FINAL REPORT

An Impact Assessment of Investment in FRDC Project 2016-044:

Next-Generation Close-Kin Mark Recapture: Using SNPs to Identify Half-Sibling Pairs in Southern Bluefin Tuna and Estimate Abundance, Mortality and Selectivity

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An Impact Assessment of Investment in FRDC Project 2016-044: Next-Generation Close-Kin Mark Recapture: Using SNPs to Identify Half-Sibling Pairs in Southern Bluefin Tuna and Estimate Abundance, Mortality and Selectivity
FRDC Project 2016-134

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The Fisheries Research and Development Corporation plans, invests in and manages fisheries research and development throughout Australia. It is a statutory authority within the portfolio of the federal Minister for Agriculture, Fisheries and Forestry, jointly funded by the Australian Government and the fishing industry.

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Abbreviations

ABARES	Australian Bureau of Agricultural Resource Economics and Sciences
AFMA	Australian Fisheries Management Authority
CBA	Cost-Benefit Analysis
CCSBT	Commission for the Conservation of Southern Bluefin Tuna
CKMR	Close-kin Mark–Recapture
CPUE	Catch per Unit Effort
CRRDC	Council of Rural Research and Development Corporations
DAWR	Department of Agriculture and Water Resources
DNA	deoxyribonucleic acid
FRDC	Fisheries Research and Development Corporation
HSP	Half Sibling Pairs
MR	Mark-Recapture
OCS	Office of the Chief Scientist
POPS	Parent–offspring Pairs
PVB	Present Value of Benefits
R&D	Research and Development
RD&E	Research, Development and Extension
SBT	Southern Bluefin Tuna
SBTF	Southern Bluefin Tuna Fishery
SBT MAC	Southern Bluefin Tuna Management Advisory Committee
SNP	single-nucleotide polymorphism
TAC	Total Allowable Catch

Executive Summary

Fisheries Research and Development Corporation (FRDC) Project 2016-044 was carried out by personnel from the CSIRO Marine Laboratories, Hobart, and was current over the period October 2016 to April 2018. The Southern Bluefin Tuna fishery (SBTF) is managed under the 1994 Convention for the Conservation of Southern Bluefin Tuna (CCSBT). In 2011, the CCSBT adopted a management procedure that is analogous to a harvest strategy. This has been used to set the global total allowable catch (TAC) since 2012. The management procedure aims to achieve rebuilding of the southern bluefin tuna stock to 20% of its initial unfished biomass by 2035, with a 70% probability.

In 2019, the CCSBT adopted a new management procedure (the Cape Town Procedure) that aims to achieve rebuilding of the southern bluefin tuna stock to 30% of its initial unfished biomass by 2035, with a 50% probability. The new management procedure maintains the 70% probability that the stock rebuilds to 20% by 2035. This new management procedure will be used to set the global TAC from 2021 onwards.

The global TAC is allocated to members and cooperating non-members, as agreed by the CCSBT under the 2011 CCSBT Resolution on the Allocation of the Global Total Allowable Catch. The Australian Fisheries Management Authority sets the TAC for the SBTF with reference to Australia's CCSBT allocation.

The management of fisheries usually relies on the relationship between fishery catches and effort (catch per unit effort or CPUE). The principle is that as a fish population declines, the effort required to catch a given number of fish increases. However, such relationships can be uncertain and sometimes unreliable. An alternative approach for estimating population abundance can use genomics and close-kin mark-recapture (CKMR). This alternative approach was the subject of the FRDC funded CKMR Project 2016-044.

The project investment has improved the stock assessment of SBT and has assisted the CCSTB via an improved accuracy of stock assessments that can be used in improving the future management of SBT. Implications of the project findings for SBT management include, potentially, increased profits received by SBT fishers and an enhanced future environmental sustainability of the SBT population.

Funding for the project over the three years totalled $0.71 million (present value terms) and produced estimated total expected benefits of $2.67 million (present value terms). This gave a net present value of $1.96 million, a benefit-cost ratio of 3.7 to 1, an internal rate of return of 16.0% and a modified internal rate of return of 10.5%. However, as there were several other potential impacts identified but not valued in monetary terms, the investment criteria as provided by the valued benefits are likely to be an underestimate of the total value of the project impacts.

Introduction

The Fisheries Research and Development Corporation (FRDC) required an annual series of impact assessments to be carried out on a sample of completed investments from 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 funding partners and other stakeholders.
- Reporting to the Council of Rural Research and Development Corporations (CRRDC).
- Reporting RD&E impact and performance to FRDC levy payers and other fisheries and aquaculture stakeholders as well as the broader Australian community.

