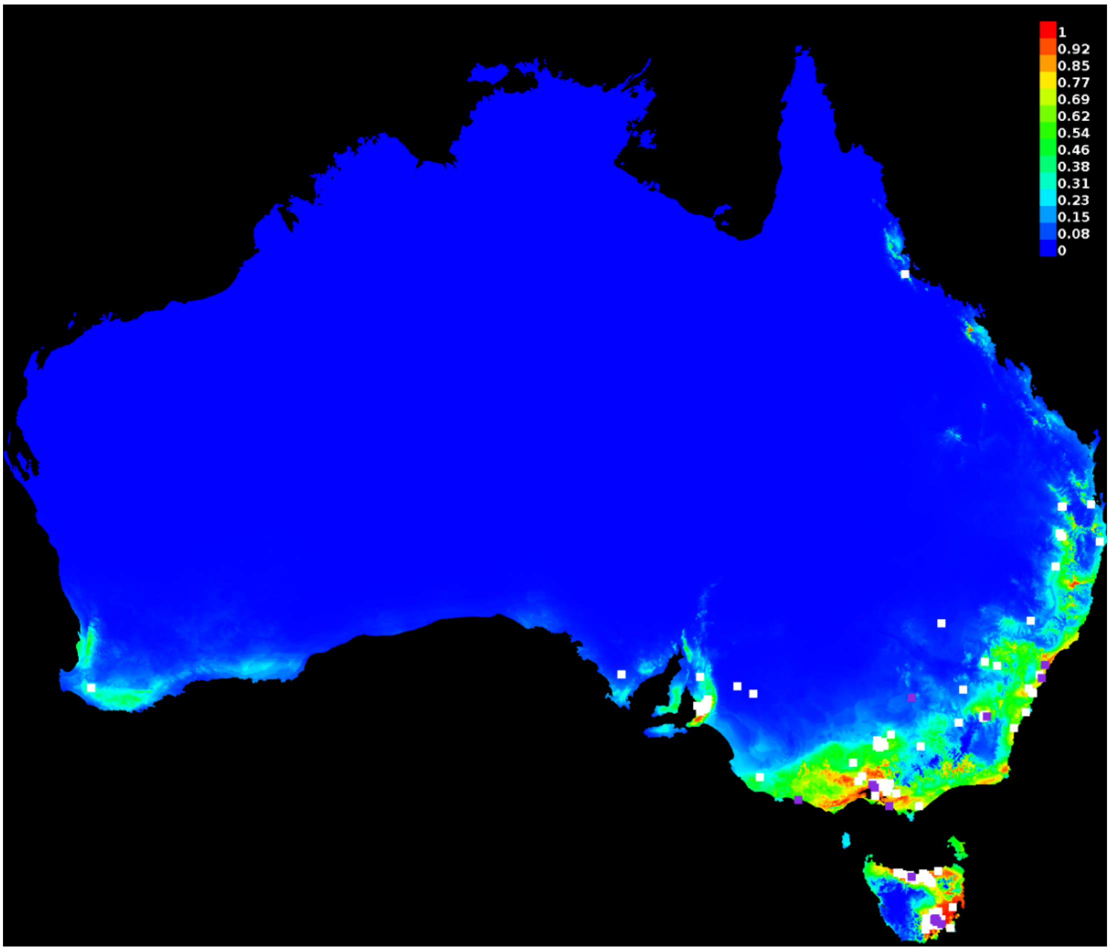


Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6 * training omission rate + .04 * cumulative threshold + 1.6 * fractional predicted area.

Cumulative threshold	Cloglog threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.014	Fixed cumulative value 1	0.211	0.017	0.000	7.251E-11
5.000	0.076	Fixed cumulative value 5	0.120	0.035	0.000	1.507E-14
10.000	0.154	Fixed cumulative value 10	0.084	0.070	0.067	1.271E-14
0.529	0.007	Minimum training presence	0.250	0.000	0.000	9.162E-10
13.790	0.221	10 percentile training presence	0.069	0.096	0.067	7.638E-16
12.588	0.202	Equal training sensitivity and specificity	0.073	0.070	0.067	1.792E-15
12.588	0.202	Maximum training sensitivity plus specificity	0.073	0.070	0.067	1.792E-15
14.528	0.237	Equal test sensitivity and specificity	0.067	0.104	0.067	4.785E-16
30.159	0.463	Maximum test sensitivity plus specificity	0.036	0.217	0.067	8.521E-20
0.529	0.007	Balance training omission, predicted area and threshold value	0.250	0.000	0.000	9.162E-10
10.179	0.157	Equate entropy of thresholded and original distributions	0.084	0.070	0.067	1.115E-14

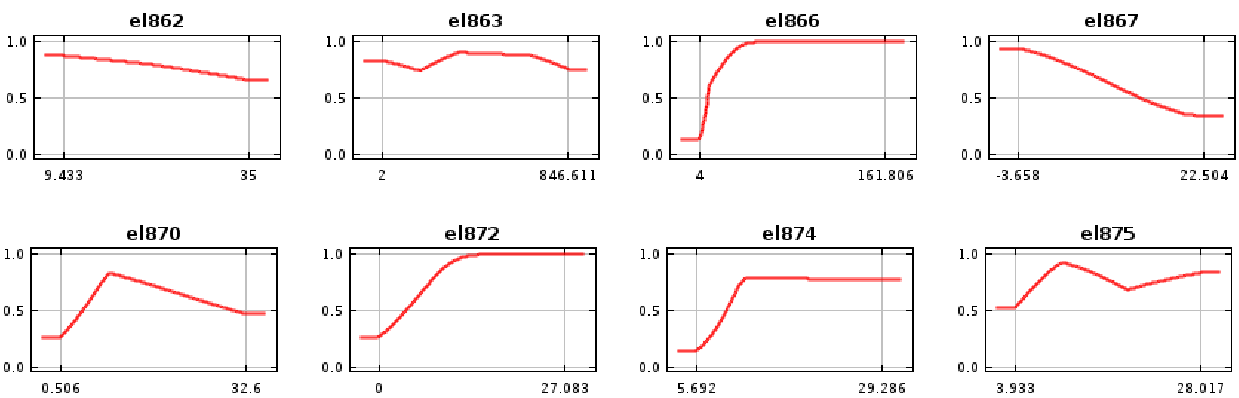
Pictures of the model

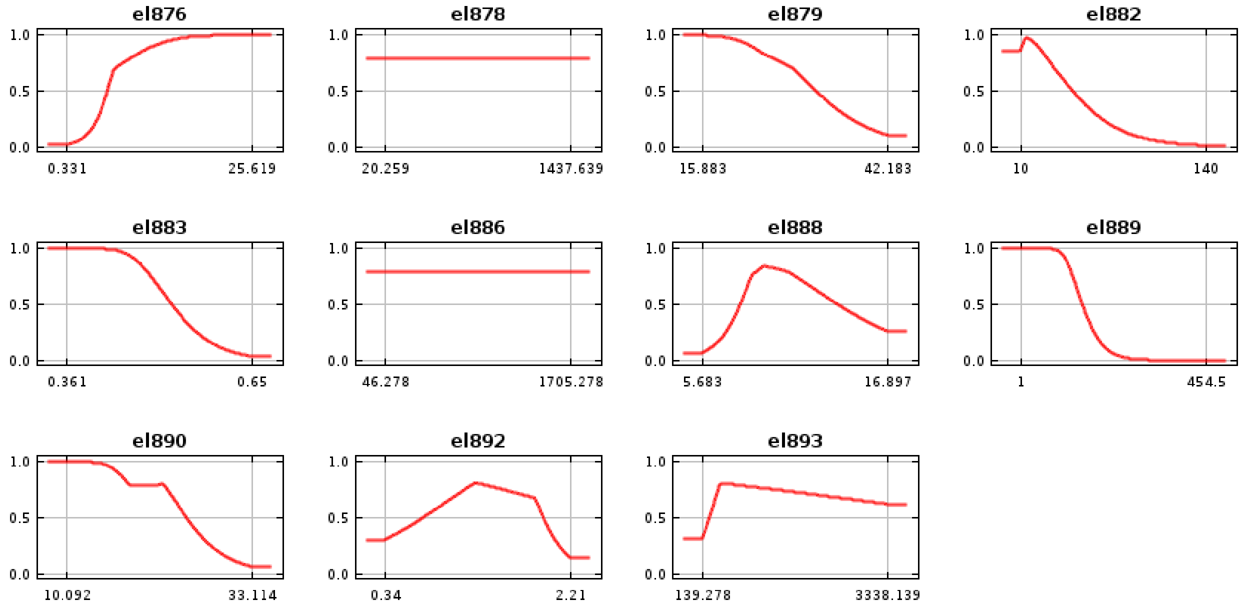
This is a representation of the Maxent model for My dataset. Warmer colors show areas with better predicted conditions. White dots show the presence locations used for training, while violet dots show test locations. Click on the image for a full-size version.



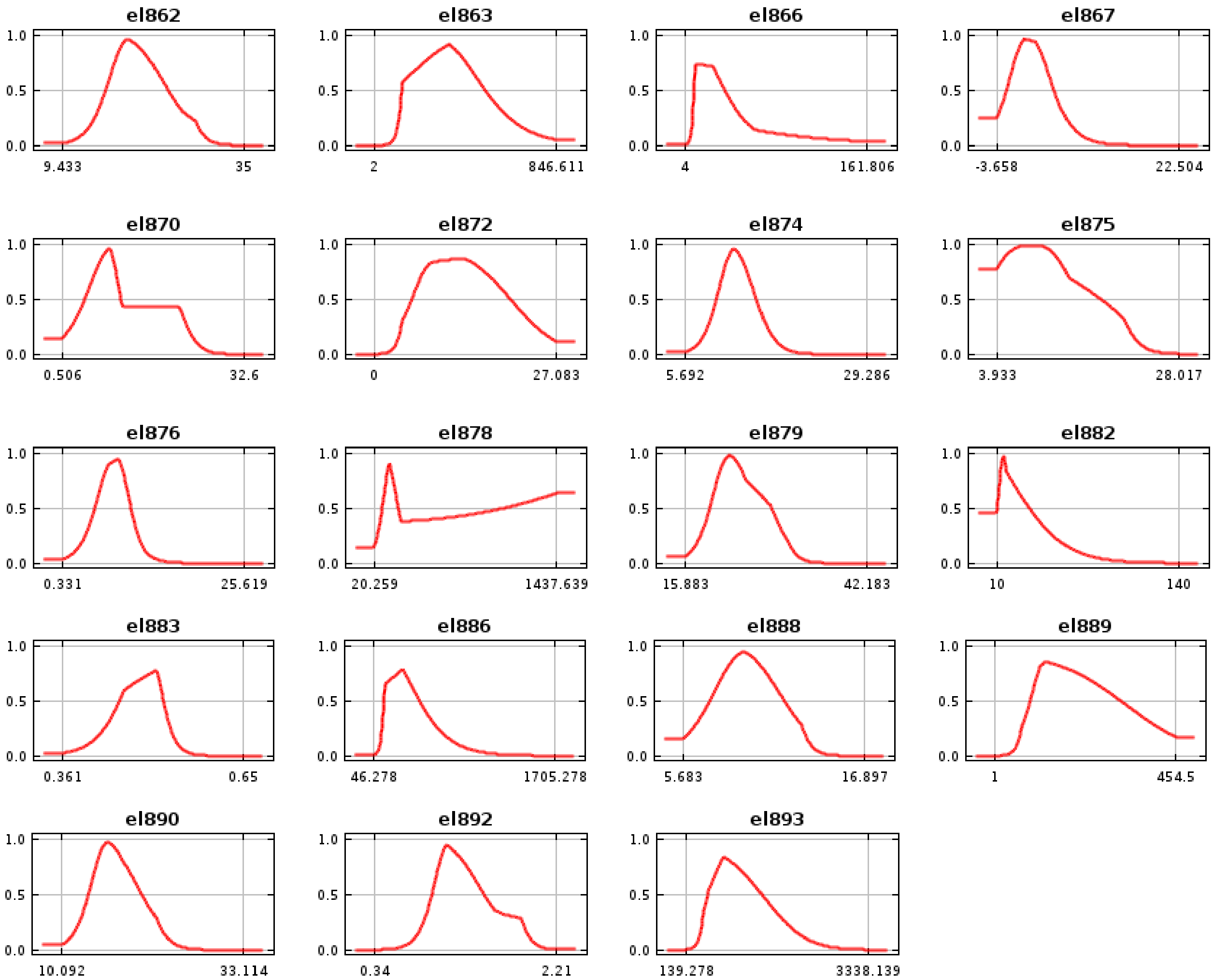
Response curves

These curves show how each environmental variable affects the Maxent prediction. The curves show how the predicted probability of presence changes as each environmental variable is varied, keeping all other environmental variables at their average sample value. Click on a response curve to see a larger version. Note that the curves can be hard to interpret if you have strongly correlated variables, as the model may depend on the correlations in ways that are not evident in the curves. In other words, the curves show the marginal effect of changing exactly one variable, whereas the model may take advantage of sets of variables changing together.





In contrast to the above marginal response curves, each of the following curves represents a different model, namely, a Maxent model created using only the corresponding variable. These plots reflect the dependence of predicted suitability both on the selected variable and on dependencies induced by correlations between the selected variable and other variables. They may be easier to interpret if there are strong correlations between variables.

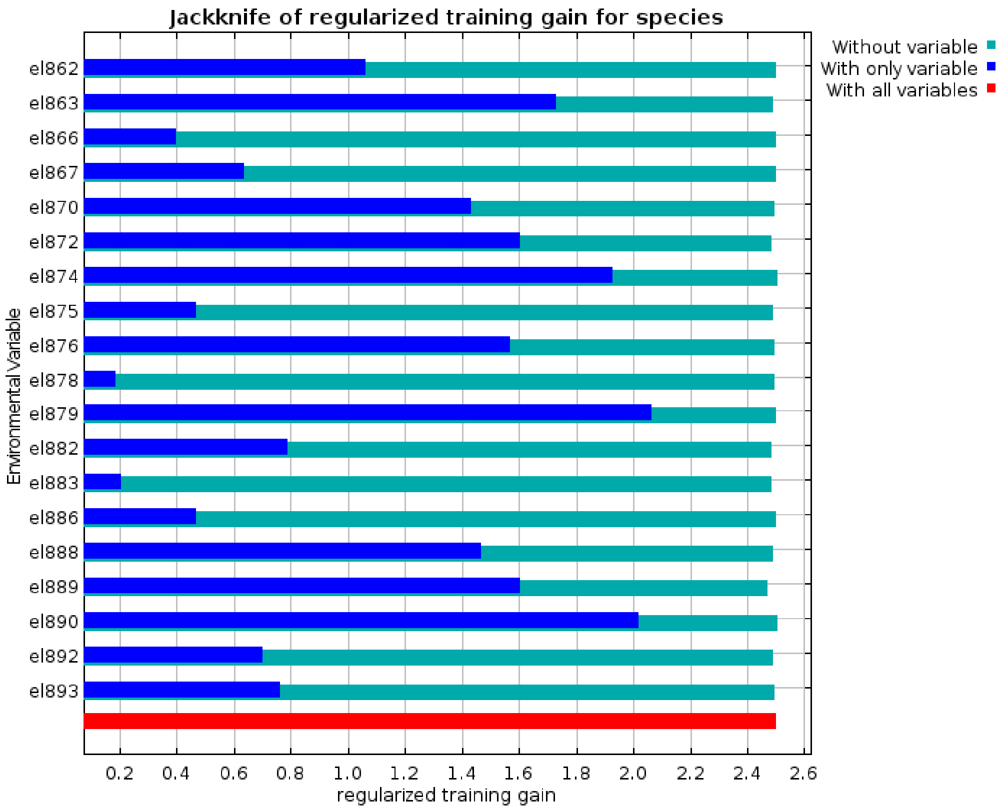


Analysis of variable contributions

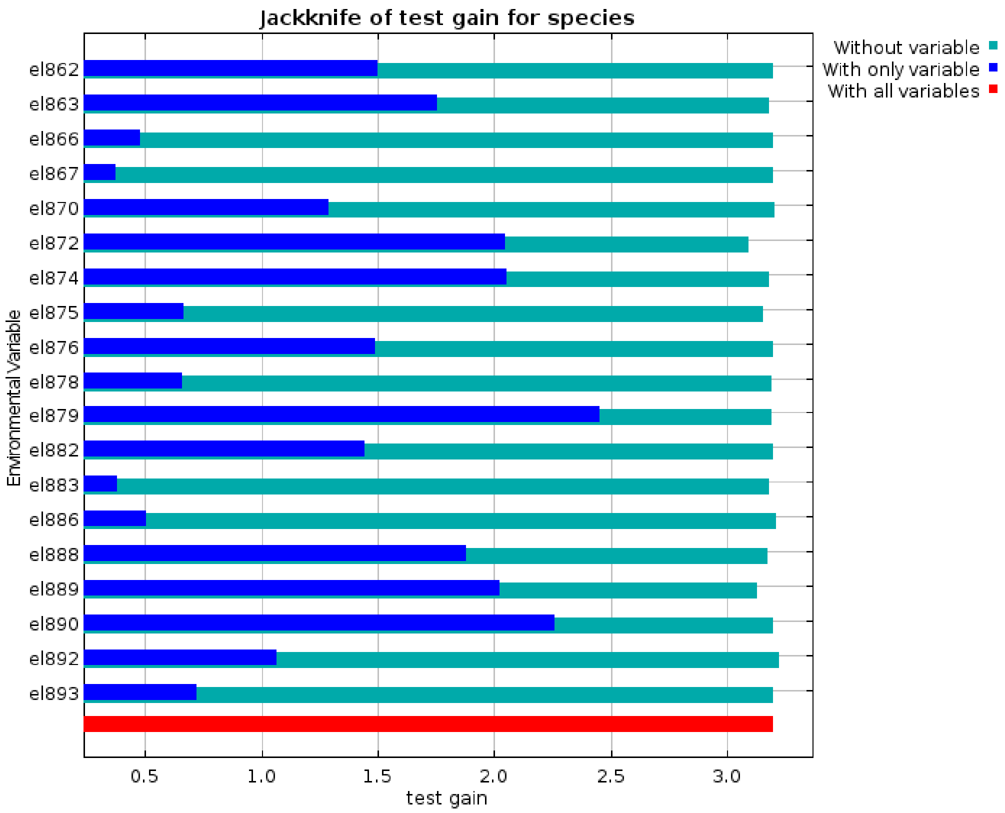
The following table gives estimates of relative contributions of the environmental variables to the Maxent model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable, or subtracted from it if the change to the absolute value of lambda is negative. For the second estimate, for each environmental variable in turn, the values of that variable on training presence and background data are randomly permuted. The model is reevaluated on the permuted data, and the resulting drop in training AUC is shown in the table, normalized to percentages. As with the variable jackknife, variable contributions should be interpreted with caution when the predictor variables are correlated.

