Australian Government
Fisheries Research and Development Corporation

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Committee Secretary
Senate Environment and Communications References Committee
PO Box 6100
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Canberra ACT 2600

Fisheries Research and Development Corporation

Updated submission to the Inquiry into the environmental, social and economic impacts of large capacity fishing vessels

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1. Introduction

The Fisheries Research and Development Corporation (FRDC) is a statutory corporation within the Australian Government's Agriculture portfolio and is accountable to the Parliament of Australia through the Minister for Agriculture and Water Resources. The portfolio aims to enhance the sustainability, profitability and competitiveness of Australia's agriculture, food, fisheries and forestry industries. Formed on 2 July 1991, the FRDC operates under two key pieces of legislation: (i) *Primary Industries Research and Development Act 1989* (PIRD Act) and (ii) *Public Governance, Performance and Accountability Act 2013*.

The PIRD Act sets out FRDC's objectives as follows:

a) Make provision for the funding and administration of research and development relating to primary industries with a view to: i) increasing the economic, environmental and social benefits to members of primary industries and to the community in general by improving the production, processing, storage, transport or marketing of the products of primary industries,

ii) achieving the sustainable use and sustainable management of natural resources,

iii) making more effective use of the resources and skills of the community in general and the scientific community in particular,

iv) supporting the development of scientific and technical capacity,

v) developing the adoptive capacity of primary producers, and

vi) improving accountability for expenditure on research and development activities in relation to primary industries; and more recently;

b) Make provision for the funding and administration of marketing relating to products of primary industries. The primary users of these resources, and of the FRDC's RD&E investment, are divided into four sectors: aquaculture, commercial fishing, Indigenous fishing and recreational fishing.

FRDCs RD&E investment is largely priority driven. As gaps in research across the four sectors are identified, funds are sourced to address high priority research needs; successful projects are managed by a project team and a FRDC project manager; final reports/papers are peer reviewed; new knowledge is made public to stakeholders; and this information is used by the appropriate end-users to inform management decisions. Knowledge adoption using evidence-based science underpins the effective management of Australian fisheries.

On 7 September 2015, the Senate referred the following matter to the Environment and Communications References Committee for inquiry and report by 30 April 2016:
The environmental, social and economic impacts of large-capacity fishing vessels operating in Australia's marine jurisdiction, with particular reference to:

(a) the effect of large fishing vessels on the marine ecosystem, including:

(i) impacts on fish stocks and the marine food chain, and

(ii) bycatch and interactions with protected marine species;

(b) current research and scientific knowledge;

(c) social and economic impacts, including effects on other commercial fishing activities and recreational fishing;

(d) the effectiveness of the current regulatory framework and compliance arrangements; and

(e) any other related matters.

This submission provides an overview of FRDC funded or co-funded research used to inform the sustainable use and management of fisheries for small pelagic stocks (Australian Sardine, Australian Anchovy, Blue Mackerel, Jack Mackerel and Redbait), Blue Grenadier and Patagonian Toothfish (see Appendix 1: Scientific Names of Cited Fish Species) taken in Australian's State/Territories and Commonwealth waters in the Small Pelagic Fishery (SPF), Southeast Scalefish and Shark Fishery (SESSF) and Sub-Antarctic Fishery, which currently use large fishing vessels.

2. Key Points

(b) Current research and scientific knowledge

- All information provided in this submission relates to current research and scientific knowledge that has emanated from FRDC-funded research projects, and how this has been designed to inform the management of Australian fisheries (small pelagic, Blue Grenadier and Toothfish fisheries) where large vessels are used.
- FRDC-funded research has not specifically investigated the potential effects of vessel size or capacity on increasing (or decreasing) the risks of fishery-related impacts. However, some potentially relevant information on the effects of vessel size has been reported during the course of certain FRDC-funded research projects. Where this has occurred, that information is reported in this submission.
- The size or capacity of fishing vessels should be relevant only if vessel size itself (rather than how or where the vessel operates, or which gear it uses) has the effect of increasing a particular fishery-related risk: by increasing the risk of overfishing the stock, causing localised depletion that persists for long enough to impact other users or dependent species, or increasing the risk of mortality or injury to bycatch species of concern.

(a) The effect of large fishing vessels on the marine ecosystem: (i) impacts on fish stocks and the marine food chain

- Since 1991, the FRDC has assisted with the planning, coordination and funding of research to improve the understanding, sustainability, management and environmental responsibility of Australian fisheries for small pelagic species.
- Small pelagic research initially focussed on understanding the stock structure, distribution ranges and seasonal movements of key pelagic species, and on estimating stock sizes and sustainable harvest rates, to facilitate the development of sustainable pelagic fisheries, initially for Australian Sardine in the Great Australia Bight[2].
- Substantial regional experience has been developed with the use of the Daily Egg Production Method (DEPM) to develop estimates of spawning stock size for an increasing number of small pelagic species along the southern and eastern Australian coasts. The precision and reliability of DEPM estimates has been improved, and current projects continue to pursue options for further improvement[20].
- DEPM approaches have been found to provide robust and reliable estimates of stock size for the four main pelagic target species: Australian Sardine, Blue Mackerel, Redbait and Jack Mackerel[5,6,9]. Estimates of stock size have been used to develop and test sustainable harvest strategies for the small pelagic fisheries. Results have been used to estimate alternative sustainable annual harvest rates, depending on how much information is available and how current the most recent DEPM estimates are.
- Ecosystem modelling work using a range of approaches has confirmed that the stock size estimates provided using DEPM are consistent with what is known about predator-prey biomass and feeding requirements off Southern and Eastern Australia[11].
- Recent updated management strategy evaluation has found these harvest rates to be conservative for the faster growing Sardine and Blue Mackerel, but has recommended reductions in harvest rates for slower growing Redbait and Jack Mackerel[15]. Implementation of decision rules based on these tested harvest strategies has a high probability of maintaining stocks above target levels.
- Catches in the small pelagic fisheries have been managed using Fishery Harvest Strategies which can include mechanisms such as quota management and catch limits determined using stock assessments. The fisheries have proven to be sustainable at the recommended catch levels, with

no pelagic stock showing depletion or collapse as a result of fishing, as has happened in many international pelagic fisheries.

- The Blue Grenadier fishery is the largest and most valuable component of the SESSF. Some 90% of the catch is made by large factory trawlers that have operated in this fishery since 1997[21,22]. These vessels were introduced to provide the capability of fishing across the extent of the winter spawning fishery off western Tasmania and producing sea-frozen high quality fish for human consumption. Most of the net economic returns generated by this fishery are derived from these vessels as a result of production of high quality frozen product.
- Integrated stock assessments for Blue Grenadier were initially developed under FRDC funding in the mid-1990s[21]. Stock assessments have been steadily improved and used to estimate sustainable annual catches, providing increasingly robust and reliable estimates of Blue Grenadier stock size and biological productivity[28]. Limits on total allowable catches based on these recommended biological catches, set under SESSF Harvest Strategy decision rules, have maintained this stock above the management target level, contributing to the awarding of full Marine Stewardship Council certification for this fishery in 2015.
- FRDC also funded research to develop reliable stock assessment methods and harvest strategies for the Australian sub-Antarctic Toothfish fisheries from 2000 onwards[30,31,33]. Integrated stock assessment methods have been developed incorporating tag-recapture data, and ongoing work is underway to develop and test harvest strategies based on these integrated assessments.
- The SPF, SESSF and Sub-Antarctic Toothfish fisheries are all managed using output controls, whereby catches are limited by Total Allowable Catch (TAC) levels. The TACs are determined using stock assessments and harvest strategies to ensure that they are sustainable. Provided catches are limited to these recommended levels, the size of the vessel making those catches would not pose differential risks to sustainability of the target species.
- Several FRDC-funded research projects have commented on the requirement for vessels in these fisheries needing to be large enough to be equipped with refrigerated seawater tanks[4] or onboard filleting and freezing plants[21,23] to enable these fisheries to produce high quality fish product suitable for human consumption. This requirement is especially relevant to fish with high oil content such as the small pelagic species, which tend to become unfit for human consumption if not processed soon after capture.

(a) The effect of large fishing vessels on the marine ecosystem: (ii) bycatch and interactions with protected marine species

- The size of vessel, type of gear used, time of day, season and area of operation may all be factors contributing to increased risk of fishery impacts on bycatch species, including threatened, endangered and protected (TEP) species. This occurs if these factors result in increased likelihood of interaction with protected species, or increased risk of injury or mortality if interaction occurs. Different factors have contributed to risk of protected species interactions in different fisheries and areas. In the SPF, for example, marine mammal interactions have been experienced with small and large vessels, using either purse-seine[2] or trawl nets[37].
- Small pelagic fishes are also known as 'forage species' in recognition of their importance in marine food webs and the diets of marine mammals, seabirds and predatory fishes. Research into the ecology of these food webs and the direct and indirect effects of pelagic fisheries on predator populations commenced in the early-2000s[39].
- This research has steadily improved the understanding of the distribution and foraging ranges of key migratory tuna, marine mammal and seabird predators in Australia pelagic ecosystems, and the composition of their diets in different regions and seasons.

