ACIL ALLEN CONSULTING

Case Study

Orange Roughy and Southern Bluefin Tuna

Key findings

This case study examines two projects being conducted by CSIRO's Oceans and Atmosphere (O&A) Business Unit, namely the Orange Roughy (OR) project and the Southern Bluefin Tuna (SBT) body of research. The outputs and outcomes of these two projects are summarised below:

The OR research project:

- Outputs:
  - Led to the development of the fishing industry-based Acoustic Optical System (AOS), a high-confidence method for accurately measuring the size of the OR stock using dual-frequency acoustic assessments combined with the collection of optical data to verify methods.
  - Included stock biomass estimates of OR fisheries in Australian and New Zealand from 2006 to 2015.
  - Led to the development of the 2015 Base-case model of pre-fishing OR stock size which showed the fishery was recovering.
  - Led to the development of the Orange Roughy rebuilding strategy 2006-2015.
- Outcomes:
  - The AOS method is a significant improvement upon the previous approach and is more cost effective as it maximises industry equipment and knowledge. It increases the reliability and accuracy of OR stock assessments.
  - The AOS data has been used to improve monitoring and sustainable management of OR stocks in national and international deep-water OR fisheries and led to the development of the Australian rebuilding strategy 2006 to 2015 Final Base-case Model, which provided an accurate estimate of female spawning biomass.
  - Allowed sustainable management of the total allowable catch (TAC) in Australia and New Zealand as a result of increased confidence in the assessments of stock size and more effective stock management. This resulted in general increases in TAC, with decreases needed in some areas to maintain sustainability.
  - A method that provided precise biomass estimate advice that was accepted by industry, government and non-government organisations. Industry trusted both low and high estimates as they were integral to the process of obtaining the result.
  - Enabled New Zealand to obtain Marine Stewardship Certification for three OR fisheries.

The SBT research:

- Outputs:
  - Led to the development of an aerial stock size estimate used in the Great Australia in Bight in the early 1990s to determine SBT stock size.
  - Led to the development of SBT management procedure to reduce further decline and rebuild the SBT stock.
  - Led to the development of novel, internationally recognised stock assessment methods: Close Kin and gene-tagging for determining absolute SBT spawning stock size and recruitment of juvenile fish into the adult stock through targeted capture-release methods and complex mathematical modelling.
  - Conducted stock assessment estimates of SBT internationally for use in determining global TAC.
  - Led to the development of a biopsy tool for use in collecting tissue samples from SBT for subsequent DNA analysis and input into stock size estimates.

— Outcomes:
  - Increased the reliability, accuracy and confidence in international SBT stock assessments.
  - Developed Close Kin and gene-tagging technologies, which have substantially improved upon previous methods for estimating SBT stocks.
  - Helped to enhance international coordination and collaboration to adopt a scientifically rigorous and internationally recognised management procedure designed to rebuild the stock.
  - The combination of more accurate stock assessments and the use of a management procedure to set the global TAC has seen the stock size increase and has led to progressive increases in global TAC.

These two projects have delivered significant benefits for the OR and the SBT fisheries. These benefits include:

— Environmental benefits generated by enabling the stocks of endangered fish species to rebuild to sustainable levels.

— Social benefits resulting from recreational fishers having greater access to SBT.

— Improved international relationships between SBT fishing nations.

— The recovery and improved sustainability of OR and SBT stocks provides greater certainty for the people reliant on harvesting these fish for their incomes.

— Substantial economic benefits to Australia (as well as New Zealand for OR and internationally for SBT) as a result of more sustainable commercial fishing and export.

Cost-benefit

— Under a 7 per cent real discount rate, the present value (PV) of total R&D costs across the OR and SBT projects is $65.1 million in 2018-19 dollars, $22.0 million of which was contributed by CSIRO.

— The PV of total project benefits to Australia under the same discount rate is projected to be approximately $880.7 million in 2018-19 dollars, approximately 70 per cent or $616.5 million of which is attributed to CSIRO.

— Assessing the benefits against costs, the combined net present value (NPV) of the two projects attributable to CSIRO is estimated to be 28.03.

Innovation impact

CSIRO developed and applied AOS, and the Close Kin and gene-tagging technologies. These technologies are recognised internationally as world-leading, further CSIRO is seen as a trusted adviser by industry and management in Australia and internationally. CSIRO also developed an innovative sampling tool that avoids cross contamination between samples and reduces the time and resources required to process tissue samples, making large-scale biopsy programs cost-effective and practical. Further, CSIRO led the design of a scientifically tested management decision rule and collaborated on adoption through the CCSBT. This management procedure is the world's first for internationally managed tuna stocks.

As a result of this research, the following impacts have been achieved:

The OR research project:

— Economic:
  - The Australian fishery catch has generated a total of 1500 tonnes of OR from 2009, valued at ~$12 million (or more than $20 million when the fish are sold commercially). CSIRO is currently recommending the fishery TAC be increased to 1000 tonnes.
  - The New Zealand fisheries are open to fishing, representing 8,736 tonnes a year, with an annual export value of NZD $54 million.
  - Sustainable harvest has resulted in the development of a sustainable fishing industry and associated jobs and economic growth.

— Environmental:
  - Australia has fulfilled the Commonwealth Fisheries Harvest Strategy Policy and Guidelines and adhered to international, Regional Fisheries Management Organisations (RFMOs) and high seas fisheries obligations.
  - The Australian OR fishery was shown to be in recovery, resulting in a reopening of the fishery for targeted catch in 2015, after a 10-year closure.
  - The New Zealand MPI can reliably assess and monitor stocks and obtained New Zealand obtained Marine Stewardship Council certification for three OR fisheries in 2016 (representing two-thirds of the New Zealand OR catch).
  - The AOS technology and methodology has potential for use monitoring other species.

— Social:
  - OR are harvested sustainably, increasing food security.
  - Consumers can purchase sustainably fished OR.

The SBT research:

— Economic:
  - The responsibility for funding the project was transferred from CSIRO and the Australian government to the CCSBT in 2016, reducing Australia's direct funding of the work.
  - Sustainable management of the fishery has resulted in improved security of the SBT fishing industry, including benefit from commercial fishery revenue ($80 million per year, $2.5-3 billion over the last 10 years) and Port Lincoln value-add BST farming operations and the associated employment and economic returns ($259 million and 807 full-time employees in 2015/16).

— Environmental:
  - The conservative management procedure has resulted in international management and successful rebuilding of the SBT stock.

— Social:
  - CSIRO has played an important role in enhancing international coordination and collaboration ensured broad acceptance of the scientific findings and enhanced the operation and function of CCSBT.
  - Recreational fishers benefit from the increased catch available as a result of the effective management procedure.
  - Consumers can purchase sustainably fished OR.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework for this case study into the OR Project and the SBT research are summarised in **Figure 1.**

