FINAL

An Impact Assessment of FRDC Investment in 2012-047: Characterising benthic pelagic interactions in Macquarie Harbour

Agtrans Research

November 2017

FRDC Project No **2016-134**

An Impact Assessment of FRDC Investment in 2012-047: Characterising benthic pelagic interactions in Macquarie Harbour
Project 2016-134

2017

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Researcher Contact Details

Name: Joseph Abell
Address: Suite 36, Benson House,
Toowong QLD 4066
Phone: 07 3870 4047
Fax: 07 3371 3381
Email: joseph@agtrans.com.au

FRDC Contact Details

Address: 25 Geils Court
Deakin ACT 2600
Phone: 02 6285 0400
Fax: 02 6285 0499
Email: frdc@frdc.com.au
Web: www.frdc.com.au

In submitting this report, the researcher has agreed to FRDC publishing this material in its edited form.

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Acknowledgments

Agtrans Research and Consulting would like to thank Patrick Hone (Executive Director) and Nicole Stubing (Project Manager) of the Fisheries Research and Development Corporation for facilitating contact with relevant project personnel and for their guidance and feedback throughout the Impact Assessment process.

Wes Ford, Director, Environmental Protection Agency, Tasmania
Joshua Fielding, Project Manager, Fisheries Research and Development Corporation

Abbreviations

ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
CRC	Cooperative Research Centre
CRRDC	Council of Rural Research and Development Corporations
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWR	Department of Agriculture and Water Resources (Commonwealth)
DIC	Dissolved Inorganic Carbon
DO	Dissolved Oxygen
FRDC	Fisheries Research and Development Corporation
OCS	Office of the Chief Scientist
PVB	Present Value of Benefits
R&D	Research and Development
RD&E	Research, Development and Extension
UTAS	University of Tasmania
WHA	World Heritage Area

Executive Summary

What the report is about

This report presents the results of an impact assessment of a Fisheries Research and Development Corporation (FRDC) investment *characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics*. The project was funded by FRDC and the University of Tasmania (UTAS) for the period October 2012 – August 2015.

Methodology

The investment was analysed qualitatively within a logical framework that included activities and outputs, outcomes and impacts. Impacts were categorised into a triple bottom line framework. Principal impacts identified were then valued. Benefits were estimated for a range of time frames up to 30 years from the year of last investment. Past and future cash flows were expressed in 2016/17 dollar terms and were discounted to the year 2016/17 using a discount rate of 5% to estimate the investment criteria.

Results/key findings

The major impacts identified were of a financial nature involving increased long-term biomass of Atlantic Salmon in Macquarie Harbour, and a reduction in the probability of fish mortality events. Environmental and social impacts were also identified but not valued, despite their importance. The main beneficiaries of the project will be the three Atlantic Salmon operators in Macquarie Harbour, as they will be able to capture the financial benefits of the project.

Investment Criteria

Total funding from all sources for the project was $0.66 million (present value terms). The value of benefits was estimated at $2.97 million (present value terms). This gave an estimated net present value of $2.31 million, and a benefit-cost ratio of approximately 4.5 to 1.

Conclusions

The analysis provided a good example of an investment in research into effects of industry on the environment. The project allowed vital information that both industry and regulators needed to make sustainable decisions to preserve the operating environment and ensuring sustainable operations could continue. While no environmental impacts were valued, the continuing sustainability of Atlantic Salmon to operate in the harbour can be viewed as being the result of policy decisions protecting the environment.

Several environmental and social impacts were not valued due to lack of data, and difficulty placing credible monetary value on the impacts. Some of these impacts may have a large effect on the valuation if they were to be valued. Therefore, the investment criteria reported are likely an underestimate of the performance of the investment, as the environmental benefits are not valued, but are presumed to be highly significant. There was also a high degree of uncertainty in valuing the impacts. This was due to the valuation being driven by the counterfactual, with conservative assumptions having to be made.

The subsequent projects and research funded by FRDC, UTAS, Atlantic Salmon operators, and others involved suggest that there is a high commitment to making sure that Macquarie Harbour is a sustainable location to farm Atlantic Salmon.

Keywords

Impact assessment, Atlantic Salmon aquaculture, Macquarie Harbour, benthic conditions, dissolved oxygen

Introduction

The Fisheries Research and Development Corporation (FRDC) required a series of impact assessments to be carried out annually on a number of investments in the FRDC research, development and extension (RD&E) portfolio. The assessments were required to meet the following FRDC evaluation reporting requirements:

- Reporting against the FRDC 2015-2020 RD&E Plan and the Evaluation Framework associated with FRDC's Statutory Funding Agreement with the Commonwealth Government.
- Annual Reporting to FRDC stakeholders.
- Reporting to the Council of Rural Research and Development Corporations (CRRDC).

The first series of impact assessments included 20 randomly selected FRDC investments worth a total of approximately $6.31 million (nominal FRDC investment). The investments were selected from an overall population of 136 FRDC investments worth an estimated $24.98 million (nominal FRDC investment) where a final deliverable had been submitted in the 2015/16 financial year.

The 20 investments were selected through a stratified, random sampling process such that investments chosen spanned all five FRDC Programs (Environment, Industry, Communities, People and Adoption), represented approximately 25% of the total FRDC RD&E investment in the overall population (in nominal terms) and included a selection of small, medium and large FRDC investments.

Project 2012-047: *Characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics* was selected as one of the 20 investments and was analysed in this report.

General Method

The impact assessments followed general evaluation guidelines that are now well entrenched within the Australian primary industry research sector including Research and Development Corporations, Cooperative Research Centres, State Departments of Agriculture, and some Universities. The approach includes both qualitative and quantitative descriptions that are in accord with the impact assessment guidelines of the CRRDC (CRRDC, 2014).