- Where forage species form critical links between lower and higher levels in the food chain the ecosystem is referred to as a 'wasp waist' system. In these systems energy transfer is through a narrow link, usually a single species. Harvesting forage species in such systems can have significant consequences on food availability for higher order predators. Ecosystem studies and modelling have found that Australian systems are not wasp waist, and that predators can flexibly exploit a wide variety of alternative prey, adapting their diets depending on prey availability[40]. As a result, key predators have relatively low dependency on many of the small pelagic fishes, and depletion of these species has been predicted, using ecosystem models, to have only minor effects on predator populations.
- As has been found in other pelagic ecosystems around the world, research into the environmental drivers of pelagic fish movement and distribution patterns has found that the distribution of these species is closely related to preferred water temperatures (for spawning) and plankton productivity (for feeding)[4,45]. Changes in oceanographic conditions as a result of wind and current-induced upwelling result in rapid shifts in water masses, and therefore in pelagic fish distribution. This rapid movement of small pelagic species results in a low risk of persistent localised depletion, and so a low risk of reducing prey availability to predators.
- Midwater trawl nets used by vessels in the Blue Grenadier fishery have been found to pose a risk to seals that forage around and in trawl nets during trawling operations. FRDC funded research in 2001 to identify and implement effective measures to reduce interactions and mitigate the risk of injury and mortality[37]. Subsequent implementation of a Code of Fishing Practice and installation of seal exclusion devices on trawl nets halved the incidence of seal bycatch per trawl shot. Seal mitigation measures continue to be improved to further reduce fishery-related injury or mortality to seals. In addition to the Code of Conduct, educational resources were produced to assist fishers to identify seals species and provide guidelines to reporting interactions with seals[1].
- Research into the reduction of fishery impacts on protected species in the sub-Antarctic fisheries has focussed on evaluating impacts of bottom fishing gears on vulnerable benthic ecosystems[44]. Results show that spatial protection measures implemented by Australia and CCAMLR have ensured that impacts on benthic ecosystems have been limited to less than 1% of the seafloor area within the Australian EEZ around Heard Island and the McDonald Islands.

(c) Social and economic impacts, including effects on other commercial fishing activities and recreational fishing

- The dynamic nature of small pelagic fish distribution patterns, with rapid movement in response to wind and current-induced changes in oceanographic conditions, results in a low risk of persistent localised depletion occurring in any area. The key threat to availability in any particular area is overfishing, resulting in overall depletion, contraction of the stock range to preferred core areas and disappearance of the stock from parts of the previously occupied range.

(d) The effectiveness of the current regulatory framework and compliance arrangements

- No comment is submitted on this aspect.

(e) Any other related matters

- No comment is provided on other related matters.

3. Categorisation of Fishery Impacts

For the purposes of demonstrating how FRDC funded research has informed the responsible and sustainable management of Australian fisheries, fisheries impacts are categorised in this submission into two broad categories, each of which consists of a number of components:

- Direct impacts on the current abundance and future availability of targeted fish resources as a result of unsustainably high catches or overfishing which result in:
  - Reduction in overall biomass of the targeted fish stock, reducing the size of the stock below long-term sustainable levels. This reduces availability to the commercial fishery itself, as well as to other sectors fishing for those species, including recreational sectors and indigenous fishers (referred to as 'stock depletion').
  - Reduction in the localised availability of the targeted fish stocks even though the entire stock has not been overfished, as a result of persistent reductions in abundance in limited geographic areas, resulting in reduced availability to other sectors in these areas for some period of time (referred to as 'localised depletion').
- Direct or indirect impacts on species that are associated with, or dependent on, the targeted fish resources, as a result of:
  - Direct mortality or injury to unintended bycatch species that are found in association with the target species as a result of being caught in, entangled in, or otherwise injured by the fishing gear. These would include predators that are feeding on the targeted fish stock, such as tunas, sharks, marine mammals and seabirds.
  - Indirect negative impacts on predator species as a result of reduction in availability (either overall or localised) of targeted fish stocks which are important prey species for predators, particularly species such as seabirds and marine mammals.

The FRDC has funded or co-funded targeted research into options for reducing or mitigating each of the above risks. The results of this research have been used to inform the ongoing development of, and improvement in, fisheries management policies and practices, to ensure the long-term sustainability of targeted fish stocks, and to continually improve mitigation measures, to reduce direct and indirect impacts of fisheries on bycatch, particularly of protected species.

4. Effects of Vessel Size

The size or capacity of fishing vessels should be relevant only if vessel size itself (rather than how or where the vessel operates, or which gear it uses) has the effect of increasing one of the risks identified above: by increasing the risk of overfishing the stock, causing localised depletion that persists for long enough to impact other users or dependent species, or increasing the risk of mortality or injury to bycatch species of concern. FRDC-funded research has not specifically investigated the potential effects of vessel size or capacity on increasing (or decreasing) the risks of the impacts categorized above. However, some potentially relevant information on the effects of vessel size has been reported during the course of certain FRDC-funded research projects. Where this has occurred, such information is included in this submission.

For the purpose of this submission, cited research results are focused on the SPF, Blue Grenadier component of the SESSF, and the Heard Island and McDonald Islands (HIMI) and Macquarie Island Toothfish fisheries. These are the Australian fisheries in which the largest vessels currently operate, due to a requirement for on-board fish processing facilities. The vessels operating in these fisheries range in size, with the length of vessels in the SESSF ranging from 14–85 m; those in the Macquarie Island and Heard Island and Macdonald Island Fisheries from 44–91 m, and those in the SPF from 12–95 m (information provided by the Australian Fisheries Management Authority - AFMA). These vessels also use a number of different fishing methods, with vessels in the SPF using purse-seine nets

and pelagic or midwater trawls, vessels in the SESSF Blue Grenadier fishery using midwater or bottom trawls, and vessels in the Toothfish fisheries using bottom trawl or longlines.

These fisheries are primarily managed using 'output controls', whereby impacts on sustainability of stocks are kept within assessed sustainable levels using limits on Total Allowable Catches (TACs). Provided catches are successfully limited to within recommended levels, the size of the vessel making those catches should not pose differential risks to sustainability of the target species. Many of the FRDC-funded projects outlined below in the section on *Impacts on Fish Stocks* have informed the development of reliable assessment approaches, to ensure that scientific advice regarding sustainable catch levels of target species is reliable.

The size of vessel, type of gear used and area of operation may all be factors contributing to increased risk of fishery impacts on bycatch species, including protected species, if these factors result in an increased likelihood of interaction with protected species, or increased risk of injury or mortality if interaction occurs. A number of the FRDC-funded research projects outlined below in the section on *Interactions with Protected Marine Species* have been conducted in response to recognition of risk posed to protected species by certain gear types, fishing operations or in certain areas. These projects have focussed on developing effective bycatch reduction and mitigation practices and devices to reduce these risks.

5. Research and Scientific Knowledge

As a result of the fact that the primary role of the FRDC is the coordination and funding of appropriate research to support the responsible and sustainable management of Australian fisheries, all of the information provided in this submission relates to the Inquiry question regarding current research and scientific knowledge. Key research information and scientific knowledge emanating from FRDC-funded projects is presented below under the terms of reference relating to impacts of fisheries on stocks, impacts on bycatch or dependent species and potential impacts on other sectors.

(a) The effect of large fishing vessels on the marine ecosystem: (i) impacts on fish stocks and the marine food chain

Small Pelagic Fishery

FRDC Project 1998-130: A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters, with special reference to pilchards (Sardinops sagax) extension into Queensland and New South Wales (stage 2)

FRDC funded research on Sardines in the SPF started in 1998 with a project to investigate the potential use and stock assessment of bait fishes in southern and eastern Australian waters, particularly Australian Sardine[2], after commencement of the South Australian Sardine Fishery in about 1995. This project saw the first application of the daily egg production method (DEPM) to estimate the spawning (adult) biomass of sardines off Queensland, New South Wales and South Australia in 1997 and 1998. Results estimated the size of the sardine stock to be at least 25,000 t in both years, and indicated that southern Queensland could support a viable sardine fishery with an annual sustainable catch in excess of 1,000 t. However, stock size estimates were highly uncertain as a result of the variability in estimates of egg production, largely resulting from problems with estimating spawning fraction (the proportion of female adult fish that spawn) and batch fecundity (the number of eggs spawned by each female) during each spawning event.

FRDC Project 2000-125: Implementation of an age structured stock assessment model for Sardine (Sardinops sagax) in South Australia

Efforts to develop reliable stock assessment methods for sardines off South Australia continued with a project that sought to develop a reliable age determination method and to implement an age-structured stock assessment model for the South Australian Sardine Fishery[3]. The age-structured assessment model for Western Australian sardine was adapted for South Australia, but biases in the age samples from the commercial catch and resulting difficulties with the development of a reliable recruitment index limited the capacity of the model to reliably estimate stock size, limiting the usefulness of this model as a tool for managing the South Australian Sardine Fishery. The authors concluded that DEPM estimates should remain the basis for managing the South Australian Sardine Fishery for the foreseeable future.

FRDC Project 2002-236: Optimising at-sea post-harvest handling procedures for the Australian sardine (Sardinops sagax)

Research was initiated in 2002 into options for improving the quality of sardines landed from the Port Lincoln-based sardine fishery[4]. This fishery developed to provide food for the Southern Bluefin Tuna ranching operation in the area, but fishers sought opportunities to develop a value-adding component, to produce fish for human consumption. This work provided some commentary relating to the influence of vessel size in increasing options for improving fish quality. The main effect on quality of sardines was found to be the detrimental consequence of not chilling the fish as quickly as possible after capture. The rate at which fish quality deteriorates if they are not immediately chilled requires the installation of onboard refrigerated seawater chilling plants if fish are to be produced for human consumption. The economic viability of operating onboard fish-chilling plants was found to increase with the throughput rates of such equipment, with larger plants producing high quality fish at lower prices. Larger chilling plants then require the use of larger vessels to support such plants.

FRDC Project 2002-061: Development and evaluation of egg-based stock assessment methods for Blue Mackerel Scomber australasicus in southern Australia

Having established methods for DEPM surveys for Australian Sardine, attention turned in 2002 to the extension of these methods to other pelagic species off South Australia, initially focusing on Blue Mackerel[5]. Analysis of fish parasite composition and otolith chemistry from different regions found differences between fish from a number of regions, suggesting that there are several stocks of Blue Mackerel in Australian waters, particularly east and west of the Bass Strait. It was found that, while late-stage Blue Mackerel eggs can be reliably visually identified, early stage eggs resemble those of other species, requiring development of cost-effective and reliable methods for genetic identification or early-stage Blue Mackerel eggs. Estimates of Blue Mackerel spawning biomass in the areas surveyed off southern and eastern Australia, estimated to be within the ranges of 45,000–70,000 t and 20,000–60,000 t respectively, were therefore possibly biased low, as a result of including only those eggs that could be reliably identified.