FIGURE 1 OR & SBT CASE STUDY – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
Investment from: – CSIRO – research and implementation – AFMA – contracting, management – NZ Sealord – purchased AOS – NZ DWG – industry – SETFIA – industry – SIOFA – international management – New Zealand MPI – Attorney Generals Department – DAFF – policy development and implementation – FRDC – research management and investment – CCSBT – regulatory – DAWR – policy development and implementation – ABARES – CCSBT lead delegation – ASBTIA – industry cooperation/ facilitation – Industry (Stehr Group, Port Lincoln companies, Australian Fishing Enterprises, Tony's Tuna, Mori Seafood) – charter access, processing facilities, data processing and design expertise	**OR project:** Research into advanced survey methods with acoustics and imagery Development and optimisation of cost effective survey methods. Stock assessments of OR fisheries in Australian and New Zealand SBT research: Aerial surveys of SBT International coordination and collaboration to establish a new management procedure Development and testing of fishery independent stock assessment methods: Close Kin, gene-tagging International stock assessment of SBT	**OR project:** – High confidence biomass estimate method – Acoustic species identification, target strength methods – Robust acoustic and optical (AOS) instrumentation suitable for industry application – Development of the 2015 Base-case model of pre-fishing OR stock size which showed the fishery was recovering – Orange Roughy rebuilding strategy 2006-2015 – Stock assessment estimates of OR fisheries in Australian and New Zealand – Publications **SBT research:** – Aerial survey estimate of recruitment (juvenile SBT) – SBT management procedure to set global TAC – Fisheries-independent stock assessment methods: Close Kin (spawners) and gene-tagging (recruits) – International stock assessment estimates of SBT – Biopsy tool and genetic markers – Publications	**OR project:** – Transfer of AOS to industry vessels enabling improved stock assessment – Improved monitoring and sustainable management of OR fisheries – Increases in TAC in Australia and New Zealand **SBT research:** – Increased reliability, accuracy and confidence in stock assessment – Uptake and use of SBT management procedure – Steady increases in SBT stock size – Allowed increases in global TAC of SBT – International recognition of benefits of management procedure approach to setting TAC – Widely applicable fisheries independent monitoring methods	**OR project:** Economic: – Commercial value: Australia ($20M) and New Zealand (NZD$54M) – Sustainable fishing industry jobs and economic growth – More cost-effective monitoring instrumentation and methods Environmental: – Adherence to national and international fishery obligations – OR fishery recovery and reopening – Marine Stewardship Council certification for three New Zealand OR fisheries Social: – Sustainable harvest, food security and meeting consumer preferences for sustainably fished OR **SBT research:** Economic: – CCSBT now funds CSIRO to conduct SBT research – Commercial value of the Australian catch ($80 million/year, $2.5-3 billion over the last 10 years) – Sustainable fishing industry jobs and economic growth – More cost-effective monitoring instrumentation and methods Environmental: – Adherence to national and international fishery obligations – Management and successful rebuilding of the SBT stock – Uptake of Close-Kin for other fisheries and wildlife applications Social: – Enhanced international collaboration – Increased recreational catch – Consumers can purchase sustainably fished SBT

SOURCE: ACIL ALLEN

1. Purpose and audience for case study

This case study assesses the economic, environmental and social benefits arising from O&A's research into OR and SBT. This assessment is being undertaken to estimate the positive impacts arising from O&A's research.

The information in this case study is provided for accountability, communication and continual improvement purposes. The case study can be read as a standalone report or aggregated with other case studies to estimate the impact and value of the O&A Business Unit's activities as a whole, relative to the funds invested in these activities. Its primary purpose is as an input into the independent review of the O&A Business Unit. Other audiences for this report may include Members of Parliament, Government Departments, CSIRO and the general public.

2. Background

OR project

OR, a deep-water fish stock, was first discovered in waters near Australia (from New South Wales, south around Tasmania and to southern Western Australia) and New Zealand in the 1970s. This discovery led to wide-spread commercial fishing.

OR is particularly vulnerable to over-exploitation as they are long-lived, late-maturing and low-recruitment[1] fish that display vulnerable aggregating behaviours[2]. Lack of regulation of early catches combined with overfishing led to significant depletion of the OR stocks in the 1980s and 1990s, and subsequent collapse or near-collapse of the fisheries. At its peak in 1989, the global catch of OR was approximately 90,000 tonnes, with 40,000 tonnes caught in Australian waters and 50,000 tonnes caught in New Zealand waters. To account for the depletion in OR stocks, in the mid-1990s the total allowable catch (TAC) in New Zealand was reduced from a high of 65,000 to 25,000 tonnes, prior to the fisheries closing.

In 2006 the estimated Australian OR stocks were well below the limit reference point set for the fishery, and OR became the first commercial fish to be listed as conservation-dependent under the *Environment Protection and Biodiversity Conservation Act (1999)*.[3] OR became an example of poor fisheries management, and the Australian OR fisheries were closed to commercial fishing (with the exception of the Cascade Plateau Zone).

In October 2006, an Orange Roughy Conservation Program was implemented to:

"Ensure that orange roughy do not become vulnerable, endangered or critically endangered, as defined by the Environment Protection and Biodiversity Act 1999, within a period of 5 years".

– *AFMA Workshop Report, 2007*

The Australian Conservation Program requires the OR stock status to be monitored over time at key sites, including the major spawning site at St Helens seamount and St Patricks Hill.

Fishery management is grounded in the ability to accurately assess and monitor stock size, in order to inform annual TAC. Stock assessment methods in the 1980s were inappropriate for measuring OR stock, due to the OR residing in deep-waters and forming multi-species aggregations. As such, new deep-water technologies were necessary to determine the proportion of OR in the aggregation to accurately estimate stock size.

CSIRO began the OR project in 1987 in response to a growing need for cost-effective advice for the sustainable management of Australia's OR fisheries. The OR project aimed to develop a low-cost, high-precision monitoring method to accurately assess stock size and determine changes in stock size.

The OR project is a collaboration between CSIRO's Advanced Survey Methods, Technology Development and Stock Assessment teams. CSIRO collaborated with external partners including the Australian Fisheries Research Development Corporation (FRDC), Australian Fisheries Management Authority (AFMA), the South East Trawl Fishing Industry Association

[1] Recruitment refers to the number of fish surviving juvenile years to enter the fishery as adult fish.

[2] OR form large schools when spawning, making them vulnerable to overfishing.

[3] Commonwealth Government *Environment Protection and Biodiversity Conservation Act 1999*: A native species is eligible to be included in the ***conservation dependent*** category at a particular time if, at that time:
(a) the species is the focus of a specific conservation program the cessation of which would result in the species becoming vulnerable, endangered or critically endangered; or
(b) the following subparagraphs are satisfied: (i) the species is a species of fish; (ii) the species is the focus of a plan of management that provides for management actions necessary to stop the decline of, and support the recovery of, the species so that its chances of long term survival in nature are maximised; (iii) the plan of management is in force under a law of the Commonwealth or of a State or Territory; (iv) cessation of the plan of management would adversely affect the conservation status of the species.

(SETFIA), the fisheries industry (Sealord, New Zealand Deepwater Group (DWG)), the New Zealand Ministry for Primary Industries (MPI) Ministry of Fisheries (MFISH), the National Institute of Water and Atmospheric Research (NIWA), and the Southern Indian Ocean Fisheries Agreement (SIOFA).

SBT research

Southern Bluefin Tuna (SBT) is a highly migratory species which spawns only in the Java Sea and migrates annually from the west Indian Ocean (South Africa) to New Zealand, through the Great Australian Bight (juvenile fish) or the High Seas (mature fish). SBT is vulnerable to overfishing due to late spawning (10-12 years old) and, relatively low mortality and longevity. The management of SBT is complicated by the international waters it travels through and the number of nations involved in commercial fishing operations across its range.

Global commercial SBT fishing reached 80,000 tonnes per year in the early 1960s, with the Australian SBT fishery commencing commercial fishing in the 1970s. The combined effect of high seas longline catches and Australian pole and line and purse-seine catches caused a substantial decline in mature SBT, very low recruitment of juvenile fish into the fishery and sustained decline in the annual catch. This reached crisis point in the mid-1980s with the collapse of the surface fishery in southern NSW and closure of processing plants. CSIRO began developing aerial survey methods for SBT in the Great Australia in Bight in the early 1990s as a fishery independent basis to monitor the recruitment of juvenile (2-4 years old) SBT.

An increasing need for international management and conservation stimulated dialogue formal tri-lateral arrangements between the major SBT fishing nations, Australia, New Zealand and Japan, who began to apply voluntary Individual Transferable Quotas from 1984-1994. This was formalised in 1994 with the formation of an international Regional Fisheries Management Organisation (RFMO): The Commission for the Conservation of SBT (CCSBT). The CCSBT, founded by Australia, was established to address growing concerns regarding the sustainability of SBT fishery. The CCSBT was unable to agree on global catch limits for more than a decade, leading Australia and New Zealand to take formal proceedings against Japan in the International Tribunal for the Law of the Sea in 1998. The outcome of these proceedings was the appointment of an independent scientific committee and panel members who are responsible for mediating a scientific consensus to ensure the CCSBT's objectives of conservation and optimum utilisation of the global SBT fishery are met.

