Impact assessment of the investment:

Macadamia Integrated Disease Management (MC16018)

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Hort Innovation

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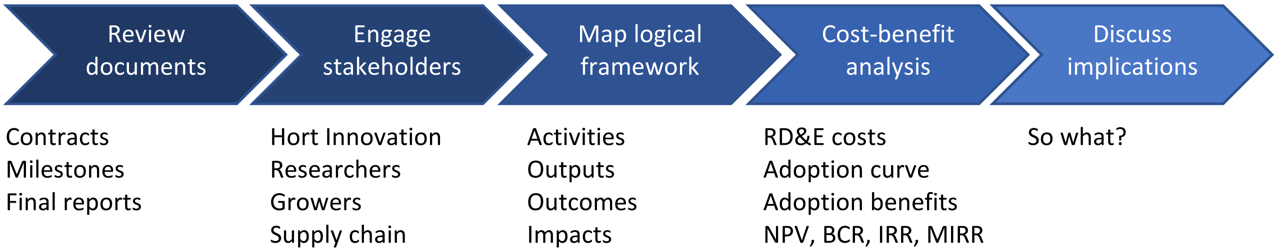
Executive summary

What the report is about

Ag Econ conducted independent analysis determine the economic, social, and environmental impact resulting from delivery of the vegetable project *Macadamia Integrated Disease Management (MC16018)*. The project was funded by Hort Innovation over the period November 2017 to January 2023 using the macadamia research and development levy and contributions from the Australian Government. The project was delivered by the University of Queensland (UQ).

The analysis applied a five step analytical process to understand the impact pathway and collect supporting data.



Research background

MC16018 was established to further progress an integrated disease management (IDM) program for the Australian macadamia industry. MC16018 was designed to build on and advance the husk spot and Phytophthora root rot outcomes of the previous disease management projects (MC03007, MC07003 and MC12007, delivered by the University of Queensland), while also improving knowledge of and diagnostics for emerging disease threats including husk rot, flower bight and branch dieback.

Key findings

The nominal investment cost of $2.83 million was adjusted for inflation (ABS, 2024) and discounted (using a 5% real discount rate) to a 2023-24 present value (PV) of costs equal to $3.99 million.

Through a logical framework process, including discussing the project with nine industry stakeholders and reviewing of the project impact pathway was identified. The process highlighted that MC16018 (as part of the longer term program of disease management RD&E) had generated practical and positive results for industry to manage key diseases. Most notably, stakeholders identified husk spot and phytophthora as two diseases where the long term RD&E program had generated an improvement in industry understanding of the disease risk, as well as improved management options.

Reflecting the stakeholder feedback, a model was developed to evaluate the impact of improved disease management relating to husk spot and phytophthora with regards to improved productivity and profitability.

The baseline figures showed a PV benefits of $5.68 million, with a modest impact benefit cost ratio (BCR) of 1.42:1.

A lack of specific disease impact data for the macadamia industry was a clear limitation of the analysis, particularly relating to the impact of phytophthora on Australia's macadamia production. In consideration of the compounding uncertainties, conservative estimates were made for all variables, which were also sensitivity tested across a reasonable range.

This sensitivity testing identified a relatively narrow potential impact (BCR) range of between 0.54:1 and 2.59:1, with 90% of results falling between 0.81:1 and 1.83:1, with 76% of a BCR greater than 1:1. The results gave a moderate to high level of confidence that the investment will generate a positive impact over the 30 year analysis period, which largely reflected the uncertainty in the modelling inputs due to a lack of data.

Given these results, the analysis highlighted the importance of collecting data that is relevant to RD&E activities and outcomes so that success can be clearly demonstrated. To this end, it is recommended that the existing disease data collected through the industry benchmarking project is refined to demonstrate the estimated scale of losses (e.g. t/ha NIS losses) resulting from each disease.

The key findings of the MC16018 impact assessment are summarized in Figure 1 below.

Keywords

Impact assessment; cost-benefit analysis; macadamia; Integrated Disease Management (IDM), husk spot, phytophthora

Figure 1. Summary of impact assessment findings

MC16018 Integrated disease management

Total RD&E costs:

- $2.83 million (nominal value)
- 54% R&D levy and Government matching, and 46% UQ in-kind.

Research activities:

- From 2017 to 2023, the project built on the findings of previous projects to refine knowledge and recommendations for managing husk spot, husk rot, flower bight, phytophthora root rot, and branch dieback within an IPDM framework.
- The project conducted laboratory and field studies to understand the identity, biology and ecology of the causal agent(s) of diseases in macadamia and develop tools for diagnostics and screening of macadamia pathogens.
- Pathogen services were provided to support responsive identification and management of macadamia diseases.

Extension activities:

- In collaboration with industry extension & communication, MC16018 delivered over 80 outputs via the industry channels, including updating the *Macadamia plant protection guide*, and conducting disease identification and management workshops for 65 agronomists in NSW and QLD.

Outcomes:

- Twelve known plant pathogens and 14 novel pathogens were identified for the first time as causes macadamia diseases.
- New knowledge of different disease severity among macadamia cultivars.
- Over 185 diagnostic samples were analysed to provide timely feedback to manage local disease outbreaks.
- Refined recommendations for disease monitoring and risk assessment.
- The registration of two new agrochemical products was supported.
- Cultural control recommendations were refined to reduce pathogen inoculum.

Industry adoption:

- Stakeholder feedback indicated that no one RD&E output had been a panacea to reduce disease risk, and their adoption and integration into a disease management program varied widely across industry. However, it was recognised that the tools and recommendations generated through the long term disease management RD&E program had been effective at reducing disease risk over time, particularly for husk spot and phytophthora.

Industry economic impacts:

- Reduced production losses resulting from key diseases husk spot and phytophthora.

Socio-economic impacts:

- Increased flow-on employment and economic stimulant to supply chains and local communities from more profitable macadamia growers.

Total attributable benefits and impact:

- Present value (PV @ 5% discount) RD&E costs of $3.99 million.
- PV attributable benefits of $5.68 million between 2018 and 2053.
- Net PV (NPV) of $1.68 million.
- Benefit cost ratio (BCR) of 1.42:1 with a 90% confidence of a BCR between 0.81:1 and 1.83:1

Introduction

Evaluating the impacts of levy investments is important to demonstrate the economic, social and environmental benefits realised through investment to levy payers, Government and other industry stakeholders. Understanding impact is also an important step to inform the ongoing investment agenda.

Reflecting its commitment to continuous improvement in the delivery of levy funded research, development and extension (RD&E), Hort Innovation required a series of impact assessments to be carried out annually on a representative sample of investments of its RD&E portfolio. Commencing with MT18011 in 2017-18, the impact assessment program consisted of an annual impact assessment of up to 15 randomly selected Hort Innovation RD&E investments (projects) each year. In line with this ongoing program, Ag Econ was commissioned to deliver the *Horticulture Impact Assessment Program 2020-21 to 2022-23* (MT21015).