At this time, with progress being made on application of DEPM stock assessment methods to a number of pelagic species, this work also informed the development in 2007 and 2008 of the SPF Harvest Strategy by the SPF Resource Assessment Group (SPF RAG) established by AFMA to provide scientific advice on sustainable catch levels for the SPF. This SPF Harvest Strategy is tiered to provide alternative assessment approaches, depending on the amount of information available. At Tier 1, recommended biological catches are set as a proportion of the best estimate of spawning biomass obtained using DEPM stock size estimates, with the maximum harvest rate (proportion of the estimated total stock caught each year) decreasing from 20% to 10%, depending on the frequency that the DEPM is applied (from twice in three years down to once every five years). Tiers 2 and 3

then provided for harvest rates to be set at decreasing levels if DEPM surveys are not conducted at least every five years, as available information on stock size decreases.

FRDC Project 2004-039: Evaluation of egg production as a method of estimating spawning biomass of redbait off the east coast of Tasmania

During the mid-1980s a major purse-seine fishery for small pelagic fishes, mainly Jack Mackerel, had developed off Tasmania. Catches exceeded 40,000 t in the late 1980s but were prone to large inter-annual fluctuations, due mainly to variation in the availability of surface schooling fish. By 2000 purse-seine fishing had effectively ceased, at which time industry commenced trialling mid-water trawling for small pelagic species, with Redbait comprising the bulk of the catch.

This project was initiated to extend DEPM assessment techniques to Redbait off eastern Tasmania, to provide a scientific basis for estimating stock size of Redbait[6]. Spawning habitat of Redbait was described from egg, larval and environmental data collected over shelf waters between north-eastern Bass Strait and the lower south-west coast of Tasmania in October 2005 and 2006. Attributes of the reproductive biology and spawning dynamics of Redbait indicated that the species was suitable for the application of daily egg production models and biomass estimates based on the preferred DEPM assessment model were 86,990 t in 2005 and 50,782 t in 2006.

FRDC Project 2009-021: Movement patterns and stock structure of Australian Sardine (Sardinops sagax) off South Australia and the east coast: implications for future stock assessment and management

Research to improve understanding of the stock structure of Australian Sardine was continued under this project, which reviewed information on movement patterns and fish distribution around Australia and used analyses of otolith shape and otolith chemistry to detect differences between stocks in different regions[7]. Similarity matrices of available information suggested that there was a high degree of separation between sardines off Western Australia, South Australia and the east coast (Queensland, New South Wales and eastern Victoria). The two otolith-based techniques generally supported the population structure for south-eastern Australia suggested by the weight of evidence approach, indicating separate stocks off the south coast (South Australia, Port Phillip Bay) and east coast (including Lakes Entrance and southern Queensland). These results contributed to an increasing understanding of a separation at the Bass Strait between eastern and western stocks of a number of pelagic species.

SARDI Project R2010-0812: Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2011-2013

Available information on most recent stock biomass estimates for the species targeted in the Commonwealth SPF was summarised in this report to AFMA, to inform advice on recommended biological catches at Tiers 1 and 2 under the SPF Harvest Strategy[8]. The best estimate of spawning biomass of Australian Sardine off eastern Australia was ~29,000 t in 2004, with most estimates derived using a range of likely values of mean daily egg production and spawning fraction producing estimates in the range of 25,000–35,000 t. Preliminary DEPM assessments for Blue Mackerel from the 2005 survey provided a mid-range best estimate of spawning biomass of ~56,000 t in the west. For Blue Mackerel in the east, the SPF Resource Assessment Group agreed to use a mid-range estimate of spawning biomass of 40,000 t after a sensitivity analysis was done. DEPM estimates for Redbait in the east indicated a spawning biomass in excess of 50,000 t.

FRDC Project 2013-053: Summer spawning patterns and preliminary DEPM survey of Jack Mackerel and Australian Sardine off the east coast

Extension of egg surveys and DEPM stock estimation methods to other pelagic species was continued under this project, with the first dedicated application of DEPM to Jack Mackerel[9]. An initial DEPM-based estimate of the Jack Mackerel stock size was based on Jack Mackerel eggs collected incidentally during an earlier DEPM survey designed around spawning areas and peak times of other species, primarily Blue Mackerel[10]. There were concerns that this estimate may be unreliable if the spawning areas and times for Jack Mackerel were not similar to those for Blue Mackerel. This project provided the first estimate of the spawning biomass of Jack Mackerel off eastern Australia based on concurrent, targeted surveys of both eggs (to provide estimates of egg production) and adults (to provide measures of spawning rations and batch fecundity needed to estimate spawning stock biomass from egg production).

The estimate of spawning biomass of Jack Mackerel obtained from the January 2014 survey was 157,805 t, with a 95% confidence interval of 59,570 t to 358,731 t. This estimate was found to be robust to variation in the contributory variables, with most of the estimates of spawning biomass obtained in sensitivity analyses being between 95,000 t and 215,000 t, within the 95% confidence interval of the primary estimate. This estimate is also within the range of earlier estimates of spawning biomass for Jack Mackerel off eastern Australia of 114,900 t to 169,000 t, and within the range of plausible estimates of 130,000 t to 170,000 t obtained using Atlantis ecosystem modelling of the system[11], showing consistency in these results.

FRDC Project 2013-063: Benchmarking Australia's small pelagic fisheries against world's best practice

In July 2014, an international workshop and stakeholder forum on fisheries for small pelagic species was held at the South Australian Aquatic Sciences Centre benchmark Australia's fisheries for small pelagic species against world's best practice to identify options for improvement[12]. International experts working on small pelagic fisheries in the United States, Chile, Spain, Portugal, Netherlands and Greece provided overviews of experiences with assessing small pelagic stocks in their respective regions, primarily from the perspective of using DEPM methods. The workshop was structured to address Issues of particular interest in the Australian SPF: reliability of estimates of spawning biomass obtained using DEPM; operational interactions with threatened, endangered and protected species; potential trophic (food web) effects on other components of the ecosystem; and possible impacts of localised depletion on predatory species and other fisheries.

The workshop focused on the South Australian Sardine Fishery (SASF) and concluded that the assessment and management frameworks for Australia's fisheries for small pelagic species, particularly the South Australian Sardine Fishery, are consistent with world's best practice with respect to application of fishery-independent DEPM assessment methods, use of formal harvest strategies or operational management procedures, assessment of the ecosystem effects of fishing and mitigation of fishery interactions with wildlife. The workshop also identified several areas of research that could improve the assessment and management of Australian small pelagic fisheries, particularly relating to improving inputs to DEPM models relating to possible differences between adult parameters obtained using gill-nets, purse-seines and trawls, and reviewing approaches taken to estimating spawning fraction in the SASF. The workshop also agreed that consideration should be given to establishing guidelines to reduce the risk of localised depletion in the SPF, but offered no advice in this regard.

Many of the international pelagic fisheries have experienced overfishing and collapse of the resources, with a number of the fisheries being closed for period of time to allow for stock recovery. In contrast, biomass estimates and catches in the most intensely fished Australia small pelagic fishery, the Southern Australian Sardine Fishery, have remained stable for over a decade, while

catch-per-unit-effort has increased steadily over almost the entire history of the fishery (Figure 1), testifying to the effectiveness of the combination of DEPM surveys and low exploitation rates set using a tested harvest strategy for this fishery.

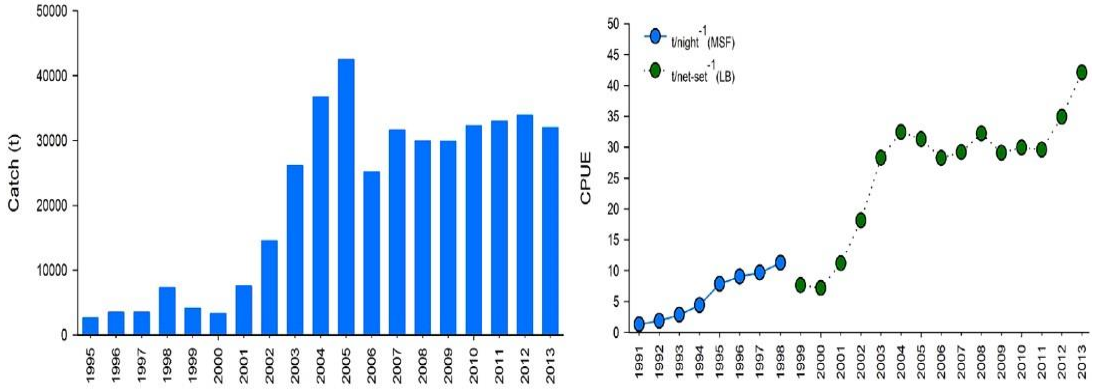

Figure 1. Trends in catch and catch-per-unit-effort (CPUE) in the South Australian Sardine Fishery over the period 1995 to 2013.

Another notable aspect in presentations by the international experts was that most major international pelagic fisheries use acoustic surveys to generate abundance indices for the entire stock or for certain components of the stock, in addition to DEPM surveys. Two additional abundance indices are used for the US Pacific Sardine fishery: aerial surveys off the Pacific North-west (Oregon-Washington) since 2009 and acoustic surveys off California since 2011. Chile conducts acoustic surveys to provide indices for sardine recruitment and anchovy total biomass. Spain conducts acoustic surveys in addition to DEPMs and Portugal uses acoustic surveys to provide an index of abundance and to collect age composition data, in addition to their triennial DEPM survey. Acoustic surveys are used in many fisheries as the primary method to provide fishery-independent abundance estimates, being capable of producing indices of abundance in selected areas, seasons or depth strata, as needed to inform assessments. Acoustics would also provide a useful method for assessing the abundance of pelagic fish in an area pre- and post-fishing, to directly evaluate whether localised depletion has occurred.