CCSBT is responsible for establishing TAC and allocation of the TAC among members, performing scientific research, fishery management and conservation activities as well as regulatory functions to meet the objectives of the *Convention for the Conservation of Southern Bluefin Tuna*. The CCSBT (and the Extended Commission) now includes the Republic of Korea, Indonesia, Taiwan, the European Union and South Africa. CSIRO has been engaged in SBT research since the 1950's and was a central member of the scientific processes associated with the tri-lateral meetings that lead to the formation of the CCSBT.

In 2006 large, long-term under-reporting of catches from the long-line fisheries were identified. As long-line data was a key input into stock assessments, this generated considerable uncertainty in the accuracy of historical stock assessments. Contributions by CSIRO were central to identifying the implications of this over-catch on the CCSBT stock assessment and subsequent assessments showed that SBT stock levels were severely reduced (3-5 per cent of unfished levels) and the fishery was on the brink of collapse. The global TAC was subsequently reduced to its lowest level in an attempt to reduce the risk of further declines and rebuild the stock. By 2010, the SBT stock had shown no recovery and was listed as conservation-dependent under the *Environment Protection and Biodiversity Conservation Act (1999)* and as critically endangered under by the International Union for Conservation of Nature.

The immediate situation required the development and implementation of a scientifically tested and precautionary rebuilding plan for the SBT stock using the available monitoring series. In 2011 a management procedure incorporating the scientific aerial survey, as an "early warning" for low recruitment, and longline catch rates was subsequently agreed by the CCSBT as the basis for setting TAC for the global fishery. In parallel, CSIRO had initiated development of new fishery independent methods to accurately monitor stock size with a particular focus on the abundance of adult/reproductive component of stock and juveniles, or recruits to the fishery, with a view to these fisheries independent methods being used in future stock assessments and, potentially, a longer-term management procedure.

The SBT research is a collaboration between more than 20 CSIRO researchers across multiple CSIRO teams over 13 years (CCSBT team, Data61 and the Engineering and Technology group). CSIRO also partnered with the Department of Water and Agricultural Resources (DAWR), the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES), AFMA, CCSBT (and individual members), Australia SBT Industry Association (ASBTIA), Fisheries Research and Development Corporation, the Attorney Generals Department (AGD) and industry bodies.

3. Impact Pathway

3.1 Project Inputs

The total funding for the Orange Roughy (OR) project was $13,480,000 in cash and in-kind contributions, while the total funding for the Southern Bluefin Tuna (SBT) project was $30,549,558 in cash and in-kind contributions (see **Table 1**).

CSIRO made co-contributions to both projects totalling $14,460,006 (around 33 per cent of the total cost of the combined project elements).

TABLE 1 SUPPORT FOR THE OR AND SBT RESEARCH PROJECTS

Contributor/ type of support	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	Total
OR Project																	
Cash																	
CSIRO		136,500	65,500	106,667	106,667	173,667	35,000	341,833	292,333	342,833	51,000	119,000	98,500	81,500			1,951,000
AFMA		294,000		159,667	159,667	159,667											773,000
NZ MPI (MFISH)		134,500	134,500				142,000										411,000
NZ Sealord						269,000		420,000	420,000	740,000							1,849,000
NZ DWG								37,500	37,500		304,000	350,000	295,000	301,000			1,325,000
SETFIA								331,000	113,000	113,000		128,500	128,500				814,000
SIOFA													21,000	21,000			42,000
Total																	**7,165,000**
In-kind/Co-contribution																	
AFMA		400,000		40,000	40,000	40,000											520,000
NZ MPI (MFISH)		122,500	122,500														245,000
NZ Sealord						180,000		350,000	350,000	975,000							1,855,000
NZ DWG											1,225,000	700,000	875,000	400,000			3,200,000
SETFIA								255,000	60,000	60,000		60,000	60,000				495,000
Total																	**6,315,000**
OR Total																	**13,480,000**

Contributor/ type of support	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	Total
SBT research*																	
Cash																	
AGD	27,500																27,500
FRDC	40,000	40,000	40,000	568,204	40,000	243,425	114,980	40,000				82,186	82,186				1,290,981
DAFF	40,000	378,761	481,007	334,061	496,067	489,898	356,848	197,169									2,773,810
CCSBT	40,000	40,000	40,000	40,000	40,000	40,000	40,000	40,000		307,591	465,419	732,163	902,317	611,478	233,333		3,572,302
CSIRO	51,429	219,429	658,507	768,129	354,921	368,679	1,270,512	2,084,500	879,539	922,716	971,442	1,180,291	1,405,636	1,024,013	246,827	102,438	12,509,006
AFMA		160,037	747,852	186,743	399,445	246,848	1,209,598	457,354	1,077,970	900,241	330,857	319,342	290,222	340,015			6,666,523
DAWR											403,648	464,512	470,776	216,000	216,000	216,000	1,986,937
Total																	**28,827,058**
In-kind/Co-contribution#																	
Japan (SA/MP)	75,000	75,000	75,000	75,000	75,000	75,000	75,000				7,000		15000				547,000
Independent Advisory Panel (SA/MP)	30,000	30,000	30,000	20,000	30,000	20,000	30,000		30,000		30,000		30,000				280,000
ABARES (SA/MP)	72,000	72,000	72,000	72,000	72,000	72,000	72,000										504,000
AFMA (SA/MP)	15,000	15,000	15,000	15,000	15,000	15,000	15,000										105,000
ASBTIA (SA/MP)	15,000	15,000	15,000	15,000	15,000	15,000	15,000										105,000
DAWR (SA/MP)	10,000	20,000	10,000			10,000	15,000										65,000
ASBTIA (Close Kin)	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000	2,000			28,000
Research Centre for Fisheries (Indonesia) (Close Kin)	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000	5,000			70,000
ASBTIA and Port Lincoln companies (gene-tagging)												500	8,000	10,000			18,500
Total																	**1,722,500**
SBT Total																	**30,549,558**
GRAND TOTAL																	**44,029,558**

Note: * a 2003 review identified since 1985, 149 SBT research projects have been conducted with a total value of $25 million, # stock assessment (SA), management procedure (MP)

SOURCE: ACIL ALLEN BASED ON CSIRO ADVICE

3.2 Project activities

OR project

Research on OR between 1990-93 focused on developing an acoustic method to accurately identify OR among aggregations of different fish species. This method measured the sound reflectance, or 'target strength' (TS) of fish at multiple frequencies (38 and 120 kHz) to resolve aggregations. This method was refined over time in collaboration with FRDC and the fishing industry, by reducing the distance between the target fish and the survey instrument (that is, using deep-towed rather than vessel-mounted transducers).

However, the method was unable to completely resolve OR and the difficulty of accurately estimating stock size remained. Hence, research in 2009 focussed on integrating an optical, photographic survey method to verify the acoustic assessments. The combined Acoustic Optical System (AOS) was attached to fishing vessel trawl nets and operated from a fishing vessel, offering the opportunity to visually confirm spawning OR as they are herded into the trawl and come within range of the AOS acoustic and optical sensors:

"AOS (multifrequency acoustics, optics, and trawl catch) provides a "multiple-lines-of-evidence approach" in a single instrumentation and deployment system previously done by multiple devices"

– *Ryan, T. E. & Kloser, R. J. (2016), doi.org/10.1093/icesjms/fsw009*

The AOS methods were first developed on research platforms and then transferred to industry platforms for further application and development. The use of industry platforms reduced the cost of surveying, which, prior to successful trials in 2011, was previously conducted using both a research and industry vessel and required more personnel.