The evaluation process involved identifying and briefly describing project objectives, activities and outputs, outcomes, and impacts. The principal economic, environmental and social impacts were then summarised in a triple bottom line framework.

Some, but not all, of the impacts identified were then valued in monetary terms. Where impact valuation was exercised, the impact assessment uses Cost-Benefit Analysis as its principal tool. The decision not to value certain impacts was due either to a shortage of necessary evidence/data, a high degree of uncertainty surrounding the potential impact, or the likely low relative significance of the impact compared to those that were valued. The impacts valued are therefore deemed to represent the principal benefits delivered by the project. However, as not all impacts were valued, the investment criteria reported for individual investments potentially represent an underestimate of the performance of that investment.

Background and Rationale

Background

Macquarie Harbour is located on the West coast of Tasmania. It has a unique freshwater/salt water environment due to the mouth of the harbour, known as Hells Gate, only being 5 metres deep, while other parts of the harbour can be as deep as 50 metres. This narrow entrance to the harbour limits salt water inflow, while the harbour is also fed by fresh water inflows from the Gordon and King Rivers. Parts of Macquarie Harbour are listed under the UNESCO Tasmanian Wilderness World Heritage Area (WHA).

Salmonid aquaculture is a relatively new industry in Macquarie Harbour, commencing operation in the 1980s. Macquarie Harbour is an ideal location for salmonid aquaculture operations. The fresh and salt water mix of the harbour combined with the deep water available where the Atlantic Salmon pens are sited prohibits common Atlantic Salmon diseases, such as amoebic gill disease, from propagating. This makes Atlantic Salmon farming in Macquarie Harbour a desirable option when compared to other Atlantic Salmon farming locations.

Dissolved oxygen (DO) levels are traditionally low in Macquarie Harbour. This is due to the tannin rich waters that do not allow oxygen to easily penetrate the surface as well as the sediment inflows from the Gordon and King Rivers. The water inflows into the harbour from a hydroelectric plant and sediment run off from an old mine up-river, cause the DO levels in the harbour to fluctuate.

Before this project, the effect of Atlantic Salmon aquaculture on the benthic conditions and DO levels were unknown.

Rationale

Prior to 2012, there was a lack of ecological data on the capacity of sediments to process organic matter and nutrients in Macquarie Harbour. Atlantic Salmon aquaculture operators in Macquarie Harbour aim to expand operations in the future if expansion is found to be environmentally sustainable. As there was industry pressure to increase farming in Macquarie Harbour, the study aimed to fill a knowledge gap to improve environmental modelling of the sediment interaction between the farm sites and the harbour.

To aid in the expansion of the Atlantic Salmon industry, it was recognised that proper environmental modelling needed to be undertaken. Nutrient dynamics in the harbour are key for continuing aquaculture expansion, with sediment interactions requiring further knowledge so an environmental model could be established. The environmental model would help inform regulators of the correct biomass limit to set, allow Atlantic Salmon producers to monitor their actions, and to allow for a better response to Atlantic Salmon aquaculture operations to environmental conditions.

Project Details

Summary

Project Code: 2012-047

Title: *Characterising benthic pelagic interactions in Macquarie Harbour - organic matter processing in sediments and the importance for nutrient dynamics*

Research Organisation: University of Tasmania (UTAS)

Principal Investigator: Jeffrey Ross

Period of Funding: October 2012 – August 2015

Objectives

The project included four key objectives:

1. To quantify sediment - water column nutrient fluxes at both the farm (local) and harbour (regional) scales,
2. To generate sediment nutrient - dissolved oxygen respiration maps for Macquarie Harbour, and identify the extent to which nutrients are released from sediment enriched with farm waste,
3. Calibrate the sediment - water column interaction terms in the Macquarie Harbour environmental model using process information from 1 and 2 above, and
4. Identify ecologically relevant and practical indicators of key ecosystem processes.

Logical Framework

Table 1 provides a brief description of the project in a logical framework.

Table 1: Logical Framework for Project 2012-047

Activities and Outputs	• Six sites within Macquarie Harbour were chosen for sediment sampling. Some of the sites sampled, for example, included two sites, each 50 metres from Atlantic Salmon cage sites and a control site 500-1,000m from the Atlantic Salmon cages. • Sampling of sediment and bottom water (1m above floor) took place between November 2012 and September 2013. • Water column profiles of salinity, temperature and dissolved oxygen were also taken at each site. • Data on a range of sediment variables (such as temperature, salinity, dissolved inorganic carbon (DIC), nitrates, dissolved oxygen (DO) and phosphates), were collected and analysed for each sample site. The purpose of the sampling was to measure nutrient fluxes in the water. • The project found that oxygen consumption was higher at Atlantic Salmon farm sites and that farm sites also had higher DIC, lower carbon/nitrogen ratios, lower nitrate levels and lower DO levels compared to control sites. • The lower nitrate levels suggest denitrification in the water column around farm sites, but the interactions were not clear. However, lower nitrate levels suggested higher sediment levels supporting lower DO near farm sites. • Higher de-nitrification in the water column around farm sites creates ammonia, demanding more oxygen from the water column. It was hypothesised that the increased de-nitrification could be due to increased sediment activity from fish feed and faeces.