Macadamia Integrated Disease Management (MC16018) was randomly selected in the 2022-23 sample. This report presents the analysis and findings of the project impact assessment.

The report structure starts with the general method of analysis used, followed by the RD&E background and an outline of the impact pathway in a logical framework, then describes the approach used to quantify the identified costs and benefits including any data gaps and limitations to the analysis, presents the results including from the sensitivity analysis, and finally discusses any implications for stakeholders.

General method

The impact assessment built on the impact assessment guidelines of the CRRDC (CRRDC, 2018) and included both qualitative and quantitative analysis. The general method that informed the impact assessment approach is as follows:

1. Review project documentation including project plan, milestone reports, outputs and final report.
2. Discuss the project delivery, adoption and benefits with the Hort Innovation project manager, project researcher/consultant, growers and other relevant stakeholders (see *Stakeholder consultation*).
3. Through a logical framework, qualitatively map the project's impact pathway, including activities, outputs, and outcomes to identify the principal economic, environmental, and social impacts realised through the project
4. Collect available data to quantify the impact pathway and estimate the attributable impacts using cost-benefit analysis (over a maximum 30 years with a 5% discount rate), and then sensitivity test the results to changes in key parameters.
5. Discuss the implications for stakeholders.

Contracts Milestones Final reports	Hort Innovation Researchers Growers Supply chain	Activities Outputs Outcomes Impacts	RD&E costs Adoption curve Adoption benefits NPV, BCR, IRR, MIRR	So what?

The analysis identified and quantified (where possible) the direct and spillover impacts arising from the RD&E. The results did not incorporate the distributional effect of changes to economic equilibrium (supply and demand relationships) which was beyond the scope of the MT21015 impact assessment program. A more detailed discussion of the method can be found in the *MT21015 2022-23 Summary Report* on Hort Innovation project page Horticulture Impact Assessment Program 2020/21 to 2022/23 (MT21015).

Project background

The five-year project was delivered during a time of significant industry expansion. In 2016, the industry consisted of about 650 growers and 17,000 ha planted to macadamias, while in 2021 this had increased to about 800 growers and 32,500 ha, of which approximately 25,000 ha were bearing (Hort Innovation 2024). In 2022, the industry was continuing to expand rapidly, with substantial new plantings underway in new and existing regions (AMS, 2022). At the same time, strong international growth in macadamia production—particularly in African countries, as well as China, Vietnam and South America—meant that Australia's historical dominance of global production was slipping (ABC, 2021).

Ongoing growth in areas planted to macadamias around the world and the focus on maintaining Australia's reputation as a supplier of premium nuts highlighted the importance of a strategic and industrywide approach to increasing production and profitability.

Previous macadamia disease management projects (MC03007, MC07003 and MC12007, delivered by the University of Queensland) had focused on understanding the biology and epidemiology of husk spot and phytophthora in macadamia. The 2017-2021 Macadamia Strategic Investment Plan (SIP) (Hort Innovation, 2017) recognised that an ongoing focus was required to reduce the production and profitability losses associated with key macadamia diseases. Industry benchmarking data in 2017 also highlighted the ongoing production impact of diseases, with phytophthora identified as being production limiting by more than 50% of growers in both QLD and NSW, followed by husk spot (approximately 20% of growers) (QDAF 2016-2022).

With the ongoing impact of diseases on macadamia production, MC16018 was established to further progress an integrated disease management (IDM) program for the Australian macadamia industry. MC16018 was designed to build on and advance the outcomes of the previous disease management projects for control of husk spot and Phytophthora root rot, focusing on non-chemical options, while also improving knowledge of and diagnostics for emerging disease threats including husk rot, flower bight and branch dieback.

MC16018 aligned with the Macadamia SIP 2022-2026 through:

- Outcome 2: Industry supply, productivity and sustainability. Strategy 6. Support an integrated pest and disease management (IPDM) program that addresses key economic, social and environmental outcomes for the macadamia industry.

Project details

MC16018 was funded from 2017 to 2023 (Table 1).

Table 1. Project details

Project code	MC16018
Title	Macadamia Integrated Disease Management (MC16018)
Research organization(s)	University of Queensland (UQ)
Project leader	Olufemi Akinsanmi
Funding period	November 2017 to January 2023
Objective	To deliver a holistic integrated disease management program, compatible with integrated pest management, to increase productivity and profitability of growers and the Australian macadamia industry.

Logical framework

The impact pathway linking the project's activities and outputs, and their assessed outcomes and impacts have been laid out in a logical framework (Table 2).

Table 2. Project logical framework detail

RD&E activities

- Building on the findings of previous projects (MC03007, MC07003, and MC12007) MC16018 refined existing knowledge and recommendations to manage key diseases husk spot, husk rot, flower bight, Phytophthora root rot, and branch dieback within an IPDM framework.
  - **Laboratory studies**
    - Understanding of identity, biology and ecology of the causal agent(s) of diseases in macadamia.
    - Development of tools for diagnostics and screening of macadamia pathogens.
    - In vitro efficacy of chemical and biological products in SARP against major macadamia pathogens.
    - Provide diagnostic services to the industry to monitor priority disease issues.
  - **Field studies**
    - Surveys and field trials were performed in commercial macadamia orchards at different locations in NSW and QLD to identify, review and develop biological and chemical control option (in coordination with the Strategic Agrichemical Review Process).
    - Further field studies were also conducted to optimise a mechanical tree shaker to reduce sticktights (source of husk spot inoculum), which was first developed through MC07003 and MC12007.
  - **Extension and communication** activities in collaboration with industry extension (MC15004 and MC20000), communication (MC15003 and MC18000) to upskill growers and crop consultants.
  - **Develop new research capacity**. One PhD scholarship was funded through MC16018 and the project supported the studies of additional three full scholarships provided by the UQ.
  - **Collaborate and coordinate with other RD&E.** Including with IPM (MC16003-8), industry benchmarking projects (MC15005 and MC18002), Macadamia regional variety trials (MC11001), transforming subtropical-tropical tree crop productivity (AI13004), and international networks to reduce the risk of exotica and endemic disease spread in Australian macadamias.

RD&E outputs

A wide range of resources were developed and disseminated to support macadamia grower and crop advisor disease management decisions.

Research outputs

- 40 scientific publications as refereed articles, conference abstracts and presentations.

Extension outputs

- Over 80 outputs were produced and disseminated to the industry via the industry News Bulletin, as published articles, factsheets, video presentations, digital materials.
- Disease risk and management recommendations were updated in the *Macadamia plant protection guide*.
- Disease identification and management workshops for 65 agronomists at Alstonville, NSW, Nambour, and Bundaberg in QLD between 10-13 September 2018.