OR stock assessments were also conducted in New Zealand from 1992 using expensive and unreliable research vessel-based trawl net surveys. A similar need to improve stock assessment methods was evident and in 1998, CSIRO was contracted to conduct trials of the AOS method in New Zealand waters. This continued to build upon the research conducted by CSIRO in Australia and offered a more reliable and less expensive alternative to the research being conducted. The New Zealand MPI contracts service providers who subcontract CSIRO to conduct 4-yearly stock assessments. This is used to inform TAC.

CSIRO has conducted ongoing assessment, as required under the Conservation Program, to monitor changes in stock size and improve the accuracy of assessments (as the proportion of females spawning is variable year on year). This data contributed to the development of a base-case model in 2014, that is, an estimate of the early 1990's pre-fishing stock size. This was presented at the May 2014 Australian Orange Roughy workshop organised by AFMA (including New Zealand participants) at CSIRO Hobart.

Initial research was done under partnership between CSIRO, industry and management with models for ongoing monitoring and research evolving as the fishery has now been reopened. In recent years the South East Resource Assessment Group has provided advice to the AFMA Commission regarding the requirements for the OR assessments and AOS biomass surveys. The responsibility for conducting AOS surveys is then contracted by AFMA to SETFIA, who publicly tender the industry vessels for the surveys. CSIRO is contracted in partnership with industry as the only organisation that has the equipment and capability to conduct and estimate a biomass from the surveys. This biomass estimate is incorporated into a stock assessment that is reported back to AFMA and the AFMA Commission who set the TAC.

SBT research

The SBT research began in 1985 in response to aerial surveys identifying large surface schools of SBT in the Great Australia Bight. From 1993 CSIRO was contracted as an independent body to determine the SBT stock size and population dynamics. Previous estimates of SBT stock size relied on imperfect Japanese long-line catch estimates[4]. The aerial survey method developed by CSIRO in 1993 and used until 2016, provided an independent, Australian data source to support stock assessments. However, aerial surveys are an estimate of relative not absolute abundance, and as such, their usefulness is limited. CSIRO's SBT research was designed to meet a growing need to accurately and reliably assess SBT stock size and dynamics for use in planning and monitoring.

[4] Japanese long-line catch estimates are relative as the relationship between reported catch and abundance is not linear. Further, estimating absolute abundance is difficult for highly migratory fish.

This included three parallel pieces of work: determining the impact of the unreported catches on the stock assessment (at the time), development of a new Management Procedure (MP) to reduce the risk of further decline and rebuild stock to 20 per cent by 2035 (interim rebuilding objectives) and the development of new stock assessment methods.

Impacts of unreported catches on stock assessment

The work on the stock assessment indicated that the stock was at a historically low level and at risk of further decline. In response, the CCSBT agreed two major reductions in global TAC (2006 and 2009) to reduce the immediate risk of further declines in the stock. The MP, a scientifically tested utilised available data at the time, namely Japanese long-line data and Australian aerial survey data and included strategies for managing unreported catches.

SBT Management Procedure

CSIRO began assisting the CCSBT Scientific Committee in 2006 to conduct assessments of unreported catches and to identify the implications of SBT over-catch on the fishery. This information contributed to the development of a Management Procedure in 2011. This was adopted following 18 months of intensive development, consultation and refinement. This was the first international tuna fishery management procedure to be adopted and implemented.

New stock assessment methods

CSIRO developed two new stock assessment methods: Close Kin and Gene-Tagging[5] to accurately determine the abundance of the adult spawning stock and the recruitment of juveniles, respectively. These projects gained significant industry and management support; the close-kin due to deep concerns about the impact of the unreported catches on the accuracy of the current stock assessment; and, gene-tagging as a potentially more accurate and cost-effective alternative to the aerial survey.

1. Close-kin Mark Recapture

   The development of the Close Kin approach began in 2005, as a means to estimate the abundance of parents using kin relationships determined from genetic matching of samples of juveniles and adults. Adult spawning SBT are sampled in Indonesian each spawning season as part of a long-term collaborative program with the Agency for Marine Research and Human Resources. The DNA from the adult samples are compared with tissue samples from juveniles in the Great Australian Bight using specifically designed genetic markers. The two sets of DNA are used to identify parent-offspring pairs and thus estimate the size of the reproductive component of the population using mathematical modelling, with abundance inversely proportional to the number of matches. The original trial of the method involved 13,300 samples (5800 adults and 7,500 juveniles), five years of sample collection, ~40 million individual comparisons and development of a complex estimation model. The results showed the expected and actual recapture rates were 70 and 45 pairs, respectively, indicating the stock size was larger than expected, which was subsequently confirmed by a standalone close-kin assessment model. In addition, the data were incorporated into the international CCSBT integrated stock assessment in 2013 and substantially reducing the uncertainty in stock abundance and productivity.

   The method was extended to include half-sibling pairs, as well as parent-offspring pairs. Analysis in 2016-17 of a longer time-series of 17,000 samples using newer genomic technologies (next-generation sequencing and the use of single nucleotide polymorphisms) identified 77 parent parent-offspring and 140 half-sibling pairs. These data were included in the 2017 CCSBT stock assessment and an updated standalone close-kin model.

2. Gene-tagging.

   Gene-tagging methods were piloted in 2016. The method estimates absolute abundance of 2-year-old SBT stock using mark-release-recapture but, instead of using a conventional plastic tag, a tissue biopsy is taken from each fish at the time of release. Tissue samples from 4,000 two-year-old SBT were collected followed by release and sampling of 16,000 fish three-year-old fish. The tissue samples are processed for individual DNA genotypes, which are compared to identify recaptures. The technique enables cost-effective analysis of large numbers of tissue samples to find matching DNA genotypes between a set of 'tagged' fish and the subsequent harvest sample. The DNA data analysis necessitated the development specific genetic assays and quality control protocols to confidently identify recaptures. The successful pilot study provided the first estimate of absolute abundance of two-year-old SBT in 2018.

[5] The method is simple and elegant: every animal must have two parents; take a random sample of adults and juveniles and compare their genotypes to identify Parent-Offspring-Pairs in the sample. The number of Parent-Offspring-Pairs and total number of adult-juvenile comparisons provides the basis for a mark recapture estimate of the number of reproductively successful adults. The method is known as Close-kin Mark Recapture (CKMR) and is widely applicable to estimating abundance of marine and terrestrial wildlife.

3.3 Project outputs

OR project

The major outputs from the OR project include the development of an accurate and reliable AOS method to provide high confidence biomass estimates. This now combines a battery-powered, dual-frequency, split-beam acoustic system with a low-light video and still cameras. The optical system provides critical visual information required for species discrimination and confirmation of size and orientation for the acoustic technologies. The method has been adapted to enable use on deep-tow trawl nets attached to industry vessels for cost effective surveys. The AOS method was developed to solve two world leading data analysis algorithms of multi-frequency species discrimination and target strength to determine OR stock size.

The data produced from regular AOS surveying was used to develop and implement sustainable management plans for OR stocks in Australia and New Zealand, including the *Orange Roughy Rebuilding Strategy 2015*[6].

Publications and awards

The OR project resulted in the publication of 16 direct articles and ~33 uptake journal articles and in excess of ~19 conference publications (including 3 keynote presentations), ~40 fisheries assessment presentations with industry and management reviews, ten conference posters, numerous magazine articles, two honours theses and more than 40 client reports. Peer reviewed publications and fisheries assessment presentations were important for generating the credibility necessary for adoption by industry/government.

Patents

No patents were developed during the OR project. The intellectual property is generated by the combination of the methods/technology, the challenging assembly and implementation of the systems and the expert advice, rather than the technology hardware itself. For example, the service providers contracted by New Zealand MPI to conduct stock assessments in New Zealand waters have faced challenges attempting to duplicate this overall integrated package. As such, CSIRO is repeatedly contracted to provide these services.

Innovation/commercialisation

The OR project generated novel industry-based survey methodology and AOS technology, both now used as world's best practice for monitoring deep water fisheries.