	• Increased fish sediment (feed and faeces) near farm sites leads to higher bacteria levels in the water that contribute to depleted DO levels. Low DO levels have implications for marine health in the harbour, as a certain level of DO is needed for marine life to be sustainable. Below this level, there is an increased risk of fauna and other marine species not being able to survive. • Data on sediments suggest that sediment recovers (with a decrease in ammonia production) under Atlantic Salmon cages after fallowing Atlantic Salmon, suggesting that the harbour can recover back to a pre-farming state with such management interventions. There were signs of recovery during stocking at one sample site as well. This suggested that other factors other than Atlantic Salmon farming are affecting DO levels (Ross et al, 2015, p 33), but this issue requires further investigation. • The project recognised that other factors (such as the Gordon River Dam and the old copper mine located upstream) may be playing a role in nitrate levels in the harbour and that Atlantic Salmon farming may not be the only contributing factor to nitrate levels. • An existing environmental model was re-calibrated using data from the project to represent water bottom dynamics for Macquarie Harbour. Specific information (e.g. DO, nitrate levels etc.) was added to the model to allow for future data on these factors to be added and updated to improve the model's accuracy for harbour conditions (Ross, et al., 2015). This filled a significant gap in the knowledge of the harbour and its sediment chemistry. • Based on the low DO levels recorded in the last two surveys in the project, further research was recommended to monitor the benthic conditions of the harbour including oxygen dynamics. The project noted that compounds from fish feed and faeces seem to influence the benthic conditions of the harbour under the Atlantic Salmon cage sites.
Outcomes	• Knowledge from the project influenced management decisions of Atlantic Salmon farmers and other stakeholders in relation to how they deal with the environment/benthic conditions of Macquarie Harbour (Ross, et al., 2015, p. 9). The knowledge enabled potential investment by aquaculture companies to mitigate the effects of activities on the health of the harbour by using strategies such as fallowing, lower stocking, etc. to reduce sediment from Atlantic Salmon aquaculture. The strategies have led to a lowering of the rate of decreasing DO levels. • Macquarie Harbour has unique environmental conditions compared to other locations. As a result, the MHDOWG[1] determined further investigations into the low DO levels should take place. • Further research was undertaken to research benthic cycles/conditions and DO levels in Macquarie Harbour. FRDC research projects 2015-024 and 2016-067 were funded because of the results of Project 2012-047. In the application of Project 2015-024, it was stated that the methods developed in Project 2012-047 project were crucial for Project 2015-024. • The information on the deteriorating conditions below/around Atlantic Salmon cages in Macquarie Harbour contributed to the decision of the Tasmanian Environment Protection Agency (EPA) decision to reduce biomass limits for aquaculture operations, along with the findings of the subsequent projects funded because of Project 2012-047. • Information from the project contributed to the Macquarie Harbour health report update, April 2016. The updated report was subsequently used in the EPA's biomass decision (EPA, 2017a). • Measurement of sediment oxygen consumption and carbon dioxide in the project lead to the calculation of Atlantic Salmon farming's oxygen consumption (Ross & MacLeod, 2017, p15).

[1] Macquarie Harbour Dissolved Oxygen Working Group

	• Information on sediment recovery between fallowing has resulted in Atlantic Salmon companies undertaking fallowing as a management strategy, allowing less environmentally destructive practices. • Due to the project, there has been continued monitoring of Macquarie Harbour oxygen and nitrate levels with more robust monitoring taking place by industry, researchers, and regulators.
Impacts	• An environmental impact delivered is the maintenance of the biological and ecological integrity of the harbour, particularly the improved marine life biodiversity and ecological sustainability near the cages. The project helped avoid environmental damage from occurring in Macquarie Harbour. • Project 2012-047 findings on the effects of farming sediments on the harbour, in conjunction with projects 2014-038, 2015-024 and 2016-067 contributed to the decision in Macquarie Harbour to reduce Atlantic Salmon farming biomass from 21,500 tonnes in June 2016 to 12,000 tonnes in May 2017. Potentially reducing profit in the short term for Atlantic Salmon operators. • However, Project 2012-047 in conjunction with the other FRDC projects listed above, has potentially contributed to the avoidance of a larger biomass reduction than the drop to 12,000 tonnes experienced to date. In turn, this would have avoided a lower profitability for Atlantic Salmon companies long-term. • Another potential economic impact is the avoided short-term economic loss for Atlantic Salmon companies due to a lower probability of Atlantic Salmon deaths (from bottom DO levels rising, resulting in Atlantic Salmon deaths in pens) and fish and smolt culling. • A potential improved animal welfare impact may have been delivered through avoided Atlantic Salmon deaths and culling processes. • The impacts described above have potentially contributed to the maintenance of the social licence for Atlantic Salmon aquaculture to continue operating in Macquarie Harbour, and potentially wider afield across the state of Tasmania, due to the avoided fisheries collapse. • The project contributed to the maintenance of the environmental value and sustainability of Macquarie Harbour, continuing its claim to World Heritage Listing status and the "Clean Green Tasmania" marketing image. • Potentially positive economic spillover benefits may have occurred to other industries and the wider community with continued industry employment in Western Tasmania. • Increased scientific understanding and research capacity have been delivered.

Project Investment

Nominal Investment

Table 2 shows the annual investment for the project funded by FRDC and UTAS (including in-kind contributions). Other contributors include the Tasmanian Salmon Growers Association, Monash University, Aquenal, and the Danish Hydraulic Institute.

Table 2: Annual Investment in the Project 2012-047 (nominal $)

Year ended 30 June	FRDC ($)	UTAS ($)	OTHER ($)	TOTAL ($)
2013	97,057	173,503	58,891	329,451
2014	70,335	67,267	6,647	144,249
2015	20,924	0	0	20,924
2016	20,924	0	0	20,924
Totals	209,240	240,770	65,538	515,547

Program Management Costs

For the FRDC investment the cost of managing the FRDC funding was added to the FRDC contribution for the project via a management cost multiplier (1.115). This multiplier was estimated based on the share of 'employee benefits' and 'supplier' expenses' in total FRDC expenditure reported in the FRDC Cash Flow Statement (FRDC, 2016). This multiplier then was applied to the nominal investment by FRDC shown in Table 2.