Variable	**Percent contribution**	**Permutation importance**
Precipitation - coldest quarter (Bio19)	29	0.4
Precipitation - driest period (Bio14)	24.1	7.1
Temperature - warmest quarter (Bio10)	15.1	11.7
Temperature - diurnal range mean (Bio02)	6.2	2.5
Temperature - warmest period max (Bio05)	5.3	4.9
Temperature - annual mean (Bio01)	5	0.3
Temperature - annual range (Bio07)	3.4	0.4
Temperature - coldest quarter mean (Bio11)	2.6	4.9
Temperature - wettest quarter mean (Bio08)	1.9	0.6
Temperature - isothermality (Bio03)	1.8	8.3
Temperature - driest quarter mean (Bio09)	1.4	0.9
Temperature - seasonality (Bio04)	1.3	4.7
Precipitation - driest quarter (Bio17)	1.1	9.8
Precipitation - seasonality (Bio15)	1	24.2
Precipitation - annual (Bio12)	0.5	0.9
Precipitation - wettest period (Bio13)	0.1	17.9
Temperature - coldest period min (Bio06)	0.1	0.5
Precipitation - warmest quarter (Bio18)	0	0
Precipitation - wettest quarter (Bio16)	0	0

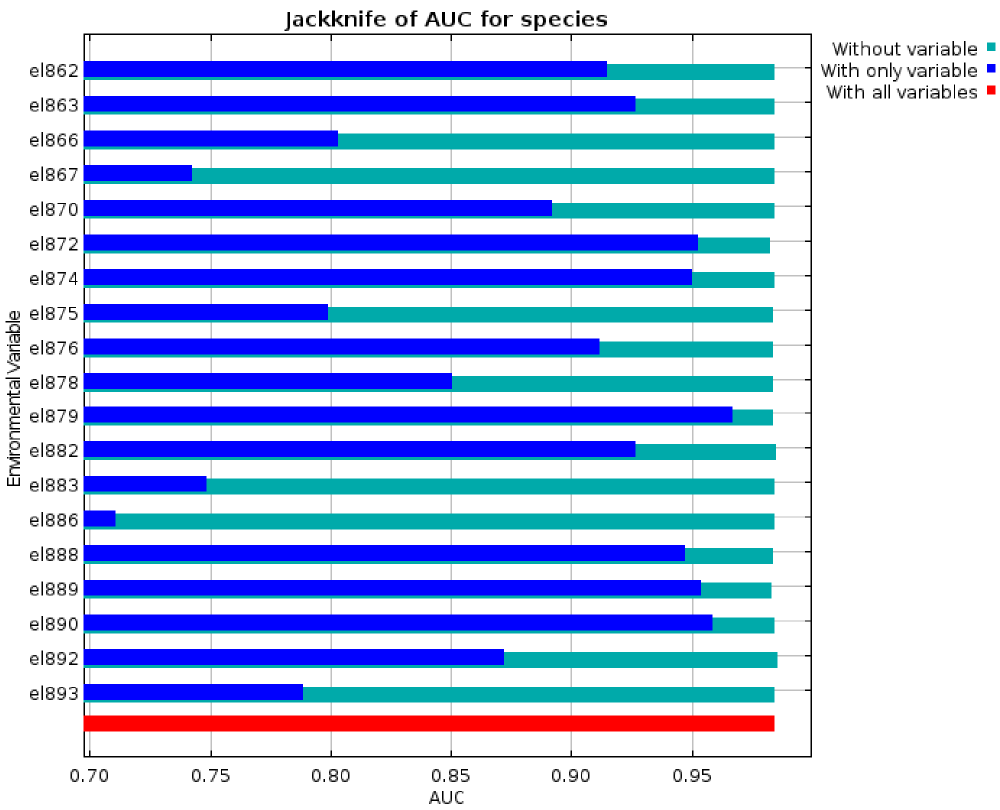
The following picture shows the results of the jackknife test of variable importance. The environmental variable with highest gain when used in isolation is el879, which therefore appears to have the most useful information by itself. The environmental variable that decreases the gain the most when it is omitted is el889, which therefore appears to have the most information that isn't present in the other variables.



The next picture shows the same jackknife test, using test gain instead of training gain. Note that conclusions about which variables are most important can change, now that we're looking at test data.



Lastly, we have the same jackknife test, using AUC on test data.



Raw data outputs and control parameters

The data used in the above analysis is contained in the next links. Please see the Help button for more information on these.

The model applied to the training environmental layers
The coefficients of the model
The omission and predicted area for varying cumulative and raw thresholds
The prediction strength at the training and (optionally) test presence sites
Results for all species modeled in the same Maxent run, with summary statistics and (optionally) jackknife results

Regularized training gain is 2.501, training AUC is 0.973, unregularized training gain is 2.719.
Unregularized test gain is 3.197.
Test AUC is 0.984, standard deviation is 0.007 (calculated as in DeLong, DeLong & Clarke-Pearson 1988, equ 2).
Algorithm terminated after 500 iterations (16 seconds).

The follow settings were used during the run:
115 presence records used for training, 15 for testing.
10115 points used to determine the Maxent distribution (background points and presence points).
Environmental layers used (all continuous): Temperature - annual range (Bio07) (el862) Precipitation - coldest quarter (Bio19) (el863) Precipitation - wettest period (Bio13) (el866) Temperature - coldest period min (Bio06) (el867) Temperature - wettest quarter mean (Bio08) (el870) Precipitation - driest period (Bio14) (el872) Temperature - annual mean (Bio01) (el874) Temperature - driest quarter mean (Bio09) (el875) Temperature - coldest quarter mean (Bio11) (el876) Precipitation - warmest quarter (Bio18) (el878) Temperature - warmest period max (Bio05) (el879) Precipitation - seasonality (Bio15) (el882) Temperature - isothermality (Bio03) (el883) Precipitation - wettest quarter (Bio16) (el886) Temperature - diurnal range mean (Bio02) (el888) Precipitation - driest quarter (Bio17) (el889) Temperature - warmest quarter (Bio10) (el890) Temperature - seasonality (Bio04) (el892)

Precipitation - annual (Bio12) (el893)
Regularization values: linear/quadratic/product: 0.050, categorical: 0.250, threshold: 1.000, hinge: 0.500
Feature types used: hinge product linear quadratic
responsecurves: true
jackknife: true
outputdirectory:
samplesfile: tmp/1587968323911/species_points.csv
environmentallayers: /tmp/1587968249877/
warnings: false
tooltips: false
randomtestpoints: 12
autorun: true
visible: false
threads: 4
prefixes: false

e records used for training, 15 for testing.
10115 points used to determine the Maxent distribution (background points and presence points).
Environmental layers used (all continuous): Temperature - annual range (Bio07) (Temperature - annual range (Bio07) (el862)) Precipitation - coldest quarter (Bio19) (Precipitation - coldest quarter (Bio19) (el863)) Precipitation - wettest period (Bio13) (Precipitation - wettest period (Bio13) (el866)) Temperature - coldest period min (Bio06) (Temperature - coldest period min (Bio06) (el867)) Temperature - wettest quarter mean (Bio08) (Temperature - wettest quarter mean (Bio08) (el870)) Precipitation - driest period (Bio14) (Precipitation - driest period (Bio14) (el872)) Temperature - annual mean (Bio01) (Temperature - annual mean (Bio01) (el874)) Temperature - driest quarter mean (Bio09) (Temperature - driest quarter mean (Bio09) (el875)) Temperature - coldest quarter mean (Bio11) (Temperature - coldest quarter mean (Bio11) (el876)) Precipitation - warmest quarter (Bio18) (Precipitation - warmest quarter (Bio18) (el878)) Temperature - warmest period max (Bio05) (Temperature - warmest period max (Bio05) (el879)) Precipitation - seasonality (Bio15) (Precipitation - seasonality (Bio15) (el882)) Temperature - isothermality (Bio03) (Temperature - isothermality (Bio03) (el883)) Precipitation - wettest quarter (Bio16) (Precipitation - wettest quarter (Bio16) (el886)) Temperature - diurnal range mean (Bio02) (Temperature - diurnal range mean (Bio02) (el888)) Precipitation - driest quarter (Bio17) (Precipitation - driest quarter (Bio17) (el889)) Temperature - warmest quarter (Bio10) (Temperature - warmest quarter (Bio10) (el890)) Temperature - seasonality (Bio04) (Temperature - seasonality (Bio04) (el892)) Precipitation - annual (Bio12) (Precipitation - annual (Bio12) (el893))
Regularization values: linear/quadratic/product: 0.050, categorical: 0.250, threshold: 1.000, hinge: 0.500
Feature types used: hinge product linear quadratic
responsecurves: true
jackknife: true
outputdirectory:
samplesfile: tmp/1587968295079/species_points.csv
environmentallayers: /tmp/1587968248759/
warnings: false
tooltips: false
randomtestpoints: 12
autorun: true
visible: false
threads: 4
prefixes: false

Appendix 2: Import permit for sterile codling moth

Australian Government
Department of Agriculture, Water and the Environment

Permit to import conditionally non-prohibited goods
This permit is issued under *Biosecurity Act 2015* Section 179 (1)

Permit: 0003919181

Valid for: multiple consignments between 7 April 2022 and 7 April 2024

This permit is issued to: Dr Guy Westmore
165 Westbury Road
Kings Meadows
PROSPECT TAS 7250
Australia

Attention: Dr Guy Westmore

This permit is issued for the import of Biological or Plant Products (Non-standard goods).

Exporter details:	Specific exporter/s
Exporter contact:	Okanagan-Kootenay Sterile Insect Release Program (OKSIR) 1450 KLO Road Kelowna BRITISH COLUMBIA V1W 3Z4 Canada
Country of export:	Canada

This permit includes the following good(s). Refer to the indicated page for details of the permit conditions:

1. Biological control agents		
Description:	Cydia pomonella (Codling moth)	
End use:	Biological control	
Other end use:	Direct release into the environment	
Country of origin:	Canada	
Permit Conditions:	Processed materials for research	Page 3

NOTE: Where a good has more than one set of permit conditions please read each set to determine which set of permit conditions applies to a specific consignment.

-- **End of commodity list** --

This permit is granted subject to the requirement that fees determined under section 592(1) are paid.

Adam Zur
Delegate of the Director of Biosecurity — Date: 07 April 2022

Important information about this permit and the import of goods

***Note:** This permit covers Department of Agriculture, Water and the Environment import conditions. It is the permit holder's responsibility to ensure all legal requirements relating to the goods described in this permit are met. While the permit holder should rely on their own inquiries, the following information is provided to assist the permit holder in meeting legal obligations in relation to the importation of the goods described in this permit.*

Information about this permit

Authority to import

The permit holder is authorised to import the goods described in this permit subject to the listed conditions specified in this permit.

Compliance with permit conditions and assessment and management of biosecurity risk

All imports are subject to biosecurity control and may be subject to biosecurity inspection on arrival to determine compliance with the listed permit conditions and to assess the level of biosecurity risk associated with the goods. Imports that do not comply with the import conditions specified in the permit may present an unacceptable level of biosecurity risk and may be subject to biosecurity measures that may include treatment, export or destruction at the permit holder's expense or forfeited to the Commonwealth.

Additionally, non-compliance with import permit conditions may constitute an offence or contravention of a civil penalty provision under section 187 of the *Biosecurity Act 2015*.

Change of import conditions

The Director of Biosecurity may, in accordance with section 180 of the *Biosecurity Act 2015* vary or revoke the conditions on a permit or impose further conditions.

General information about importing goods

Notification of import

Notification of the import must be provided to the Department of Agriculture, Water and the Environment for all imported goods other than goods imported as accompanied baggage or goods imported via the mail and not prescribed under *the Customs Act 1901*, or where other exceptions specified in the *Biosecurity Regulation 2016* apply. Notification must be provided in accordance with section 120 of the *Biosecurity Act 2015* and Part 1 of Chapter 2 of the *Biosecurity Regulation 2016*. Please refer to 'Sending your goods to Australia' on the Department of Agriculture, Water and the Environment website.

Provision of required documentation

It is recommended that all required documentation accompanies each consignment. Required documentation must be presented to the Department of Agriculture, Water and the Environment for assessment. Airfreight or mail shipments should have all required documentation securely attached to the outside of the package, and clearly marked "Attention Department of Agriculture, Water and the Environment". Documentation may include the permit (or permit number), government certification and invoice.

If the product description on the permit varies from the identifying documentation provided, the goods will not be released from biosecurity control unless evidence is provided to the biosecurity officer that the permit covers the goods in the consignment.

Any documentation provided must comply with the Department of Agriculture, Water and the Environment's minimum documentation requirements policy.

Non-commodity cargo clearance

In addition to the conditions for the goods being imported, non-commodity biosecurity risks are assessed including container cleanliness, packaging and destination concerns, and may be subject to inspection and treatment on arrival. Please refer to the Non-Commodity Cargo Clearance BICON case for further information.

Fees

Fees are payable to the Department of Agriculture, Water and the Environment for certain services (see the *Biosecurity Charges Imposition (General) Regulation 2016*, Part 2 of Chapter 9 of the *Biosecurity Regulation 2016* and Part 3 of Chapter 11 of the *Biosecurity Act 2015*). Detail on how the department applies fees and levies may be found in the Charging guidelines.

Compliance with other regulatory provisions

Goods imported into Australia may be subject to regulatory requirements under other legislation. It is the permit holder's responsibility to identify and ensure they have complied with all requirements of any other regulatory agency or advisory body prior to and after importation.

Permit conditions

It is the importer's responsibility to ensure that the following permit conditions are met in relation to each consignment. Where more than one set of permit conditions is shown for a good please read each set of conditions to determine which applies to a specific consignment.

1. Processed materials for research

This section contains permit conditions for the following commodity (or commodities):

1.	Biological control agents	
	Product Description:	Cydia pomonella (Codling moth)

1.1. Biosecurity Pathway

a. These conditions allow for the importation of the following material for research for laboratory work only:

Cydia pomonella (Codling moth) which have been sterilised by gamma irradiation treatment at the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility, located in Canada.

Cydia pomonella (Codling moth) must also be marked internally with dye, in order to ensure sterile moths can be distinguished from wild moths.

b. The imported material must only be used for:

Direct release into the environment for biological control use and is limited to only apple orchard field sites in South Australia and Tasmania, as part of a sterile insect release research program.

c. Each consignment must meet all of the specified requirements.