Outcomes

End of project outcomes

- Updated **research skills and capacity** through the long term support and development of collaboration networks and domestic expertise in macadamia disease research, including the training of four PhDs in the area of macadamia diseases.
- Updated **research tools and knowledge** of the causes of key diseases in macadamias.
    - A new In vitro macadamia whole-leaf dip assay was developed as a simple and effective way to screen and compare cultivar susceptibility to various Phytophthora species.
    - The studies undertaken to characterize the causal agents of the major diseases revealed for the first time that 12 known and 14 novel pathogen species are associated with husk rot, flower bight, Phytophthora root rot, and branch dieback in macadamia, suggesting each of the disease is a complex pathosystem.
    - Significant differences in disease severity were observed among major macadamia cultivars to husk rot, flower bight, Phytophthora root rot, and branch dieback.
- Expanded **industry IPDM resources and recommendations**
    - **First responder diagnostic services.** Over 185 samples were received for diagnostics from macadamia growers and crop consultants, with timely feedback ensuring industry has access to targeted information to increase confidence to manage any local disease outbreaks. In 2020, leaf diseases emerged as a threat to macadamia in the Bundaberg region, which thereafter, became a major concern in several orchards in different growing regions. Information on leaf diseases in macadamia was published in the AMS News Bulletin Spring Edition, providing industry with diagnostic tools for the five different types of leaf diseases in macadamia.
    - **Disease monitoring and risk assessment.** The development and extension of simple on farm monitoring and self-assessment tools, combined with knowledge of the principal source of inoculum, helped growers to identify and respond to key diseases more rapidly, and with appropriate IPDM controls relevant to crop growth stages and weather conditions.
    - **Chemical controls**. The data and research findings obtained in this project supported the registration of two new agrochemical products - Belanty® (mefentrifluconazole) and Merivon® (Fluxapyroxad and Pyraclostrobin) in macadamia.
    - **Cultural controls**. Further refine cultural control recommendations including use of a tree shaker (building on previous research MC0703 and MC12007) to break the Husk Spot disease cycle. MC12007 field trials showed a significant reduction in disease severity when sticktights were removed with the tree shaker compared with the untreated control. MC16000 further developed the recommendations for the mechanical tree shaker to improve its efficiency, determine the optimal timing of application and to reduce damage to trunk and possible impact on tree health in macadamia.

The improved knowledge, resources, and confidence to adopt IPDM in macadamias has the potential to generate the following impacts:

- [Economic] Increased productivity and profitability from improved long term efficacy of control options reducing the incidence and effects of disease on macadamia yield and quality, or reduced cost of disease suppression, or both.
- [Socio-economic] Increased macadamia industry spillovers including employment and economic stimulant to local communities (The CIE 2023).
- [Environmental] Reducing the reliance on chemical control options, thereby reducing unintended off target impacts on native ecosystems (NSW DPI 2023)
- [Social] Supporting the long-term supply of affordable domestic macadamia nuts to Australian consumers, resulting in increased consumption (Kantar 2022) and an increase in associated health and wellbeing benefits (AMS 2024; Hort Innovation 2020).

Project costs

The project was funded by Hort Innovation, using the macadamia research and development levies and contributions from the Australian Government, with additional funding from research partner UQ.

Nominal investment

The project funding period was 2017-18 to 2022-23 (Table 3). Hort Innovation overhead costs were added to the direct project cost to capture the full value nominal of the RD&E investment.

Table 3. Project nominal investment

Year end 30 June	Hort Innovation (MC levy and Gov't matching) ($)	Hort Innovation overheads[1] ($)	Other funding ($)[2]	Total nominal cost ($)
2018	250,000	50,479	248,242	548,721
2019	234,000	47,767	232,354	514,121
2020	272,000	51,856	270,087	593,943
2021	193,000	31,463	191,643	416,106
2022	91,000	14,811	90,360	196,171
2023	$260,000	42,316	258,172	560,488
Total	**1,300,000**	**238,692**	**1,290,858**	**2,829,550**

1. The overhead and administrative costs were calculated from the Financial Operating Statement of the Macadamia Fund Annual Reports, averaging 18% for the MC16018 funding period (2017-2023).
2. In kind funds from UQ for salaries, equipment, and facilities use were provided in the contract as a lump sum, so have been apportioned yearly based on Hort Innovation cash costs.

Present Value of investment

The nominal total investment cost of $2.83 million identified in Table 3 was adjusted for inflation (ABS, 2024) into a real investment of $3.30 million (2023-24 equivalent values). This was then further adjusted to reflect the time value of money using a real discount rate of 5% (CRRDC 2018), generating a present value (PV) of costs equal to $3.99 million (2023-24 PV). The results were sensitivity tested changes in the discount rate between 2.5% and 7.5%.

Project impacts

The impact pathway identified in Table 2 were evaluated against available data to determine if their impact could be quantified with a suitable level of confidence.

Data availability to quantify the impact pathways

In discussion with the MC16018 research lead and industry growers and agronomists, the key research and industry outcomes have been in improving the knowledge and skills in managing husk spot and phytophthora. It was also highlighted that success in these areas reflects the long-term investment in disease management research with MC16018 building on and refining the recommendations from earlier work (MC03007, MC07003, MC12007) starting over 20 years ago. Over the 20 years of research advances have been made across the whole program of disease management, including identifying diseases, applying the right fungicide at the right time, incorporating cultural controls to minimise disease carry-over and spread, using varieties that are less susceptible, and maximising soil and tree health. Stakeholders also highlighted that no single new practice had been a panacea for disease management, but the research has progressively improved management options over time. Stakeholders also noted that "best practice" varies between orchards and regions. Given the complex nature of IDM, it was deemed unrealistic to focus the analysis on a single RD&E output (such as the tree shaker for husk spot, or new disease monitoring and risk assessment recommendations such as the "snappy" system for phytophthora). Instead, the analysis focused on the long-term achievements of reducing disease risk as a result of ongoing improvements in IDM.

Data relating to industry losses attributed to husk spot and phytophthora are limited. For Phytophthora, production losses were estimated at $8 million per year in 2013 (Akinsanmi and Drenth, 2013), with the same source being scaled up to $20 million in losses (Jeff-Ego et al, 2020). No follow up productivity data was identified that would indicate progress in combatting the disease. No research on husk spot productivity losses was identified.

Since 2017, the industry benchmarking projects (MC18002 and MC22000) have surveyed growers to identify the key factors limiting production, as well as the primary disease limitation. The benchmarking data has shown a general decline in the production impact of phytophthora and husk spot relative to other diseases (*Appendix A. Macadamia industry data and projections*). However, while this data provides insight into the *relative* concern of industry with regards to disease effects on production, as a ranking (e.g. most to least significant factors limiting production) there is no way to quantify the *actual* level of production losses due to disease. Benchmarking data also captures crop protection costs, which have trended up over time; however, these have not been separated into pest and disease costs.