The workshop also noted that Australia is the only jurisdiction of those that participated that considers DEPM estimates to provide indices of absolute abundance, using these estimates directly to estimate biomass. All other jurisdictions consider DEPM estimates to provide relative indices of abundance, feeding these into integrated statistical stock assessments together with acoustic indices, catch-at-age data and biological parameters relating to growth and recruitment characteristics, allowing the assessment models to determine the statistically most probably stock biomass from all of the available data. The workshop therefore recommended that the benefits and limitations of using a population model and/or DEPM estimates of spawning biomass to set TACs for Australian Sardines and other species should be examined.

FRDC Project 2013-064: Small Pelagic Research Coordination Program

In view of substantial and escalating interest in the SPF at the time, and calls for additional research to answer question relating to stock sustainability and potential threats to marine mammals posed by a proposed escalation in fishing activity, the FRDC established a dedicated *Small Pelagic Research Coordination Program* in 2013[13]. The intention of this program is to co-ordinate the activities of FRDC funded small pelagic research and support participation in research conferences and international workshops to address these questions. A technical workshops was conducted under the auspices of this Program in 2015 on *Options for mitigating marine mammal interactions in the Small Pelagic Fishery* (reported on under section (a)(ii) below).

FRDC Project 2013-028: Review and update of harvest strategy settings for the Commonwealth Small Pelagic Fishery - Single species and ecosystem considerations

The SPF Harvest Strategy has been used since 2009 to determine recommended biological catches for the SPF. Increasing problems have been experienced in interpreting and applying the strategy under declining catches and infrequent DEPM surveys. There have also been international developments questioning the appropriateness of 'standard' single species target reference points for low trophic level species[14] and the adoption of more conservative reference points for key low trophic level species by the Marine Stewardship Council (MSC). The same harvest rate, albeit conservative, was also being applied to species with rather different productivities, resulting in calls for a project to review the SPF Harvest Strategy and provide advice on best practice reference points for the four main target species in the SPF, and suitable exploitation rates to achieve management targets for the four target species in the SPF.

The study used an adaptation of the Atlantis ecosystem model specifically tailored to the SPF (Atlantis-SPF) to evaluate the dependence of key predators and other species in the ecosystem on small pelagic prey species, and the potential negative effects on predators of depleting small pelagic species to various levels[15]. Results confirmed those from earlier ecosystem models[16], finding that, both singly and in combination, depleting these small pelagic species has only minor impacts on other parts of the ecosystem, as a result of the wide variety of prey species consumed in the ecosystem, and the flexibility in predator diets. None of the key higher trophic level predators in SE Australia, such as seals, penguins and tunas, were found to have a high dietary dependence on these species.

This study recommend that the target reference point for the SPF target species should be set at 50% B_0 and the limit reference point at 20% of unfished biomass. These are in line with the default settings in the Commonwealth Harvest Strategy Policy[17]. To ensure that SPF species are managed towards, or maintained at, the recommended 50% of unfished biomass target level, ecosystem and population modelling indicates that different maximum exploitation rates must be implemented, to match fishing exploitation to the differing productivity of the four species. This study found that the SPF Harvest Strategy average Tier 1 harvest rate of 15% appears to be too high for eastern Redbait, and may also be too high for western Redbait and Jack Mackerel.

Analysis results found that, for Tier 1 (where DEPM surveys are conducted at least every five years), the maximum exploitation rates required to achieve a median depletion of 50% of unfished biomass, while maintaining less than a 10% chance of falling below a limit reference point of 20% of unfished biomass, should be as shown in Table 1.

Table 1. Summary of recommended maximum exploitation rates for the fish stocks comprising the Small Pelagic Fishery.

Stock	Recommended Maximum Exploitation Rate
Eastern Redbait	9%
Western Redbait	10%
Jack Mackerel	12%
Eastern Blue Mackerel	23%
Western Blue Mackerel	23%
Eastern Sardine	33%
Western Sardine	33%

Tier 2 harvest rates in the current harvest strategy are set at half the Tier 1 rate. Analyses found that it is generally not safe to apply Tier 2 at these levels for long periods of time, and can result in unacceptable probabilities of depletion within 5 or 6 years for shorter lived species (Blue Mackerel and Australian Sardine), although only after about 20 years for longer-lived Redbait and Jack

Mackerel. It is suggested that the Tier 2 rate should be more precautionary (less than half the Tier 1 rate) and/or the period over which it is applied should be reduced to not more than 5 years.

FRDC Project 2014-033: Egg distribution, reproductive parameters and spawning biomass of Blue Mackerel, Australian Sardine and Tailor off the East Coast during late winter and early spring[18]

This project extended DEPM approaches to estimate the distribution and abundance of eggs and larvae of Blue Mackerel, Australian Sardine and Tailor off the East Coast during winter/spring.

The spawning biomass of Blue Mackerel off eastern Australia during August-September 2014 was estimated to be ~83,300 t (95% CI = 35,100 - 165,000 t). Most estimates of spawning biomass obtained in the sensitivity analyses were mainly 50,000 t and 100,000 t. The estimate of spawning biomass should be treated with caution as adult samples were not collected during the study. Sampling intensity for estimates of egg production in the region was higher than in exploratory surveys conducted in 2003 and 2004. Current estimates of egg production and spawning area are likely to be more robust than those previously reported.

The spawning biomass of Australian Sardine off eastern Australia during August-September 2014 was estimated to be ~49,600 t (95% CI = 24,200 - 213,300 t). Most estimates of spawning biomass obtained in sensitivity analyses were between 30,000 t and 110,000 t. Credible values for only one parameter (spawning fraction) provided estimates of spawning biomass that were outside that range; this parameter was estimated with a high degree of confidence in the present study. The proportion of the adult biomass of Australian Sardine off eastern Australia that occurred outside the survey area during the survey period is unknown.

Egg production, spawning area and spawning biomass for Tailor could not be estimated due to the lack of eggs collected.

FRDC Current Small Pelagic Research Projects

A number of research projects are currently underway to address some of the improvements to small pelagic species assessments that have been identified in previous research. FRDC Project 2014-022: *Developing a rapid molecular identification technique to improve egg production based fish biomass assessments*[19] is addressing the difficulties experienced in differentiating the similar-looking eggs of some pelagic species. This project has successfully developed fluorescent genetic markers that can be bound to eggs, allowing them to be identified and counted automatically by machine.

FRDC Project 2014-026: *Improving the precision of estimates of egg production and spawning biomass obtained using the Daily Egg Production Method*[20] is investigating approaches to improve the precision of DEPM-based pelagic stock size estimates. Based on options discussed at the international workshop to benchmark the SPF against international best, this project will: compare the performance of alternative statistical methods for estimating egg production for several species; conduct simulations to evaluate the performance of different approaches to sampling and statistical analysis; and establish improved methods for estimating daily egg production using DEPM.

SESSF Blue Grenadier Fishery

Blue Grenadier are the primary target species in the SESSF. The SESSF has limited entry (a limit on the number of statutory fishing rights issued) but stock sustainability is primarily managed using output controls, whereby annual limits on total allowable catches (TACs) serve to ensure that catches remain within limits assessed to be sustainable. The SESSF stocks are managed under the SESSF Harvest Strategy, using tested decision rules designed to ensure a high probability that stocks remain above limit reference levels, and are managed towards target reference levels above maximum sustainable yield, to achieve maximum economic yield. Significant reported commercial

catches of Blue Grenadier were first reported in 1979, at about 500 t. Catches increased steadily to between 3000 t and 4000 t as a fishery developed on winter spawning aggregations off western Tasmania, and then increased substantially to about 9000 t over 1999−2003 following increases in TACs based on stock assessments indicating good recruitment and large stock size.

FRDC Project 1997-115: Modelling the population dynamics of high priority SEF species

At the time this project was initiated, there were 16 species for which total allowable catches (TACs) were set in the Southeast fishery. This project was initiated to develop improved approaches for conducting robust and reliable stock assessments of the top three species: Blue Grenadier, Pink Ling and Silver (Spotted) Warehou[21]. To solve problems that can arise as a result of gaps in some of the data inputs, this project implemented the first application of a flexible age-structured integrated assessment approach in the SESSF.

Large Blue Grenadier aggregate off the west coast of Tasmania during winter to spawn, supporting a winter spawning fishery during which most of the annual catch is made. Catches by the non-spawning fleet primarily comprise sub-adult and small adult fish whereas the spawning fleet concentrates on mature fish, including large adults that are poorly represented in the catches by the non-spawning fleet. From 1997 onwards, most of this catch was made by several large factory trawling vessels from New Zealand capable of operating across the extent of the western Tasmanian shelf, and of filleting and freezing Blue Grenadier at sea to produce high quality product for human consumption. With the entry of these vessels into the fishery the quantity of fish taken by mid-water trawl rather than demersal trawl increased.

By 2000, catches of Blue Grenadier in the SESSF were larger than any other species, but the fishing industry was concerned at declining catch rates seen in the early 1990s. There was controversy regarding the status of Blue Grenadier stocks by the mid-1990s due to disparity between optimistic scientific advice (based on acoustic and egg production estimates) and the more pessimistic view of industry representatives. Stock assessments conducted under this project resolved these opposing views by determining that there had been two years of exceptionally good recruitment in 1994 and 1995 that resulted in an increased stock size, but the fish had not yet grown to a size where they could be caught in the winter spawning fishery.

This project, and subsequent assessment work, demonstrated that the Blue Grenadier Fishery experiences occasional years of very high recruitment and increase in stock size that appear to be able to sustain catches around 10,000 t for a period of years, before the stock declines back to lower levels over periods of lower average recruitment.

FRDC Project 2000-102: Spawning and reproductive biology of Blue Grenadier in south-eastern Australia and the winter spawning aggregation off Western Tasmania

This project reported that catches by freezer trawlers in the winter spawning fishery were contributing over 90% of total Blue Grenadier catches by the late 1990s, supported by the two strong 1994 and 1995 year classes passing through the fishery[22]. In recognition of the critical importance of spawning success and annual year-class strength to Blue Grenadier stock assessments, this project was initiated to provide a better understanding of Blue Grenadier spawning dynamics, investigating reproductive biology, fecundity estimates, maturity curves and the proportion of mature fish that spawn each year.