CSIRO is in the process of developing technology platforms that are easier to use (smaller/readily deployable) and incorporate broadband methodologies. This will facilitate use on many more industry vessels in Australia and New Zealand. Industry has been a close collaborating partner from the mid-2000s and were essential in testing and applying the research as it was developed. Industry have a fundamental role in monitoring stock and supporting fishery recovery and sustainability.

SBT research

The major outputs from the SBT research include the development of a scientifically tested management procedure for recommending the global Total Allowable Catch for the internationally managed SBT fishery and new methods for estimating abundance of stock reproductive (Close Kin) and juvenile components of the stock. This includes the complex mathematic models required to analyse the extensive data collected by these methods.

Publications and awards

This SBT research resulted in the publication of 42 journal articles, 6 book chapters, 111 conference publications (including 5 keynote presentations), 4 conference posters, 68 technical reports, 3 PhD and 1 honours theses and 4 magazine articles. Regular stakeholder engagement from concept through to delivery, peer review through use of international experts and senior industry and management staff on project steering committee and review of design and implementation studies by the Scientific Committee of the CCSBT were central for adoption by industry/government and members of the international management organisation.

[6] The primary objective of this Strategy is to return all Orange Roughy stocks to levels where they can be harvested in an ecologically sustainable manner consistent with the *Commonwealth Fisheries Harvest Strategy Policy 2007* (HSP) and ultimately maximise the economic returns to the Australian community.

This research has been nominated for two CSIRO Awards this year: The Sir Ian McClennan Award, which is an external award from the Sir Ian McClennan Trust, awarded for research innovation and impact for industry, and the Chairman's Medal for Science.

Patents

As part of the fundamental research done to underpin close-kin, gene-tagging and other applications, CSIRO developed a biopsy tool for collecting tissue from live animals. The tool improves on current, enabling rapid collection, avoiding cross contamination and minimising labour associated with the subsequent laboratory processing steps. The tool is estimated to reduce the tissue processing costs in the order of 30 per cent. This tool was trialled with cooperation of industry at Port Lincoln, South Australia. The tool was granted design protection in Australia, the European Union, the United States, Canada and Japan, which has been recently renewed following design alterations.

Innovation/commercialisation

No commercialisation opportunities have been realised to date. However, CSIRO has developed a commercially viable panel of single nucleotide polymorphisms for use in identifying species and ocean identification.

3.4 Project Outcomes

OR project

The most significant outcome from the OR project is the development of the AOS method and the integral role for AOS data in monitoring and sustainably managing national and international deep-water OR fisheries. The AOS method substantially improved upon previous stock estimate methods. This improved confidence in the stock size and harvest sustainability, which is best demonstrated by development of the 2015 Final Base-case Model, which estimated female spawning biomass to be 26 per cent of the unfished level. Further, improved modelling techniques enabled more accurate monitoring of stock rebuilding over time.

The findings from the OR project have contributed to OR fishery management strategies, including limiting TAC to enable rebuilding of OR stock size (from 1999) and the development of the *Orange Roughy Rebuilding Strategy 2015*. This has enabled rebuilding of OR stock and sustainable fishing of OR for commercial purposes. As a result of this research, the five Australian OR fisheries are all currently listed as sustainable by the AFMA and New Zealand obtained Marine Stewardship Certification for three of its OR fisheries. Marine Stewardship Certification is an international benchmark in sustainable fishing.

The OR fishery management plans have enabled government to meet international sustainability goals and have fostered good will among conservation groups who trust the AOS science and CSIRO's independent and rigorous reputation. Further, close collaboration with industry has been essential for developing and trialling AOS and for gaining valuable access to industry infrastructure, skills and specialist knowledge.

SBT research

The most significant outcome of the SBT research are the development of the Close Kin and gene-tagging methods for accurately and reliably assessing stock size and population dynamics, and the development of an internationally recognised management procedure to rebuild the stock, while providing for a viable commercial fishery.

The Close Kin and gene-tagging methods are more accurate and reliable, substantially improving upon the traditional fisheries dependent methods for assessing stock size (e.g. catch and effort data from the commercial fisheries). Incorporating this data into regular international stock assessments has substantially reduced uncertainty and enabled measurement against stock rebuilding objectives.

CSIRO's SBT research and effective engagement in the domestic and international management processes facilitated the development of an effective monitoring and decision-making framework, which generates transparent and consistent advice. This has fostered confidence in a highly contentious area of natural resource management and has allowed for progressive increases in TAC since 2012 (3-yearly) As a result of the management action taken by CCSBT, the 2017 stock assessments show reduction in mortality due to fishing and progressive increases in stock size (from 3-8 per cent of unfished level in 2009 to 11-18 per cent in 2017). As a result of this research, CCSBT is seen as one of the more successful of the international fisheries management organisations and the experience and methods are being sought and used for other internationally managed fisheries.

3.5 Adoption

OR project

The primary users of the OR project outputs are the fisheries management organisations (AFMA and New Zealand MPI) and the fishery industry. AFMA and New Zealand MPI have adopted the AOS technology for use in developing sustainable management strategies including the *Orange Roughy Rebuilding Strategy 2015*.

Other users of the AOS method include the South Indian Ocean Fisheries Agreement (for examining stocks in the South Indian Ocean), the South Pacific Regional Fisheries Management Organisation (for examining stocks in the South Pacific) and Sealord, a New Zealand organisation who purchased the AOS technology in 2014 and are using this to assess New Zealand OR stocks. Use of the AOS technology and methodology currently requires the user to collaborate with CSIRO.

The barriers and challenges for adoption of the outputs of the OR project were limited due to the close ongoing relationships developed between CSIRO's researchers and industry, and between CSIRO and Australian and New Zealand fishery management organisations, who were in critical need of cost-effective methods for conducting stock assessments in order to manage OR fisheries.

SBT research

The primary users of the SBT research outputs are the fisheries management organisations (AFMA and CCSBT), the fishery industry, DAWR, conservation NGOs and recreational fishers. The Close Kin and gene tagging methods are used to develop sustainable fisheries management plans. Industry has supported this research due to a real need for the SBT fishery to be well-managed for the fishery to recover and support local employment and economic recovery. National and international management agencies have adopted and funded the ongoing use of the research due to the demonstrable contribution to reducing the uncertainty in stock assessments, improving cost-effectiveness of monitoring programs and provision of robust management advice (i.e. using a scientifically tested MP for setting the global TAC to rebuild the stock).

The close-kin method is also being applied, in collaboration with Australian researchers from state agencies and universities, to a number of shark species, including white sharks, northern river sharks, grey nurse and school sharks. Internationally, close-kin design and implementation projects are underway, or completed for Atlantic and Pacific bluefin tuna and a number of groundfish species in the EU.

The tissue biopsy tool is being trialled by international researchers: in Ireland for mixed stock fisheries for North Sea Herring and in the Canada and the United States on Atlantic bluefin tuna for close-kin and stock identification.

3.6 Impacts

OR project

The OR project has generated significant economic, social and environmental impacts for the Australian government and the broader community. The OR project has improved the accuracy and reliability of OR stock size assessment in Australian and international waters. AOS is internationally regarded as the world-best practice method for measuring OR stock size and is the AFMA and New Zealand MPI-recommended best practice for measuring stocks and set harvest quotas. The data generated through this technology has contributed to the development and implementation of sustainable management plans, including the *Orange Roughy Rebuilding Strategy 2015*. As a result, Australia has fulfilled the *Commonwealth Fisheries Harvest Strategy Policy and Guidelines* and adhered to international obligations.