In April 2017, FRDC commissioned Agtrans Pty Ltd (Agtrans) to undertake the annual impact assessments for RD&E projects funded under the FRDC 2015-2020 RD&E Plan and completed in the years ended 30 June 2016 to 2020 (FRDC Project 2016-134). Between 2016/17 and 2020/21, four series of annual impact assessments were completed. Each of the four series of assessments included a set of 20 randomly selected FRDC RD&E investments as well as an aggregate analysis across all 20 investments evaluated in each year. Published reports for the annual FRDC evaluations can be found at: https://www.frdc.com.au/frdc-project-impact-assessments-benefits-research.

The fifth and final series of impact assessments under Project 2016-134 was for a set of FRDC RD&E investments completed in the year ended 30 June 2020, the final year of the FRDC 2015-2020 RD&E Plan. As in previous years, the fifth series of impact assessments included 20 randomly selected FRDC RD&E investments. The 20 investments had a total value of approximately $5.30 million (nominal FRDC investment) and were selected from an overall population of 81 FRDC investments worth an estimated $17.66 million (nominal FRDC investment) where a final deliverable had been submitted in the 2019/20 financial year.

The 20 RD&E 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 30.0% 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 (total nominal FRDC investment of ≤ $50.000, $50,001 to $250,000, and > $250,000 respectively).

Project 2016-044: *Next-Generation Close-kin Mark Recapture: Using SNPs to identify half-sibling pairs in Southern Bluefin Tuna and estimate abundance, mortality and selectivity Conference* was randomly selected as one of the 20 RD&E investments completed in 2019/20 for evaluation in the fifth series of annual impact assessments (2019/20 sample). The current report presents the Project 2016-044 analysis and findings.

Method

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

The evaluation process utilised an input to impact continuum RD&E project inputs (costs), objectives, activities, and outputs were briefly described and documented. Actual and expected outcomes, and any actual and/or potential future impacts (positive and/or negative) associated with project outcomes then were identified and described. The principal economic, environmental, and social impacts were then summarised in a triple bottom line framework and validated through consultation with expert personnel and review of published literature.

Once impacts were identified and validated, an assessment then was made about whether to quantify/value any of the impacts in monetary terms as part of the project-level analysis. The decision to value an impact identified was based on:

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

Where one or more of the identified impacts were selected for valuation, the impact assessment used cost-benefit analysis (CBA) as a principal tool. The impacts valued therefore were deemed to represent the principal benefits delivered by the project investment. However, as not all impacts were valued (based on the selection criteria), the investment criteria estimated for the project investment evaluated are likely to represent an underestimate of the true performance of the FRDC project.

The qualitative and quantitative analysis processes, data sources, assumptions, specific valuation frameworks (where applicable), and evaluation results were clearly documented and then integrated into a written report.

Project Background

Background

Southern Bluefin Tuna – Fishery Management

Southern Bluefin Tuna (SBT) (*Thunnus maccoyii*) are found throughout the southern hemisphere mainly in waters between 30- and 50-degrees latitude south but only rarely in the eastern Pacific. The only known breeding area is in the Indian Ocean, south-east of Java, Indonesia. SBT are highly valued, and their primary market is the Japanese Sashimi market (Commission for the Conservation of Southern Bluefin Tuna (CCSBT), 2021a).

The SBT fishery is managed under the 1994 Convention for the Conservation of Southern Bluefin Tuna (ABARES, 2021). In 2011, the CCSBT adopted a management procedure (the Bali Procedure) that is analogous to a harvest strategy. This has been used to set the global total allowable catch (TAC) since 2012. The management procedure aims to achieve rebuilding of the southern bluefin tuna stock to 20% of its initial unfished biomass by 2035, with 70% probability.

In 2019, the CCSBT adopted a new management procedure (the Cape Town Procedure) that aims to achieve rebuilding of the southern bluefin tuna stock to 30% of its initial unfished biomass by 2035, with 50% probability. However, this new procedure maintains the 70% probability that the stock rebuilds to 20% by 2035. This new management procedure will be used to set the global TAC from 2021 onwards. The global TAC is allocated to members and cooperating non-members, as agreed by the CCSBT under the 2011 CCSBT Resolution on the Allocation of the Global Total Allowable Catch. The Australian Fisheries Management Authority sets the TAC for the SBT Fishery (SBTF) with reference to Australia's CCSBT allocation.