During the time that this project was underway, acoustic estimates of biomass were developed to provide an abundance index using acoustic snapshots of biomass. To use these in stock assessments, an estimation of the turn-over rate (or residency time) of spawning fish in the surveyed area became a research priority. This project provided estimates of the proportion of non-spawning adults and the turn-over rate during the spawning season, subsequently used to improve the reliability of stock assessments.

FRDC Project 2003-044: Development of a sustainable industry-based acoustic observation system for Blue Grenadier at the primary spawning sites

Substantial increases and subsequent declines occurred in Blue Grenadier stock size and availability in the winter spawning fishery during the 1900s, in response to changes in year-class strength. This showed that Blue Grenadier biomass is closely tied to recruitment success which, given its cyclic nature, appears to be environmentally driven. High variability in year-class strength led to identification of the need for a reliable index of abundance to use in stock assessments. This project was initiated to develop and implement an industry-based acoustic monitoring system to provide annual estimates of absolute Blue Grenadier abundance for use in assessments.

This project successfully developed an industry-based acoustic observation system for Blue Grenadier at the primary spawning sites[23]. Based on acoustic surveys, the biomass of Blue Grenadier in the surveyed spawning area was estimated for the years 2003−05 and used in stock assessments. These acoustic biomass estimates provided confidence about the lower bound of the stock size, despite uncertainties about the proportion of the stock surveyed and target strength.

At the time, there were questions about the acoustic target strength of Blue Grenadier (which needs to be well estimated to convert acoustic return signals to biomass estimates), with substantial differences between target strength estimates used in Australia for Blue Grenadier, and in New Zealand for Hoki (the same species). These differences in target strength between New Zealand and Australia were subsequently investigated and partially resolved using an Acoustic Observation System (AOS), which showed high variability in target strength depending on fish size and swimming angle, and possibly smaller fish in New Zealand[24].

FRDC Project 2005-006: The influence of environmental factors on recruitment and availability of fish stocks in south-east Australia

Whereas research into environmental effects on small pelagic species focussed on understanding their movement patterns, this project was initiated to investigate the influence of environmental and oceanographic conditions on recruitment success and fish availability in the southeast trawl fishery, and to develop hypotheses about the major environmental drivers and their potential influence on key fishery characteristics such as catch composition and seasonal variations in recruitment and availability[25].

Models investigating the influence of environmental and oceanographic factors on fisheries in south-east Australia indicated that SST and temperature-at-depth suggested some potential for improving catch-per-unit effort (CPUE) abundance indices. However, with a few exceptions (such as Pink Ling) it was found that the addition of extra environmental variables made very little difference to the standardised CPUE time series and that the current practice of using month and depth as proxies for these environmental factors appears to be appropriate in most cases.

The recruitment patterns of several species inhabiting geographically similar distributions were found to be significantly correlated, suggesting that common external influences, probably environmental factors such as water temperature and changes in current patterns, do affect recruitment. A more detailed exploration of the ecosystem influences on the recruitment dynamics of blue grenadier showed that the inter-annual fluctuations in biomass and changes in recruitment year-class strength observed for this population can be derived from natural cycles in prey and predator dynamics.

FRDC Project 2006-028: Implementation of a Fishery Independent Survey for the Southern and Eastern Scalefish and Shark Fishery

This project was implemented to: determine the fishery-independent survey methods most suitable for the main species in the SESSF; design cost-efficient fishery independent surveys to

provide indices of abundance for most major species in the SESSF; and implement a long-term (5 – 10 year) survey program that can be progressively funded by industry under standard AFMA Cost Recovery Impact Statement Policy[26].

This project reviewed options for design of such surveys, concluding that model-based survey designs are more suitable, being logistically more flexible, making full use of the data and providing relatively unbiased abundance estimates with low variance. This project successfully designed a multi-species fishery independent survey capable of providing relative abundance indices for a number of major quota and non-quota species in the SESSF. Analysis of the 2010 survey results showed that conducting just a winter survey could provide reasonable (< 30%) coefficients of variation (CVs) for 15 species, which account for 87% of catch weight and 83% of catch value, with a saving of about 44% in survey costs.

A successful trial of the survey design was conducted during 2008, with only minor modifications required for a 2010 survey. Given that a program of annual acoustic surveys had been implemented to provide fishery-independent abundance indices for Blue Grenadier, this was not originally one of the target species around which the survey was designed. Nonetheless, Blue Grenadier was the second most abundant species caught and the surveys provided acceptable estimates of Blue Grenadier abundance, with CVs of 18% in 2008 and 20% in 2010.

FRDC Project 2007-030: Use of otolith chemistry and shape to assess stock structure of blue grenadier (Macruronus novaezelandiae) in the Commonwealth Trawl and Great Australian Bight fisheries

This project determined that comparisons of otolith shape, elemental chemistry and stable isotopes of blue grenadier from three key regions of the Southern and Eastern Scalefish and Shark Fishery (SESSF) (western Tasmania, eastern Bass Strait, Great Australian Bight) indicate that the blue grenadier fisheries in the Commonwealth Trawl and Great Australian Bight Sectors of the SESSF are based on separate stocks[27]. This information, combined with earlier studies of larval distributions and dispersal processes, provided a basis for consideration of independent management arrangements for blue grenadier in these two sub-fisheries of the SESSF.

AFMA-CSIRO Assessment Report: Stock assessment of Blue Grenadier Macruronus novaezelandiae based on data up to 2012

Following the successful development of integrated stock assessment approaches and acoustic survey methods under FRDC-funded projects summarised above, future survey and assessment work continued under industry and AFMA funding. Although this ongoing work (which is still conducted and provides the basis for Blue Grenadier stock assessments) is not FRDC funded, mention should be made of the most recent stock assessment for this stock, to demonstrate how these approaches have been successful in ensuring the long-term sustainability of the Blue Grenadier stock and fishery.

The most recent Blue Grenadier assessment available is that produced under the AFMA - Commonwealth Scientific and Industrial Research Organisation (CSIRO) stock assessment contract[28]. The 2013 assessment of Blue Grenadier continued to use an integrated age- and size structured model, which has been improved and updated since the first model developed in 2001. Results estimated that the female spawning biomass in 2012 was around 77% of the unexploited spawning stock biomass, and in 2014 was projected to be about 94% of the unexploited spawning stock biomass, both well above the management target of 48% of unexploited spawning biomass (see Figure 2).

The marked increase in biomass is due to the estimation of a large cohort in 2010. As occurred following the strong 1994 and 1995 year classes, the assessment estimated a substantial increase in recommended biological catch to over 8,000 t, although with a long-term recommended

biological catch of about 4,155 t assuming recruitment returns to average levels. Sensitivity analyses excluding estimated high 2009 / 2010 recruitments continued to show that the stock is projected to remain above the management target level to 2030, even under lower average recruitment.

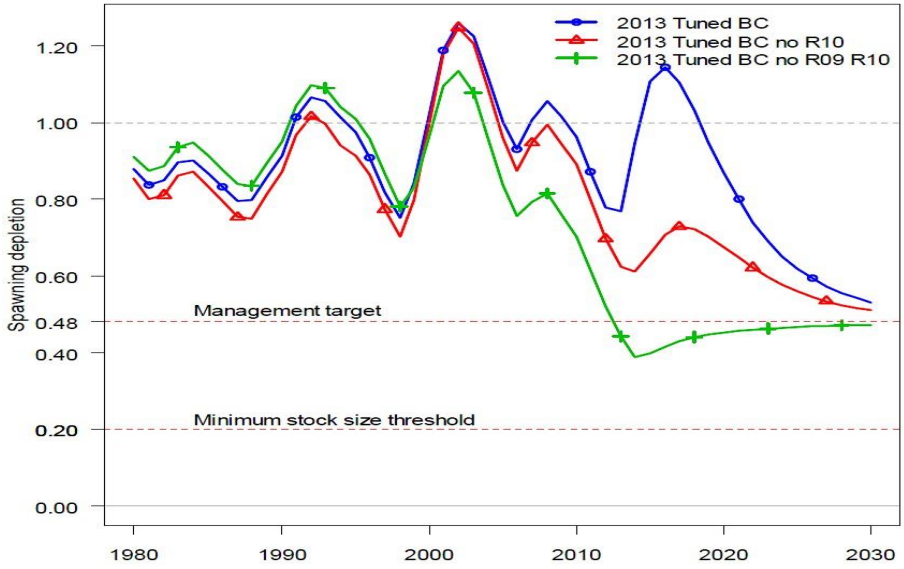

Figure 2. Stock assessment trend in female Blue Grenadier spawning biomass from 1980 to 2012 in relation to limit and target reference levels, with forecast biomass trends to 2030, for the base case model (blue) and models with no estimation of the high 2010 recruitment (red) and no estimation of the 2009 and 2010 recruitment (green).

Blue Grenadier MSC Assessment: Australia Blue Grenadier fishery MSC full-assessment public certification report

Reliable stock assessments and effective management under the SESSF Harvest Strategy, maintaining the Blue Grenadier stock above the management target level throughout the history of this fishery, was a substantial contributory factor to this fishery receiving full Marine Stewardship Council (MSC) certification in August 2015 (backdated to 1 June 2015), receiving no objections from the public consultation process. The Final Principle Scores accorded in the full-assessment report were: Principle 1 – Target Species 95, Principle 2 – Ecosystem 85, Principle 3 – Management System 96[29]. The high score for target species sustainability was largely based on the results of the 2013 assessment, and the conclusion that Blue Grenadier are not overfished and not subject to overfishing.

Macquarie, Heard and McDonald Islands Toothfish fisheries

FRDC Project 2000-109: Stock Assessment and Management Strategy Evaluation for Sub-Antarctic Fisheries

Work to develop more reliable stock assessment approaches, and to develop management strategies, for Toothfish in the Australian sub-Antarctic territories around Macquarie Island and Heard and McDonald Islands was initiated under this project, linking tag-based models to age-structured and spatially structured population models[30].