Since the benchmarking commenced in 2009 (starting with MC15005) data has been collected on reject kernel recover (RKR) which includes rejects due to immature nuts. Each benchmark report has noted that immaturity may be related to premature nut drop associated with husk spot damage. The Macadamia Plant Protection Guide (NSW DPI 2023) also identifies heavy premature nut shedding as the primary symptom of husk spot. Some stakeholders noted that immature nut drop can also be due to factors such as water stress.

Impacts valued and valuation framework

In line with the above, a model was developed to estimate:

- [Economic] Increased productivity and profitability from improved long term efficacy of control options reducing the incidence and effects of disease on macadamia yield and quality, or reduced cost of disease suppression, or both.

Reduction in husk spot productivity losses

Given the clearly stated causal relationship between hust spot and immature nut drop, and the availability of detailed data on the productivity implications of husk spot over time, this impact was quantified in the analysis. A "with investment" and "without investment" scenario was developed using the following approach:

With investment. A model was developed to calculate the yearly quantity of production rejected due to immature nut drop. The model incorporated benchmarking data on immature nut drop by tree age (which increases with tree age), plantings by tree age, and nut in shell (NIS) yield by tree age. The model showed progressively decreasing rates of immature nut losses (as a percentage of NIS yield), which reflects improvements in disease management to reduce the incidence and consequences of husk spot in the industry.

Without investment. The same model considered the scenario whereby there had been no investment and therefore no improvement in husk spot management. This scenario kept the rate of immature nut loss at a constant rate providing a baseline against which the "with investment" scenario could be compared.

Comparing the "with investment" and "without investment" scenarios identified the yearly yield benefit of improved husk spot management. The yield benefit was valued at the NIS price per kilogram, less yield related costs per kilogram that would be incurred if nuts were held to maturity and sold (nutrition, irrigation, sorting, freight, levies). In addition to the yield benefit, the benefit of an avoided price discount was calculated reflecting the price bonus and penalty associated with different levels of RKR, with immature nut rejects being one contributing factor to RKR. Changes in disease management costs were not included due to the inability to separate crop protection data into pest and disease cost components, with the implied assumption that the new practices are cost neutral. Finally the proportion of the total benefits attributed to MC16018 was estimated based on the investment cost of MC16018 relative to the whole program of investment (MC03007, MC07003, MC12007 and MC16018).

Reduction in Phytophthora productivity losses

While previous research had estimated production losses of $8 million per year (Akinsanmi and Drenth, 2013) and $20 million per year (Jeff-Ego et al, 2020), these both used the 2013 loss estimates (scaled up with higher production and prices in 2020), with no follow up data identified to support an estimate of progress in combatting the disease. However, stakeholders noted that improving phytophthora management had been one of the key areas of focus and success for the disease management RD&E program (MC03007, MC07003, MC12007 and MC16018). When combined with the significance of the disease (typically noted in benchmarking reports as the number one disease issue for the industry), this highlighted the importance of estimating the value of improved phytophthora management resulting from the RD&E program. As the benefits of improved husk spot management were able to be estimated (outlined above), this was also used as an indicator of the potential benefits of improved phytophthora management. To reflect the uncertainty over the scale of phytophthora productivity losses, or the success in the disease management research in reducing the losses, the husk spot benefits were weighted by an adjusting factor.

While the impact approach has a high level of uncertainty (particularly for phytophthora), it is considered the best possible approach given the available (or lack of) data. In consideration of the uncertainty, conservative estimates were made for all variables, which were also sensitivity tested across a reasonable range.

Impacts unable to be valued

The following impacts were unable to be valued:

- [Socio-economic] The contribution of the macadamia industry as a source of employment and economic stimulant to regional communities has been highlighted in previous Hort Innovation research (The CIE 2023). Increased macadamia farm yield, revenue, and profitability would generate flow on benefits to the regional communities in which the industry operates. While this analysis quantified the direct impacts for macadamia industry value, the flow-on effects require additional analysis using economic models that capture regional and national linkages, which are beyond the scope of the R&D impact assessment program (CRRDC 2018).
- [Social] Supporting the long term supply of affordable domestic macadamia nuts to Australian consumers, resulting in increased consumption (Kantar 2022) and an increase in associated health and wellbeing benefits (AMS 2024; Hort Innovation 2020). While increased production has the potential to put downward pressure of prices and thereby encourage increased domestic consumption, as an increasingly export focussed industry (72% exported in 2023, Hort Innovation 2023) the macadamia price is primarily driven by global supply and demand. As such, while it is possible for health and wellbeing benefits associated with increased macadamia production, the size of this benefit is potentially minor, and furthermore requires equilibrium modelling to capture the supply-price-demand effect, which is typically beyond the scope of the R&D impact assessment program (CRRDC 2018).
- [Environmental] Reducing the reliance on chemical control options, thereby reducing unintended off target impacts on native ecosystems (NSW DPI 2023). Stakeholders noted the benefits of the RD&E in identifying cultural and mechanical control options to compliment and minimise the use of fungicides. While this reduces the off target effects of high fungicide use, the registered products are generally noted as having low off-target impact (NSW DPI 2023). As such, the size of this benefit is likely minor.

Data and assumptions

The required data relating to the impact pathway was collected from the project documents and other relevant resources (Table 4). Where available, actual data was applied to the relevant years, with estimates applied for any data gaps and projections into the future based on analytical techniques (for example correlations and trend analysis), or stakeholder estimates, or both. A data range was incorporated to reflect underlying risk and uncertainty. This was particularly relevant where estimates were needed due to data gaps, and where projections were made into the future. These ranges were then analysed through sensitivity testing (see *Results*).