For the UTAS investment, it was assumed that the management and administration costs for the project were already built into the nominal amounts reported in Table 2.

Real Investment and Extension Costs

For the purposes of the investment analysis, the investment costs of all parties were expressed in 2016/17 dollar terms using the Implicit Price Deflator for Gross Domestic Product (ABS, 2016). No additional costs of extension were included.

Impacts

Table 3 provides a summary of the principal types of potential impacts from those listed in Table 1. The impacts are categorised into economic, environmental and social impacts.

Table 3: Triple Bottom Line Categories of Impacts from the Research into Benthic Conditions in Macquarie Harbour

Economic	• Reduction in farming profit in the short-term due to a contribution to a decreased Atlantic Salmon biomass limit. • Potentially increased profit long-term due to a higher biomass limit than otherwise would have occurred. • Potentially a lower probability of Atlantic Salmon deaths from low DO levels.
Environmental	• Maintenance of biodiversity and sustainability in the Macquarie Harbour, through avoiding worsening environmental conditions.
Social	• Increased incomes to Macquarie Harbour community due to spillovers from sustainable Atlantic Salmon aquaculture industry and maintained harbour health. • Potentially increased animal welfare due to fish deaths not occurring • Maintenance of Tasmania's "Clean Green" image for other industries and maintenance of WHA status. • Maintenance of social licence for Atlantic Salmon aquaculture in Tasmania. • Increased knowledge and research capacity.

Public versus Private Impacts

There are both private and public impacts from the project. The main private impact is the net increase in profits for the Atlantic Salmon companies operating in Macquarie Harbour. The maintained social licence is another private impact that will flow to the Atlantic Salmon companies. While there are significant private benefits, there are significant benefits that flow to the public. The main public benefit is in the form of a healthier environment in Macquarie Harbour. There are also additional benefits in the form of increased animal welfare, and increased regional incomes.

Distribution of Private Impacts

The majority of the private impacts will flow to the three Atlantic Salmon aquaculture operators in Macquarie Harbour. There are also some positive impacts to operators along the supply chain, including employees, other regional businesses, equipment suppliers and processors due to the continued operation of the Atlantic Salmon industry in Macquarie Harbour. There may also be impacts to tourism businesses operating in Macquarie Harbour.

Impacts on other Australian industries

There may be direct spillovers to other Australian industries. This will mainly be to tourism operators in Macquarie Harbour, as this project increases the likelihood of the harbour retaining its WHA listing. There may be indirect positive spillovers from the project to both other food and tourism operators due to the sustained "Clean Green" image for Tasmania. There also will be spillovers on local businesses around Macquarie Harbour due to increased incomes from Atlantic Salmon aquaculture, compared to what may have occurred without the project.

Impacts Overseas

There are expected to be no significant impacts overseas because of the project. There may be some minor benefit of research outputs to other unique estuary environments that also have farmed Atlantic Salmon.

Match with National Priorities

The Australian Government's Science and Research Priorities and Rural RD&E priorities are reproduced in Table 4. The project findings and related impacts will contribute primarily to Rural RD&E Priority 3 and to Science and Research Priority 2.

Table 4: Australian Government Research Priorities

Australian Government	
Rural RD&E Priorities (est. 2015)	**Science and Research Priorities (est. 2015)**
1. Advanced technology 2. Biosecurity 3. Soil, water and managing natural resources 4. Adoption of R&D	1. Food 2. Soil and Water 3. Transport 4. Cybersecurity 5. Energy and Resources 6. Manufacturing 7. Environmental Change 8. Health

Sources: (DAWR, 2015) and (OCS, 2015)

Valuation of Impacts

Impacts Valued

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

The three economic impacts identified in Table 3 are valued. The first two are the reduction in short-term profit due to the project, and the higher profits due to the avoidance of a greater lowering of the biomass limit long-term. The two impacts are highly linked so are valued as one impact. The third impact valued is the lower probability of fish mortalities occurring because of the biomass decisions.

Impacts Not Valued

Not all impacts identified in Table 3 could be valued in the assessment.

The environmental impact identified was the maintenance of biodiversity and environmental sustainability in Macquarie Harbour, through avoiding worsening environmental and ecological conditions under and around the Atlantic Salmon cages. The additional information from the project caused action to be taken that avoided possible further drawdown of oxygen in bottom waters. This led to bottom water sediments to recover, allowing a lesser reduction of benthos being affected by hypoxia than what would have happened without the project. While the impact was presumed to be highly significant, it was not valued.

The environmental impact identified was difficult to value because of the difficultly to accurately quantify the causal relationships and pathways between the increased knowledge of benthic conditions and the specific future environmental impacts. This is due to the inherent uncertainty around the counterfactual, and the associated difficulty in making appropriate assumptions.

The five social impacts were not valued due to their relative minor importance compared to the other impacts, along with the difficulty in estimating the impacts due to lack of evidence and data, and associated difficulty in making appropriate assumptions.

The social impacts identified but not valued included*:*

- Maintenance of image of WHA in Macquarie Harbour.
- Potentially increased animal welfare.
- Maintenance of social licence.
- Increased knowledge and research capacity.
- Increased incomes to regional Tasmanian community

Valuation of Impact 1: Increased profits of Atlantic Salmon farms from biomass allocation decisions

Counterfactual biomass decision

Without Project 2012-047, the two projects 2015-024 and 2016-067 would likely not have been funded as to further investigate sediment-nitrate-oxygen benthic processes in Macquarie Harbour. Without these three projects, it is likely that there would have been less knowledge and quantitative readings of how Atlantic Salmon aquaculture was affecting the areas under and around the Atlantic Salmon pens.