The Australian component of the SBTF mainly uses the purse seine fishing method. This is a net that encloses a school of fish. However, rather than landing the fish, the fish are towed to waters near the Australian mainland and placed in floating cages anchored to the ocean floor. The tuna then are fattened for several months and sold direct to Japanese markets as frozen or chilled fish (CCSBT, 2021a).

As mentioned previously, the overall SBTF is subject to an annual TAC. In recent years the TAC has risen from 12,449 tonnes in 2014 to its current level of 17,647 tonnes in 2020/21 (CCSBT, 2021b). The SBT TAC is split between the members of the CCSBT with Japan and Australia holding a majority (34.6% and 35.4% respectively).

The management of fisheries usually relies on the relationship between fishery catches and effort (catch per unit effort or CPUE). The principle is that as a fish population declines, the effort required to catch a given number of fish increases. However, such relationships can be uncertain and sometimes unreliable. An alternative approach for estimating population abundance can use genomics and close-kin mark-recapture (CKMR).

Close-Kin Mark–Recapture (CKMR)

The CKMR method is based on the principle that an individual's genotype can be considered a "recapture" of the genotypes of each of its parents and analyses the number and patterns of parent–offspring pairs (POPs) in a mark–recapture (MR) framework. Assuming the sampling of offspring and parents to be independent of each other, the number of POPs genetically identified in samples from both groups can be used to estimate species abundance.

Rationale for Project 2016-044

By avoiding the need for CPUE data, CKMR has the potential to change the way marine harvested SBT populations are monitored. Project 2016-044 extended the previous use of CKMR by incorporating POPs and Half-Sibling Pairs (HSPs) using approximately 15,000 samples of SBT spanning the years 2006-2014 plus additional samples supported by an earlier CSIRO project.

The results of the analyses were expected to address the following needs regarding the future monitoring, assessment, and management of SBT:

1. A reduction in the uncertainty in the status of spawning stock and the impact of unreported longline catches on the assessment results.
2. A direct index of the spawning stock for use in a Management Procedure.
3. Cost-effective and repeatable methods for long-term monitoring.

Project Details

Summary

Project Code: 2016-044

Title: *Next-Generation Close-kin Mark Recapture: Using SNPs to identify half-sibling pairs in Southern Bluefin Tuna and estimate abundance, mortality and selectivity*

Research Organisation: CSIRO Marine Laboratories, Hobart

Principal Investigator: Campbell Davies, Senior Principal Research Scientist

Period of Funding: October 2016 to April 2018

FRDC Program Allocation: Environment 70%

Objectives

Four objectives were listed in the project proposal:

1. Process archived tissue samples, extract DNA and genotype (~16,000 individuals, from 2006 to 2014).
2. Combine genotypes from objective 1 with those from a related CCSBT project (2015 to 2016).
3. Estimate time series of total adult abundance, spawning potential and total mortality for the spawning population.
4. Report outcomes for the Southern Bluefin Tuna Advisory Committee (SBT MAC), the Australian Fisheries Management Authority (AFMA), and the Scientific Committee of the CCCSBT for incorporation into the 2017 update of the CCSBT operating model.

Logical Framework

Table 1 provides a description of the project in a logical framework developed for the evaluation.