Table 4. Summary of data and assumptions for impact valuation

Variable	Value	Source & comment
General data and assumptions		
Discount rate	5% (± 50%)	CRRDC Guidelines (2018)
Macadamia industry growth (ha)	Average 1162 hectares per year	See *Appendix A. Macadamia industry projections*.
Baseline yield	Mature tree yield of 3.22 t/ha NIS	See *Appendix A. Macadamia industry projections*.
Macadamia NIS price outlook	Reaching $4.5/kg NIS by 2028 (-16% +11%)	See *Appendix A. Macadamia industry projections*.
Reject Kernel Recover penalty $/kg NIS	-$0.01/kg NIS per 0.1% RKR	Marquis Macadamias (2024) Notional Price Table.
Macadamia yield related costs)	$0.75/kg NIS (± 36%)	Costs associated with additional yield included sorting, freight, and levies, which were estimated at $0.5/kg NIS from benchmarking data (QDAF 2016-2022 & 2024) and stakeholder consultation. Retaining nuts through to maturity may also impact tree water and nutritional requirements, which increased the costs to $1.06/kg NIS, with a midpoint of $0.75/kg NIS.
Phytophthora benefit factor	1:1 (-50%, +25%)	Analyst assumption. Industry benchmarking (QDAF 2016-2022 & 2024) typically identifies phytophthora as the number one disease issue limiting production, but at the same time, stakeholders noted that MC16018 and earlier work has had a strong focus on phytophthora which has helped to improve management of this disease and thereby reduce the risk and impact on production from what it would otherwise have been. Without any specific data on impact, a factor was applied to the Hust Spot benefit assuming the phytophthora benefit was between 50% and 125% of that estimated for phytophthora.
Impact attributable to MC16000	25%	The modelling framework estimated the total benefit of improved disease management; however, MC16018 only made up part of the broader disease management RD&E program which also included MC03007, MC07003, MC12007. As such, the attribution of benefits to MC16018 considered the cost share of MC16018 relative to all other investments in the program. See *Appendix B. Total program cost.*
Counterfactual attribution	100% (- 25%)	A high attribution was applied in the baseline, reflecting the need for long term applied scientific research, for which there would be little capacity or incentive without industry levy funding.

Results

The analysis identified PV costs (PVC) of $3.99 million (2023-24 PV) between 2017-18 and 2022-23, and estimated attributable PV benefits (PVB) of $5.68 million (2023-24 PV) accruing between 2017-18 and 2052-53 (Table 5). When combined, these costs and benefits generate a net present value (NPV) of $1.68 million, an estimated benefit-cost ratio (BCR) of 1.42 to 1, an internal rate of return (IRR) of 9% and a modified internal rate of return (MIRR) of 7%.

Table 5. Impact metrics for the total investment in project MC16000

Impact metric	Years after last year of investment						
	0	5	10	15	20	25	30
PVC ($m)	3.99	3.99	3.99	3.99	3.99	3.99	3.99
PVB ($m)	0.82	1.73	2.94	3.83	4.51	5.15	5.68
NPV ($m)	-3.17	-2.26	-1.06	-0.17	0.52	1.16	1.68
BCR	0.21	0.43	0.73	0.96	1.13	1.29	1.42
IRR	Negative	Negative	3%	6%	8%	9%	9%
MIRR	Negative	Negative	4%	6%	7%	7%	7%

Figure 2 shows the annual undiscounted benefit attributable to MC16018, as well as the MC16018 RD&E costs and earlier RD&E costs.

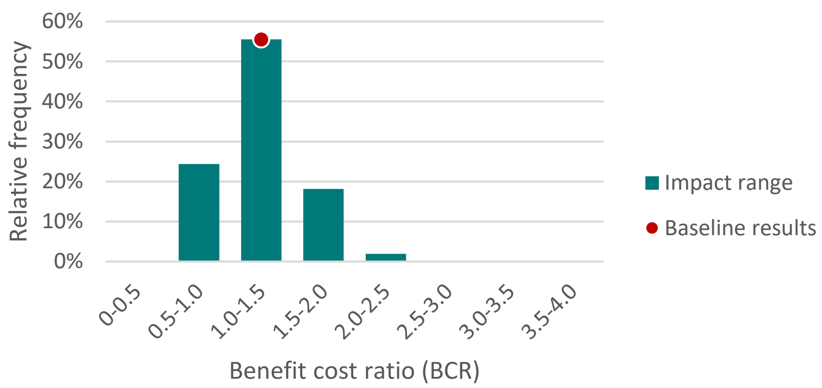
Figure 2. Annual cash flow of undiscounted total benefits and total investment costs

Sensitivity analysis

Given the risk and uncertainty associated with a number of underlying modelling variables, the potential model variation was estimated and drivers of variation identified. The sensitivity testing used @Risk stochastic modelling to incorporate the combined effect of changing all variables across their full ranges over 1000 simulations. This process showed:

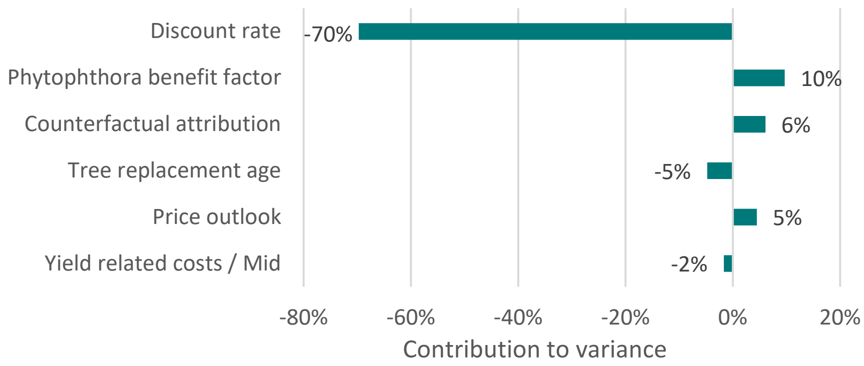
- **Impact variation (Figure 3)**. Compared to the baseline BCR or 1.42:1, the 1000 simulation showed a potential BCR range of between 0.54:1 and 2.59:1, with 90% of results falling between 0.81:1 and 1.83:1 (i.e. excluding the low probability tails), and a simulation average of 1.24:1 (below the baseline results). Of the 1000 simulations, 76% had a BCR greater than 1:1 (benefits greater than RD&E costs), giving a moderate-high level of confidence that the investment will generate a positive impact over the 30 years following project completion.

Figure 3. Impact variation in results over 1000 simulations



- **Contribution to variance (Figure 4)**. Contribution to variance is a measure of how much a variable contributes to the total variance of an output. Contribution to variance also shows whether a variable is positively or negatively correlated with impact. A negative contribution to variance, with bar extending to the left, indicates that this input has a negative effect on BCR: increasing this input will decrease the impact. The discount had the largest contribution to variation of -70%%. The breakeven discount rate is reflected in the IRR (9%), or the MIRR (7%) if generated cashflows are reinvested at the risk-free discount rate. The phytophthora benefit factor accounted for 10% of variance. The phytophthora benefits had to be at least 40% of the Hust Spot benefit to generate a positive impact. The Counterfactual Attribution contributed 6% of total variance, with a breakeven value of 70% (i.e. a maximum 30% chance that the R&D would have been completed without Hort Innovation funding). The tree replacement age had a 5% contribution to variance with a negative correlation to impact. As there is a greater risk of husk spot with increased tree age, a lower tree replacement age means there is a lower industry risk of husk spot as the national tree population ages, which in turn reduces the benefit of improved husk spot IDM generated through RD&E. The farmgate price outlook also had an 5% contribution to variance, but with a positive correlation to impact; higher prices increase the benefit of avoiding husk spot yield losses. Yield related costs had a limited contribution to variance of 2%.