If these research investments had not been made, video and DO monitoring of the benthic conditions under and around the Atlantic Salmon pens would have occurred (Wes Ford, pers. comm., May 2017), likely by the Atlantic Salmon operators, but not extensive research. There was video evidence of *beggiatoa* (bacteria mats) from Project 2014-038, suggesting that the benthic conditions would have worsened. Bacteria mats are present when a high concentration of sedimentation is found, suggesting deteriorating environmental conditions (Ross & MacLeod, 2017). Project 2014-038 would have been funded without Project 2012-047, so the increased information from the bacterial mats would have been produced and noted by the regulator. DO monitoring and the video benthic surveys that would have taken place without Project 2012-047, would not have been as useful as the information gained from Project 2012-047 and the other subsequently funded projects.

The DO monitoring and benthic surveys would have influenced biomass decisions, but not to the extent with Projects 2012-047, 2015-024, and 2016-067. The video surveys cannot give a full explanation of the benthic process (Knight, Forrest, & Johnston, 2015, p. 16) as they are not as informative as sediment-nitrate-oxygen interaction surveys. It is highly likely that the biomass in the harbour also would have dropped due to performance issues with the Atlantic Salmon (Wes Ford, pers. comm., May 2017) and other information available, but at a later date than what has occurred under the current EPA ruling. Without projects 2012-047, 2015-024, and 2016-067 there is an increased probability that different biomass decisions would have been made, due to the information on environmental conditions being less robust.

Hence, it is assumed the biomass would have decreased from the high of 21,500 tonnes in April 2016. This would have been due only to DO data and visual evidence of bacterial mats being available but without knowledge of the interaction of sediment with oxygen dynamics and its link to Atlantic Salmon impacts on the environment near the pens. This may have led to a potential lag in feedback of the condition of the harbour without the project. In turn, this may have resulted in a higher stocking density and a subsequent deterioration of the environment. Due to an increase in sediment loading, it is likely that DO levels under the Atlantic Salmon cages would be lowered, as it is estimated that Atlantic Salmon contributes between 3%-12% of oxygen drawdown in Macquarie Harbour beneath a 15 metre depth (Ross & MacLeod, 2017), so further low DO levels potentially would have been recorded, along with bacterial mats.

It is assumed that the biomass would have been reduced to 14,000 tonnes in 2017/18 due to this information. This still would have had the potential to cause ecological strain on the harbour, due to reduced DO levels. DO levels were stated as being historically low in the harbour around this time (EPA Tasmania, 2017b). Eventually, this would have led to greater visual evidence of environmental stress and decreased Atlantic Salmon farming performance. The assumption is made that this would have resulted in an eventual decrease to 10,000 tonnes in 2018/19 from the information available without the project until eventually increasing to 12,000 tonnes in 2024/25.

The Initial Drop in Farmed Biomass: With the Project

Project 2012-047 provided information on the sediment effects produced by of Atlantic Salmon farms on the harbour's environment. The project found that there was a significant drop in DO levels under the Atlantic Salmon pens compared to other sites in the harbour and that nitrate levels between farm and non-farm sites were significantly different. Initially, after the release of the report, the biomass in the harbour increased to 21,500 tonnes, but recommendations of the project suggested further investigation was needed to better understand the drivers behind the drop in DO levels in the last two readings and the benthic-sediment relationship. The report on Macquarie Harbour by Knight, Forrest, & Johnston (2015), also suggested that increases in biomass be taken in a cautious manner.

Further projects were subsequently funded to answer these questions of the effects of interaction, and some of their preliminary results have been subsequently released. The additional projects funded by FRDC found there was some deterioration of environmental conditions under Atlantic Salmon pens, along with video footage of bacteria mats. Project 2012-047 and the succeeding FRDC projects allowed more robust decision making in terms of the biomass decisions, due to the data on the benthic conditions in the harbour.

The yearly biomass in the harbour has been reduced by the EPA from its high of 21,500 tonnes at the start of July 2016 to 12,000 tonnes from June 2017 (EPA Tasmania, 2017a). This was partly due to the benthic indicators provided by the Institute for Marine and Antarctic Studies, FRDC Projects 2014-038, 2015-024 and 2016-067 (EPA Tasmania, 2017a). The reduction was, in part, a result of Project 2012-047, with some benefits attributed to the project (*see attribution)*. Along with DO readings and other evidence, this supported the EPA biomass decision to reduce the stocking density.

The Expected Increase in Farmed Biomass: With the Project

Biomass decisions in Macquarie Harbour are based on ensuring the sustainability of both Atlantic Salmon operations and the environment in the harbour. With the project and subsequent projects findings, appropriate and sustainable Atlantic Salmon biomass decisions based on the available knowledge would not have occurred. The biomass decisions, in part a result of the project, ensures that the biomass limit is set sustainably.

For this analysis, an assumption is made that the future biomass allocation of Atlantic Salmon in Macquarie Harbour will be 12,000 tonnes, the current biomass allocation. Biomass decisions in Macquarie Harbour are made each year and are highly dependent on the environmental conditions of the harbour and the available scientific information, so future biomass allocations cannot be predicted with any accuracy.

The biomass with the project would have been higher in the longer term than without the project, as information from the project lowered the risk of ecological damage within Macquarie Harbour. While the biomass limit was reduced significantly in the short term with the project, the project findings have allowed a more consistent and higher Atlantic Salmon biomass limit in the longer term.

A summary of the assumed biomass limits with and without the project is provided in Table 5.