The Australian fishery for Patagonian Toothfish began in 1994 in the waters surrounding Macquarie Island, with a single vessel licensed to fish in the area. The Heard and McDonald Islands (HIMI) Toothfish fishery began in April 1997, with two vessels licensed to fish the region. In the 1995/96 season a tagging program in the Macdonald Islands fishery was established by the Australian Antarctic Division to assist stock assessments and monitor fish movement. By the 2000–01 fishing

seasons, over 4700 Patagonian Toothfish had been tagged, of which over 500 were recaptured. Tagging in the HIMI fishery commenced in May 1998 with around 1000 fish tagged each season thereafter.

Stock estimates based on tag-recapture models indicated about a 50% decline in Toothfish abundance in the HIMI fishery during the course of the tagging experiment, possibly attributable to pirate fishing occurring in the area at the time. Tag-recapture assessments for the Macdonald Islands fishery showed substantial and rapid changes in availability and apparent abundance, too large and rapid to be explained by the commercial catches. This project developed alternative stock-structure models to explain these changes, including two-stock models and an alternative assuming an external transient population of Toothfish that occasionally moves into the region occupied by a resident population.

FRDC Project 2008-046: Evaluating gear and season specific age-length keys to improve the precision of stock assessments for Patagonian Toothfish at Heard Island and Mcdonald Islands

This project was implemented to improve Toothfish stock assessments by refining protocols for the reliable and efficient large scale ageing of Toothfish otoliths, and evaluating the sensitivity of integrated assessment models for Toothfish at Heard Island and McDonald Islands to the inclusion of gear and/or season-specific age-length keys[31]. Prior to this project, Toothfish catch-at-age was estimated using a growth curve, which has limitations compared to using annual age length keys if there is variation in growth function between years or between fisheries, as is evident in HIMI Toothfish.

This project developed an efficient high-throughput methodology for reliable ageing of Toothfish using thin-sectioned otoliths, enabling the consolidation of length at age estimates for Toothfish, collected across seasons, gear types (commercial and survey trawl, long line and trap), length classes and fishing grounds, since the fishery started. The precision of stock assessment parameters relating to rate of recruitment and the selectivity of different gear types was found to be sensitive to the inclusion of season and gear specific age-length keys. Inclusion of such keys should provide increased confidence in the reliability of Toothfish stock assessments.

FRDC Project 2010-064: The spawning dynamics of Patagonian Toothfish in the Australian EEZ at Heard Island and the McDonald Islands and their importance to spawning activity across the Kerguelen Plateau

Prior to this project, the nearest substantial spawning location to the HIMI fishery was considered to be in the French EEZ west of Kerguelen. However, in 2009 a number of spawning Toothfish were captured during prospective longline fishing on the deep slope to the west of HIMI, leading to the establishment of this project. This research identified several areas on the deep slope to the west and south of HIMI that support spawning activity[32]. Together with the fact that large areas of apparently suitable habitat remain to be sampled, this indicates that spawning within the Australian EEZ is likely to make an important contribution to the overall spawning output of the populations on the Kerguelen Plateau.

Biological data collected in this study were used to estimate maturation curves and provide improved estimates of Toothfish size at maturity. The sensitivity of integrated stock assessment models to revised estimates of maturity was tested. It was found that updated assessment models incorporating these revised estimates indicate that the current Toothfish harvest rate in the Australian EEZ at HIMI has less than a 10% probability of causing the spawning stock to be depleted to below 20% of the estimated median pre-exploitation biomass, with a greater than 50% chance of remaining at or above 50% of pre-exploitation biomass. Under these projections, the current harvest rate satisfies the decision rules, target and limit reference points established by the

Commission for the Conservation of Antarctic Living Marine Resources (CCAMLR), as defined in the Harvest Strategy for the HIMI fishery.

FRDC Project 2013-013: Development of robust assessment methods and harvest strategies for spatially complex, multi-jurisdictional Toothfish fisheries in the Southern Ocean

Work to improve Toothfish stock assessments continues under this project which primarily aims to: evaluate the performance of stock assessment methods for spatially-structured and multi-jurisdictional Toothfish fisheries using simulated and real data collected from the French and Australia EEZs on the Kerguelen Plateau; and provide recommendations for data collection, stock assessment and harvest strategies that maximise the likelihood of long-term sustainability of the Toothfish fisheries across the Kerguelen Plateau[33].

National Stock Status Reports

FRDC Project 2011-513: Status of key Australian fish stocks reports 2012. The inaugural process of production and lessons learned

Up until 2011, the Commonwealth, State and Territory governments all produced separate reports on the status of commercial wild capture fisheries within their jurisdictions. This project was initiated to produce the first National Fishery Status Reports, using a national evidence-based reporting framework to improve consistency in reporting across jurisdictions, and to provide for shared stocks (those that span the waters of more than one jurisdiction) to be assessed as single biological stocks within the biological boundaries of fish stocks, rather than man-made boundaries of management units or jurisdictions[34].

The *Status of Key Australian Fish Stocks* (SAFS) *Reports 2012* provided the first national, scientifically robust status assessments 49 key Australian species, describing the distribution of stocks around the country and providing stock status classifications at the biological stock level where possible. The species chapters also included some species specific preliminary information on fishing methods, management measures, vessels numbers, catch quantities, the effects of fishing on the marine environment and environmental factors that can affect fish stocks.

FRDC Project 2012-513: Status of key Australian fish stocks reports and companion national fishery status reports review of the 2012 reporting process and planning for future reports

In a follow-up review of experiences during the production of the SAFS Reports 2012, workshops were held with industry representatives, environmental non-government organisations, retailers, external peer reviewers, authors of the initial report chapters and the SAFS Advisory Group, to build on the achievement of the SAFS Reports 2012 and establish a sustainable long term approach[35]. The workshops resulted in agreement on content and a process for producing a second edition of the SAFS reports in 2014.

FRDC Project 2014-030: Status of key Australian fish stocks (SAFS) reports 2014 and beyond

The second SAFS Reports were produced in 2014, building on the 2012 reports, with minor alterations to the national stock status classification framework and species chapters and the addition of 19 new species, bringing the total number of species reported by the SAFS reports to 68 species or species complexes[36].

The SAFS 2014 Reports (FRDC: www.fish.gov.au) provide national stock status chapters and classifications for four biological stocks of Australian Sardine and two stocks of Blue Grenadier, confirming that none of these stocks are overfished, and that all are assessed to be sustainable (see Table 2 below).

Table 2. Summaries of stock status for Australian Sardine and Blue Grenadier from the Status of Key Australian Fish Stocks 2014 (FRDC: www.fish.gov.au).

Australian Sardine

Jurisdiction	**Commonwealth, New South Wales, Victoria**	**South Australia, Victoria**	**Western Australia**	
Stock	Eastern Australian	Southern Australian	Western Australian west coast	Western Australian south coast
Stock status	**Sustainable**	**Sustainable**	**Sustainable**	**Sustainable**
Indicators	Spawning biomass, exploitation rate	Exploitation rate, catch data	Biomass, fishing mortality	Catch

Blue Grenadier

Jurisdiction	**Commonwealth**	
Stock	Commonwealth Trawl Sector	Great Australian Bight Trawl Sector
Stock status	**Sustainable**	**Sustainable**
Indicators	Spawning stock biomass, fishing mortality	Current and historical fishing pressure

FRDC Project 2015-034: Status of Australian Fish Stocks (SAFS) reports 2016, and further development of the SAFS production and dissemination system

The Status of Australian Fish Stocks (SAFS) reports has become widely recognised as a key source of information on the sustainability of key commercial fish species. The reports continue to collate available biological, catch and effort information to determine the status of Australia's key wild catch fish stocks against a nationally agreed reporting framework.

The third edition of the reports will be published online in December 2016 and will include an additional 15 species which brings the total count to 83 species or species complexes. Species in the next edition of the reports include Australian Sardine, Common Jack Mackerel and as a new addition Blue Mackerel.

(a) The effect of large fishing vessels on the marine ecosystem: (ii) bycatch and interactions with protected marine species

Small Pelagic Fishery

FRDC Project 1998-130: A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters, with special reference to pilchards (Sardinops sagax) extension into Queensland and New South Wales

DEPM estimates of a stock of 25,000 t of Australian Sardines off southern Queensland resulted in development of a small-scale sardine purse-seine fishery between September 1997 and October 1998[2]. At the time it was considered that the potential ecological (indirect) effects that a conservatively-managed sardine fishery would have on predatory fishes, birds and mammals would be low as a result of the targeting of only one of the region's many species of potential prey (sardines), the removal of only a small percentage (5–10%) of sardine adult biomass, and the opportunistic feeding habits of the region's predatory species, which feed on a variety of prey species.

Seventy-seven dolphins were encircled in the developmental fishery, of which sixty-eight were released alive and nine died. This identified potential fishing risks posed to dolphins feeding on nearshore sardine aggregations, even by these small purse-seine vessels. As a result of community concerns at the dolphin mortalities, the fishery was temporarily halted in February 1999 pending the consideration of mitigation options, and prohibited in May 1999. As a consequence, this project was the first to identify the importance of establishing a suitable structure for the ongoing consideration of the views of different user-groups relating to such risks.

FRDC Project 2001-008: Assessment of seal–fishery interactions in the winter Blue Grenadier fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers

Although this project was designed to evaluate and recommend options for reducing seal interactions and mortalities in the Blue Grenadier winter spawning fishery, it did make some observations on seal interactions in the SPF[37]. It was noted that problems with dolphin bycatch had been experienced in 2004–05 in midwater trawl operations targeting small pelagic species, principally Redbait, off eastern Tasmania. A pilot study aimed at monitoring marine mammal interactions in this fishery used video cameras to assess such interactions and the effectiveness of a 'soft-mesh' exclusion device[38]. Although no dolphins were observed or captured during that study, seals (probably all Australian fur seals) were observed in 89% of the shots monitored using underwater filming. Seals primarily interacted with the exclusion device, feeding at the escape opening or entering and exiting the net via this opening. A total of 1,864 seal interactions were recorded on video during the 19 shots monitored. Seals were recorded as fully entering the net via the escape opening in over half the shots observed, remaining in the net for up to 8.7 minutes before exiting again via the opening.