Figure 4. Contribution to variance



Implications and learnings

Stakeholder engagement indicated that MC16018 (as part of the longer term program of disease management RD&E) had generated practical and positive results for industry to manage key disease. Most notably, stakeholders identified husk spot and phytophthora as two diseases where the RD&E had generated an improvement in industry understanding of the disease risk, as well as improved management options.

Reflecting the stakeholder feedback, a model was developed to evaluate the impact of improved disease management relating to husk spot and phytophthora with regards to improved productivity and profitability. The analysis considered the full program cost, including previous disease RD&E investments from 2004 (75% of total discounted total program costs), the MC16000 investment (25% of total costs). When considering the benefits, the model included six key variables, which were all tested for sensitivity.

The lack of specific disease impact data for the macadamia industry was a clear limitation of the analysis. RKR relating to immature nut drop was identified as an indicator of husk spot production losses through the Macadamia benchmark project (QDAF 2016-2022 & 2024), the Macadamia plant protection guide (NSW DPI 2023) and discussions with stakeholders. While other factors such as water stress were also identified as contributing to immature nut drop in some years, the modelling effectively assumed the long term downward trend in immature nut drop could be attributed to improved husk spot management.

Unfortunately, no similar data was identified to quantify changes in phytophthora risk over time (such as changes in production losses). However, because of the feedback from stakeholders regarding the success of R&D in improving phytophthora management, combined with the significance of the disease (typically noted in benchmarking reports as the number one disease issue for the industry), the model included an estimate of phytophthora benefits by applying a simple multiplier to the husk spot benefits. This effectively assumed that the estimated husk spot benefits provide a reasonable indicator of what the phytophthora benefits have been.

From the above approach, the baseline figures showed a modest impact BCR of 1.42:1.

In consideration of the compounding uncertainties, conservative estimates were made for all variables, which were also sensitivity tested across a reasonable range. This sensitivity testing identified a relatively narrow potential impact range of between 0.54:1 and 2.59:1, with 76% of results having a BCR greater than 1:1, giving a moderate to high level of confidence that the investment will generate a positive impact over the 30 year modelling period.

A key area of uncertainty in the modelling came from the reduction in phytophthora risk as a result of the RD&E. The results showed that a total undiscounted phytophthora benefit of $9.2 million (40% of the total undiscounted Husk Spot benefit) would be required to generate a positive industry impact. Given that phytophthora is typically noted as the number one disease issue for the industry, and stakeholder anecdotal feedback on the success of the RD&E program in increasing awareness and skills to reduce phytophthora risk, a phytophthora risk reduction of less than half that of husk spot seems conservative.

While this impact approach had a high level of uncertainty (particularly for phytophthora), it was considered the best possible approach given the available (or lack of) data. The analysis highlights the importance of collecting data that is relevant to RD&E activities and outcomes so that success can be clearly demonstrated. To this end, it is recommended that the existing questions on diseases collected through the industry benchmarking project are refined to demonstrate the estimated scale of losses (e.g. t/ha NIS losses) resulting from each disease.

Given the close integration of pest and disease management, as well as the difficulty in separating cost data, the impact approach taken in this analysis could be expanded to evaluate the broader benefits of improved pest and disease management over time. This would allow the inclusion of both pest and disease RKR, as well as combined changes in pest management costs, which would give a more accurate picture of total changes in pest and disease impact over time, to which pest and disease RD&E has contributed.

Stakeholder consultation

Where possible, Ag Econ sought to engage multiple stakeholders across key areas of the logical framework and impact pathway to augment existing information and data sources, and reduce any uncertainty or bias from individual stakeholders. All stakeholders were engaged through telephone or online meetings, with follow up emails as necessary. Consultation followed a semi-structured approach in line with broad topics relating to the impact pathway and associated data requirements. Table 6 outlines the stakeholders consulted as part of this impact assessment and the topics on which they were consulted.

Table 6. Stakeholder consultation by theme

Stakeholder details		Consultation topics						
Stakeholder and organisation	**Stakeholder type**	**Related research**	**Research inputs**	**Research outputs**	**Research immediate outcomes**	**Follow on research**	**Stakeholder adoption**	**Impact areas and data**
Araz Solomon, Hort Innovation, R&D Manager	RD&E process owner / manager	✓			✓	✓		
Femi Akinsanmi, UQ, Theme Leader for Healthy Agriculture, Food and Communities	RD&E practitioner (MC16018 lead)	✓	✓	✓	✓	✓	✓	
Steve McLean, Macadamia Allsorts, Grower and consultant	Industry stakeholder				✓	✓	✓	✓
Grant Bignell, QDAF, Principal Research Scientist	RD&E practitioner (related research)	✓				✓	✓	✓
Chris Fuller, Nutworks, Grower Liaison	Industry stakeholder						✓	✓
Chris Searle, MacAvo Consulting Consultant	Industry stakeholder	✓					✓	✓
Jarrah Coates, Coates Horticulture, Consultant	Industry stakeholder						✓	✓
Graham Wessling, CL Macs Manager	Industry stakeholder						✓	✓
Clayton Mattiazzi, Hinkler Park, General Manager	Industry stakeholder						✓	✓

Glossary of economic terms

Benefit-cost ratio (BCR)	The ratio of the present value of investment benefits to the present value of investment costs.
Cost-benefit analysis (CBA)	A conceptual framework for the economic evaluation of projects and programs in the public sector. It differs from a financial appraisal or evaluation in that it considers all gains (benefits) and losses (costs), regardless of to whom they accrue.
Direct Effects	Impacts generated for the funding industry as a result of adoption of the RD&E outputs and recommendations, typically farm level outcomes relating to productivity and risk.
Discounting and Present Values	The process of relating the costs and benefits of an investment to a base year to reflect the time value of money or opportunity cost of RD&E investment. The analysis applies a real discount rate of 5% in line with CRRDC Guidelines (CRRDC 2018) with results sensitivity tested at discount rates of 2.5% and 7.5%.
Economic Equilibrium	Due to a market's underlying supply and demand curves, changes in supply will have an impact on price and vice-versa. The Economic Equilibrium is the point at which market supply and price are balanced. Estimating the magnitude of market response to changes in supply or demand is a complex and demanding task that is considered beyond the scope of most CRRDC Impact Assessments (CRRDC 2018).
Gross Margin (GM)	The difference between revenue and cost of goods sold, applied on a per hectare basis and excluding fixed or overhead costs such as labour and interest payments.
Internal rate of return (IRR)	The discount rate at which an investment has a net present value of zero, i.e. where present value of benefits = present value of costs.
Modified internal rate of return (MIRR)	The internal rate of return of an investment that is modified so that the cash inflows generated from an investment are re-invested at the rate of the cost of capital (in this case the discount rate).
Net present value (NPV)	The discounted value of the benefits of an investment less the discounted value of the costs, i.e. present value of benefits - present value of costs.
Nominal and real values	Nominal values reflect the actual values in a given year (e.g. contracted RD&E expenses). These are converted to real (inflation adjusted) values to make them comparable across time.
Spillover Effects	Impacts generated for stakeholders who did not fund the RD&E, including other agricultural industries, consumers, communities, and the environment.