To demonstrate compliance with this requirement you must present the following on a Manufacturer's declaration or Supplier's declaration:

Certification must be provided on a company letterhead (signed and dated) by a recognised expert at the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility:
i. The Cydia pomonella (Codling moth) have been laboratory reared; and
ii. The Cydia pomonella (Codling moth) have been sterilised by gamma irradiation treatment, at a minimum absorbed dose of 200 Gy at the OKSIR facility; and
iii. The Cydia pomonella (Codling moth) are free of contaminating pests such as diseases, insects/mites or parasitoids; and
iv. The species has been identified as Cydia pomonella (Codling moth).

The declaration must be provided by:
Okanagan-Kootenay Sterile Insect Release Program (OKSIR)
1450 KLO Road
Kelowna, V1W 3Z4
British Columbia
CANADA

d. Air freight shipments (including courier) must use the following goods description when lodged in the Integrated Cargo System:
"FOR RESEARCH - IMPORT PERMIT ATTACHED"

e. Imported material must be packed in clean and new packaging.

f. All material must be presented on arrival for inspection by a biosecurity officer.

g. Under the Biosecurity Charges Imposition (General) Regulation 2016 and Chapter 9, Part 2 of the Biosecurity Regulation 2016, fees are payable to the Department of Agriculture, Water and the Environment for all services. Detail on how the department applies fees and levies may be found in the Charging guidelines.

h. In addition to the conditions for the goods being imported, non-commodity concerns must be assessed including container cleanliness, packaging and destination concerns, and may be subject to inspection and treatment on arrival. Please refer to the Non-Commodity Cargo Clearance BICON case for further information.

---------------------------------- **End of permit conditions** ----------------------------------

Appendix 3: Economic analysis

AP18001: Pilot sterile codling moth releases for the apple industry

Activity 11. Economic assessment of release programs. Undertake an economic cost benefit analysis on SCM on a per hectare basis for industry and orchardists: establish benchmarks (impact of control measures, aggregate costs etc.); evaluate different release strategies and effect of SCM over a number of years and their influence on aggregate costs, benefits (social and economic); quantify effects on stakeholder (Australian apple industry) and participants (apple growers); evaluate risks and uncertainties due to changes in climatic events and costs; determine benefits in real world situation for commercialisation. We believe that it is too early to develop a commercialisation plan as this would be dependent on the outcome of the cost/benefit analysis.

Prepared by Nic Finger, Horticultural Consultant

nic@fruit.help

Content

1.0 Overview

This report details an economic analysis of a potential sterile codling moth (SCM) release program. The analysis aimed to establish an approximate per hectare cost, potential release strategies and potential effect of a longer term timeframe in terms of aggregate costs, benefits and opportunities.

Consideration to potential shift in climate, agrichemical effectiveness and social considerations were evaluated but without wider stakeholder surveying were not able to be quantified in the context of this analysis.

2.0 Economic impact of codling moth on apple and pear production

Codling moth is one of the key pests of apple and pear production. Damage from codling moth sees fruit downgraded or destroyed due to damage, and losses can be extensive when control of the pest is poor.

In the context of the current project, fruit damage comparisons between grower standard control measures and sterile insect technique (SIT) for codling moth were compared. The results of the two years of data were variable, however, consideration to the time taken for population collapse needs to be considered. Regardless, the current project saw mixed results with two of the three release sites seeing a reduction in fruit damage relative to grower-control; the paired group that saw an increase in fruit damage in the release site was split, with the control and release sites at two different orchards in a similar area.

Comparison of SIT control relative to pesticide and mating disruption in Canada (Gill, 2014) demonstrated a clear difference in injury levels between techniques with pesticide control, mating disruption and SIT measured to have 3.1%, 0.41% and 0.04% fruit damage levels in their study. Using this scenario (Table 1) the potential gains on previous damage losses identified in Table 1 would suggest potential gains are between $40.35 and $45.9 per tonne for using mating disruption and SIT respectively.

Table 1. Effect of control method on fruit value utilising data from Gill (2014)

Method	**Damage**	**Fruit value loss per 50 tonnes due to pest at $1.5/kg Class 1 (to orchard gate)**	**Relative position to pesticide based control**
Pesticide control	3.10%	$2,325	-
Mating disruption	0.41%	$307.5	+ $2,017.5
Sterile insect technique	0.04%	$30	+ $2,295

3.0 Current practise and associated costs

Current codling moth control practises typically rely on chemical control supplemented by pheromone-based mating disruption, *Bacillus thuringiensis* (Bt) sprays and the use of codling moth granulosis virus. In some areas, the use of drape netting (for bird and hail protection) also provides some level of crop exclusion by restricting flight between rows.

Most growers employ a combination of these techniques dependent on site pressure, pest control in the previous season and any other market restriction (for example, MRL requirements for target markets on certain chemicals, timing to harvest and phytosanitary requirements). In addition, organic producers are limited to Bt, virus and disruption techniques with conventional agrichemical sprays not an option under organic certification body requirements.

The number of codling moth generations vary between regions with 2-3 full generations typically observed across the spread of Australian growing climates.

Assuming an average dilute spray volume of 1,500L/ha and standard chemical/application costs as per Table 2.

Table 2. Typical control agents and prices used as base assumptions for costings of chemical control

ID	Control measure	Chemical cost *sourced at average price from 2023/24 season at a large commercial farm	Application cost *assuming $35/hour labour unit	Total cost (per hectare)
A	Pheromone ties deployed into orchard	$550 / ha	$250/ha 5 hours / ha using cherry picker; costing cherry picker at $15/hour	$800
B	Bt spray (1.5kg/ha)	$18.20 / ha	$70/ha Or combined with other spray	$88.20
C	Fenoxycarb	$50.96 / ha	$70/ha Or combined with other spray	$120.96
D	Codling moth granulosis virus	$93.10 / ha	$70/ha Or combined with other spray	$163.10
E	Chlorantraniliprole	$144.78 / ha	$70/ha Or combined with other spray	$214.78
F	Spinetoram	$220.5 / ha	$70/ha Or combined with other spray	$290.50
G	Novaluron / Acetamiprid	$82.71 / ha	$70/ha Or combined with other spray	$152.71
H	Tetraniliprole	$126.20 / ha	$70/ha Or combined with other spray	$196.20
I	Thiacloprid	$49.73 / ha	$70/ha Or combined with other spray	$119.73
J	Indoxacarb	$140.09 / ha	$70/ha Or combined with other spray	$210.09
K	Other registered chemicals	$80-225 / ha	$70/ha Or combined with other spray	$150-295

Using these base assumptions, the below scenarios have been selected as potential control options under minimal and heavy pressure scenarios (Table 3). A typical average spend has been estimated at $1500/ha for control measures and application costs.

Table 3. Different control scenarios and associated costs (referencing Table 2)

Scenario	Products used	Total estimated cost per ha
Minimal (with mating disruption)	A B C x 3	$1,251.08

Heavy pressure without mating disruption	G x 2 H x 2 I x 2 G x 2	$1,242.70
No conventional agrichemicals	A B x 4 D x 4	$1,936.24
Approximate range		$1,250-2,000
Average costing (estimated)		$1,500

4.0 Costings of implementation

Implementation of SIT requires specialised approaches as well as area wide management to ensure continued success. Given the relatively limited range of codling moth flights, relatively small areas have the potential to be under SIT for this pest assuming a positive cost:benefit can be achieved to justify the implementation of the program.

Given this technique is only employed in Canada for control of codling moth, analysis of their cost structure, as well as costs incurred in this trial and information gathered from New Zealand's trial approach have been considered and presented below.

Tasmania trial costs per hectare

Costings of importation as part of this trial are outlined below (Table 4). In total, a 17 week release season was used at an average cost of $6,073/ha for the two years of releases. This does not include the cost of releases (walking every third row), which was estimated to be an additional $35/ha in line with other typical insect release costs (allowing 1 hour per hectare inclusive of handling, preparation and waste disposal). Different methodologies to release would be possible under commercial scenarios (ATV, walking, drone etc.), but all would be expected to fall at $35/ha direct cost or are estimated at $70/ha under commercial arrangements.

As such, the total cost for the trial releases was $6,108/ha, however, exclusion of the freight and associated costs (assuming managed in Australia at a commercial scale at a similar cost to produce) actual sterile codling moth and application costs would be closer to $2,000/ha under this trial scenario.

Table 4. Costs incurred for importation and sourcing of sterile codling moth from Canada.

Year	**2022-2023**	**2023-2024**
<u>Purchase of SCM from OKSIR, Canada</u>		
Sterile moths	$1,490	$1,647
Packaging/labour/transport	$46	$775
Freight	$2,284	$2,237
<u>Quarantine & import charges</u>		
Import GST charges	$188	$212
Quarantine processing charge	$38	$43
Border Force charges	$243	$248
Biosecurity charges	$143	$222
Customs Broker charges	$108	$108

Qantas Freight charges	$137	$138
Total Weekly Costs	$5,377	$5,768
Total season costs (17 weeks)	$91,409	$98,056
Project cost per hectare	**$5,860**	**$6,286**

Canadian example

Evaluation of OKSIR's financial statements (Table 5) suggests that implementation of their program results in a net cost per hectare (of treated orchard) to be ~CAD$1,300/ha (AUD$1,430/ha at time of writing). With an estimated treated area of 3035 hectares in the SIT program. This program has now been in continuous operation since 1994 and represents the most likely "real" costs of ongoing management, implementation, research and development and economic stability.

Table 5. Adaptation of OKSIR Financial Statements for the 2021 and 2022 financial years (OKSIR, 2024). Estimated area for the treated area and subsequent cost/ha have been calculated in this table.

Revenue	**2021**	**2022**
Land tax (residential)	$1,710,728	$1,779,157
Parcel tax (orchard)	$1,025,598	$1,071,603
Interest	$4,203	$21,921
Miscellaneous income	$716,468	$912,513
Grants	$13,145	$44,000
Loss on disposal of assets	-$291	
WSU Decision Aid System	$0	$154,059
	$3,469,851	**$3,983,253**
Expenses		
Amortisation	$210,967	$208,263
Community relations	$4,713	$1,921
Diet ingredients	$278,691	$323,594
General overhead	$385,882	$358,790
Operations	$86,903	$52,442
Postage	$10,036	$33,585
R&D/development	$81,382	$246,021
Supplies - admin	$12,627	$11,242
Supplies - operational	$139,378	$175,926
Utilities	$224,184	$238,777
Vehicles and travel	$161,676	$152,647
Wages	$2,229,947	$2,207,282
Waste management	$20,126	$20,178
	$3,846,512	**$4,030,668**
Annual balance	-$376,661	-$47,415
Treated orchard area (ha) estimated*	3035	3035
Cost per hectare	**$1,267**	**$1,328**

NZ experience

Recent New Zealand trial experience suggested costs of their pilot SIT program was $NZD238/ha (subsidised by OKSIR) with the real price estimated at NZD$500/ha. These trials also evaluated delivery methods, with significant gains in efficiency for unmanned options, particularly in larger orchards with application as low as 1 minute per hectare for moth delivery (Lo *et al*, 2021). Moreover, the New Zealand data would suggest that any implementation should greatly consider aerial methods to release moths at scale to reduce costs.

Ongoing control costs in addition to SIT for codling moth

Whilst sterile codling moth does provide reduced wild moth numbers across treated areas, some level of control is still required to ensure economic damage control of other pests (eg. light brown apple moth) as well as the capability for threshold spraying wild moth catches. This is estimated to be ~$350/ha annually (a reduction of ~$900/ha).

If widespread SIT was introduced, the initial release year would be expected to require a standard program with reductions to sub spray thresholds expected within the next two years and a 'maintenance' at the above $350/ha figure where moth catches are low.

Regional suitability and potential model of implementation

Australia's apple and pear growing region extends across all states with the largest production density being in Victoria's Goulburn Valley region. With ~60% of the national planted area for apples and pears, Victoria is the largest region nationally, with the remaining area relatively similar across all other states (8-10%).

All regions would largely be considered suitable for implementation of SIT techniques with density generally restricted to key growing regions. "Satellite" growers (those outside the main centres) would have the potential for participation through undertaking releases themselves.

The greatest challenge identified to implementation is likely to be funding of the program. Under a user-pays scenario, regulatory framework (most likely at each state's level would be required and desire from both the wider growing industry, or for co-funding from other sources (eg. residential) is likely to face significant opposition.

Managing risk

Whilst a potential solution to implementation of SIT would be sourcing direct from OKSIR, it became evident during the course of the current project that disruption is a possibility. Given COVID-19 disruptions are unlikely to be seen at such a scale this is unlikely, however, the Australian season coincides with Canada's winter period and flight delays due to snowfalls and similar impacts are possible.

Given these risks, irradiation of a codling moth population, or consideration to importation of eggs and on-shore irradiation or production at a local SIT facility would need to be considered if implementation was pursued.

5.0 Benefits, risks and opportunities

Whilst there are significant challenges to overcome (namely, funding) to allow implementation of area wide management of codling moth under SIT, consideration toward direct cost reduction benefits as well as market access, social and potential shifts in longer term climate, agrichemical availability and consumer demand all need to be considered.

Perceived benefits

In addition to direct reductions in fruit damage and associated increases in gross return to the producer, other benefits should also be considered. Under this analysis, no quantification of these benefits has been completed. Surveying at various stakeholder levels would be required to establish these thresholds.

Other benefits identified in addition to direct fruit damage attribution are:

- Reduction in the use of chemicals required to control the pest
  - British Columbia usage in the SIT zone in <10% of levels at start of implementation (OKSIR)
  - Associated improvements in beneficial insect levels
- Potential for area wide management approaches to market access for codling-moth sensitive markets
- Area wide structure to support other SIT control programs (eg. Queensland Fruit Fly)
- Preparedness for further shifts in consumer demands for pesticide free products
- Potential export market for SIT to neighbouring countries
- Preparedness for warmer climate and increased codling moth seasonal pressure as a result of it
- Preparedness for agrochemical resistance in the codling moth population

Impact/economic analysis

Comparisons of three greenfield scenarios under equivalent assumptions for all aspects outside of damage due to codling moth and cost of control for method (Tables 1 and 2) were completed (Appendix 1). The base assumptions used in this scenario can be viewed there. Perceived social benefits were not quantified in this analysis due to limited data.

Under base assumptions, slight improvements for investment scenarios were observed (Table 5). Further analysis of the breakeven point of SIT relative to mating disruption was established as $1491.19/ha. It is important to note that the total cost of SIT would still likely require some sprays and is estimated to be ~$350/ha per year. As such, the cost of SIT application would need to be $1141.19/ha or less direct cost to break even under this scenario.

Table 5. Outcome of 20 year depreciated cash flow for greenfield single hectare investments under different control scenarios under equivalent assumptions.

Method of control for scenario	Cost of codling moth control (per hectare)	Class 1 packout	IRR to year 20	NPV (8%) after 20 years	Relative to pesticide only	Relative to mating disruption
Pesticide	$1,242.70	71.9%	3.3%	-$481,334	-	-$137,083
Mating disruption	$1,251.08	74.6%	4.8%	-$344,251	$137,083	-
SIT at $750/ha	$750	74.96%	5.4%	-$285,766	$195,568	$58,485
SIT at $1000/ha	$1,000	74.96%	5.2%	-$305,493	$175,841	$38,758
SIT at $1500/ha	$1,500	74.96%	4.8%	-$344,947	$136,387	-$696

6.0 Conclusions and recommendations

An economic analysis and consideration of broader potential costs and benefits of the program has demonstrated:

- Damage from codling moth to apples between control techniques varies
    - SIT is reported to have the lowest damage rates (Table 1) relative to mating disruption and pesticide use only
        - Gains in gross orchard gate income are expected to be higher under SIT relative to mating disruption (+$277.5) or pesticide use only (+$2295)
- Implementation cost benefit is largely dependent on actual cost of release which requires significant levels of assumptions
    - Modelling of NPV over 20 years (considered life of orchard) for different codling moth control techniques demonstrated benefit over pesticide/mating disruption (Table 5) where cost was less than $1491.19/ha
        - As such, cost to growers for application of codling moth would need to be $1191.19/ha or less to achieve a positive cost:benefit relationship (assuming a $350/ha spray control requirement for threshold exceedance)
            - Any business case for sterile codling moth import or local production would require that these costs are feasible for the size of the Australia industry
            - Without regulatory framework to collect mandatory payments to fund this initiative it is highly unlikely to be possible
                - State and federal barriers would likely be encountered
        - Cost of implementation in Canada is currently ~AUD$1430/ha
- Additional benefits would be (or potentially be) gained from:
    - Reduce pesticide use and associated social benefits
    - Reduced pesticide use and beneficial insect population improvements
    - Potential to negotiate area-wide approaches to export program phytosanitary requirements
    - Shifts in climate resulting in increased codling moth pressure
    - Changes in agrochemical resistance profiles of codling moth or significant price changes

Recommendations based on these findings:

- All growers should have the benefits of utilising mating disruption clearly communicated to ensure they are following best practise
- Sterile codling moth releases may be viable in Australia with clear target use cases and longer term vision for implementation (including potential subsidy in initial years for establishment)
- An analysis of requirements to allow SIT of codling moth in Australian facilities is completed and the minimum area required under control to produce viable volumes is necessary
    - Low property density growing regions are unlikely to be suitable for area wide management in a cost-effective manner

- If sterile codling moth application was to be implemented, a clear funding model would need to be regulated to allow area wide management and funding
    - This would likely require some level of land tax input which would be incredibly difficult to regulate consistently in all regions and would be likely to face significant opposition from both industry and other potential co-funders (eg. residential)
    - Consideration to aerial release method should also be strongly considered as per findings of *Lo et al, 2021)*
- Consult export partners and experts regarding likelihood of improved market access or phytosanitary requirements for implementation of SIT for codling moth
- Given the geographical spread of the Australian apple and pear industry, considerations of potential other co-beneficiaries should be considered (residential properties, quince and walnut producers and to a lesser extent due to pest preference, stone fruit producers).