This project noted that the SPF occurs at much shallower depths (100–120 m) than that for Blue Grenadier, and that midwater trawl shots targeting small pelagic species lie well within the Australian fur seal's diving range and are thus accessible to seals throughout the shot. The high level of net-entry by seals observed strongly supports the assumption made in the Blue Grenadier Fishery study that seals were entering trawl nets via the SED escape hatch. Furthermore, these observations suggest that current SED designs may not reduce, and may increase, seal bycatch by trawlers in shelf waters, and that some kind of one-way (exit only) SED escape hatch is required.

FRDC Project 2003-072: Trophodynamics of the GAB: assessing the need for an ecological allocation in the SA pilchard fishery

Increasing international and regional awareness of the importance of pelagic species in the diets of many fishes, seabirds and marine mammals, and therefore of the importance of ensuring that fishing does not reduce pelagic stocks to levels that may jeopardise the successful feeding of these predators, resulted in directed research from 2003 onwards to investigate the feeding ranges and food requirements of key predator species.

Focusing on the ecological role of Australian Sardines, this project investigated seasonal oceanographic patterns in upwelling and productivity, and the dietary composition and food-web relationships between predator and prey species such as Southern Bluefin Tuna, New Zealand fur seal, Australian sea lion and little penguins, in the eastern Great Australian Bight (GAB)[39]. Shelf waters in this region support the world's only northern boundary current ecosystem and although productivity in the eastern GAB is low during winter, coastal upwelling at several locations during the austral summer-autumn results in localised increases in surface phytoplankton (as indicated by chlorophyll-*a* concentrations) and consequent increases in zooplankton biomass. Chlorophyll-*a* concentrations in the eastern GAB during summer-autumn are higher than those recorded in other parts of Australia, supporting a spawning biomass of pilchard in South Australia that is an order of magnitude higher than elsewhere in Australia.

Oceanographic circulation and upwelling models developed for this region show it to be subject to highly dynamic and annually variable wind and current induced upwelling. Season, year and sea surface temperature have been found to significantly affect the concentration and distribution of chlorophyll-*a* (indicating food availability), in turn driving dynamic seasonal shifts in distribution of pelagic species, annual spawning and recruitment success of pelagic species, and food availability for predators.

Dietary composition studies found the diets of key predators in the eastern GAB to be highly variable, depending on availability of alternative small pelagic fish and cephalopods (squid, octopus and cuttlefish) prey species. Little penguin and New Zealand fur seal diets varied between locations in the same season. Southern Bluefin Tuna diet samples indicate considerable variation between years with Pilchard and Anchovy being the most important prey on average, but ranging between years from almost zero in some years to over 90% in others. A conceptual food web model for the region detailing the trophic relationships between predator and prey species illustrated the wide range of prey that may alternatively be used by a number of predators, but highlighted the need for better information on the biomass and dietary composition of a number of predator groups.

FRDC Project 2005-031: Establishing ecosystem-based management for the South Australian Sardine Fishery: developing ecological performance indicators and reference points to assess the need for ecological allocations

Research to improve estimates of dietary composition and food-web models was continued by under this project which found that most of the consumption by the five key land-breeding apex predators (seabirds and marine mammals) consisted of fish (53%), squid (39%) and krill (7%)[16]. While small pelagic fish accounted for 28% of the total consumption and 52% of the total fish consumed in the eastern GAB, sardines only made up about 1% of the total prey biomass consumed by the five apex predators, and only 2% of the total fish biomass consumed. Marine mammals and seabirds were found to have wide foraging ranges in the eastern GAB, including large areas outside those used by the fishery. In comparison with these foraging ranges, the fishery is concentrated in a relatively small area focused on the mouth of the Spencer Gulf (see Figure 3), with large areas of the GAB where predators consume more fish than caught by the fishery.

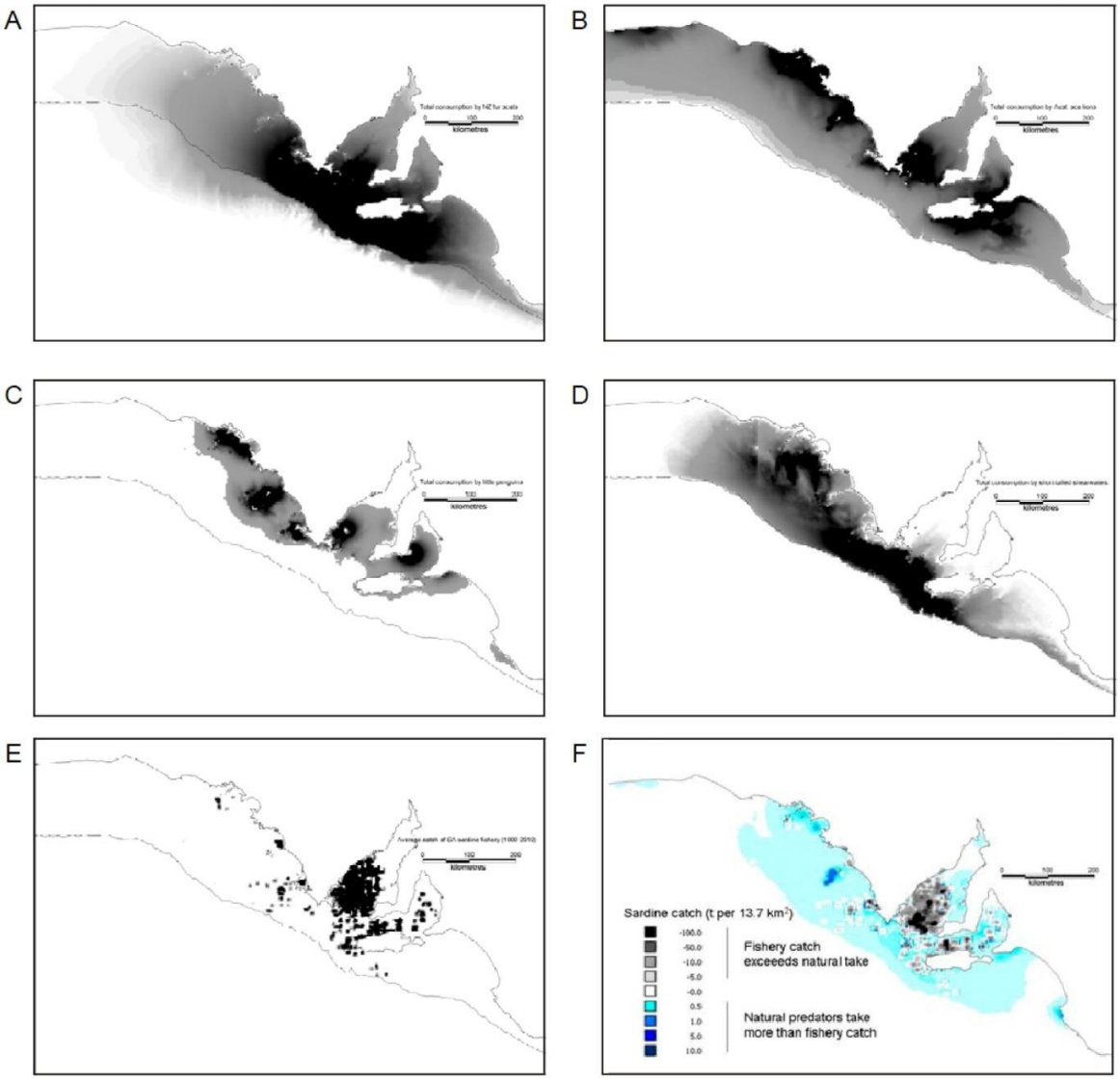

Figure 3. Estimated spatial distribution of foraging and consumption (tons/year) by four key land-breeding apex predators: A) New Zealand fur seal; B) Australian sea lion; C) Little penguin; and D) Short tailed shearwater (foraging outside of shelf waters excluded). Predator feeding ranges are compared with: E) Spatial distribution of the mean annual catch of Sardines (1999–2010) by the South Australia Sardine Fishery; and F) Overlap in relative fishery catch and apex predator consumption rates.

The total estimated consumption of sardines by these predators (753 t/year) is small relative to the current annual Total Allowable Commercial Catch (TACC) of 30,000 t for of the South Australian Sardine Fishery. Despite this, as a result of the conservative annual exploitation rates (in relation to estimated stock size) and the low average proportion of sardines in seabird and marine mammal diets in the region, impacts of the sardine fishery on feeding success by these predators is assessed to be low. Ecosystem models also predict negligible fishery ecological impacts on other predators.

FRDC Project 2008-023: The trophodynamics of small pelagic fishes in the southern Australian ecosystem and the implications for ecosystem modelling of southern temperate fisheries

This project expanded on previous ecosystem modelling work for the Great Australian Bight (GAB) and Eastern Bass Strait (EBS) areas, to improve understanding of the role of small pelagic species in the functioning of southern Australian ecosystems, particularly with respect to food web control[40]. Using the most recent developments in ecosystem modelling, this study found food webs and

higher tropic level biomass in both the GAB and EBS systems are largely controlled by initial productivity of plankton, so called 'bottom-up' controlled systems, although heavy fishing pressure and could result in food web changes in the EBS as a result of reduction in predator fish biomass, in a 'top-down' effect.

None of the small pelagic species in the southeast Australia ecosystem were found to occupy a strong controlling role at the mid-trophic levels, referred to as 'wasp-waist' control. In contrast, the modelling of heavy predation pressure on a high initial biomass of mesopelagic fishes and krill (both of which are known to occur in high abundance in these systems) produced the most significant results in this study, supporting the results of earlier studies showing the higher importance of these groups in comparison to the small pelagic fish species.