Abbreviations

CRRDC Council of Rural Research and Development Corporations

NIS Nut in shell

RD&E Research, Development and Extension

RKR Reject Kernel Recovery (as a percentage of NIS yield)

SIP Strategic Investment Plan

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Appendix A. Macadamia industry data and projections

Macadamia relative disease impact

Macadamia benchmarking data (QDAF 2016-2022 & 2024) has reported data on the primary diseases limiting production for each season starting in 2017 (Figures 5 and 6). The data shows that husk spot was the disease of most concern for growers in both QLD and NSW in 2017 (the first year of MC16018). The data also shows that since 2017, there has been a trend decline in the number of respondents in both QLD and NSW identifying phytophthora and husk spot as diseases limiting production. The data for other key diseases branch dieback and flower diseases is less consistent, showing marginal decreases or increases in NSW and QLD.

When considered in the context of the macadamia research program (MC03007, MC07003, MC12007, and MC16018) which has had a long term focus on husk spot and phytophthora, the data supports stakeholder feedback that the RD&E has been successful in reducing the risk of these two diseases.

Figure 5 Key diseases limiting production (QLD)

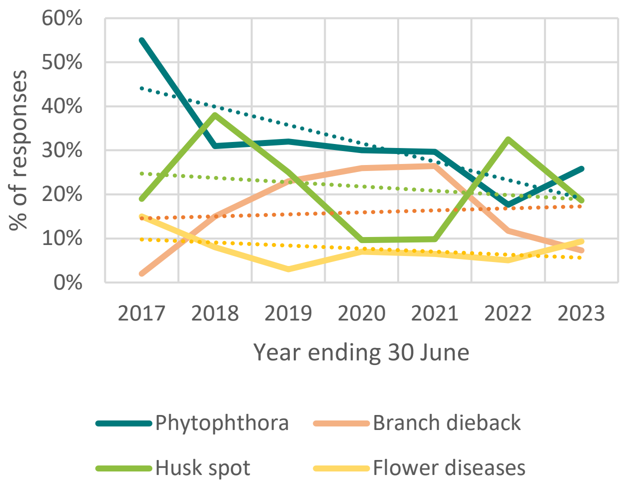
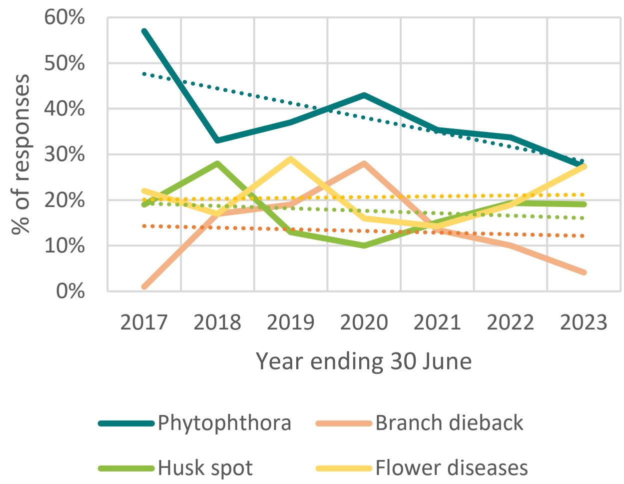


Figure 6 Key diseases limiting production (NSW)



Crop protection costs and reject kernel recovery (RKR) from immature nut drop

Macadamia benchmarking (QDAF 2016-2022 & 2024) reports total crop protection costs (figure 7). The data shows a compound annual growth rate (CAGR) of 9%. As disease management data is not separated from pest management data it is not possible to determine the trend change in disease management costs alone.

Reject Kernel Recovery (RKR) from premature nut loss was taken from benchmarking data for the years 2015 to 2021 (QDAF 2016-2022). The trend over this period was applied to the period 2009 and 2023 (Figure 8). Beyond 2023 (the end of MC16018) premature nut drop was assumed to flatline without follow on research to improve husk spot management.

Figure 7 Crop protection costs

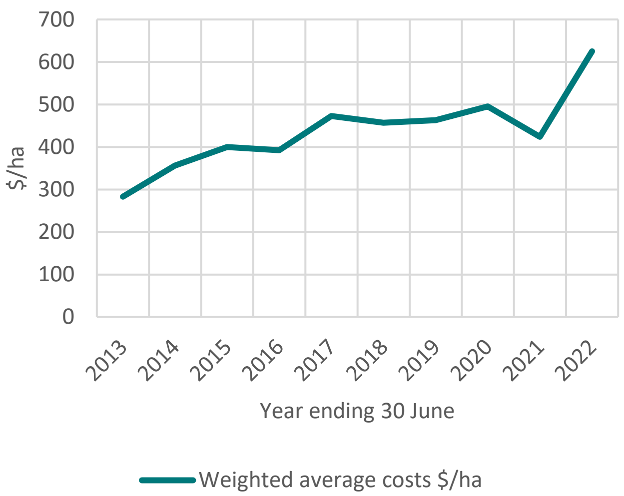
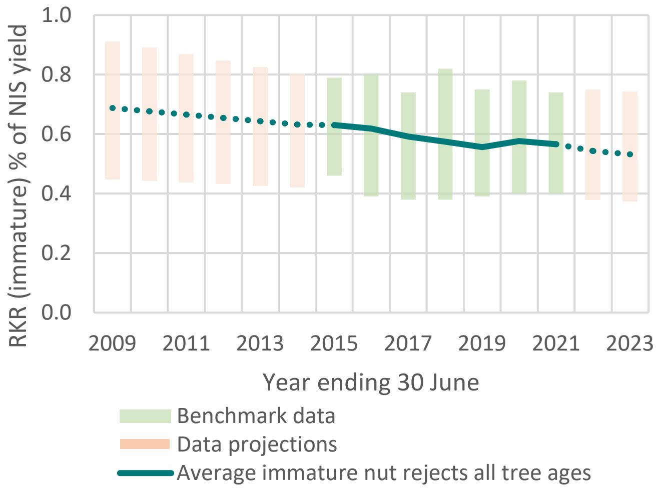


Figure 8 Average immature nut rejects, all tree ages



Macadamia plantings and yield by age

From the current 40,685 hectares of macadamia orchards reported in the Australian Tree Crop Map Dashboard (AARSC, 2024), newly developed macadamia orchards were assumed to continue to grow the total industry area until around 2030 before plateauing at approximately 45,000 hectares (Stakeholder consultation). Annual replanting was also assumed to occur for older trees becoming unproductive. Industry stakeholders said there is no established age for replacing older macadamia trees. Benchmarking data (QDAF 2016-2022 & 2024) shows tree productivity (saleable kernel yield) peaks at 20-34 years. It was assumed that trees would be replaced at 35 years (tested between 30-40 years). This replacement age was then applied to the industry tree age data (QDAF 2016-2022 & 2024) to generate the annual replacement area. Figure 9 shows the total macadamia plantings by year. The annual yield growth of new plantings was based on benchmark yield by tree age (QDAF 2016-2022 & 2024) with a maximum mature tree yield of 3.22 t/ha (NIS) (Figure 10).