Table 5: Assumed Salmon Biomass Limits for Macquarie Harbour with and without the Project

Year (ending)[2]	**Without Project (estimated)**	**With Project**	**Difference in Atlantic Salmon farmed (With project less without project)**
	Biomass allowed (tonnes)	**Biomass allowed (tonnes)**	**Tonnes**
2012	15,490	15,490	0
2017	21,500	21,500 up to Feb	0
2017	21,500	14,000[3] Feb to Jun	-3,125
2018 (estimated)	14,000	12,000	-2,000
2019 (estimated)	10,000	12,000	2,000
2020 (estimated)	10,000	12,000	2,000
2021 (estimated)	10,000	12,000	2,000
2022 (estimated)	10,000	12,000	2,000
2023 (estimated)	10,000	12,000	2,000
2024 (estimated)	10,000	12,000	2,000
From 2025 (estimated)	12,000	12,000	0

Source: EPA Tasmania, 2017a and EPA Tasmania, 2017b plus Agtrans Research

[2] The year ending refers to the financial year ending on 30th June of that year.
[3] The biomass is allocation is split in 2015/2016 due to a decision by the EPA to lower the biomass from 21,500 tonnes to 14,000 tonnes in February 2017.

Valuation of Increased Biomass

The gross value for a tonne of Tasmanian Atlantic Salmon is $13,150 (ABARES, 2016). In the analysis, it is assumed that producers are price takers, so they will utilise the entire biomass allocation for each year. The 10% profit assumption is applied to the difference in farmed biomass as shown in Table 5. As the future decisions of the biomass are inherently uncertain (due to the unknown course of action that would have been taken), a probability of impact of 75% as been attached to the benefit.

A summary of specific assumptions for valuing the impact are provided in Table 6.

Valuation of Impact 2: Lower probability of fish mortality event

Counterfactual of Benefit 2

Oxygen re-charge events can occur from storm surges, ocean water inflows, or water inflows from the Gordon and King rivers, replacing low DO water in benthic conditions. The water inflows replace low DO waters, already found in the benthic conditions, with fresh DO. The oxygen re-charge events may push the low DO water found in the benthic conditions higher into the water column because of the oxygen re-charge. Low DO levels within Atlantic Salmon pens may increase stress levels in Atlantic Salmon, leading to mortalities. The oxygen-recharge events are exogenous to Atlantic Salmon farming, and cannot be predicted when they will occur.

As Atlantic Salmon aquaculture is estimated to contribute between 3% – 12% of oxygen demand of water beneath a 15 metre depth, it is likely that there would be some probability of Atlantic Salmon mortalities due to increased sediment load from farms leading to lower DO levels.

The probability of fish mortalities occurring in this scenario is estimated to be 20%, with 3% of the biomass being affected, until the farmed Atlantic Salmon biomass in the harbour is at or below 12,000 tonnes. Below this level the probability of Atlantic Salmon mortalities occurring is assumed lower at 10%.

With the project

It is expected that due to the varying DO levels, river discharge, storm surges, and oxygen resupply in the harbour, there is always a probability of low DO oxygen at benthic levels of the harbour upwelling through the water column and killing Atlantic Salmon. There have been a number of events in the past that have resulted in fish mortalities (e.g. Atlantic Salmon farming companies such as Petuna and Tassal in 2015). It is likely that fish mortalities through low DO bottom water still will occur into the future, but with a lower risk because of the project. This is because the reduction of biomass should lessen the factors lowering the DO levels. A probability of a fish mortality event occurring in a year is assumed to be lower at 10%, with 3% of the biomass being affected. This is applied to the value of Atlantic Salmon lost, estimated at 50% of their prospective market value of $13,150 per tonne.

Initially, there will be a greater benefit with the project, due to a lower expected value of fish mortality. The benefit will then become negative, as stocking density will be higher than without the project, subjecting more Atlantic Salmon to the possibility of a mortality event because of low DO levels.

The valuation is an underestimate as it considers only the loss of the fish that died, not the cost of cleaning up the fish after the fish mortality event.

Costs of other projects

The biomass decisions by the EPA in 2017, were heavily influenced by Projects 2015-024 and 2016-067. The 2012-047 project results stimulated funding for these two projects. To accommodate this contribution, the costs of 2015-024 and 2016-067 have been subtracted from the benefit stream in the year in which the costs were incurred. Not all the costs for 2015-024 can be associated with Macquarie Harbour, as Project 2015-024 also studied reefs in southern Tasmania. Hence, only 50% of the costs of Project 2015-024 has been subtracted from the benefit stream. For both Projects 2015-024 and 2016-067, cost multipliers were added and costs expressed in 2016/17 dollar terms.

Attribution

The results of 2014-038, along with Project 2012-047, have contributed to the Macquarie Harbour biomass decisions in 2017. To isolate the benefits to Project 2012-047 alone, the proportion of the costs of Project 2012-047 was calculated as a percentage of the combined costs (with multipliers and in 2016/17 dollar terms) of Project 2012-047 and Project 2014-038. This percentage (82.65%) has been applied to the gross benefits estimated for both Benefit 1 and Benefit 2. Other monitoring investment (from Atlantic Salmon companies or the regulator) has not been considered, due to cost information not being readily available.

Summary of Assumptions

A summary of key assumptions made for valuation of the impacts is shown in Table 6.