Table 1: Logical Framework for FRDC Project 2016-044

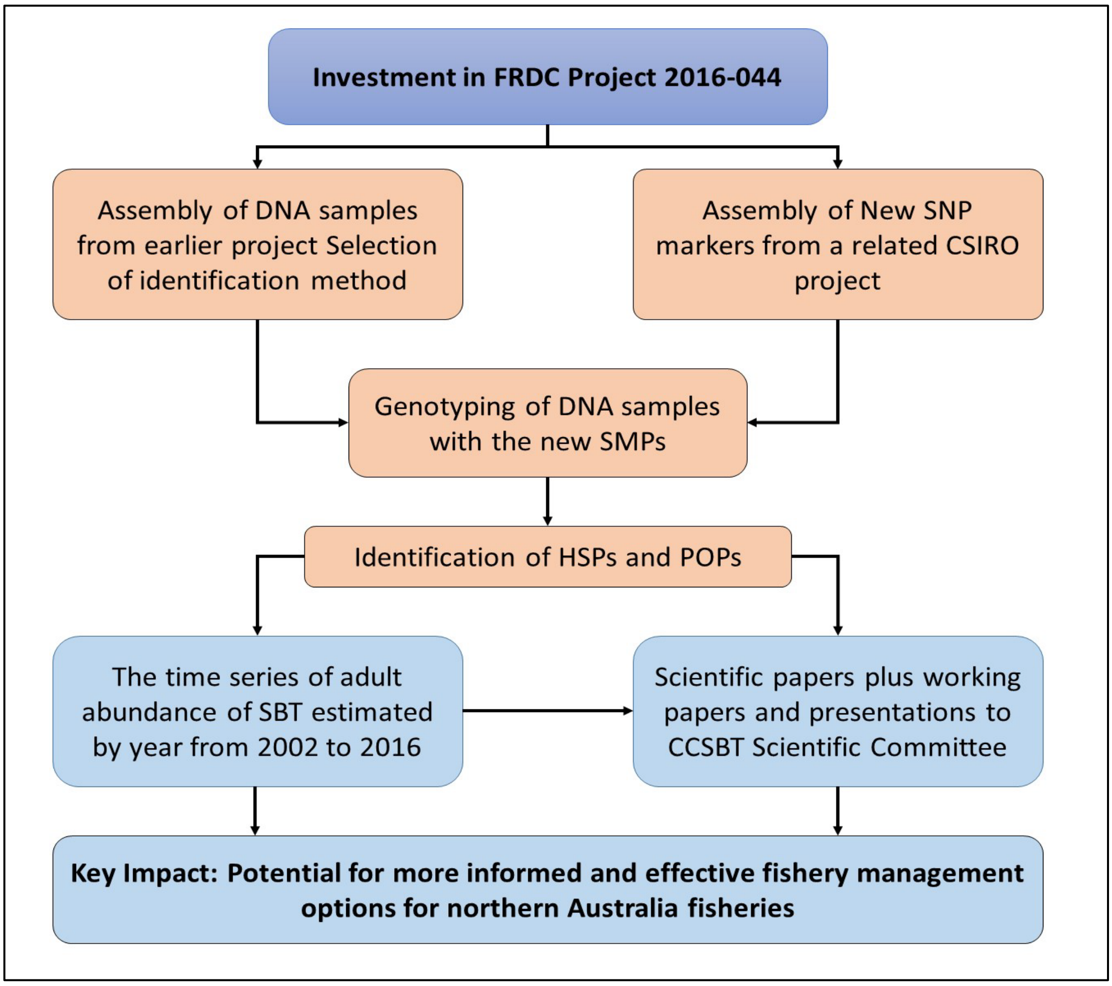
Activities	• Assembly of new markers (single nucleotide polymorphisms - SNPs) developed by CSIRO in a related project. • Assembly of DNA samples from earlier/related projects for years 2006-2010, from 2011-2014 and from 2015-2016. • Genotyping of DNA samples with the new SNPs. • Identification of HSPs and POPs. • The identification of HSPs and POPs has allowed a time series of adult abundance of SBT to be estimated by year.
Outputs	• A time series of abundance of SBT adults from 2002-2016. • Additional information on SBT stock status. • A series of peer-reviewed scientific papers. • Working papers and presentations to the CCSBT Scientific Committee. • Working papers and presentation toe SBT MAC and AFMA
Outcomes	• Inclusion of a new time series of SBT abundance in the 2017 SBT stock assessment and Management Procedures for testing in 2018. • Use of the new time series as an assessment of the status and trend of the spawning component of the SBT stock. • Additional data for the CCSBT Operating Model for assessments of stock status and productivity and associated management procedures.

	• More generally, CKMR is considered one of the most significant developments in fisheries assessment and is likely to be used increasingly over the next decade for both stock assessment purposes and as input data for harvest strategies and management procedures (Gavin Begg, pers. comm., 2022). • At the most recent World Fisheries Congress in 2021, it was noted that CKMR provides absolute abundance of a population, is a revolution in fisheries science, and is a game changer for fisheries and conservation management (Gavin Begg, pers. comm., 2022).
Impacts	• A reduction in the uncertainty of stock assessments resulting in an improved accuracy and effectiveness of stock assessments associated with management of SBT, in turn resulting in an increased confidence in management decisions. • Overseas research organisations and management agencies using HSPs and POPs (CKMR) methods for other fisheries. • Contribution/endorsement of Australia's image world-wide as being an effective fisheries science provider and sustainable fisheries manager. • Contribution to increased capability and capacity of Australian scientists with respect to assembling key fisheries information at a species level for fisheries management purposes.

Pathway to Impact

A diagram describing the simplified pathways to impact for the investment in Project 2016-044 is provided Figure 1.