References

Cartier, Lee. (2015). Economic Benefits of Using Sterile Insect Technique and Mating Disruption to Control Codling Moth. Journal of Agricultural Science. 7. 10.5539/jas.v7n9p14.

Gill, P. (2014). Statistical analysis of codling moth prevalence and fruit damage data. Paper presented at the May 2014 Regular Meeting of the Okanagan-Kootenay Sterile Insect Release Program, Kelowna, British Columbia. Downloaded from https://www.oksir.org/wp-content/uploads/2016/08/SIR_Report_PGill_June15_2014.pdf

Lo PL, Rogers DJ, Walker JTS, Abbott BH, Vandervoet TF, Kokeny A, Horner RM, Suckling DM. Comparing Deliveries of Sterile Codling Moth (Lepidoptera: Tortricidae) by Two Types of Unmanned Aerial Systems and from the Ground. (2021) J Econ Entomol. 114(5):1917-1926. doi: 10.1093/jee/toab052. PMID: 34180512.

OKSIR SIR Board Financial Statements, *OKSIR Financial Statements,* accessed 12/5/2024 https://www.oksir.org/program-administration/oksir-board/financial-statements/

Walker, J. (2023, August 8). Development of a pilot codling moth SIT program in New Zealand [Video]. Youtube. https://www.youtube.com/watch?v=dJ9RHsqt

AP18001: Pilot sterile codling moth releases for the apple industry

Appendix 1:

M&E (including program logic); Risk management; Stakeholder engagement

Monitoring and Evaluation Plan

Pilot Sterile Codling Moth Releases for the Apple Industry (AP18001 – CON-001733)

18 November 2019

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Contents

Background to the project

Codling moth (*Cydia pomonella)* (CM) is a key pest in most pome-fruit production regions worldwide, including Australia where it is considered one of the most economically damaging pests in many production regions. If unchecked, CM can damage 50% to 90% of fruit, resulting in decimation of the industry. Other industries affected by CM in Australia include cherry, summer fruit, nashi and walnut. Current management strategies include chemical control, phenology modelling, regular monitoring, mating disruption and biological control, but chemicals used as part of CM control programs disrupt beneficial insects, substantially affecting integrated pest management (IPM) systems. Codling moth has also developed some resistance to insecticides presently used, making it more difficult to control. Pheromone trapping, feeding attractants and mating disruption have a greater effect in large commercial blocks of trees. However, orchards are reinfested easily from neglected orchards, roadside and unmanaged backyard apple, pear, and stone fruit trees where no CM control is undertaken.

Australia's apple and pear production is valued at $620 million-dollars with fresh exports of $24 million dollars (Australian Horticulture Statistics Handbook for Fruit 2016/17). Nationwide, if 1% fruit losses occur due to CM in the Australian apple and pear industry based on 2016/17 estimates, this equals a loss of $6.2 million dollars in production. In addition to the value of crop loss, the cost of control measures (chemical sprays, monitoring and pheromone traps, biological control and mating disruption practices), discarding damaged fruit during harvesting and adhering to regulatory requirements for export need to be added. Conservative estimates place these additional costs at approximately $0.02 per kilogram based on data from APAL, the Australian Pip Industry "Orchard Business Analysis" and Model Future Orchard 2012 walk. Furthermore, export markets of China, Japan, Thailand and Taiwan require pest monitoring activities be carried out by registered crop monitoring services and future Australian apple market development will be based on how well Australia can control CM. Codling moth will substantially affect exporting apple and pear orchardists as well as stone fruit, cherries, nashi and walnuts.

Development of new technologies that can be integrated into existing IPM strategies will be of considerable benefit to Australian apple and pear growers, improving returns by an estimated $136 million. Sterile Insect Technology (SIT) is a relatively new strategy used for mobile pests. Canada has used SIT within an area-wide approach for CM control in South Okanagan since 1994, and in central and north Okanagan since 2002. As a result, wild CM populations and pesticide use have both been reduced by over 90% (https://www.oksir.org/).

Introduction of a pilot SIT codling moth program to Australia will provide an opportunity for the apple and pear industry to attain substantial improvements in IPM practices, thus reducing reliance on chemical control methods and enabling a practical safe and socially acceptable method for management of CM infestations in neglected orchards and unmanaged trees in backyard and on roadsides. This will provide a substantial benefit to all horticultural crops impacted by CM.

The goal of this pilot project is to develop recommendations for the integration of sterile codling moth (SCM) into existing apple and pear management and production programs in Australia. This pilot project will review the current-status of codling moth in Australian apple and pear growing regions and establish release sites to determine the efficacy of SCM in control of wild populations.

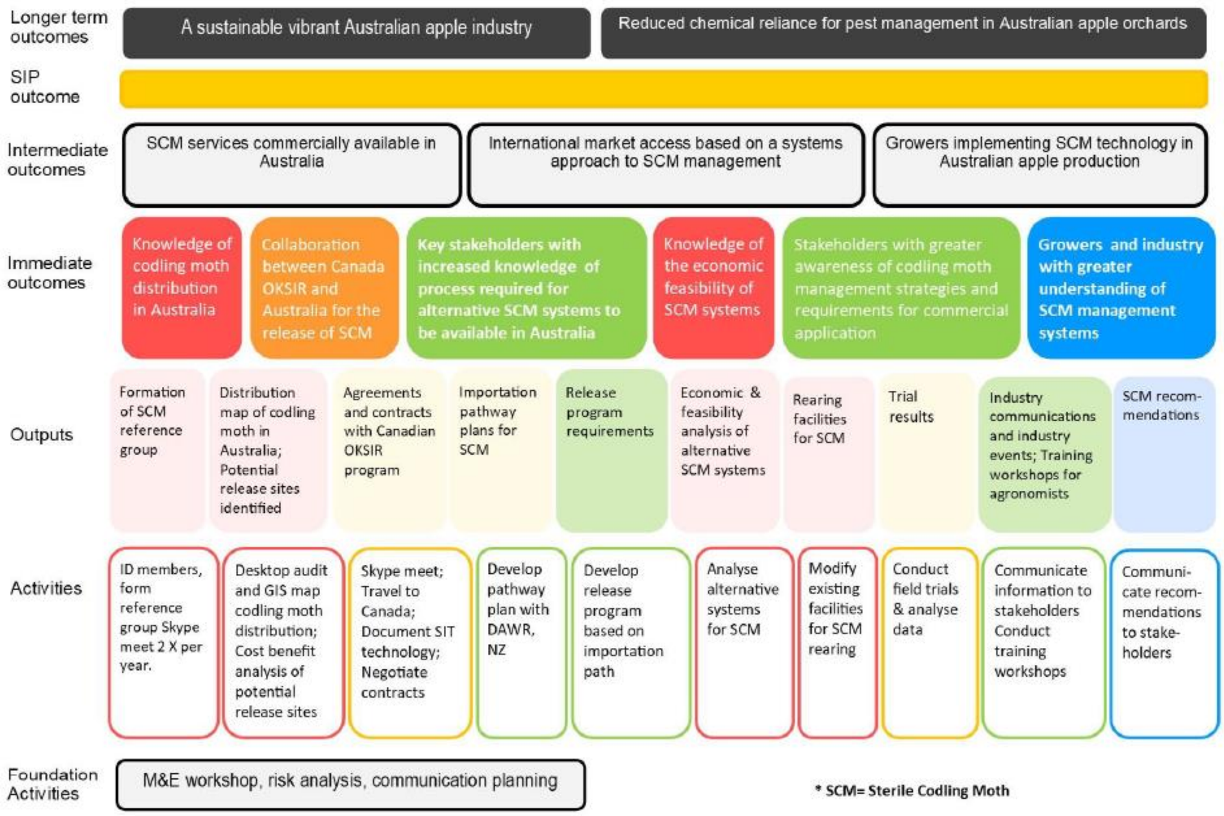
The project will:

- Review, assess and map codling moth distribution/status in Australian apple and pear production regions;
- Identify suitable test regions representative of Australian domestic and export apple production zones for the safe release and testing of SCM;
- Liaise with DA re import restrictions, conditions and possible options; particularly can we develop testing protocols to enable import and release of sterile insects;
- Investigate safe secure biosecurity pathways for entry of SCM from Canada's OKSIR sterile insect program;
- Cooperate and work with industry grower participants and community stakeholders to determine the effectiveness of SCM within existing area-wide integrated pest management (IPM) programs;
- Undertake pilot releases of SCM, including testing and optimising release systems, and quantifying the impact of sterile releases on the effectiveness of control of codling moth;
- Investigate sterile insect release options e.g. static release within target orchards, roving from a vehicle or area wide aerial release;
- Provide a highly accessible point of contact for community and industry enquiries about this pilot program ensuring community and stakeholder engagement on its scientific progress and findings;
- Develop decision support systems for SCM release for area-wide IPM systems based on environmental conditions, topography, vegetation and host density;
- Conduct an economic assessment of the release program and a cost benefit analysis of sterile insect technologies for control of codling moth for the apple and pear industry, including the potential of on-shore rearing and sterilisation within Australia;
- Make recommendations for the adoption and integration of SCM into existing pest management programs for all Australian apple and pear growing regions.

Abbreviations:

APAL	Australian Apple and Pear Limited
BT	Biosecurity Tasmania
CM	Codling Moth
DA	Department of Agriculture
DPIPWE	Tasmanian Department of Primary Industries, Water and Environment
HIA	Hort Innovation Australia
IPM	Integrated Pest Management
KEQ	Key Evaluation Questions
SARDI	South Australian Research and Development Institute
SCM	Sterile Codling Moth
SIAP	Strategic Industry Advisory Panel
SIT	Sterile Insect Technology
TIA	Tasmanian Institute of Agriculture

1 Program logic



2 Scope of the project M&E

2.1 Next users of the project outputs

Table 1: Next users of project outputs

Next Users (Stakeholders)	Purpose of engagement with the project	What the project will deliver to these groups
Project team (primary)	Deliver the outputs and outcomes of the project; Implementers of the evaluation, user of evaluation findings	Knowledge and understanding of SCM pathways; Strategies for release
Grower participants in trials (apple growers/ levy payers)	Provision of trial sites. Provide input into the development and review of SCM strategies	Knowledge and skills to implement SCM program
Canada OKSIR program	Supply of SCM to Australia	Expanded out of season production opportunity for SCM
Australian apple growers (Farm managers, employees, agronomists)	To provide information on current management strategies and distribution of CM. To review SCM strategies. Next users of SCM services and project findings	Knowledge and skills to implement SCM program
Apple and IPM Service industry (Biocontrol agent suppliers, chemical resellers, agronomists, consultants)	Provide technical expertise. Support the apple industry through development of a delivery service for SCM. are compatible with IPM strategies. Next user of the project findings.	Knowledge and understanding of SCM delivery requirements and SCM implementation in orchards.
Wider community (includes the broader pome fruit industry, advisors, agronomists, technicians and the general public)	Support of the SCM project through an understanding of the impact of CM on industry and Sterile insect technology as an alternative management option	Awareness of the project and its impact on apple production in Australia. Awareness of the benefits of sterile insect technology
Current investors and collaborators (HIA, TIA, UTAS, APAL, DPIPWE, DA, BT)	To support the SCM project through an understanding of the impact of CM on the industry	Knowledge of the feasibility of implementing SCM technology in Australia
Researchers, technical experts	To provide technical feedback on the project	Awareness of the project.

2.2 Evaluation Audience

Table 2: Monitoring and evaluation audience

Who will use the evaluation?	What do they want to know?	How will they use the M&E results?
Primary audience		
Project team	Relevance Appropriateness Effectiveness Impact Efficiency	Continuous improvement; demonstrate our track record to future collaborators and investors; Reporting to stakeholders; Compliance with funding guidelines and progress against milestones
HI	Impact Relevance Effectiveness	Reporting to growers and other stakeholders the value of the project
Secondary audience		
TIA, SARDI	Impact Effectiveness Efficiency	Reporting to stakeholders; Create new opportunities for RD&E based on performance

2.3 Key evaluation questions and sub-questions

Effectiveness

Overarching KEQ

To what extent was the project implemented as planned?

Project specific KEQ

To what extent were the proposed activities and outputs delivered?

- Was a distribution map of CM in Australian produced?
- Was formal collaboration with Canada's OKSIR program delivered?
- Was an importation pathway for SCM achieved?
- Were the requirements for releasing SCM established?
- Was the economic feasibility of SCM systems established?

To what extent were the immediate project outcomes achieved?

- Did the project establish the feasibility of SCM management systems in Australia?

Process Appropriateness / Relevance

Overarching KEQ

To what extent was the project relevant to the needs of stakeholders in the context described?

Project specific KEQ

- How relevant was the project to the needs of stakeholders?
- Did the project engage with the right people?
- To what extent were the engagement methods and activities appropriate to the needs of stakeholders? How did the stakeholders value the activities, were they relevant to their business?
- Did stakeholders have sufficient and appropriate participation to achieve the goals of the project?
- To what extent were the project goals feasible given the time, resources and scope?

Impact

Overarching KEQ
What changes can be attributed to the project?

Project specific KEQ

- What are the attitudes and aspirations of next users at the conclusion of the project?
- Do growers aspire to implement SCM strategies?
- To what extent does the service industry aspire to provide a SCM service in Australia?
- To what extent do growers intend to implement SCM strategies?
- What was the impact on next user's knowledge and skills?
  - To what extent did the project increase next users (apple growers/ service providers/consultants) knowledge and understanding of SCM management strategies?

Efficiency

Overarching KEQ
To what extent was the project delivered efficiently?

Project specific KEQ

- Did the project deliver on time and on budget with an efficient use of resources?
- What efforts were made to improve efficiency?

Sustainability

How likely is the project to continue to have an effect once it ceases?