Figure 9 Total macadamia plantings

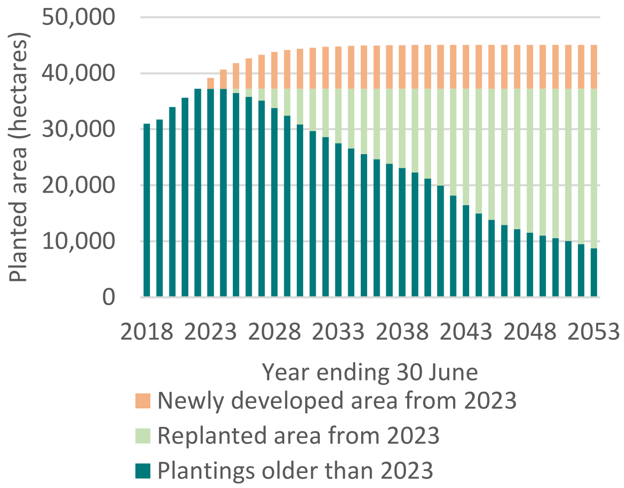
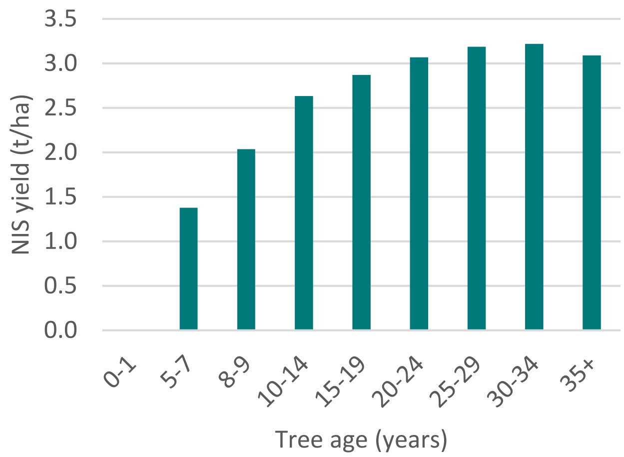


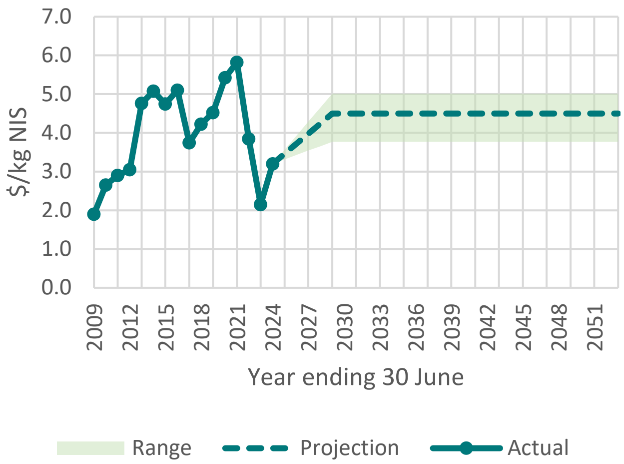
Figure 10 Baseline macadamia yield by tree age



Macadamia yield and prices

NIS prices were projected based on industry consultation (Figure 11). It was assumed that the current low prices of approximately $3.2/kg NIS would recover over the five years to 2029 to be $4.5/kg, with a range estimated by the 10-year 25th percentile ($3.8/kg) and 75th percentile ($5.0/kg).

Figure 11 Macadamia NIS price $/kg



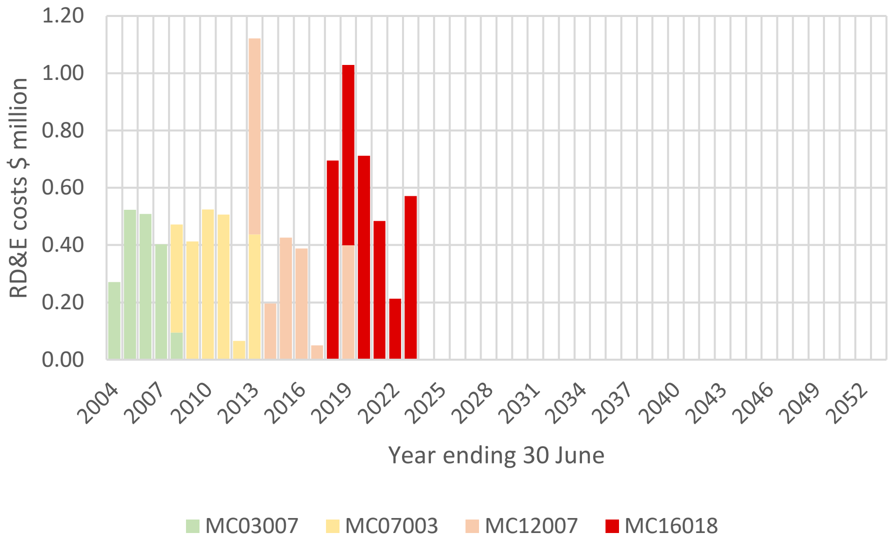
Appendix B. Total Program costs

Four investments were identified as part of the broader RD&E program addressing disease management in macadamias. Total costs include Hort Innovation direct project costs, Hort Innovation management overheads, and in-kind contributions. The present value cost share of MC16018 was used to attribute a share of the total program benefits to the project (Table 7 and Figure 12).

Table 7 Total program cost by investment stage

Investment stage	Total PVC ($m)	% Total PVC	Years	Annual average PVC
MC03007	4.39	27%	5	0.88
MC07003	4.54	28%	6	0.76
MC12007	3.30	20%	6	0.55
MC16018	3.99	25%	6	0.67
Total program	16.23	100%		

Figure 12 Undiscounted program costs by investment stage



Ends.