Figure 1: Pathway to Impact for Project 2016-044



Nominal Investment

Table 2 shows the annual investment made in Project 2016-044 by FRDC and CSIRO.

Table 2: Annual Investment in Project 2016-044
(nominal $)

Year ended 30 June	FRDC ($)	CSIRO ($)	TOTAL ($)
2016	0	44,323	44,323
2017	98,384	95,765	194,149
2018	230,359	0	230,359
Totals	328,743	140,088	468,831

Source: FRDC Project Agreement

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 (x1.179). This multiplier was estimated based on the share of 'employee benefits' and 'supplier' expenses in total FRDC expenditure reported in the FRDC's Cash Flow Statement (FRDC, 2017-2021). This multiplier then was applied to the nominal investment by FRDC shown in Table 2. A multiplier of x1.00 was used for administration and management costs for CSIRO.

Real Investment and Extension Costs

For purposes of the investment analysis, the investment costs of all parties were expressed in 2020/21-dollar terms using the Implicit Price Deflator for Gross Domestic Product (ABS, 2021). No additional costs of extension were included as the outcomes and impacts were largely driven by project activities including communication with CCSBT and AFMA carried out within the project.

Impacts

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

Table 3: Triple Bottom Line Categories of Principal Impacts from Project 2016-044

Economic	• Continued and/or improved effectiveness of stock assessments associated with management of SBT resulting in avoidance of under-utilisation of the stock.
Environmental	• Continued and/or improved effectiveness of biodiversity and environmental management of the SBT fishery, with reduced likelihood of a species decline.
Social	• Contribution/endorsement of Australia's image world-wide as being an effective fisheries science provider and sustainable fisheries manager. • Contribution to increased capability and capacity with respect to assembling key fisheries information at a species level for fisheries management purposes, both in Australia and world-wide.

Public versus Private Impacts

The impacts identified in this evaluation are related to improvements in effective management of SBT. Both private and public impacts are likely to have been delivered by investment in Project 2014-022. The public impacts will include a more reliable environmental management of the SBT fishery by Australian authorities and potentially, by other SBT fishery managers around the world, an enhanced image of Australian science and fisheries management, and an increase in the capacity of Australian scientists. The private impacts will include Australian SBT fishers as well as, potentially, fishers from a range of countries that pursue SBT target catches that have been set with additional information than was not available hitherto.

Distribution of Private Impacts

The long-term private benefits will be captured by SBT fishers from Australia, as well, potentially, from a range of other countries. These benefits will be shared with the supply chains with which they interact. Such private benefits likely will be shared by members of the various fishery supply chains according to associated supply and demand elasticities.

Impacts on Other Australian Industries

It is expected that there would be negligible impacts on other Australian primary industries.

Impacts Overseas

It is likely there will be impacts that are captured overseas from use of the method. Such impacts may lead to improved management of SBT world wide by a range of SBT fishers from overseas countries including Japan, New Zealand, South Korea, Indonesia, Taiwan, and South Africa.

Match with National Priorities

Australian Agriculture, Science, and Research Priorities

The Australian Government's National Science and Research Priorities and Agricultural Innovation Priorities are reproduced in Table 4. Project 2016-044 directly contributed to National Science and Research Priority 1. Further, the RD&E investment is likely to contribute indirectly to Agricultural Innovation Priorities 1 and 2 by contributing to sustainable and productivity use of the SBT stock.

Table 4: Australian R&D Priorities

<table>
<tr><th colspan="2">Australian Government</th></tr>
<tr><th>National Science and Research Priorities[1]</th><th>National Agricultural Innovation Priorities[2]</th></tr>
<tr><td>1. Food – optimising food and fibre production and processing; agricultural productivity and supply chains within Australia and global markets.
2. Soil and Water – improving the use of soils and water resources, both terrestrial and marine.
3. Transport – boosting Australian transportation: securing capability and capacity to move essential commodities; alternative fuels; lowering emissions.
4. Cybersecurity – improving cybersecurity for individuals, businesses, government, and national infrastructure.
5. Energy and Resources – supporting the development of reliable, low cost, sustainable energy supplies and enhancing the long-term viability of Australia's resources industries.
6. Manufacturing – supporting the development of high value and innovative manufacturing industries in Australia.
7. Environmental Change – mitigating, managing, or adapting to changes in the environment.
8. Health – improving the health outcomes for all Australians.</td><td>On 11 October 2021, the National Agricultural Innovation Policy Statement was released. It highlights four long-term priorities for Australia's agricultural innovation system to address by 2030. These priorities replace the Australian Government's Rural Research, Development and Extension Priorities which were published in the 2015 Agricultural Competitiveness White Paper.