3 Performance expectations, data collection and analysis

3.1 Performance expectations, Key Performance Indicators (KPI's)

50% of Australian apple growers have increased awareness of SCM as an IPM tool for codling moth

25% of Australian apple growers have increased knowledge of SCM management systems necessary to implement SCM in orchards

50% of targeted service providers have increased knowledge of SCM production and release requirements

Economic feasibility report completed

Assessment of SCM release program analysed and reported

Regional pilot release of SCM at 2 locations

Rear-out facilities established in Tasmania if moths are unable to be imported at the adult life-stage – Year 2

Importation plan produced and process approved by DA & AQIS

Feasibility assessment of domestic SCM production

Agreements with Canada OKSIR to allow import of SCM

Distribution map of CM in Australia - Year 1

Web page produced in year 2 and updated biannually (via Australian Apple and Pear IPDM_extension AUS)

Agronomist/service provider workshop conducted Year 3

Field day presentations - Year 3

E-news communications: Updates biannually in Year 2 and Year 3

Industry journal updates: Year 2 and Year 3

Community awareness via mainstream media (print/radio) – Year 3

3.2 Data sources, data collection and data analyses

Table 3: Project monitoring plan

Program logic level	What to monitor	Performance expectation (KPI)	How to monitor (methods)	Data source	When	Responsibility - who reports	Reports
Activities	Technical Reference group	Members Identified; 2 meetings/season	Project records	Project team	1-Dec -19	**S Bound**	Milestone 102
	Distribution map of codling moth	Desktop audit of codling moth distribution conducted	Project records	Project team	31-Apr-20	**G Westmore** P Crisp, S Paterson	Milestone 103
	Cost-benefit of pilot release sites	Pilot release site identified	Project records	Project team	30-Apr-20	**FGT** I Cover, M Tarbath	
	Collaboration with Canada OKSIR	Travel to Canada completed and communications documented	Project records	Project team	30-Jun_20	**G Westmore** P Crisp	Milestone 104
	Investigation of secure entry pathways for SCM	Importation process approved by DA & AQIS.	Project records	Project team	30-Jun-20	**G Westmore** P Crisp C Hull	
	Communication with industry, stakeholders	Communication outputs completed	E-analytics, Project records Survey	Project team	Ongoing	**FGT**, M Buntain	
STOP / GO	Project review	Review process completed	Project records	Hort Innovation	30-Jun-20	**S Bound**	Milestone 104
	Regional pilot release program	Field trials at minimum of 2 sites	Project records	Project team		**S Bound, P James,** S Paterson, FGT	Milestone 105
	Assessment of SCM releases	Monitoring of CM populations	Project records	Project team		**P James,** S Paterson	Milestone 106
	Training programs for agronomists, service providers	Workshops conducted	Project records	Project team		**S Bound,** P James, S Paterson	Milestone 107
	Industry & community awareness program	Communication outputs produced	E-analytics, Project records	Project team		**FGT,** M Buntain	
	Distribution map	Accurate distribution map of codling moth in Australia	Project records	Project team		**G Westmore** P Crisp, S Paterson	

Program logic level	What to monitor	Performance expectation (KPI)	How to monitor (methods)	Data source	When	Responsibility - who reports	Reports
Outputs	Technical Reference group	Reference group established	Project records	Project team		**S Bound**	
	OKSIR collaboration	Agreements signed to import SCM into Australia	Project records	Project team		**G Westmore** P Crisp	Milestone 104
	Importation pathway	Importation pathway plan produced	Project records	Project team	30-Jun-20	**G Westmore** P Crisp C Hull	Milestone 104
	Onshore production	Feasibility of onshore SCM production established	Project records	Project team	30-Jun-20	**G Westmore** P Crisp	
Stop/Go	Independent review of project feasibility	Report on project feasibility	Project records	HI, S Bound	20-Jul-20	S Bound, HI	Milestone 104
	Rear-out facility In Tasmania	Rear-out facility modifications completed if required	Project records		31-Dec-20	**S Bound,** G Westmore	Milestone 105
	Industry communications & training	Articles in industry magazine (APAL) Industry Juice – E-news Industry conference presentation IPDM website Training workshops conducted	Project records, E-analytics,		Ongoing	FGT, S Bound, M Buntain	
	Trial results - pilot release program analysis	Results of pilot release program analysed and reviewed	Project records				Milestone 107
	Economic analysis	A cost-benefit analysis of SCM feasibility in Australia	Project records				Milestone 107

Program logic level	What to monitor	Performance expectation (KPI)	How to monitor (methods)	Data source	When	Responsibility - who reports	Reports
Immediate outcomes	Knowledge of the extent of codling moth distribution in Australia	A GIS referenced map of codling moth locations in Australia	Project records	Project team,		**G Westmore**	Milestone report
	Collaboration between Canada OKSIR and Australia for release of SCM	Agreements in place with Canada OKSIR	Project records			G Westmore, P Crisp	
	Knowledge of the economic feasibility of SCM systems	Report reviewed and accepted by key stakeholders (HI, TIA, Expert panel)	Project records	Project team			Milestone Report, Evaluation report, Publication
End of Project outcomes	Apple growers and with greater understanding of SCM management systems	50% of Australian apple growers have increased awareness of SCM as an IPM tool for codling moth 25% of Australian apple growers have increased knowledge of SCM management systems necessary to implement SCM in orchards	Survey, web and e-analytics, pre and post event survey, observations and responses at events	Growers		**S Bound, FGT** M Buntain	Final report, evaluation report, Industry publications
	Specialist service providers with greater understanding of the requirements for SCM production and release	50% of targeted service providers have increased knowledge of SCM production and release requirements	Pre-Post event survey	Agronomists, service providers		**S Bound, FGT** M Buntain S Paterson, P Janes	Final report, evaluation report, Industry publications

4 Evaluation

The project team will self-evaluate the project based on the key evaluation questions.

Table 4: Data collection and evaluation method

KEQ	Sub KEQ	Data Source (who?)	Data collection method	Analysis
Relevance / Appropriateness To what extent was the project relevant / appropriate to the people (stakeholders) in the context described?	Did the project engage with the right people? Did stakeholders have sufficient and appropriate participation to achieve the goals of the project? To what extent were the engagement methods and activities appropriate to the needs of stakeholders? How did the stakeholders value the activities, were they relevant to their business? To what extent were the project goals feasible given the time, resources and scope?	OKSIR program Hort Innovation Grower trial participants Australian Apple growers Participants in workshops Consultants and service industry Project team Wider Community	Project records Project review (Stop/Go) Grower survey Records of participation E-news and web analytics	Quantitative analysis of survey data Quantitative records Quantitative analysis of e-activity
Effectiveness To what extent was the project implemented as planned?	To what extent were the proposed activities and outputs delivered/achieved? To what extent were the immediate project outcomes achieved? What challenges were there in implementing the project? What worked well? Were there any unexpected positive or negative outcomes?	Project team Hort Innovation Grower participants	Project team records (notes, images, meeting notes) Project review (Stop/Go)	Quantitative assessment of project outputs from project records Qualitative assessment of observations

KEQ	Sub KEQ	Data Source (who?)	Data collection method	Analysis
Impact What changes can be attributed to the project?	What are the attitudes and aspirations of next users at the conclusion of the project? What was the impact of the project on next user's knowledge and skill? What value did next users gain from the project?	Grower participants in trials Australian Apple growers Participants at field days and workshops	Pre and post event surveys to assess changes in knowledge	Qualitative and quantitative analysis of survey responses
Efficiency To what extent was the project delivered efficiently?	Did the project deliver on time and on budget with efficient use of resources?	Project team	Project team records of resource use	
Legacy How likely is the project to continue to have an effect once it ceases?	Do growers aspire to implement SCM technology? Do service providers aspire to provide a SCM service	Australian apple growers Service industry	Survey	Qualitative and quantitative analysis of survey responses

Table 5: Schedule of evaluation activities

Activity /task	People involved	Start	Finish	Resources	Output delivered to
Develop M&E & stakeholder engagement plan and risk analysis	**M Buntain**,S Bound,	1-Nov-19	30-Nov-19	Staff time, venue, catering, sticky wall/notes, writing materials, white board, flip charts	Project team, HI
Evaluation Plan & risk analysis reviewed	**S Bound**, Project team	11-Nov-19	30-Nov-19	Staff time	Project team, HI
Data collection					
1: E-news/web activity collection	**FGT, M Buntain,**			Staff time, internet, campaign monitor/mailchimp, Web services	Project team, HI, TIA, FGT
2: Continuous collection of project records	**S Bound**, G Westmore	1 Nov-19		Staff time, IT, camera, phone	Project team, HI, TIA
3: Field day Pre/post survey	**FGT**, M Buntain			Staff time	Project team, HI, TIA
4: Agronomist workshop Pre-post survey	**FGT**, M Buntain				
5: End of project survey interview with subset of participants	**M Buntain**, FGT	10-Jul-20		Staff time, Voice recorder/ Phone	Project team, HI
6: Data analyses, plan and write evaluation report	**M Buntain**	2-Sep-20		Staff time	Project team
7: Review report	**S Bound** Project team	1-Oct-20		Staff time	Project team & HI

5 Reporting and continuous improvement

Table 6: Project progress reporting

Report type	Report audience	When
Milestone reports	Hort Innovation, TIA	Six monthly
Final reports	Hort Innovation, TIA	At end of project
Financial reports	Hort Innovation, TIA, Project team	Annual
Written and verbal updates	Project team	Six monthly
Industry reporting	APAL	Annual
Partner reports	Grower participants	Annual

Table 7 Project continuous improvement activities

Continuous improvement process	Details	When
Hort Innovation R&D Manager and project CI	Skype meeting to discuss project progress and any modifications required	Annually
Project team	Meeting between project team members to review project plan, methodology, results and engagement with industry and grower participants	Six monthly

Risk Management plan

Pilot Sterile Codling Moth Releases for the Apple Industry (AP18001 – CON-001733)

21 November 2019

Risk	Potential causes/ sources	Potential impacts	Controls	Likelihood with controls in place	Consequence with controls in place	Treated risk assessment	Risk Evaluation	Responsible person
Loss of key project personnel	Resignation, redeployment or redirection of staff particularly with redirection due to biosecurity incursion	Loss of technical skill, knowledge, experience.	- Project team has broad skill set. - Regular project meetings. - Central shared storage of project information.	Possible	Medium	Medium	Yes	Project Leader
Import of SCM prevented or delayed	Canada OKSIR program unable or unwilling to supply SCM to the project; Lengthy approval time or non-approval of SCM import by DAWR	Inability to deliver project outcomes.	- Project outputs renegotiated and management moves to domestic irradiation program.	Possible	Minor	Medium	Yes	Project Leader
SCM imports unsuccessful or with low viability	Import pathway logistics affect survivability of SCM	Delay in delivering project outputs.	- Investigate multiple entry pathways. - Domestic irradiation as an alternative.	Possible	Minor	Medium	Yes	Project Leader
SCM import and release not economically viable	High costs of import, purchase, rearing, distribution	Inability to deliver longer term project outcomes.	- Investigate NZ production system as a model. - Investigate alternative options such as domestic irradiation.	Possible	Minor	Medium	Yes	Project Leader

Risk	Potential causes/ sources	Potential impacts	Controls	Likelihood with controls in place	Consequence with controls in place	Treated risk assessment	Risk Evaluation	Responsible person
Grower participation in trials	Difficulty enlisting growers willing to be trial participants	Inability to deliver intended project outputs.	- Stakeholder relations well established through FGT, PIRSA. - Close liaison with APAL. - Project team members well respected by industry.	Unlikely	Insignificant	Low	Yes	Project Leader
Inability to domestically rear SCM	Rear-out facilities not ready in time; failure in rearing technology;	Delay in delivering project outputs.	- SCM facility requires only minor modifications. - Project team has and can draw on expertise in rearing CM.	Possible	Insignificant	Low	Yes	Project leader
Pest populations levels at trial sites insignificant or too high	Seasonal conditions, grower practices	Delay in delivering project outputs.	- Liaise with grower pre-trial. - Have back up sites enlisted. - Utilisation of neglected orchards.	Unlikely	Minor	Low	Yes	Project Leader
Loss of trial site	Trial site sold, natural disaster (storm, fire); Inadvertent harvest or spraying	Delay in delivering project outputs.	- Regular liaison with cooperating growers. - Good signage in-crop. - More than one trial site in different locations.	Possible	Minor	Medium	Yes	Project Leader

Risk	Potential causes/ sources	Potential impacts	Controls	Likelihood with controls in place	Consequence with controls in place	Treated risk assessment	Risk Evaluation	Responsible person
Low grower engagement in adoption activities	Growers unable or unwilling to attend; Activities not relevant, Inappropriate timing or strategy for the audience;	Low uptake of new practices; Underachievement of intended project outcomes.	- Develop stakeholder engagement plan. - Close liaison with FGT, APAL and local industry groups. - Project team members well respected by industry and with extension expertise.	Possible	Insignificant	Low	Yes	Project Leader
Opposition to release of SCM	Organic certification bodies may object to release of irradiated SCM	Delay in delivering project outputs.	- Liaison with organic certifying bodies. - Promotion of public good of program.	Possible	Minor	Medium	Yes	Project Leader
Data loss (electronic)	Hard drive crash, virus;	Delay in delivering project outputs.	- Regular back up of data. - Retain hard copies of data.	Remote	Insignificant	Low	Yes	Project Leader

Stakeholder Engagement Plan – Pilot Sterile Codling Moth Releases for the Apple Industry (AP18001)

Who	Stakeholder	Grower Participants	Apple Growers	Service providers (Agronomist/ Consultant/ Biocontrol suppliers)	Industry Communication Projects (APAL)	Wider Community	Collaborators (OKSIR, NZ PFR, Regulatory Agencies)	Investors (Hort Innovation, TIA, DPIPWE, FGT, Lenswood Coop, SARDI)
Why	*Why engage this group?*	To encourage participation in the project; As key industry mentors for evaluating SIT management practices to facilitate future industry adoption.	Increase awareness and knowledge of SIT pilot program, technology and management practices.	Increase awareness and knowledge of SIT management practices. To enable this group to directly support future industry adoption.	To facilitate linkage with appropriate industry members; to assist in the dissemination of information to growers.	Increase awareness and acceptance of SIT technology.	To engage key skill sets to the project.	To provide feedback on investment. Demonstrate value of project
How	*What is the level of engagement*	Inform, consult, involve, collaborate, empower	Inform, consult, involve, collaborate	Inform, consult, empower	Inform, consult	Inform	Inform, consult, collaborate	Inform, collaborate
	Proposed methods	Media; Email; Phone; Web/social media; Face to face on site; Industry journal articles; Industry conference	Media; Email; Web/social media; Workshop; Industry journal articles; Industry conference	Media; Email; Phone; Web/social media; Workshop; Industry journal articles; Industry conference	Industry journal / news articles and event notices	Media; Web/Social media;	Direct via email, phone, video conference, face to face	Reporting – milestones and final report; Media opportunity alerts at key points in project

Who	Stakeholder	Grower Participants	Apple Growers	Service providers (Agronomist/ Consultant/ Biocontrol suppliers)	Industry Communication Projects (APAL)	Wider Community	Collaborators (OKSIR, NZ PFR, Regulatory Agencies)	Investors (Hort Innovation, TIA, DPIPWE, FGT, Lenswood Coop, SARDI)
	Timing	Ongoing throughout project, see below for schedule	Ongoing throughout project, see below for schedule	Ongoing throughout project, see below for schedule	Ongoing throughout project, see below for schedule	Ongoing throughout project, see below for schedule	At project start; As needed throughout the project.	6 monthly
	Resources	Industry database; Computer/phone/ vehicle/printer	Industry database; Computer/phone/ vehicle/printer	Industry database; Computer/phone /printer	Computer/phone	Computer	Computer, phone	Computer, phone
	Responsibility	**S Bound**	**M Buntain**, FGT, Lenswood	FGT, S Bound	M Buntain, FGT	**M Buntain**, FGT,	**G Westmore**, P Crisp, S Bound, FGT	S Bound
	Key messages	Purpose of the project, who is involved, project methodology; Project findings;				Purpose of the project and potential community benefits	Purpose of study; Research methodology Research findings	Research outcomes and impact
Special Considerations		Growers are expected to have a broad range of attitudes to SIT and risk; Enlist agronomists and lead growers to assist overcoming barriers to acceptance;			Export market sensitivities	Some sections of wider community may have resistance to SIT technology SCM release	Export market sensitivities	

Stakeholder engagement schedule

When	Who	How	What	Why
Dec 2019	Hort Innovation	email	Milestone report	Inform of progress
Dec 2019 – Jun 2020	OKSIR, NZ PFR, DA	email, phone	Scoping collaborative linkages	Establish collaboration and logistics pathways
Mar 2020	Project team and collaborators	Email, skype	Desktop research results	Feedback on collaborations, regulatory and technical processes and logistics; planning
Apr 2020	Hort Innovation	email	Milestone report	Inform of progress
Apr 2020	Grower participants	Email, phone, face to face	Trial plans and protocols	Engage growers in trial process; mitigate risks to project
May 2020	Apple growers, service providers	conference, e-news	Project update	Inform industry of project progress
Jun 2020	Independent Reviewer	email	Project report	Review/ stop go decision
Jun 2020	Hort Innovation	email	Milestone report	Inform of progress
Jul 2020	APAL, service providers	web/social media, email	Project update	Inform industry of project progress
Jul 2020	Project team	face to face workshop	Workshop	Plan next phase
Aug 2020	Grower participants	face to face, phone, email	Trial plans and protocols	Engage growers in trial process; mitigate risks to project
Dec 2020	Hort Innovation	email	Milestone report	Inform of progress
Apr 2021	APAL, wider community; apple growers	web/social media, email, media	Project update; project announcement	Inform industry of project progress; awareness of project goals
April 2021	Grower participants	face to face	Review results	Gather grower feedback
May 2021	Apple growers, service providers	conference, e-news	Project update	Inform industry of project progress
Jun 2021	Hort Innovation	email	Milestone report	Inform of progress
Oct 2021	Apple grower, service providers	workshop	Pre-season project update	Inform of project plans

When	Who	How	What	Why
Dec 2021	Service Providers	workshop – face to face	Training workshop	Training in SIT methodology
Dec 2021	Hort Innovation	email	Milestone report	Inform of progress
April 2022	Wider community, apple growers	media	Project announcement	Awareness of project goals
May 2022	Apple growers	conference, e-news	Project update	Inform industry of project progress
Jun 2022	Investors, Service Providers, Grower participants, APAL	Publication, email, web	Project recommendations	Inform industry of project outcomes and future direction
Jun 2022	Hort Innovation	email	Final Report	Inform of project outcomes

AP18001: Pilot sterile codling moth releases for the apple industry

Activity 11. <u>Economic assessment of release programs</u>. Undertake an economic cost benefit analysis on SCM on a per hectare basis for industry and orchardists: establish benchmarks (impact of control measures, aggregate costs etc.); evaluate different release strategies and effect of SCM over a number of years and their influence on aggregate costs, benefits (social and economic); quantify effects on stakeholder (Australian apple industry) and participants (apple growers); evaluate risks and uncertainties due to changes in climatic events and costs; determine benefits in real world situation for commercialisation. We believe that it is too early to develop a commercialisation plan as this would be dependent on the outcome of the cost/benefit analysis.