As a result of the OR project:

- The Australian OR fishery was shown to be in recovery, resulting in a reopening of the fishery for targeted catch in 2015, after a 10-year closure. Prior to this, the TAC was 25 tonnes from by-catch alone. The resulting environmental and economic benefits from the recovery of the fishery are substantial. In economic terms, the fishery catch has generated a total of 1500 tonnes of OR from 2009: most recently 600 tonnes in 2018. This has produced a value of approximately $12 million, which compounds to more than $20 million when the fish are sold commercially. This will increase to 702 tonnes yearly in May 2019, with a commercial value of $40,000 per tonne ($28 million). CSIRO is currently recommending the fishery TAC be increased to 1000 tonnes. The New Zealand market is much larger: 8,736 tonnes a year, with an annual export value of NZD $54 million. The Government is considering a proposal to increase this from October 2018 to 11,208 tonnes. This represents a major export for New Zealand.
- OR are harvested sustainably. This has resulted in increased food security and the development of a sustainable fishing industry for public and commercial benefit, resulting in harvesting (quota owners), processing and retail jobs growth.

- OR was moved from stock assessment Tier 4 to Tier 1 in the Commonwealth Fisheries Harvest Strategy, indicating more accurate and reliable information is available to assess stock size, and a less conservative harvest strategy is required.
- Australia is capable of monitoring deep-sea resources as part of obligations through Regional Fisheries Management Organisations (RFMOs) and high seas fisheries[7].
- The New Zealand MPI can reliably assess and monitor stocks. Deepwater Group initiated the successful application for Marine Stewardship Council certification for three OR fisheries in 2016 (representing two-thirds of the New Zealand OR catch).
- Consumers can purchase sustainably fished OR.
- Improved scientific knowledge and understanding of the population dynamics and life cycle of OR fish. For example, scientists can demonstrate that not all OR fish spawn every year: younger fish are recruited to the spawning grounds and the mature population is most likely greater than the spawning population measured by the AOS.
- CSIRO has credibility and authority in optics and acoustics and is seen as a trusted adviser by industry and management in Australia and internationally.
- The AOS technology and methodology has been translated to other species (for example Blue Grenadier) and pelagic ecosystem characterisation projects for national benefit (for example PLAOS-mesopelagics).

"We would not have begun targeted fishing of orange roughy without this technology."

– *Stakeholder consultation 13 August 2018*

SBT research

CSIRO contributed to the development of a scientifically tested management procedure to reduce the risk of further declines and to rebuild the stock to a more productive level. The management procedure has been scientifically tested to have a high probability of rebuilding the fishery from 3-8 per cent to 20 per cent of the unfished level by 2035. The management procedure has been precautionary and successful to date. It is currently being revised as the stock appears to be rebuilding faster than expected when the current MP was tested and implemented. The new MP is likely to use gene-tagging and close-kin data, in addition to longline CPUE, and will be designed to achieve the longer-term management objective of the CCSBT, which is expected to be in the order of 30-35 per cent.

CSIRO's role in enhancing international coordination and collaboration ensured broad acceptance of the scientific findings and enhanced the operation and function of CCSBT, contributing to positive relationships with the Australian fisheries industry, and between Australia and other fishing nations, particularly Japan and Indonesia, home to the critical SBT spawning site.

The impact and international value of this research best is demonstrated by the transfer of funding responsibility for the close-kin and gene-tagging projects from CSIRO and the Australian government to the CCSBT.

"Gene tagging and Close Kin are one of the great pieces of science to be undertaken internationally… This has given us the confidence to know where we are today and where we want to be tomorrow. People will talk about this for the next 50 years."

– *Stakeholder consultation 14 August 2018*

This research has contributed to improved security of the SBT fishing industry.

"The CSIRO work on SBT over a long period has been central to the stock recovery, so to economic survival of the species, and to the resulting capacity of the Australian SBT industry to invest in expansion, jobs and wild catch grow-out innovation. It is that CSIRO work which has persuaded government managers, international scientists, industry, and NGOs to support the highly contentious quota changes – and now to be precautionary in the quota increases."

– *Stakeholder consultation 8 August 2018*

This research has contributed to significant economic impacts, including licensing and operation of the SBT industry leading to economic benefit from commercial fishery revenue for Australia in the order of $80 million, and globally of $300-400 million over the 2011-18 period. Combined, this industry has generated a total of $2.5-3 billion in revenue globally over the last 10 years.

An additional impact of this research has been the benefit to the developing SBT industry. For example, Port Lincoln runs a SBT value-adding farming operation through which approximately 95 per cent of Australia's TAC (35 per cent of global TAC) is fattened through tuna farming. Port Lincoln pioneered global tuna farming from the early 1990s and Australia remains the sole

[7] High Seas Permits allow Australian flagged vessels to fish for non-highly migratory species outside areas of national jurisdiction in the Southern Indian and/or Pacific Oceans in areas governed by: Southern Indian Ocean Fisheries Agreement (SIOFA) and the South Pacific Regional Fisheries Management Organisation (SPRFMO).

SBT catching country that can farm SBT from wild stock. SBT are caught at approximately 20kg, with their weight doubling in 6 months to effectively double the export value. SBT fishing supports numerous coastal towns whose primary economy is the fishing industry (including Port Lincoln, Bermagui and Ulladulla). In 2015/16 this supported a farm harvest of 8,895 tonnes valued at $259 million and supporting 807 full-time employees.

In addition to strengthening the commercial fishing industry, recreational fishers benefit from the increased catch available as a result of the effective management procedure.

3.7 Potential future impacts

OR project

The OR project has generated considerable transferable knowledge and systems that can be used to analyse shallow water, water column ecosystems and fish of different types and sizes. While water column analysis has no specific application to industry yet, this will likely spill over to other observational areas such as climate change, carbon sequestration and food security.

Planned future work includes simplifying the operation and reducing the AOS package size and complexity. By reducing the costs of surveying, surveys can be conducted more regularly, utilising fewer resources. This is likely to impact the future use of AOS in Australian OR fisheries that are not currently surveyed and in New Zealand's six OR fisheries. Further, a successful trial was conducted in 2015 of using optic-fibre connection to provide video and acoustics at 1000m depth. This creates opportunities for observing and selectively harvesting fish species in real-time.

This technology is being transferred to a range of other locations and fish (including snapper, oreos, alfonsino, blue grenadier and Johnston's cod), requiring modifications due to inherent biological differences between species.

The real time optical surveying component of AOS has provided industry with a tool to observe and record the seabed they are trawling over and adjust methods to avoid areas of high conservation values. This has implications for the industry's understanding of its effects and the ecological risk assessment and mitigation conducted by AFMA.

SBT research

The SBT research has substantial scope for application separate from SBT. The Management Procedure and MSE is being applied to four major international tuna fisheries: Inter-American Tropical Tuna Commission, International Commission for the Conservation of Atlantic Tunas, Indian Ocean Tuna Commission, and the Western and Central Pacific Fisheries Commission (in which Australia has a large political and defence interest), as well as the use of Close-Kin to monitor other Australian fisheries and recovering commercial stock (including white shark, school sharks, grey nurse sharks, Pacific Bluefin Tuna and Atlantic Bluefin Tuna).

This research has a substantial future role in supply chain sampling and species identification using species-specific genetic markers. This work is being undertaken with the Marine Stewardship Council and is of particular interest in China to monitor compliance with management procedures and protect against illegal, unreported or unregulated (IUU) fishing of SBT. This may significantly impact the industry as a recent global analysis has suggested that on average 30 per cent of seafood products are misdescribed or mislabelled, threatening sustainable fishing practices. CSIRO has developed DNA sampling kits to enable easy collection and processing of tissue samples without refrigeration. This is a major development that will soon be in use. Building on these principles, CSIRO is hoping to develop an on the spot DNA test where instant results can be obtained without needing a laboratory. This is a significant step towards fighting against and preventing IUU fishing for SBT and other species globally.

There is potential to certify Australian and additional New Zealand fisheries under the Marine Stewardship Council. This is becoming increasingly important for commercial reasons in markets such as the United States and Europe who want sustainability certification.

The use of next generation sequencing technologies enables greater data resolution and discrimination of half and full siblings, providing a better estimate of mortality and spawning rates. Better understanding of familial relationships is expected to address other population dynamic problems including management of tropical pacific tuna that migrate from the west coast of the United States to the west Pacific and are affected by sporadic harvesting.