1. Australia is a trusted exporter of premium food and agricultural products by 2030.
2. Australia will champion climate resilience to increase the productivity, profitability, and sustainability of the agricultural sector by 2030.
3. Australia is a world leader in preventing and rapidly responding to significant incursions of pests and diseases through futureproofing our biosecurity system by 2030.
4. Australia is a mature adopter, developer, and exporter of digital agriculture by 2030.</td></tr>
</table>

[1] Source: 2015 Australian Government *Science and Research Priorities*. https://www.industry.gov.au/data-and-publications/science-and-research-priorities.
[2] Source: 2021 National Agriculture Innovation Policy Statement. https://www.awe.gov.au/agriculture-land/farm-food-drought/innovation/research_and_development_corporations_and_companies#government-priorities-for-investment.

FRDC National RD&E Priorities

Through extensive consultation, the FRDC 2015-2020 RD&E Plan identified three national RD&E priorities to focus and direct FRDC investments. The three FRDC national RD&E priorities were:

1. Ensuring that Australian fishing and aquaculture products are sustainable and acknowledged to be so.
2. Improving productivity and profitability of fishing and aquaculture.
3. Developing new and emerging aquaculture growth opportunities.

Project 2016-044 addressed FRDC national RD&E priorities 1 and 2 by contributing to sustainable and productivity use of the SBT stock through improved stock assessment practices.

Valuation of Impacts

Impacts Valued

The first impact valued in the assessment of investment in FRDC Project 2016-044 is the avoidance of losses by SBT fishers if the future SBT TACs were set at a lower level in a future where the additional data for the CCSBT Operating Model had not been assembled (Impact 1).

In the 2020/21 year the TAC for SBT was set at 17,647 tonnes. The landed market value of SBT was reported by the CCSBT at $320 million per annum (CCSBT, 2021a). The proportion of the value of the landed catch representing boat and catching costs (operating and capital costs) has been assumed to be 90% with the remaining 10% assigned to profits. The assumption for valuing the impact was that, without Project 2016-044, the TAC would have been (and remained) too conservative, thus increased profits would have resulted with the project given the results of Project 2016-044.

A second impact valued was that the TAC would have been set too high without the project endangering SBT sustainability and resulting in a downward shift in the sustainability status of SBT from endangered to critically endangered; the with-project situation is assumed to have avoided this situation (Impact 2). It should be noted, however, that while there may have been an increase in fisher profits in the short-term under this scenario, such an an impact was assumed to have been significantly outweighed by the reduced sustainability in the longer term.

A degree of conservatism was used when finalising assumptions for valuing both impacts, particularly as some significant uncertainty was involved in many of the estimates. A summary of the assumptions made in the impact valuations is provided in Table 5.

Impacts Not Valued

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

- Contribution/endorsement of Australia's image world-wide as being an effective fisheries science provider and sustainable fisheries manager.
- Contribution to increased capability and capacity with respect to assembling key fisheries information at a species level for fisheries management purposes.

These two impacts were not valued in monetary terms due to the difficulty of developing credible assumptions and relationships between the project and the capability and capacity built or how the world-wide image of Australia being an effective fisheries manager could be valued.

Summary of Assumptions

Table 5 below describes the assumptions used in the valuation of Impacts 1 and 2.

Table 5: Summary of Assumptions

Variable	Assumption	Source
Impact 1: Avoidance of commercial losses by SBT fishers		
Value of total SBT catch	$320m per annum	ABARES, 2020
Fishing profit as $ catch value	10%	Based on information assembled in article in Science Advances, 2018
Probability of underestimate of TAC using CPUE only	2.5%	Analyst assumptions
Probability of underestimate of TAC using CPUE and genomics	2.0%	
Expected annual profits saved due to project investment	$160,000 per annum	$320m x 10% x (2.5%-2.0%)
First year of gain assumed	2023	Analyst assumption
Attribution of impact to project	100%	Analyst assumption
Impact 2: Reduced risk of biodiversity decline		
Willingness to pay (WTP) estimate per species extinction	$0.67 per household per annum (2004 $ terms)	Derived from van Bueren and Bennett, 2004
	$1.03 per household per annum (2020 $ terms)	0.67 x 1.5328 (implicit GDP deflator for 2004)
WTP for avoiding status change from unlisted to vulnerable	$1.03/4 = $0.26 per household per annum	Dividing $1.03 per household by the four classification stages to extinction (Analyst assumption)
Number of households in Australia	10.1 million in 2020	Australian Institute of Family Studies (2020)
Change in probability of conservation status decline from unlisted to vulnerable that is attributable to investment in project 2016-044	Decrease of 1%	Analyst assumption
First year of gain	2023	
Attribution of impact to project	100%	