Table 6: Summary of Assumptions

Variable	**Assumption**	**Source**
Benefit 1: Counterfactual		
Biomass limits assumed 2012-2024	See Table 5	Agtrans Research
Benefit 1: With Project		
Biomass limits assumed 2012-2024	See Table 5	Agtrans Research
Farm gate value of Tasmanian Atlantic salmon	$13,150 per tonne	ABARES, 2016
Estimated percentage of profit per tonne of additional Atlantic Salmon farmed	10%	Agtrans Research
Profit per tonne of Atlantic Salmon	$1,315 per tonne	$13,150 x 10%
Probability of impact	75%	Agtrans Research
Benefit 1 in 2016/17	$-3,082,031	((21,5000 t x (7/12) +14,000 t x (5/12)) x $1,315) – (21,5000 t x $1,315) x 75%
Benefit 1 in 2017/18	$-1,972,500	((12,000 t x $1,315) – (14,000 t x $1,315)) x 75%
Yearly benefit between 2018/19 – 2023/24	$ 1,972,500	((12,000 t x $1,315) – (10,000 t x $1,315) x 75%
Benefit 2: Counterfactual		
Biomass limit assumed 2012- 2024	See Table 5	Agtrans Research
Probability of fish mortality event occurring with biomass above 12,000 tonnes	20% per year	Agtrans Research
Probability of fish mortality events occurring with biomass below 12,000 tonnes	10% per year	Agtrans Research
Percentage of biomass killed	3%	Agtrans Research
Current farm gate value of Tasmanian Atlantic Salmon	$13,150 per tonne	ABARES, 2016
Percentage of prospective market value lost	50%	Agtrans Research
Opportunity cost of fish killed	$6,575 per tonne	$13,150 x 50%
Benefit 2: With Project (Lower probability of fish mortality event)		
Biomass limit assumed 2012- 2024	See Table 5	Agtrans Research
Probability of fish mortality event occurring with biomass above 12,000 tonnes	20% per year	Agtrans Research
Probability of fish mortality event occurring with biomass below 12,000 tonnes	10% per year	Agtrans Research
Percentage of biomass killed	3%	Agtrans Research

Current farm gate value of Tasmanian Atlantic Salmon	$13,150 per tonne	ABARES, 2016
Percentage of gross value killed	50%	Agtrans Research
Opportunity cost of fish killed	$6,575 per tonne	$13,150 x 50%
Benefit 2 in 2016/17	$ 123,281	(21,5000 t x 20% x 3% x $6,575) - (((21,5000 t x (7/12) +14,000 t x (5/12)) x 3% x 20% x $6,575)
Benefit 2 in 2017/18	$260,581	(21,5000 t x 20% x 3% x $6,575) - (12,000 t x 3% x 10% x $6,575)
Yearly benefit between 2018/19 – 2023/24	$-32,573 per year	(10,000 t x 10% x 3% x $6,575) - (12,000 t x 3% x 10% x $6,575)
Additional costs (with multipliers) of Projects 2015-024 and 2016-067 subtracted from total benefit stream		
Total funding for Project 2015-024	$1,217,290 from September 2016 until 30 June 2017	FRDC, 2017
Proportion of Project 2015-024 attributed to Macquarie Harbour	50%	Agtrans Research
Total funding applicable to Macquarie Harbour for Project 2015-024	$608,645 from September 2016 until 30 June 2017	$1,217,290 x 50%
Total funding for Project 2016-067	$375,405 from February until 30 June 2017	FRDC, 2017
Attribution to Benefit 1 and 2 (with multipliers)		
Total funding for Project 2012-047	$552,678 (total)	FRDC, 2017
Total funding for Project 2014-038	$116,053 (total)	FRDC, 2017
Attribution factor to Project 2012-047	82.65%	$552,678/ ($552,678+$116,053)

Results

All benefits after 2016/17 were expressed in 2016/17 dollar terms. All costs and benefits were discounted to 2016/17 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return. The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the project investment period plus 30 years from the last year of investment in Project 2012-047 (2015/16).

Investment Criteria

Tables 7 and 8 show the investment criteria estimated for different periods of benefits for the total investment and the FRDC investment. The present value of benefits (PVB) attributable to the FRDC investment only, shown in Table 8, has been estimated by multiplying the total PVB by the FRDC proportion of real investment before discounting.

Table 7: Investment Criteria for Total Investment in Project 2012-047

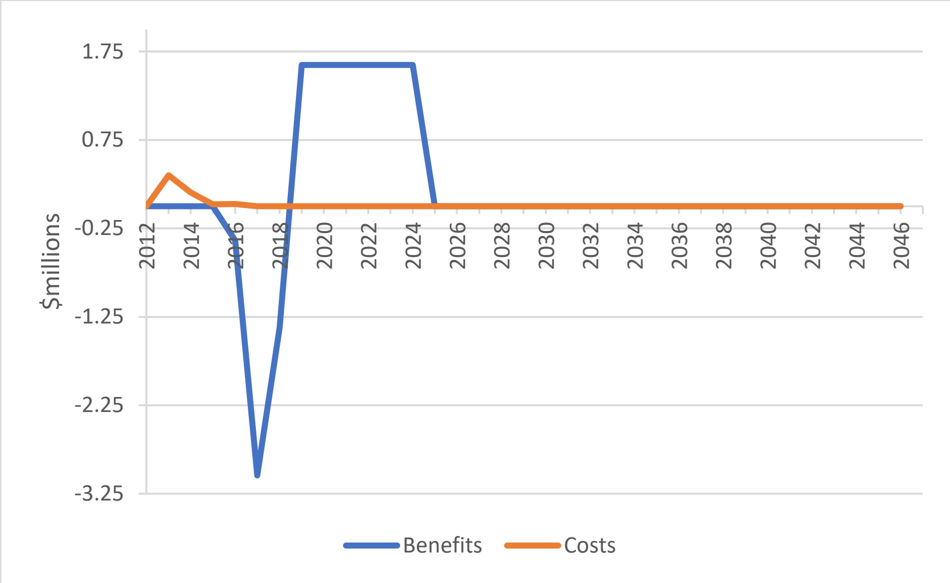
Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	-0.41	-0.61	2.97	2.97	2.97	2.97	2.97
Present Value of Costs ($m)	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Net Present Value ($m)	-1.06	-1.27	2.31	2.31	2.31	2.31	2.31
Benefit-Cost Ratio	-0.62	-0.93	4.53	4.53	4.53	4.53	4.53
Internal Rate of Return (%)	negative	negative	13.48	13.48	13.48	13.48	13.48
Modified Internal Rate of Return (%)	negative	negative	9.37	7.79	7.05	6.62	6.34