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Content

1.0 Overview

This report details an economic analysis of a potential sterile codling moth (SCM) release program. The analysis aimed to establish an approximate per hectare cost, potential release strategies and potential effect of a longer term timeframe in terms of aggregate costs, benefits and opportunities.

Consideration to potential shift in climate, agrichemical effectiveness and social considerations were evaluated but without wider stakeholder surveying were not able to be quantified in the context of this analysis.

2.0 Economic impact of codling moth on apple and pear production

Codling moth is one of the key pests of apple and pear production. Damage from codling moth sees fruit downgraded or destroyed due to damage, and losses can be extensive when control of the pest is poor.

In the context of the current project, fruit damage comparisons between grower standard control measures and sterile insect technique (SIT) for codling moth were compared. The results of the two years of data were variable, however, consideration to the time taken for population collapse needs to be considered. Regardless, the current project saw mixed results with two of the three release sites seeing a reduction in fruit damage relative to grower-control; the paired group that saw an increase in fruit damage in the release site was split, with the control and release sites at two different orchards in a similar area.

Comparison of SIT control relative to pesticide and mating disruption in Canada (Gill, 2014) demonstrated a clear difference in injury levels between techniques with pesticide control, mating disruption and SIT measured to have 3.1%, 0.41% and 0.04% fruit damage levels in their study. Using this scenario (Table 1) the potential gains on previous damage losses identified in Table 1 would suggest potential gains are between $40.35 and $45.9 per tonne for using mating disruption and SIT respectively.

Table 1. Effect of control method on fruit value utilising data from Gill (2014)

Method	**Damage**	**Fruit value loss per 50 tonnes due to pest at $1.5/kg Class 1 (to orchard gate)**	**Relative position to pesticide based control**
Pesticide control	3.10%	$2,325	-
Mating disruption	0.41%	$307.5	+ $2,017.5
Sterile insect technique	0.04%	$30	+ $2,295

3.0 Current practise and associated costs

Current codling moth control practises typically rely on chemical control supplemented by pheromone-based mating disruption, *Bacillus thuringiensis* (Bt) sprays and the use of codling moth granulosis virus. In some areas, the use of drape netting (for bird and hail protection) also provides some level of crop exclusion by restricting flight between rows.

Most growers employ a combination of these techniques dependent on site pressure, pest control in the previous season and any other market restriction (for example, MRL requirements for target markets on certain chemicals, timing to harvest and phytosanitary requirements). In addition, organic producers are limited to Bt, virus and disruption techniques with conventional agrichemical sprays not an option under organic certification body requirements.

The number of codling moth generations vary between regions with 2-3 full generations typically observed across the spread of Australian growing climates.

Assuming an average dilute spray volume of 1,500L/ha and standard chemical/application costs as per Table 2.

Table 2. Typical control agents and prices used as base assumptions for costings of chemical control

ID	**Control measure**	**Chemical cost** ***sourced at average price from 2023/24 season at a large commercial farm**	**Application cost** ***assuming $35/hour labour unit**	**Total cost (per hectare)**
A	Pheromone ties deployed into orchard	$550 / ha	$250/ha 5 hours / ha using cherry picker; costing cherry picker at $15/hour	$800
B	Bt spray (1.5kg/ha)	$18.20 / ha	$70/ha Or combined with other spray	$88.20
C	Fenoxycarb	$50.96 / ha	$70/ha Or combined with other spray	$120.96
D	Codling moth granulosis virus	$93.10 / ha	$70/ha Or combined with other spray	$163.10
E	Chlorantraniliprole	$144.78 / ha	$70/ha Or combined with other spray	$214.78
F	Spinetoram	$220.5 / ha	$70/ha Or combined with other spray	$290.50
G	Novaluron / Acetamiprid	$82.71 / ha	$70/ha Or combined with other spray	$152.71
H	Tetraniliprole	$126.20 / ha	$70/ha Or combined with other spray	$196.20
I	Thiacloprid	$49.73 / ha	$70/ha	$119.73

			Or combined with other spray	
J	Indoxacarb	$140.09 / ha	$70/ha Or combined with other spray	$210.09
K	Other registered chemicals	$80-225 / ha	$70/ha Or combined with other spray	$150-295

Using these base assumptions, the below scenarios have been selected as potential control options under minimal and heavy pressure scenarios (Table 3). A typical average spend has been estimated at $1500/ha for control measures and application costs.

Table 3. Different control scenarios and associated costs (referencing Table 2)

Scenario	**Products used**	**Total estimated cost per ha**
Minimal (with mating disruption)	A B C x 3	$1,251.08
Heavy pressure without mating disruption	G x 2 H x 2 I x 2 G x 2	$1,242.70
No conventional agrichemicals	A B x 4 D x 4	$1,936.24
Approximate range		$1,250-2,000
Average costing (estimated)		$1,500

4.0 Costings of implementation

Implementation of SIT requires specialised approaches as well as area wide management to ensure continued success. Given the relatively limited range of codling moth flights, relatively small areas have the potential to be under SIT for this pest assuming a positive cost:benefit can be achieved to justify the implementation of the program.

Given this technique is only employed in Canada for control of codling moth, analysis of their cost structure, as well as costs incurred in this trial and information gathered from New Zealand's trial approach have been considered and presented below.

Tasmania trial costs per hectare

Costings of importation as part of this trial are outlined below (Table 4). In total, a 17 week release season was used at an average cost of $6,073/ha for the two years of releases. This does not include the cost of releases (walking every third row), which was estimated to be an additional $35/ha in line with other typical insect release costs (allowing 1 hour per hectare inclusive of handling, preparation and waste disposal). Different methodologies to release would be possible under commercial scenarios (ATV, walking, drone etc.), but all would be expected to fall at $35/ha direct cost or are estimated at $70/ha under commercial arrangements.

As such, the total cost for the trial releases was $6,108/ha, however, exclusion of the freight and associated costs (assuming managed in Australia at a commercial scale at a similar cost to produce) actual sterile codling moth and application costs would be closer to $2,000/ha under this trial scenario.

Table 4. Costs incurred for importation and sourcing of sterile codling moth from Canada.

Year	**2022-2023**	**2023-2024**
Purchase of SCM from OKSIR, Canada		
Sterile moths	$1,490	$1,647
Packaging/labour/transport	$46	$775
Freight	$2,284	$2,237
Quarantine & import charges		
Import GST charges	$188	$212
Quarantine processing charge	$38	$43
Border Force charges	$243	$248
Biosecurity charges	$143	$222
Customs Broker charges	$108	$108
Qantas Freight charges	$137	$138
Total Weekly Costs	$5,377	$5,768
Total season costs (17 weeks)	$91,409	$98,056
Project cost per hectare	**$5,860**	**$6,286**

Canadian example

Evaluation of OKSIR's financial statements (Table 5) suggests that implementation of their program results in a net cost per hectare (of treated orchard) to be ~CAD$1,300/ha (AUD$1,430/ha at time of writing). With an estimated treated area of 3035 hectares in the SIT program. This program has now been in continuous operation since 1994 and represents the most likely "real" costs of ongoing management, implementation, research and development and economic stability.

Table 5. Adaptation of OKSIR Financial Statements for the 2021 and 2022 financial years (OKSIR, 2024). Estimated area for the treated area and subsequent cost/ha have been calculated in this table.

Revenue	**2021**	**2022**

Land tax (residential)	$1,710,728	$1,779,157
Parcel tax (orchard)	$1,025,598	$1,071,603
Interest	$4,203	$21,921
Miscellaneous income	$716,468	$912,513
Grants	$13,145	$44,000
Loss on disposal of assets	-$291	
WSU Decision Aid System	$0	$154,059
	$3,469,851	**$3,983,253**
Expenses		
Amortisation	$210,967	$208,263
Community relations	$4,713	$1,921
Diet ingredients	$278,691	$323,594
General overhead	$385,882	$358,790
Operations	$86,903	$52,442
Postage	$10,036	$33,585
R&D/developement	$81,382	$246,021
Supplies - admin	$12,627	$11,242
Supplies - operational	$139,378	$175,926
Utilities	$224,184	$238,777
Vehicles and travel	$161,676	$152,647
Wages	$2,229,947	$2,207,282
Waste management	$20,126	$20,178
	$3,846,512	**$4,030,668**
Annual balance	-$376,661	-$47,415
Treated orchard area (ha) estimated*	3035	3035
Cost per hectare	**$1,267**	**$1,328**

NZ experience

Recent New Zealand trial experience suggested costs of their pilot SIT program was $NZD238/ha (subsidised by OKSIR) with the real price estimated at NZD$500/ha. These trials also evaluated delivery methods, with significant gains in efficiency for unmanned options, particularly in larger orchards with application as low as 1 minute per hectare for moth delivery (Lo *et al*, 2021). Moreover, the New Zealand data would suggest that any implementation should greatly consider aerial methods to release moths at scale to reduce costs.

Ongoing control costs in addition to SIT for codling moth

Whilst sterile codling moth does provide reduced wild moth numbers across treated areas, some level of control is still required to ensure economic damage control of other pests (eg. light brown apple moth) as well as the capability for threshold spraying wild moth catches. This is estimated to be ~$350/ha annually (a reduction of ~$900/ha).

If widespread SIT was introduced, the initial release year would be expected to require a standard program with reductions to sub spray thresholds expected within the next two years and a 'maintenance' at the above $350/ha figure where moth catches are low.

Regional suitability and potential model of implementation

Australia's apple and pear growing region extends across all states with the largest production density being in Victoria's Goulburn Valley region. With ~60% of the national planted area for apples and pears, Victoria is the largest region nationally, with the remaining area relatively similar across all other states (8-10%).

All regions would largely be considered suitable for implementation of SIT techniques with density generally restricted to key growing regions. "Satellite" growers (those outside the main centres) would have the potential for participation through undertaking releases themselves.

The greatest challenge identified to implementation is likely to be funding of the program. Under a user-pays scenario, regulatory framework (most likely at each state's level would be required and desire from both the wider growing industry, or for co-funding from other sources (eg. residential) is likely to face significant opposition.

Managing risk

Whilst a potential solution to implementation of SIT would be sourcing direct from OKSIR, it became evident during the course of the current project that disruption is a possibility. Given COVID-19 disruptions are unlikely to be seen at such a scale this is unlikely, however, the Australian season coincides with Canada's winter period and flight delays due to snowfalls and similar impacts are possible.
Given these risks, irradiation of a codling moth population, or consideration to importation of eggs and on-shore irradiation or production at a local SIT facility would need to be considered if implementation was pursued.

5.0 Benefits, risks and opportunities

Whilst there are significant challenges to overcome (namely, funding) to allow implementation of area wide management of codling moth under SIT, consideration toward direct cost reduction benefits as well as market access, social and potential shifts in longer term climate, agrichemical availability and consumer demand all need to be considered.

Perceived benefits

In addition to direct reductions in fruit damage and associated increases in gross return to the producer, other benefits should also be considered. Under this analysis, no quantification of these benefits has been completed. Surveying at various stakeholder levels would be required to establish these thresholds.

Other benefits identified in addition to direct fruit damage attribution are:

- Reduction in the use of chemicals required to control the pest
  - British Columbia usage in the SIT zone in <10% of levels at start of implementation (OKSIR)
  - Associated improvements in beneficial insect levels
- Potential for area wide management approaches to market access for codling-moth sensitive markets
- Area wide structure to support other SIT control programs (eg. Queensland Fruit Fly)
- Preparedness for further shifts in consumer demands for pesticide free products
- Potential export market for SIT to neighbouring countries
- Preparedness for warmer climate and increased codling moth seasonal pressure as a result of it
- Preparedness for agrochemical resistance in the codling moth population

Impact/economic analysis

Comparisons of three greenfield scenarios under equivalent assumptions for all aspects outside of damage due to codling moth and cost of control for method (Tables 1 and 2) were completed (Appendix 1). The base assumptions used in this scenario can be viewed there. Perceived social benefits were not quantified in this analysis due to limited data.

Under base assumptions, slight improvements for investment scenarios were observed (Table 5). Further analysis of the breakeven point of SIT relative to mating disruption was established as $1491.19/ha. It is important to note that the total cost of SIT would still likely require some sprays and is estimated to be ~$350/ha per year. As such, the cost of SIT application would need to be $1141.19/ha or less direct cost to break even under this scenario.

Table 5. Outcome of 20 year depreciated cash flow for greenfield single hectare investments under different control scenarios under equivalent assumptions.

Method of control for scenario	Cost of codling moth control (per hectare)	Class 1 packout	IRR to year 20	NPV (8%) after 20 years	Relative to pesticide only	Relative to mating disruption
Pesticide	$1,242.70	71.9%	3.3%	-$481,334	-	-$137,083
Mating disruption	$1,251.08	74.6%	4.8%	-$344,251	$137,083	-
SIT at $750/ha	$750	74.96%	5.4%	-$285,766	$195,568	$58,485
SIT at $1000/ha	$1,000	74.96%	5.2%	-$305,493	$175,841	$38,758
SIT at $1500/ha	$1,500	74.96%	4.8%	-$344,947	$136,387	-$696

6.0 Conclusions and recommendations

An economic analysis and consideration of broader potential costs and benefits of the program has demonstrated:

- Damage from codling moth to apples between control techniques varies
    - SIT is reported to have the lowest damage rates (Table 1) relative to mating disruption and pesticide use only
        - Gains in gross orchard gate income are expected to be higher under SIT relative to mating disruption (+$277.5) or pesticide use only (+$2295)
- Implementation cost benefit is largely dependent on actual cost of release which requires significant levels of assumptions
    - Modelling of NPV over 20 years (considered life of orchard) for different codling moth control techniques demonstrated benefit over pesticide/mating disruption (Table 5) where cost was less than $1491.19/ha
        - As such, cost to growers for application of codling moth would need to be $1191.19/ha or less to achieve a positive cost:benefit relationship (assuming a $350/ha spray control requirement for threshold exceedance)
            - Any business case for sterile codling moth import or local production would require that these costs are feasible for the size of the Australia industry
            - Without regulatory framework to collect mandatory payments to fund this initiative it is highly unlikely to be possible
                - State and federal barriers would likely be encountered
        - Cost of implementation in Canada is currently ~AUD$1430/ha
- Additional benefits would be (or potentially be) gained from:
    - Reduce pesticide use and associated social benefits
    - Reduced pesticide use and beneficial insect population improvements
    - Potential to negotiate area-wide approaches to export program phytosanitary requirements
    - Shifts in climate resulting in increased codling moth pressure
    - Changes in agrochemical resistance profiles of codling moth or significant price changes

Recommendations based on these findings:

- All growers should have the benefits of utilising mating disruption clearly communicated to ensure they are following best practise
- Sterile codling moth releases may be viable in Australia with clear target use cases and longer term vision for implementation (including potential subsidy in initial years for establishment)
- An analysis of requirements to allow SIT of codling moth in Australian facilities is completed and the minimum area required under control to produce viable volumes is necessary
    - Low property density growing regions are unlikely to be suitable for area wide management in a cost-effective manner
- If sterile codling moth application was to be implemented, a clear funding model would need to be regulated to allow area wide management and funding
    - This would likely require some level of land tax input which would be incredibly difficult to regulate consistently in all regions and would be likely to face significant opposition from both industry and other potential co-funders (eg. residential)
    - Consideration to aerial release method should also be strongly considered as per findings of *Lo et al, 2021)*
- Consult export partners and experts regarding likelihood of improved market access or phytosanitary requirements for implementation of SIT for codling moth
- Given the geographical spread of the Australian apple and pear industry, considerations of potential other co-beneficiaries should be considered (residential properties, quince and walnut producers and to a lesser extent due to pest preference, stone fruit producers).

References

Cartier, Lee. (2015). Economic Benefits of Using Sterile Insect Technique and Mating Disruption to Control Codling Moth. Journal of Agricultural Science. 7. 10.5539/jas.v7n9p14.