Results

All benefits were expressed in 2020/21 $ terms. All costs and benefits were discounted to 2021/22 using a discount rate of 5%. A reinvestment rate of 5% was used for estimating the Modified Internal Rate of Return (MIRR). The base analysis used the best available estimates for each variable, notwithstanding a level of uncertainty for many of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2017/18) to the final year of benefits assumed.

Investment Criteria

Tables 6 and 7 show the investment criteria estimated for different periods of benefits for the total investment and FRDC investment respectively. The present value of benefits (PVB) attributable to the FRDC investment only, shown in Table 7, has been estimated by multiplying the total PVB by the FRDC proportion of real investment before discounting (73.0%).

Table 6: Investment Criteria for Total Investment in Project 2016-044

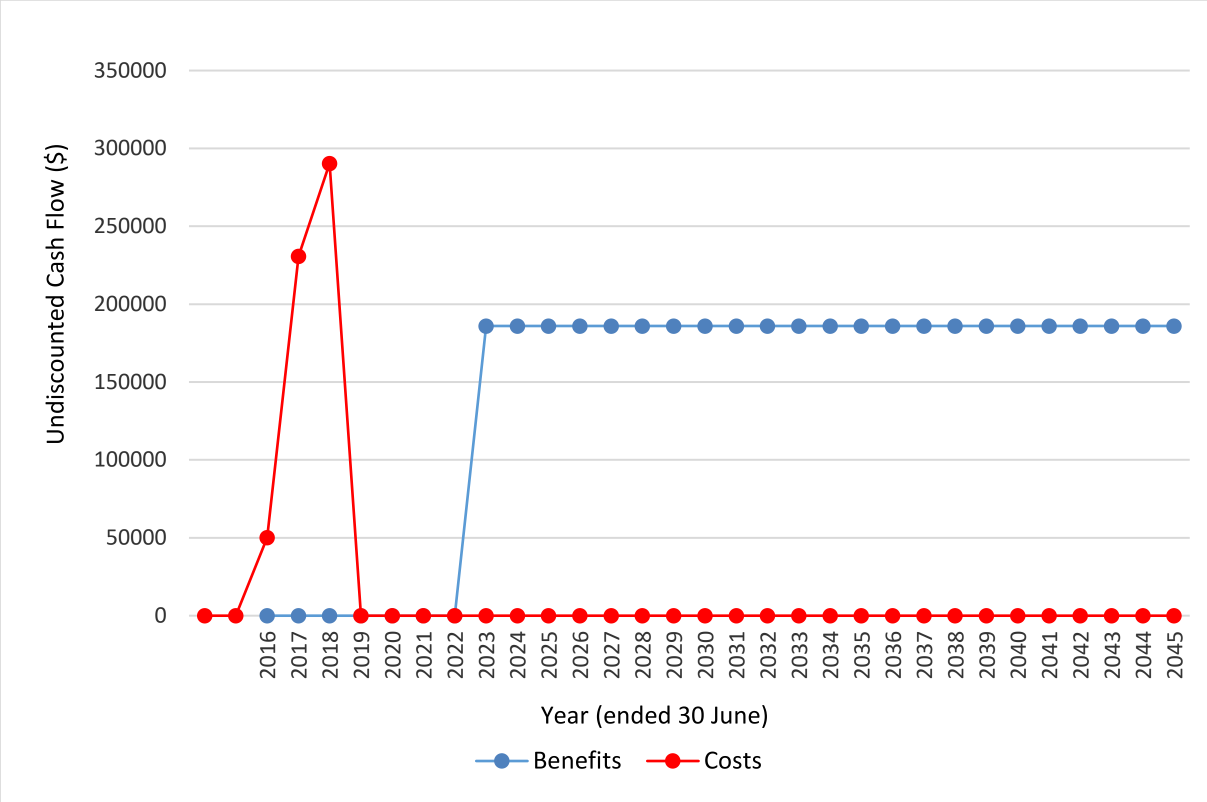
Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.18	0.94	1.55	2.02	2.38	2.67
Present value of costs ($m)	0.71	0.71	0.71	0.71	0.71	0.71	0.71
Net present value ($m)	-0.71	-0.54	0.23	0.83	1.30	1.67	1.96
Benefit-cost ratio	0.00	0.25	1.32	2.16	2.82	3.34	3.74
Internal rate of return (%)	negative	negative	8.8	13.6	15.2	15.8	16.0
MIRR (%)	negative	negative	10.0	12.6	12.0	11.2	10.5