Table 8: Investment Criteria for FRDC Investment in Project 2012-047

Investment Criteria	**Years after Last Year of Investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present Value of Benefits ($m)	-0.16	-0.05	1.50	1.50	1.50	1.50	1.50
Present Value of Costs ($m)	0.28	0.28	0.28	0.28	0.28	0.28	0.28
Net Present Value ($m)	-0.44	-0.32	1.22	1.22	1.22	1.22	1.22
Benefit-Cost Ratio	-0.58	-0.17	5.38	5.38	5.38	5.38	5.38
Internal Rate of Return (%)	negative	negative	16.08	16.08	16.08	16.08	16.08
Modified Internal Rate of Return (%)	negative	negative	10.57	8.55	7.60	7.05	6.70

The annual undiscounted benefit and cost cash flows for the total investment for the duration of Project 2012-047 plus 30 years from the last year of investment are shown in Figure 1.

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



Source of Benefits

Estimates of the relative contribution of each of the two benefits valued to their Total PVB are shown in Table 9. The total PVB in Table 9 does not match the Total PVB in other tables. The difference is due to the attribution to the associated projects (2015-024 and 2016-067) that were driven by Project 2014-047.

Table 9: Contribution to Total Present Value of Benefits from Each Source

Source of Benefits	Contribution to PVB ($m)	Share of Benefits (%)
Benefit 1: Increased profits of Atlantic Salmon farms from biomass allocation decisions	3.78	95.2
Benefit 2: Lower probability of fish mortalities	0.19	4.8
Total[4]	3.97	100.0

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 10 presents the results.

Table 10: Sensitivity to Discount Rate
(Total investment, 30 years)

Investment Criteria	Discount rate		
	0%	5% (base)	10%
Present value of benefits ($m)	4.79	2.97	1.61
Present value of costs ($m)	0.55	0.66	0.77
Net present value ($m)	4.23	2.31	0.84
Benefit-cost ratio	8.66	4.53	2.08

[4] The total benefits and percentage share of benefits stated in Table 9 do not take into account the costs of additional Projects 2015-024 and 2016-067.

A sensitivity analysis was undertaken on the assumption of when the allowable biomass in Macquarie Harbour would reach 12,000 tonnes in the counterfactual. The sensitivity analysis in Table 11 also includes any fish mortality events that took place in the years between 2022/23 and 2026/27, based on the scenario. The timing of when the counterfactual biomass would reach 12,000 tonnes was considered a key driver of the results and was a factor with a high level of uncertainty. The results, reported in Table 11, show a high level of sensitivity to the timing of the biomass under the counterfactual scenario.

Table 11: Sensitivity to Counterfactual Biomass Decision
(Total investment, 30 years)

Investment Criteria	**Year when Counterfactual Biomass Limit Reaches 12,000 tonnes**		
	2022/23	**2024/25 (base)**	**2026/27**
Present value of benefits ($m)	0.64	2.97	5.08
Present value of costs ($m)	0.66	0.66	0.66
Net present value ($m)	-0.02	2.31	4.42
Benefit-cost ratio	0.97	4.53	7.67

Confidence Ratings and other Findings

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

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

High: denotes a good coverage of benefits or reasonable confidence in the assumptions made
Medium: denotes only a reasonable coverage of benefits or some uncertainties in assumptions made
Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 12: Confidence in Analysis of Project

Coverage of Benefits	**Confidence in Assumptions**
Medium	Low

The coverage of benefits was assessed as medium due to the necessary aggregation of impacts identified to only two that were valued.

While many of the assumptions were supported, in part by FRDC, EPA, and UTAS reports and feedback from the EPA, it is difficult to accurately estimate exactly what would have occurred without the project. This leads to the assumptions being assessed as low as there is a high degree of uncertainty around what the biomass decisions would have been without the project, as the science and regulatory information needed to accurately assess the biomass decisions without the project was not available.

Conclusions

Funding for project 2012-047 totalled $0.66 million (present value terms) and produced estimated total expected benefits of $2.97 million (present value terms). This gave a net present value of $2.31 million, an estimated benefit-cost ratio of 4.5 to 1, an internal rate of return of 13.2% and a modified internal rate of return of 6.3%.

The analysis provided a good example of an investment in research into effects of industry on the environment. The project allowed vital information that both industry and regulators needed to make sustainable decisions to preserve the operating environment and ensuring sustainable operations could continue. While no environmental impacts were valued, the continuing sustainability of Atlantic Salmon to operate in the harbour can be viewed as being the result of policy decisions protecting the environment.

Several environmental and social impacts were not valued due to lack of data, and difficulty placing credible monetary value on the impacts. Some of these impacts may have a large effect on the valuation if they were to be valued. Therefore, the investment criteria reported are likely an underestimate of the performance of the investment, as the environmental benefits are not valued, but are presumed to be highly significant. There was also a high degree of uncertainty in valuing the impacts. This was due to the valuation being driven by the counterfactual, with conservative assumptions having to be made.

The subsequent projects and research funded by FRDC, UTAS, Atlantic Salmon operators, and others involved suggest that there is a high commitment to making sure that Macquarie Harbour is a sustainable location to farm Atlantic Salmon.

Glossary of Economic Terms

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

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