Gill, P. (2014). Statistical analysis of codling moth prevalence and fruit damage data. Paper presented at the May 2014 Regular Meeting of the Okanagan-Kootenay Sterile Insect Release Program, Kelowna, British Columbia. Downloaded from https://www.oksir.org/wp-content/uploads/2016/08/SIR_Report_PGill_June15_2014.pdf

Lo PL, Rogers DJ, Walker JTS, Abbott BH, Vandervoet TF, Kokeny A, Horner RM, Suckling DM. Comparing Deliveries of Sterile Codling Moth (Lepidoptera: Tortricidae) by Two Types of

Unmanned Aerial Systems and from the Ground. (2021) J Econ Entomol. 114(5):1917-1926. doi: 10.1093/jee/toab052. PMID: 34180512.

OKSIR SIR Board Financial Statements, *OKSIR Financial Statements,* accessed 12/5/2024 https://www.oksir.org/program-administration/oksir-board/financial-statements/

[Walker, J]. (2023, August 8). Development of a pilot codling moth SIT program in New Zealand [Video]. Youtube. https://www.youtube.com/watch?v=dJ9RHsqt

APPENDIX - BASE ASSUMPTIONS USED IN THE COMPARISON OF THREE GREENFIELD SCENARIOS

Scenario - Pesticide

Scenario - Pesticide	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Income										
Yield - Tonnes /ha	0	0	15	30	45	55	65	70	75	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
Packout %	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%
- Class 1 Tonnes/ha	0	0	11	22	32	40	47	50	54	58
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	0	0	16,178	32,355	48,533	59,318	70,103	75,495	80,888	86,280
Expenses										
Codling moth control practises - pesticide only	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**
Development costs	100000		40000							
Surplus/ha	(136,243)	(36,243)	(60,065)	(3,888)	12,290	23,075	33,860	39,252	44,645	50,037
Total Cash Surplus/Deficit	(136,243)	(172,485)	(232,551)	(236,438)	(224,149)	(201,074)	(167,214)	(127,962)	(83,317)	(33,280)
Net Present Value (NPV) by Year	(126,151)	(157,223)	(204,905)	(207,762)	(199,398)	(184,857)	(165,100)	(143,893)	(121,560)	(98,383)
IRR to Year 20	3.3%									
IRR to Year 6	-39.6%									
NPV (8%) after 15 years	-$933,620									
NPV (8%) after 6 years	-$911,687									
Cash Surplus at Period End	$216,907									
Breakeven year	16									

Scenario - Pesticide	Year 11	Year 12	Year 13	Year 14	Year 15	Year 16	Year 17	Year 18	Year 19	Year 20
Income										
Yield - Tonnes /ha	80	80	80	80	80	80	80	80	80	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%	3.1%
Packout %	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%	71.9%
- Class 1 Tonnes/ha	58	58	58	58	58	58	58	58	58	58
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	86,280	86,280	86,280	86,280	86,280	86,280	86,280	86,280	86,280	86,280
Expenses										
Codling moth control practises - pesticide only	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70	$1,242.70
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**	**$36,242.70**
Development costs										
Surplus/ha	50,037	50,037	50,037	50,037	50,037	50,037	50,037	50,037	50,037	50,037
Total Cash Surplus/Deficit	16,758	66,795	116,832	166,870	216,907	266,944	316,982	367,019	417,056	467,094
Net Present Value (NPV) by Year	(76,923)	(57,052)	(38,654)	(21,618)	(5,844)	8,761	22,285	34,807	46,401	57,136

Scenario – Mating disruption

Scenario - Mating disruption	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Income										
Yield - Tonnes /ha	0	0	15	30	45	55	65	70	75	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%
Packout %	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%
- Class 1 Tonnes/ha	0	0	11	22	34	41	48	52	56	60
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	0	0	16,783	33,566	50,348	61,537	72,725	78,320	83,914	89,508
Expenses										
Codling moth control practises - mating disruption	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**
Development costs	100000		40000							
Surplus/ha	(136,251)	(36,251)	(59,468)	(2,686)	14,097	25,286	36,474	42,068	47,663	53,257
Total Cash Surplus/Deficit	(136,251)	(172,502)	(231,970)	(234,656)	(220,559)	(195,273)	(158,799)	(116,731)	(69,068)	(15,811)
Net Present Value (NPV) by Year	(126,158)	(157,238)	(204,446)	(206,420)	(196,825)	(180,891)	(159,609)	(136,881)	(113,037)	(88,369)
IRR to Year 20	4.8%									
IRR to Year 6	-37.5%									
NPV (8%) after 15 years	-$850,321									
NPV (8%) after 6 years	-$903,840									
Cash Surplus at Period End	$250,474									
Breakeven year	15									

Scenario - Mating disruption	Year 11	Year 12	Year 13	Year 14	Year 15	Year 15	Year 15	Year 15	Year 15	Year 15
Income										
Yield - Tonnes /ha	80	80	80	80	80	80	80	80	80	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%	0.41%
Packout %	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%	74.6%
- Class 1 Tonnes/ha	60	60	60	60	60	60	60	60	60	60
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	89,508	89,508	89,508	89,508	89,508	89,508	89,508	89,508	89,508	89,508
Expenses										
Codling moth control practises - mating disruption	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08	$1,251.08
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**	**$36,251.08**
Development costs										
Surplus/ha	53,257	53,257	53,257	53,257	53,257	53,257	53,257	53,257	53,257	53,257
Total Cash Surplus/Deficit	37,446	90,703	143,960	197,217	250,474	303,730	356,987	410,244	463,501	516,758
Net Present Value (NPV) by Year	(65,528)	(44,379)	(24,797)	(6,665)	10,124	25,669	40,063	53,390	65,731	77,157

Scenario – SIT @ $750/ha

Scenario - Mating disruption @ $750	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 15	Year 15	Year 15	Year 15	Year 15
Income																				
Yield - Tonnes /ha	0	0	15	30	45	55	65	70	75	80	80	80	80	80	80	80	80	80	80	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%
Packout %	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
- Class 1 Tonnes/ha	0	0	11	22	34	41	49	52	56	60	60	60	60	60	60	60	60	60	60	60
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	0	0	16,866	33,732	50,598	61,842	73,086	78,708	84,330	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952
Expenses																				
Colding moth control practises	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00	$750.00
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**	**$35,750.00**
Development costs	100000		40000																	
Surplus/ha	(135,750)	(35,750)	(58,884)	(2,018)	14,848	26,092	37,336	42,958	48,580	54,202	54,202	54,202	54,202	54,202	54,202	54,202	54,202	54,202	54,202	54,202
Total Cash Surplus/Deficit	(135,750)	(171,500)	(230,384)	(232,402)	(217,554)	(191,462)	(154,126)	(111,168)	(62,588)	(8,386)	45,816	100,018	154,220	208,422	262,624	316,826	371,028	425,230	479,432	533,634
Net Present Value (NPV) by Year	(125,694)	(156,344)	(203,088)	(204,572)	(194,466)	(178,024)	(156,239)	(133,030)	(108,728)	(83,622)	(60,375)	(38,851)	(18,921)	(467)	16,619	32,440	47,089	60,653	73,213	84,842
IRR to Year 20	5.4%																			
IRR to Year 6	-36.6%																			
NPV (8%) after 15 years	-$810,515																			
NPV (8%) after 6 years	-$895,154																			
Cash Surplus at Period End	$262,624																			
Breakeven year	15																			

Scenario – SIT @ $1000/ha

Scenario - Mating disruption @ $1000	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 15	Year 15	Year 15	Year 15	Year 15
Income																				
Yield - Tonnes /ha	0	0	15	30	45	55	65	70	75	80	80	80	80	80	80	80	80	80	80	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%
Packout %	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
- Class 1 Tonnes/ha	0	0	11	22	34	41	49	52	56	60	60	60	60	60	60	60	60	60	60	60
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	0	0	16,866	33,732	50,598	61,842	73,086	78,708	84,330	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952
Expenses																				
Colding moth control practises	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00	$1,000.00
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**	**$36,000.00**
Development costs	100000		40000																	
Surplus/ha	(136,000)	(36,000)	(59,134)	(2,268)	14,598	25,842	37,086	42,708	48,330	53,952	53,952	53,952	53,952	53,952	53,952	53,952	53,952	53,952	53,952	53,952
Total Cash Surplus/Deficit	(136,000)	(172,000)	(231,134)	(233,402)	(218,804)	(192,962)	(155,876)	(113,168)	(64,838)	(10,886)	43,066	97,018	150,970	204,922	258,874	312,826	366,778	420,730	474,682	528,634
Net Present Value (NPV) by Year	(125,926)	(156,790)	(203,733)	(205,400)	(195,464)	(179,180)	(157,540)	(134,467)	(110,289)	(85,299)	(62,160)	(40,735)	(20,897)	(2,529)	14,479	30,227	44,809	58,310	70,812	82,387
IRR to Year 15	5.2%																			
IRR to Year 6	-36.9%																			
NPV (8%) after 15 years	-$824,626																			
NPV (8%) after 6 years	-$898,940																			
Cash Surplus at Period End	$258,874																			
Breakeven year	15																			

Scenario – SIT @ $1500/ha

Scenario - Mating disruption @ $1500	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12	Year 13	Year 14	Year 15	Year 15	Year 15	Year 15	Year 15	Year 15
Income																				
Yield - Tonnes /ha	0	0	15	30	45	55	65	70	75	80	80	80	80	80	80	80	80	80	80	80
Base packout	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
Loss due to codling moth for scenario	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%	0.04%
Packout %	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%	75.0%
- Class 1 Tonnes/ha	0	0	11	22	34	41	49	52	56	60	60	60	60	60	60	60	60	60	60	60
Price - Class 1 kg (to orchard gate)	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50	1.50
Total Income/ha	0	0	16,866	33,732	50,598	61,842	73,086	78,708	84,330	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952	89,952
Expenses																				
Colding moth control practises	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00	$1,500.00
Other operating expenses	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00	$35,000.00
Total expenses	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**	**$36,500.00**
Development costs	100000		40000																	
Surplus/ha	(136,500)	(36,500)	(59,634)	(2,768)	14,098	25,342	36,586	42,208	47,830	53,452	53,452	53,452	53,452	53,452	53,452	53,452	53,452	53,452	53,452	53,452
Total Cash Surplus/Deficit	(136,500)	(173,000)	(232,634)	(235,402)	(221,304)	(195,962)	(159,376)	(117,168)	(69,338)	(15,886)	37,566	91,018	144,470	197,922	251,374	304,826	358,278	411,730	465,182	518,634
Net Present Value (NPV) by Year	(126,389)	(157,682)	(205,021)	(207,056)	(197,461)	(181,491)	(160,144)	(137,340)	(113,413)	(88,654)	(65,730)	(44,503)	(24,849)	(6,651)	10,200	25,802	40,248	53,625	66,010	77,478
IRR to Year 15	4.8%																			
IRR to Year 6	-37.5%																			
NPV (8%) after 15 years	-$852,849																			
NPV (8%) after 6 years	-$906,513																			
Cash Surplus at Period End	$251,374																			
Breakeven year	15																			

Appendix 4: Communication & Extension outputs

Table 1. Output summary

Date	Output	Audience	Description		
			Where	Content	Reach
1-3-2023	Media Release	General public; Australian apple industry: growers, service providers, researchers	Key media outlets	Media release	
1-3-2023	○ TIA Research Web News ○ Project web Page ○ FAQ Web Page ○ YouTube ○ Facebook ○ Twitter	General public; Australian apple industry: growers, service providers, researchers	TIA	Research news Project web page YouTube Interview with Sally Bound - project description Twitter X	March 2023 to June 2024 web page recorded 258 sessions with 24 deeply engaged sessions YouTube video 1,027 views
3-3-2023	E-News	Tasmanian apple industry: growers, service providers, researchers	FGT Fruit E News	Project overview	735 subscribers; approx. 45% open rate
3-3-2023	Internet news	Australian apple industry: growers, service providers, researchers	HortiDaily	Project overview	
2-3-2023	Radio Interview (national)	General public; Australian apple industry: growers, service providers, researchers	ABC Radio & ABC Country Hour	Project overview – interview with Sally Bound	529,000 (RN reach)
6-3-2023	Internet story	General	National Tribune AgNews	Project overview	
10-3-2023	Rural Newspaper	Tasmanian agricultural industry	Tasmanian Country	Project overview	40,000 readership
11-3-2023	Local Newspaper	General public; Tasmanian apple growers;	The Hobart Mercury - Weekend	Codling moth management	63,000 readership
26-4-2023	Internet resource	Australian apple industry: growers, service providers, researchers	APAL website	Project update	

28-4-2023	Internet story	General science community	Smart Company	IPM Internet news story	
May 2023	Industry Journal (National)	Australian apple industry: growers, service providers, researchers	Australian Fruit Grower – APAL Autumn 2023 PP 30-35	Project update	Over 900 subscribers, free to all levy paying apple & pear growers and industry
June 15-16	FGT Conference	Australian fruit industry: growers, service providers, researchers	Launceston	Display of codling moth project	120 attendees;
Oct 2023	Industry Journal (National)	Australian apple industry: growers, service providers, researchers	Australian Tree Crop	Project Update- Appendix X	Sent free to all growers, major ag suppliers, researchers, and online
May 2024	Field Day	General public; Tasmanian agricultural community;	Agfest	Interactive display with project lead talking to growers and general public about the project	54,500 attendees – approx. 1,000 visit TIA site
June 2024	Media	General public; Australian apple industry: growers, service providers, researchers	ABC Radio	Project update and potential in Australia	529,000 (RN reach)
June 2024	Industry E-News; SMS reminders to growers	Australian apple industry: growers, service providers, researchers	APAL IJ FGT Fruit E-News FGV E-news Fruit Producers SA Serve-Ag E-news	Promotion of webinar	Over 1,500 e-news subscribers in total (some subscribe to more than 1) 70 + SMS reminders sent
17-06-2024	Industry webinar	Australian apple industry: growers, service providers, researchers	Online & In-person at FGT offices Tasmania	Project update with Q&A – Presenters Dr Sally Bound & Dr Guy Westmore	15 online attendees from SA, NSW, Vic, NZ and Tas with 8 local attendees from Tasmania including 3 agronomists.

Appendix 5: Interim Project Monitoring and Evaluation report, June 2024

The overarching goal of the pilot project was to develop recommendations for the integration of sterile codling moth (SCM) into existing apple and pear management and production programs in Australia.

These recommendations will be included in the final report in July 2024.

Activities to be completed by October 2024

1. Extension and communication activities
   - Web page update
   - Industry Journal article (Spring edition of Australian Fruit Grower)
   - Case study
2. Monitoring and evaluation final report
   - Interviews, analysis & reporting

This interim report includes:

- Summary of activities and outputs completed as described in MER plan
- Evaluation of project effectiveness
- Proposed survey questions for evaluating project appropriateness, relevance, impact & legacy (to be completed by October 2024)
- Evaluation of project efficiency
- Evaluation of project against KPI's

Completed activities, outputs and outcomes that the project said it would deliver.

Table 1: Summary of project deliverables

	Deliverables	Outcome / Comments
1	Review, assess and map codling moth distribution / status in Australian apple and pear production regions	Maps produced
2	Identify suitable test regions representative of Australian domestic and export apple production zones for the safe release	Initially releases were to occur in both SA and Tasmania but due to increased costs post Covid, only Tasmanian sites were implemented.
3	Liaise with DAFF re import restrictions, conditions and possible options, around developing testing protocols to enable	Protocols developed & permits granted
4	Investigate safe secure biosecurity pathways for entry of SCM from Canada's OKSIR sterile insect program.	Protocols developed & permits granted
5	Cooperate with industry grower participants and community stakeholders to determine the effectiveness of SCM within existing area-wide integrated pest management programs	Suitable grower participants were engaged for provision of SCM release sites, this took into consideration CM infestation levels and pest management strategies used by each participant
6	Undertake pilot releases of SCM including testing & optimising release systems and quantifying the impact of releases on effectiveness of control of codling moth	Pilot releases occurred over 2 growing seasons. Moth health studies aided decision making on release strategies for imported moths. The impact of release was determined using trapping and fruit quality evaluation.
7	Investigate sterile insect release options – eg static release with target orchards, roving from a vehicle or wide aerial release	A desktop review was made of current release strategies being used commercially in Canada and NZ. The decision to hand release moths was made to provide the most reliable outcome for assessment.
8	Provide a highly accessible point of contact for community and industry enquiries about this pilot program ensuring community and stakeholder engagement on its scientific progress and findings	A web page was established which included information about the trials, frequently asked questions and project updates. The page included contact details for the project lead. Further community and stakeholder engagement was through print and radio media, industry journals and industry and community events.

Project Effectiveness

Overarching KEQ

To what extent was the project implemented as planned?

A summary of project effectiveness is provided in Table 2.