Table 7: Investment Criteria for FRDC Investment in Project 2016-044

Investment criteria	**Number of years from year of last investment**						
	0	**5**	**10**	**15**	**20**	**25**	**30**
Present value of benefits ($m)	0.00	0.13	0.69	1.13	1.47	1.74	1.95
Present value of costs ($m)	0.51	0.51	0.51	0.51	0.51	0.51	0.51
Net present value ($m)	-0.51	-0.39	0.17	0.61	0.96	1.23	1.44
Benefit-cost ratio	0.00	0.25	1.34	2.19	2.86	3.38	3.79
Internal rate of return (%)	negative	negative	9.1	14.1	15.7	16.3	16.5
MIRR (%)	negative	negative	10.2	12.8	12.1	11.3	10.5

The annual undiscounted benefit and cost cash flows for the total investment for the duration of investment period plus 30 years from the last year of investment are shown in Figure 2.

Figure 2: Annual Cash Flow of Undiscounted Total Benefits and Total Costs



Sources of Benefits

The respective contributions of the two impacts valued are provided in Table 8.

Table 8: Contribution of Source of Benefits to Present Value of Benefits
(Total investment, 30 years)

Source of Benefit	**Total PVB (%)**	**PVB ($)**
Impact 1: Expected increase in commercial profits	86.0	2,300,030
Impact 2: Reduced risk of status vulnerability decline	14.0	373,863
TOTAL	100	2,673,892

Sensitivity Analyses

A sensitivity analysis was carried out on the discount rate. The analysis was performed for the total investment and with benefits taken over the life of the investment plus 30 years from the last year of investment. All other parameters were held at their base values. Table 9 presents the results. The results showed a moderate sensitivity to the discount rate.

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

Investment Criteria	**Discount rate**		
	0%	**5% (base)**	**10%**
Present value of benefits ($m)	4.84	2.67	1.70
Present value of costs ($m)	0.57	0.71	0.89
Net present value ($m)	4.26	1.96	0.82
Benefit-cost ratio	8.47	3.74	1.92

A sensitivity analysis was undertaken also on the assumed fall in the probability of a TAC underestimate due to Project 2016-044. Results are shown in Table 10. The break-even probability of a TAC underestimate shift would need to fall from 2.5% (without the project) to only 2.43% (with project) for the project investment to break even.

Table 10: Sensitivity to Assumption of the Fall in the Probability of a TAC Underestimate

Investment Criteria	**Reduction in estimate of fall in probability due to Project 2016-044**		
	2.5% to 2.25% (pessimistic)	**2.5% to 2.0% (base)**	**2.5% to 1.75% (optimistic)**
Present value of benefits ($m)	1.52	2.67	3.82
Present value of costs ($m)	0.71	0.71	0.71
Net present value ($m)	0.81	1.96	3.11
Benefit-cost ratio	2.13	3.74	5.35

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 11). 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 11: Confidence in Analysis of Project

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

The coverage of benefits was assessed as High-Medium. Of the four impacts identified in Table 3, the two most important impacts were valued; the values of the other two impacts were considered minor in value relative to the two impacts valued. For the impacts valued, many of the assumptions used were realistic but the critical assumption of the probability shifts was necessarily subjective. Hence, the overall rating of confidence in the assumptions was considered Medium-Low.

Conclusions

The contribution of the investment in FRDC Project 2016-044 was to improve the stock assessment of SBT that may well assist the CCSTB via an improved accuracy of stock assessments associated with management of SBT. This, in turn, could lead potentially to increased profits received by SBT fishers (though less uncertain and increased TAC) and an enhanced future environmental sustainability of the SBT population.

Funding for the project over the three years totalled $0.71 million (present value terms) and produced estimated total expected benefits of $2.67 million (present value terms). This gave a net present value of $1.96 million, a benefit-cost ratio of 3.7 to 1, an internal rate of return of 16.0% and a modified internal rate of return of 10.5%. However, as there were several other potential impacts identified but not valued in monetary terms, the investment criteria as provided by the valued benefits are likely to be an underestimate of the total value of the project investment.

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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