4. Counterfactual and Attribution

4.1 Counterfactual

OR project

This research has been a collaborative project involving many participants. CSIRO has been the head of the scientific research component and AOS and associated survey methods were integral to the change in sustainable practice management for OR fisheries in Australia and New Zealand. Without the OR project, there would be no methods for accurately and reliably assessing OR stock size and OR fisheries would likely have been closed, underfished or overfished, leading to industry decline and lack of public confidence in sustainability of wild caught fish. Further, New Zealand would not have obtained the Marine Stewardship Council certification for sustainable harvest of OR.

CSIRO has built on substantial institutional knowledge and investment over many years to cement their role as a trusted advisor for industry and government. Key players in the OR project have held high-profile international positions in the International Council for the Exploration of the Sea (ICES) Working Group on Fisheries Acoustics, Science and Technology, thus gaining recognition for the international significance of the AOS technology for fishery sustainability. Australia has been forced to lead this research due to the difficult conditions of Australia's deep waters. It is unlikely this research could have been conducted by a different organisation, although the need for an independent and reliable stock assessment method was so great that this may have spurred the development of other methods. The New Zealand equivalent of CSIRO, the New Zealand NIWA is not likely to have been able to complete this work, due to lack of science/technology and standing with industry.

"Without CSIRO's contribution, we could have sat on 25 tonnes for the TAC each year."

– *Stakeholder consultation 13 August 2018*

SBT research

The Management Procedure involved close collaboration with a range of domestic and international partners, while the Close-Kin and gene-tagging research was conducted by CSIRO and delivered through AFMA/DAWR and the CCSBT. There are very few other agencies that could have conducted the Close-Kin and gene-tagging research. This is because the research has required a long-term strategic and broad multi-disciplinary approach, which spans from fundamental biology, genetics and mathematics through to applied fisheries assessment, management and representation at the national and international level. It is very difficult to assemble, maintain and deliver research of this nature in the natural resource management context and few organisations other than CSIRO could have done so effectively. As evidence of this, AFMA contracts the SBT research yearly through an open tender process, however, CSIRO is the only organisation that bids for this work and there is clear international recognition that CSIRO is the leader in this field.

"CSIRO work has been the major ongoing contributor to the recovery of the global SBT stock. If the Harvest Strategy had not been finalised in 2011, we strongly doubt whether it could have been revived in subsequent years… the stock could not have survived economically except as a bycatch. The Australian industry could not have survived on bycatch volume"

– *Stakeholder consultation 8 August 2018*

Without CSIRO, the management procedure would still have been developed, but delayed and simpler. Further, there may not have been a fishery independent measure of stock assessment that was as robust as the Close Kin and gene-tagging methods and as reactive to juvenile recruitment. Planning is underway for the inclusion of Close-Kin and gene-tagging in the 2020 Management Procedure. The Close Kin and gene-tagging are both cutting-edge, world-class research that would not have been conducted without CSIRO. As a result, either:

- the estimations of stock size would depend on traditional, fisheries-dependent methods (such as Japanese long-line estimates and catches from other fleets). This approach would be less reliable and accurate and thus result in a more conservative global TAC; or
- the aerial surveys were suspended due to increasing and unsustainable cost of data collection (reaching $850,000/ year in 2016). There was also a concern for the lack of trained/experienced SBT spotters essential for aerial surveying. This motivated CSITO to develop gene-tagging. Without the development of Close-Kin and gene-tagging, the SBT fishery would likely have collapsed, with SBT listed as a threatened species.

Further, the stock assessment methods developed by CSIRO have an international reputation for being robust, accurate and reliable. Combined with the strategic relationship building conducted by CSIRO, this has yielded significant influence in the

international community, without which, stakeholders noted both the total global TAC and Australia's proportion of the global TAC would likely be smaller (in 2018-20 is ~35 per cent: 6,165T of a global 17,400T).

4.2 Attribution

OR project

While, as noted above, the OR project is unlikely to have been established without the work of CSIRO officials, others have contributed the research and to the development and testing of AOS. We therefore propose to attribute 70[8] per cent of the benefits that flow from the outcomes from this project to CSIRO.

SBT research

While, as noted above, the SBT research is unlikely to have been established without the work of CSIRO officials, others have contributed the research on the impacts of the unreported catches on the stock assessment and the development and implementation of the MP. The research on the development and application of close-kin and gene-tagging, however, has been led and delivered by the CSIRO team with smaller contributions from Indonesia and the CCSBT Scientific Committee. We therefore propose to attribute 70[9] per cent of the benefits that flow from the outcomes from this project to CSIRO.

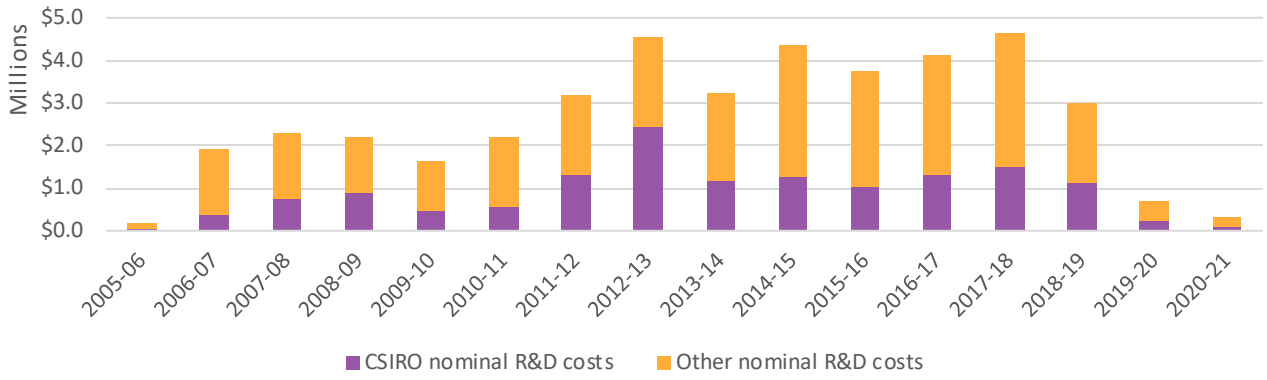
5. Evaluating the Impacts

5.1 Cost-Benefit Analysis

Costs

The R&D costs of the OR and SBT projects were discussed previously in Section 3.1. The combined R&D costs of the two projects to CSIRO and to other collaborating organisations between 2005-06 and 2020-21 are shown in **Figure 2**. The combined costs include cash and in-kind contributions by all organisations involved in the two projects.

FIGURE 2 COMBINED OR AND SBT R&D COSTS (NOMINAL)



SOURCE: CSIRO

Benefits

As discussed previously in Section 3.6, the OR and SBT R&D projects enabled an increase in the TAC for both OR and SBT.

In the case of OR, the project resulted in the reopening of the OR fishery for targeted catch in 2015 after a 10-year closure. The reopening enabled an additional TAC of 500 tonnes a year between 2015 and 2018 and is expected to enable an additional TAC of 702 tonnes a year from 2019 onwards. As data on the actual catch is unavailable for 2016 and 2017, a simplifying assumption of the actual catch being equal to the TAC is used in the cost-benefit analysis.

[8] Some stakeholders suggested this CSIRO's attribution was closer to 90 per cent, however we have adopted a more conservative estimate.
[9] Some stakeholders suggested this CSIRO's attribution was 100 per cent for the Close Kin and gene-tagging research, yet around 50 per cent for the management procedure.