Table 2: Summary of effectiveness of project in delivering activities and outputs and immediate outcomes listed in MER plan

	Activities and outputs in MER plan	Achieved	Additional information
1	Distribution map of CM in Australia produced	Yes	Projected distribution maps of CM produced to show potential range of CM using environmental predictors
2	Formal collaboration with Canada's OKSIR program established	Yes	Collaboration culminated in (i) successful import of SCM from OKSIR; (ii) information exchange prior to and during a visit to the OKSIR facility in 2024.
3	Importation pathway for SCM	Yes	A secure SCM importation process was established with the assistance of DAFF with a permit issued in April 2022. International and local freight logistics were achieved with approx. 48 hrs from shipment to release.
4	The requirements for releasing SCM	Yes	This was established with Australian biosecurity which included approved release rates and locations of release sites. A SCM release protocol was developed for the project.
5	Economic feasibility of SCM systems established?	Yes	Economic feasibility presented in a national webinar and will be reported in AFG magazine, TIA Research Project web page and in final report.
6	Feasibility of SCM management systems in Australia	Yes	Feasibility of SCM systems presented in a national webinar and will be reported in AFG magazine, TIA Research Project web page and in final report.

Project specific KEQ for project effectiveness

To what extent were the proposed activities and outputs delivered?

1. Distribution map of CM in Australia produced

Project team member, Dr Guy Westmore produced a codling moth distribution map based on 578 codling moth records. The source of the 578 records is broken down as follows:
Australian Plant Pest Database: 125 Global Biodiversity Information Facility: 131 Tasmanian Plant Pest Database: 258 Industry reports/published papers/other reliable records: 54

Projected distribution maps have also been produced using Maxent (Maximum entropy model), a species distribution modelling tool for predicting the distribution of a species from a set of records and environmental predictors. The maximum entropy model has been found to be the best in both predictive performance and model stability when compared with other similar niche models (Phillips et al. 2006, Phillips and Dudik 2008). Prior to running the Maxent analysis, 422 records were removed (leaving 156) so that there was only one record used from each locality.

2. Formal collaboration with Canada's OKSIR program established

Dr Guy Westmore established a formal collaboration with Canada's OKSIR program to import sterile codling moths from their facility and information exchange on release methods and assessment. The outcome was the successful import of sterile codling moths to Tasmania from OKSIR including 2 full seasons of weekly shipments from 28th September 2022. The collaboration culminated in a visit by Dr Westmore to their production facility in June 2024. A report of this visit and recommendations will be prepared by October 2024.

3. Importation pathway for SCM

The importation pathway was successfully achieved and included:

- Permit to import live sterile codling moth form OKSIR
- Logistics for transit to Tasmania, Australia

An application to import SCM from OKSIR was submitted on 19 December 2019 to the Department of Agriculture, Fisheries and Forestry (DAFF). A permit to import sterile codling moths was received on 7 April 2022. The regulatory approval process for OKSIR relied on a signed manufacturer's declaration from the facility (desktop audit) – this is an alternative approach for permit approval following a decision by DAFF that the OKSIR facility did not need to be approved via the offshore irradiation treatment providers scheme.

4. The requirements for releasing SCM

The requirements for releasing SCM were successfully established.

The conditions of the permit allow for the importation of *Cydia pomonella* (Codling moth) which have been sterilised by gamma irradiation treatment at the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility, located in Canada. Imported material can only be used for direct release into the environment for biological control use and is limited to only apple orchard field sites in South Australia and Tasmania, as part of the sterile insect release research program. The location of the release sites was also a requirement.

Th release sites were determined based on their history of codling moth, pesticide use and location. A SCM field release protocol was developed for the project by the project lead and NRE entomologist Dr Guy Westmore.

5. Economic feasibility of SCM systems

An economic assessment of SCM release programs for Australian apples was prepared by Nic Finger, APAL. This report underpins the recommendations made on future investment by industry in SCM technology and application in Australian orchards.

To what extent were the immediate project outcomes achieved?

6. The feasibility of SCM management systems in Australia

The feasibility of SCM management systems is presented in the final report and is based on trial data and economic analysis.

Project Appropriateness, Relevance, Impact & Legacy

The appropriateness and relevance to stakeholders will be evaluated by interviews conducted in July 2024. The short term and medium term impact of the project on stakeholders and the industry will also be evaluated through this process. The interview questions developed listed below address the questions in the MER plan.

Proposed Interview Questions of SCM Stakeholders

(July/August 2024)

Project team members (Appropriateness, Relevance, Impact)

- To what extent did the project deliver new knowledge of SCM importation pathways?
- To what extent did the project deliver new knowledge and understanding of SCM release strategies?
- In what way do you think the project (delivery, resourcing, efficiency) could have been improved ?

Grower participants & Apple Growers (Appropriateness, Relevance)

- Where have you heard about or read about the SCM program?
- How would you rate the relevance of the SCM program to your business?

Grower participants & Apple Growers (Impact & Legacy)

- Thinking back to before this program began (2021), how much do you think the project has increased your knowledge of a SCM program as a method for managing codling moth in apples?
- How would you rate your knowledge and understanding of SCM as a method for managing codling moth?
- If an affordable SCM program was available to you – how likely would you be to take up this as a management option – now – and in the future? What would influence this?

Service Industry - agronomists, resellers, biocontrol industry (Appropriateness, Relevance)

- Where have you heard about or read about the SCM program?
- How would you rate the relevance of the SCM program to your business?

Service Industry - agronomists, resellers, biocontrol industry (Impact & legacy)

- Thinking back to before this program began (2021), how much do you think the project has increased your knowledge of a SCM program as a method for managing codling moth in apples?
- How would you rate your understanding of the requirements of delivering a SCM program in apples?
- To what extent do you think your business be interested in providing or supporting a SCM service in Australia (no or in the future)?
- In what capacity do you think this would be?

Project Efficiency

Overarching KEQ

To what extent was the project delivered efficiently?

Project specific KEQ

- Did the project deliver on time and on budget with an efficient use of resources?
- What efforts were made to improve efficiency?

The project was initiated in 2019 just prior to impact of Covid-19. Up until early 2020, the project tracked on time. The intervention of Covid-19 put the project on hold for 2 years but allowed progression of the secure importation process. This was an efficient use of 'downtime' due to Covid-19. The project continued on-track until completion as forecast in July 2024.

Covid-19 also presented new logistical and budget challenges of reduced freight availability as flight schedules slowly returned to normality and increased freight charges. The project team adapted to the new landscape by restricting the pilot release program to Tasmania. Thus, efficiency was achieved and the project was able to proceed with the budget provided.

Further funds were redirected to offset the higher freight cost by importing live moths rather than larvae. This removed the added cost of modifying rearing facilities to grow out larvae.

The project also took steps to reduce risk and improve efficiency by undertaking a small trial shipment prior to the first release season. This allowed any logistical issues associated with import at both national and state borders to be resolved prior to the first full shipment and an assessment of moth viability on arrival.

The project team recruited casual staff with good familiarity of local apple orchards and pest management which aided project delivery efficiency.

Key Performance Indicators

Key Performance Indicators completed as of June 30, 2024

Table 3: Project Key Performance Indicators

Key Performance Indicator	Completed
Distribution map of CM in Australia	Yes
Agreements with Canada OKSIR to allow import of SCM	Yes
Importation plan produced and process approved by DAFF and AQIS	Yes
Rear out facilities established in Tasmania if moths are unable to be imported at the adult life-stage – Year 2	Not required
Regional pilot release of SCM at 2 locations	SCM released at 3 test sites in Tasmania
Assessment of SCM release program analysed and reported	Reports prepared and submitted.
Economic feasibility report	Submitted in final report. Presented at industry webinar.
Agronomist / service provider workshop conducted Year 3 and field day presentation	The workshop was planned to train agronomists in the requirements for releasing moths. As the import program was assessed as not economically viable, this was replaced by an information webinar.
Web page produced and updated biannually**.**	Project web page created and a research web page produced including Frequently Asked Questions
Community awareness via mainstream media (print/radio)	See Table 4
Industry Journal updates	2 Industry journal updates
E-news communication	E-news updates provided through APAL Industry Juice and FGT Fruit E-news (Table 4)

A summary of communication outputs and engagement activities is provided in Table 4:

Table 4: Communication & Extension activities

Date	**Output**	**Audience**	**Description**		
			Where	Content	Reach
1-3-2023	Media Release	General public; Australian apple industry: growers, service providers, researchers	Key media outlets	Media release	
1-3-2023	• TIA Research Web News • Project web Page • FAQ Web Page • YouTube • Facebook • Twitter	General public; Australian apple industry: growers, service providers, researchers	TIA	Research page Project web page YouTube Interview with Sally Bound - project description	 1,027 views
3-3-2023	E-News	Tasmanian apple industry: growers, service providers, researchers	FGT Fruit E News	Project overview	735 subscribers; approx. 45% open rate
3-3-2023	Internet news	Australian apple industry: growers, service providers, researchers	HortiDaily	Project overview	
2-3-2023	Radio Interview (national)	General public; Australian apple industry: growers, service providers, researchers	ABC Radio & ABC Country Hour	Project overview – interview with Sally Bound	529,000 (RN reach)
6-3-2023	Internet story	General	National Tribune AgNews	Project overview	
10-3-2023	Rural Newspaper	Tasmanian agricultural industry	Tasmanian Country	Project overview	40,000 readership
11-3-2023	Local Newspaper	General public; Tasmanian apple growers;	The Hobart Mercury - Weekend	Codling moth management	63,000 readership
26-4-2023	Internet resource	Australian apple industry: growers, service providers, researchers	APAL website	Project update	
28-4-2023	Internet story	General science community	Smart Company	IPM Internet news story	

May 2023	Industry Journal (National)	Australian apple industry: growers, service providers, researchers	Australian Fruit Grower – APAL Autumn 2023 PP 30-35	Project update	Over 900 subscribers, free to all levy paying apple & pear growers and industry
June 15-16	FGT Conference	Australian fruit industry: growers, service providers, researchers	Launceston	Display of codling moth project	120 attendees;
Oct 2023	Industry Journal (National)	Australian apple industry: growers, service providers, researchers	Australian Tree Crop	Project Update- Appendix X	Sent free to allgrowers, major ag suppliers, researchers, and online
May 2024	Field Day	General public; Tasmanian agricultural community;	Agfest	Interactive display with project lead talking to growers and general public about the project	54,500 attendees – approx. 1,000 visit TIA site
June 2024	Media	General public; Australian apple industry: growers, service providers, researchers	ABC Radio	Project update and potential in Australia	529,000 (RN reach)
June 2024	Industry E-News; SMS reminders to growers	Australian apple industry: growers, service providers, researchers	APAL IJ FGT Fruit E-News FGV E-news Fruit Producers SA Serve-Ag E-news	Promotion of webinar	Over 1,500 e-news subscribers in total (some subscribe to more than 1) 70 + SMS reminders sent
17-06-2024	Industry webinar	Australian apple industry: growers, service providers, researchers	Online & In-person at FGT offices Tasmania	Project update with Q&A – Presenters Dr Sally Bound & Dr Guy Westmore	15 online attendees from SA, NSW, Vic, NZ and Tas with 8 local attendees from Tasmania including 3 agronomists.

Key Performance Indicators to be completed by July 31, 2024

The following indicators will be assessed by grower and industry survey after completion of scheduled extension and communication activities:

1. Australian apple growers have increased awareness of SCM as an IPM tool for codling moth management.
2. Australian apple growers have increased knowledge of SCM management systems necessary to implement SCM in orchards.
3. Service providers have increased knowledge of SCM production and release requirements.

The extension and communication activities that will precede this evaluation include:

- Industry journal article – Australian Fruit Grower, Spring 2024, APAL online
- Case study publication – Australian Fruit Grower, Spring 2024, APAL online, web page update

Technology controls codling moth

Sally Bound, **Michele Buntain** *(Tasmanian Institute of Agriculture)*, **Guy Westmore** *(Department of Natural Resources and Environment)*

A pilot sterile insect release program for controlling codling moths is being evaluated in three Tasmanian apple orchards.

Codling moth (*Cydia pomonella*) is a major pest in all Australian pome-fruit production regions except Western Australia, where the codling moth is not present. It is one of the most economically damaging pests of apples, causing direct damage to fruit as it feeds.

If left unchecked, codling moth can damage 50-90per cent of fruit, decimating the crop. Codling moth also infests quince, pear, nashi, summer fruit, walnut and chestnut.

Current management strategies include monitoring, mating disruption, biological control and chemical pesticide control. While these strategies can be effective, the application of pesticides can disrupt beneficial insects, substantially affecting integrated pest management (IPM) systems.

Neglected orchards, as well as roadside and unmanaged backyard fruit trees, pose a real threat as they provide a source for re-infestation of commercial orchards. Sterile Insect Technology (SIT), in tandem with other IPM-friendly methods, has enormous potential to change the way codling moth is managed in Australian apples.

Dr Guy Westmore releasing moths in orchard.

Orchard fruit assessments.

Sterile insect technology

The use of sterile insect technology (SIT) is a relatively new strategy being developed for a range of pests, with fruit flies being a prime example of SIT technology in Australia. The method is an environmentally friendly way of controlling insect pests that can work well in conjunction with other IPM methods.

SIT programs work by flooding the wild population with large numbers of sterile males to substantially reduce the number of fertile eggs produced. When this is repeated over a number of seasons, the population crashes and infestations drop below damage threshold levels.

Successful codling moth SIT programs

In Canada, SIT has been successfully used for codling moth control since 1992, with an area-wide approach reducing wild codling moth populations by 94 per cent. A corresponding 96 per cent reduction in pesticide use for codling moth has been a win-win situation for both growers and the environment.

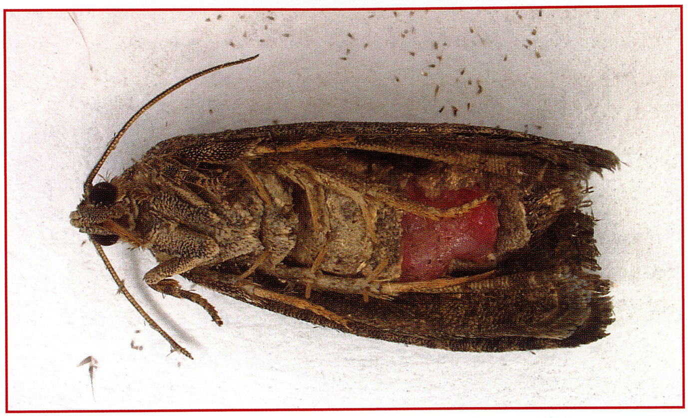
A program commenced in the Hawkes Bay region of New Zealand in 2014 with sterile codling moths (SCM) imported from the Okanagan-Kootenay Sterile Insect Release (OKSIR) facility in British Colombia. Treated regions of Hawkes Bay have recorded an impressive 98 per cent reduction in the catch of wild moths after only a few years of the program.

Sterile insect production

Codling moths are sterilised (made infertile) with highly controlled low-dose gamma radiation (200 Gy) at the OKSIR facility in Canada. This dose of irradiation sterilises the female moths and produces a high level of sterility in the male moths so that very few viable offspring are produced from wild-sterile matings.

The same technology is used to produce sterile fruit flies, which are currently produced and released in Australia to eradicate fruit fly outbreaks in pest-free areas. The sterile codling moths can be distinguished from wild moths due to a permanent internal pink-red dye marker from the larval diet.

Dr Guy Westmore-SCM quality checks.



Sterile codling moth in lab.

Pilot study in Australia

A pilot sterile codling moth release program is currently underway in Tasmania. The project will assess sterile moth viability and competitiveness, determine the logistics of importation and release, and undertake an economic assessment of the release program, with the aim of developing recommendations for the adoption and integration of sterile releases into an IPM program.

Now in its second year, the project has successfully developed secure entry pathways for importing SCM into Australia from the Canadian OKSIR facility. Quality control tests have been undertaken to check moth viability on arrival.

Trial releases commenced in late October 2022 in three selected apple orchard blocks in Tasmania's Huon Valley region and will continue on a weekly basis until mid-February.

The sterile adult moths are airfreighted from Canada each week. They are packed in small 'dixie' cups and chilled to ensure the moths remain dormant until release. Moths are gently hand-distributed throughout treatment blocks at the rate of 6,000 moths per hectare per week (3,000 male moths per hectare per week).

In New Zealand, moths are released by drones over commercial orchards. If sterile codling moth releases are adopted by the Australian apple industry, this method could also be used here.

Monitoring is an important part of the program to indicate the numbers of both wild and introduced sterile moths. Traps in both moth release blocks and nearby control sites are checked weekly for counting wild and sterile moths.

Fruit assessments are also being undertaken in the orchard to determine the incidence of damage. The import, release and monitoring program will be repeated in the 2023-24 season.

Dr Guy Westmore-orchard fruit assessments.

Moths decanting into flask.

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