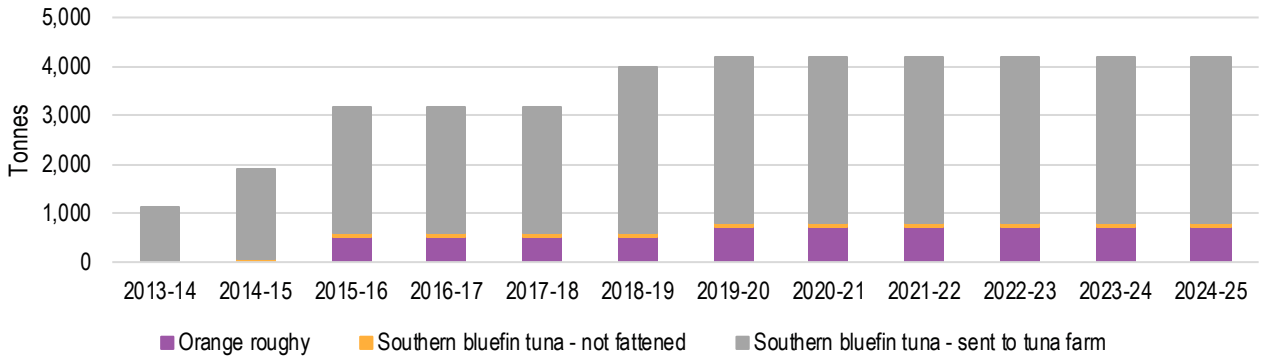
For the cost-benefit analysis, it is conservatively assumed that the benefits stream will continue until 2025, whereupon it is assumed that other evidence would have been generated at that point to enable to the fishery to be reopened in the counterfactual. That is, the CSIRO OR project is assumed to have brought forward the reopening of the OR fishery by 10 years. Based on figures cited in Section 3.6, the commercial value of OR is assumed to be $40,000 per tonne in 2018-19 dollars.

In the case of SBT, the CSIRO project enabled the TAC to be increased from 4,015 tonnes a year to 4,698 tonnes in 2013, 5,193 tonnes in 2014 and 5,165 tonnes a year in 2015, 2016 and 2017. In 2018 onwards, the TAC will be increased to 6,165 tonnes a year. In the counterfactual, without the CSIRO project, it is assumed that the TAC would have remained at 4,015 tonnes until 2025. In that year, it is assumed that some alternative evidence would have been generated so that the TAC would be the same with and without the CSIRO project (and similarly in subsequent years). As with the OR analysis, it is assumed that the actual SBT catch is equal to the TAC.

As noted previously, 95 per cent of SBT in Australia is fattened in tuna farms. The value of fattened tuna is assumed to be $20,117 per tonne (based on figures discussed previously in Section 3.6) compared with $14,122 for un-fattened tuna, both in 2018-19 dollars. Also, according to figures previously cited in Section 3.6, in 2015, 8,895 tonnes of fattened tuna was harvested from tuna farms from a TAC of 5,665 tonnes. This implicit conversion factor was used to estimate the tonnage harvested in tuna farms with and without the CSIRO projects for each year between 2009 and 2025.

Under the above assumptions, the additional OR and SBT harvested in Australia between 2013-14 and 2024-25 as a result of the CSIRO OR and SBT research projects are shown in **Figure 3**.

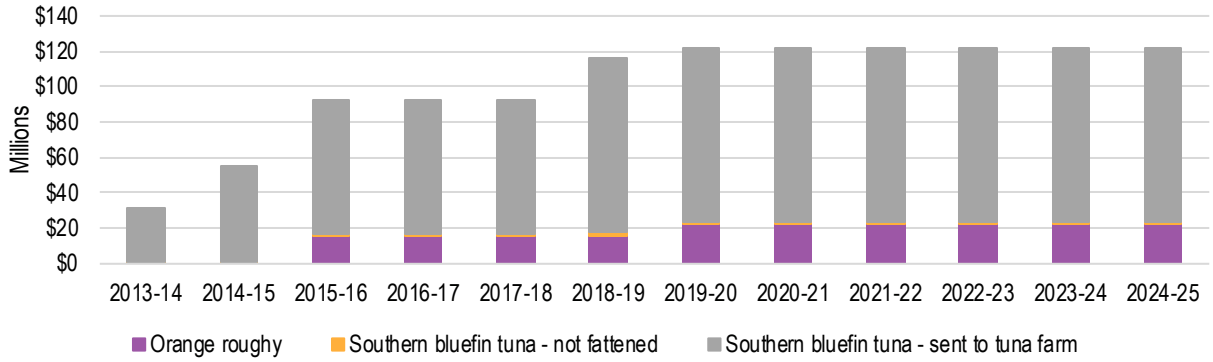
FIGURE 1 ADDITIONAL OR AND SBT HARVESTED DUE TO CSIRO PROJECTS (TONNES)



SOURCE: CSIRO

The value of the additional OR and SBT harvested in Australia due to the CSIRO projects is shown in **Figure 4**.

FIGURE 2 VALUE OF ADDITIONAL OR AND SBT HARVESTED DUE TO CSIRO PROJECT (2018-19 DOLLARS)



SOURCE: CSIRO

As discussed previously in Section 4.2, it is assumed that 70 per cent of the benefits from increased harvesting of OR and SBT in Australia can be attributed to CSIRO. In addition, it is assumed that 20 per cent of the value of the additional OR and SBT harvested in Australia due to the CSIRO project is "leaked out" of the Australian economy (for example, due to inputs sourced from overseas).

ACIL Allen has not quantified the social and environmental benefits of the OR and SBT projects.

Assessment of benefits against costs

Under a 7 per cent real discount rate, the present value (PV) of total R&D costs across the OR and SBT projects is $65.1 million in 2018-19 dollars. The PV of CSIRO R&D costs across both projects is $22.0 million in 2018-19 dollars.

The PV of total project benefits to Australia under the same discount rate is projected to be approximately $880.7 million in 2018-19 dollars, while the PV of project benefits attributable to CSIRO is projected to be approximately $616.5 million in 2018-19 dollars.

The combined net present value (NPV) of the two projects is therefore projected to be $815.6 million in 2018-19 dollars, while the benefit-cost ratio (BCR) is estimated to be 13.53. The former is obtained by subtracting the present value of total R&D costs from the present value of total project benefits, while the latter is obtained by dividing the present value of total project benefits by the present value of total R&D costs.

From CSIRO's perspective, the net benefit-investment ratio (NBIR) of the OR and SBT projects – calculated by dividing the present value of benefits attributable to CSIRO by the present of CSIRO's R&D costs – is estimated to be 28.03.

Sensitivity analysis

In the central case of the cost-benefit analysis, it is assumed that 20 per cent of the value of additional OR and SBT harvested are "leaked out" of the Australian economy. If this proportion is 10 per cent, the BCR will increase from 13.53 to 15.22 while the NBIR will increase from 28.03 to 31.54. Conversely, if this proportion is 30 per cent, the BCR will decrease to 11.84 while the NBIR will decrease to 24.53.

In the central case of the cost-benefit analysis, the commercial value of OR is assumed to be $40,000 per tonne. If the commercial value of OR is assumed to be $50,000 per tonne, the BCR will increase from 13.53 to 14.17 while the NBIR will increase from 28.03 to 29.36. If the commercial value of OR is assumed to be $30,000 per tonne, the BCR will decrease to 12.89 while the NBIR will decrease to 26.71.

In the central case of the cost-benefit analysis, a 7 per cent real discount rate was used. Under a 4 per cent real discount rate, the BCR will increase from 13.53 to 16.45 while the NBIR will increase from 28.03 to 33.92. Conversely, under a 10 per cent real discount rate, the BCR will decrease to 11.15 while the NBIR will decrease to 23.24.

In the central case of the cost-benefit analysis, it is assumed that 70 per cent of project benefits is attributable to CSIRO. With a 50 per cent attribution rate, the NBIR will decrease from 28.03 to 20.02.

5.2 Externalities or other flow-on effects on non-users

This research has flow-on effects to users and non-users of the research. This includes the social benefits of improved environmental sustainability of the fisheries and sustainability of the fishing industry, leading to improved food security and the ability to meet consumer preferences for sustainably fished produce. This has also led to enhanced international collaboration, particularly as a result of the SBT research, leading to improved environmental and economic sustainability of fishing industries globally, through adherence to national and international fishery obligations.