FRDC Project 2014-046: Technical workshop to explore options for mitigating marine mammal interactions in the Small Pelagic Fishery

In response to concerns arising from a number of interactions with Australian fur seals and common dolphins by a midwater trawler recently introduced into the Commonwealth SPF, a technical workshop was held under the auspices of the FRDC Small Pelagic Research Coordination Program to explore options for mitigating marine mammal interactions in the SPF[41]. This workshop brought together experts from around Australia and from New Zealand to explore options for mitigating marine mammal interactions in the SPF, and to develop recommendations to mitigate interactions with marine mammals.

Workshop presentation provided a substantial amount of information on current best practice relating to reducing interaction rates, or mortalities resulting from interactions, including options relating to operational fishing practices (areas, times of day, vessel behaviour), gear use (minimising opportunities for interaction, reducing likelihood of entry into nets), technological approaches (escape devises, acoustic deterrents, underwater cameras) and development of adaptive and responsive codes of practice adapted to individual areas, fleets and fishing methods. Based on this information, the workshop made a number of recommendations relating to:

- Developing an industry Code of Practice documenting procedures for mitigating the interactions of SPF mid-water trawlers with marine mammals.
- Re-establishment of the AFMA Marine Mammal Working Group to provide ongoing advice on improvement of mitigation measures.
- Improved monitoring, reporting, collation and analysis of all data relating to marine mammal interactions.
- Estimation of marine mammal population sizes and establishment of biologically appropriate species-specific trigger limits for marine mammal populations.
- Ongoing development, improvement and performance monitoring of technological mitigation measure, including escape devices and acoustic deterrents.

Effective responses to these recommendations should result in the marine mammal mitigation measures implemented in Australia pelagic meeting expectations for international best practice, improve the understanding of causes of interactions, and result in implementation of measures to ensure ongoing reduction in fishery-related marine mammal mortalities.

FRDC Project 2015-235: Critical knowledge gaps: estimating potential maximum cumulative anthropogenic mortality limits of key marine mammal species to inform management

In response to the recommendations emanating from FRDC Project 2014-046: *Technical workshop to explore options for mitigating marine mammal interactions in the Small Pelagic Fishery,* this project was established to inform management for key marine mammal species. This project collated expert information, including by holding an expert technical workshop, to review existing

data on abundance and distribution of key marine mammal species that overlap with the area of the SPF, and using a semi-quantitative structured approach, elicit expert consensus on estimating sustainable Potential Biological Removal (PBR) levels for these key species[42].

The outputs of the Expert Elicitation found that while recent abundance data were available for the seal species considered (Australian sea lion, Australian fur seal and long-nosed fur seal), available data on dolphin population structure and size were extremely limited.

Key project results include:

- The technical workshop produced a synthesis of available data and highlighted key data gaps with respect to abundance, distribution and population structure of marine mammal species. The participants agreed that expert elicitation was not an appropriate method for estimating population abundance where empirical data was lacking.
- The project identified that in order to use methods such as PBR to calculate limits to anthropogenic mortality to a given population, the key data required is a recent robust estimate of abundance and the spatial extent of that population.
- PBR calculated for long-nosed fur seal ranged from 81 to 4,498 depending on the spatial management zone considered. For Australian fur seals estimated PBR for a single management zone ranged from 2,623 to 4,721.
- A PBR of 261 individuals was calculated for short-beaked common dolphins in management zone 3. This PBR was based on an abundance estimate obtained in a small part of the zone. PBR assumes that the abundance estimate is for the total population, this may not be the case, given the small area surveyed and recent studies of population sub-structure in the region.

SESSF Blue Grenadier Fishery

FRDC Project 1997-115: Modelling the population dynamics of high priority SEF species

The entry of several large factory trawling vessels from New Zealand into the Blue Grenadier winter spawning fishery after 1997 increased the catches and economic returns from the fishery. This also resulted in accidental fur seal mortalities, raising concerns at the risk drowning of seals and sea lions caught in midwater trawl nets. This led to the first trialling of seal excluder devices on the nets of these vessels during the 2000 and 2001 winter fishery[21].

FRDC Project 2001-008: Assessment of seal–fishery interactions in the winter Blue Grenadier Fishery off west Tasmania and the development of fishing practices and Seal Exclusion Devices to mitigate seal bycatch by factory trawlers

In response to the apparent risk of mortality of fur seals in midwater trawl nets in the Blue Grenadier winter spawning fishery, this substantial project was established:

1. To improve the effectiveness of Seal Exclusion Devices (SEDs) in Blue Grenadier trawl nets in reducing seal mortalities and minimising losses of fish.
2. To assess the effectiveness of fishing techniques aimed at minimising seal bycatch.
3. To gather biological information from all seal fatalities.
4. To achieve full observer coverage of freezer-trawler activities during the 2001 and 2002 winter grenadier fishery and monitor seal numbers around vessels and all seal-trawl interactions.
5. To gather information on seal movement/residence-time in the winter grenadier fishery.

Seal bycatch by three freezer trawlers in the winter spawning fishery in 1999 caused the observed deaths of an estimated 83 seals, prompting the development of a program to mitigate seal bycatch in this fishery, the principal components of which were a Code of Fishing Practice aimed at avoiding seals and conducting trials of Seal Exclusion Devices (SEDs) in trawl nets[37]. SED trials were

conducted on the only two large freezer trawlers in the fishery during 2000 to 2003, and a Code of Fishing Practice was implemented that included: actively steaming away from seals before shooting the trawl net; removing meshed fish ('stickers') from the net prior to use; and no discarding of unwanted fish or offal on the fishing grounds.

Comparison between fisheries data for the 1999 season and equivalent data for the 2000 to 2003 seasons indicated that adopting the Code halved the incidence of seal bycatch per trawl shot. Various alternative SED designs were tested, although the total numbers of seals interacting with the trawl net and seals successfully exiting the net via the SED escape hatch during this study remained uncertain because underwater video footage was limited by water conditions. The use of SEDs enhances the survival rates of seal bycatch by preventing entry into the net codend where most seal drownings seem to occur. During these trials, an overall 2000–2003 seal bycatch survival rate of 48% occurred in midwater trawl nets with a SED, compared to zero survival for nets without a SED.

This project recommended: the use of open, forward-facing, 'top-hatch' SEDs in all midwater trawls; continuing the Code of Fishing Practice; continued shot-by-shot recording of seal bycatch in logbooks and maintain a level of scientific observer coverage and biological data collection. It was also recommended that continued trials be conducted on 'top-hatch' SEDs using improved underwater filming to document the timing and depth–frequency of net entry by seals, and the circumstances of net entry that place seals at risk.

Macquarie, Heard and McDonald Islands Toothfish fisheries

FRDC Project 2006-042: Demersal fishing interactions with marine benthos in the Australian EEZ of the Southern Ocean: An assessment of the vulnerability of benthic habitats to impact by demersal gears

The Australian sub-Antarctic Toothfish fisheries have reported few interactions with seabirds or marine mammals, with 13 seabirds interactions (11 deaths) and 16 seal interactions (13 deaths) reported in the HIMI trawl fishery, and 3 seabirds (no deaths) and 3 seals (all dead) in HIMI longline fishing, up to 2003[43]. Under their 2003 Antarctic Fisheries Bycatch Action Plan, AFMA put mitigation requirements in place, including: Marine Protected Areas in the HIMI and Macquarie Island fisheries where significant areas of seabed are closed to commercial fishing; prohibition on commercial fishing within 13 nautical miles of Heard Island and McDonald Islands; a range of mitigation measures that were successful in preventing any hooking of seabirds on longlines; and limits on the number of seabirds that may be incidentally taken in longline operations in the HIMI and high Antarctic fisheries.

These fisheries occur within the area covered by the Convention for the Conservation of Antarctic Marine living Resources (CCAMLR). In 2007, the United Nations General Assembly, in their Resolution 61/105 on Sustainable Fisheries, called upon regional fisheries management organisations (including CCAMLR) to identify vulnerable marine ecosystems (VMEs) within their areas of jurisdiction, and to implement measures to protect such VMEs from significant adverse impacts from fishing. By 2005 CCAMLR had already included a requirement into conservation measures relating to exploratory fisheries for Toothfish, to prohibit fishing in depths less than 550 m in order to protect benthic communities. The CCAMLR also initiated a process to define VME species occurring in the CCAMLR area, identify areas where these species are known or likely to occur, and implement measures to protect these from the effects of fishing. Within the CCAMLR context, VMEs are considered to be 'protected species'.

This FRDC project was therefore initiated:

- To assess the vulnerability of benthic communities in Subantarctic (Australian AFZ) and high latitude areas of the Southern Ocean (Australian EEZ) to demersal fishing using trawls, longlines or traps, using video and still camera technologies; and
- To recommend mitigation strategies by avoidance or gear modification, where identified to be needed, and practical guidelines to minimise fishing impacts on benthic communities.

This project successfully developed a versatile camera system that was deployed on trawls and longlines during commercial and research fishing activities in the EEZ at HIMI, BANZARE Bank and East Antarctica[44]. This provided direct evidence on the nature and extent of demersal longline interactions in the deep ocean, as well as documenting the types of habitats and organisms on the seafloor where fishing takes place.

This information enabled the development of an assessment model to estimate the amount of disturbance caused by the fishery. This assessment indicated that the majority of vulnerable organisms live on the seafloor in depths less than 1200 m, overlapping with the depths targeted by the trawl fishery, and to a lesser extent by the longline fishery. Due to the fact that the majority of trawling occurs on a few relatively small fishing grounds, less than 1.5% of all the biomass in waters less than 1200 m is estimated to have been impacted. The HIMI Marine Reserve, established in 2003, is estimated to contain over 40% of the biomass of the groups of benthic organisms considered to be most vulnerable to bottom fishing in the area. Overall, an estimated 0.7% of the seafloor area within the EEZ at HIMI has had some level of interaction with bottom fishing gear between 1997 and 2013.

The results of this project provide a process for assessing the levels of disturbance by bottom fishing which complements the existing processes that have been developed recently to conduct the Ecological Risk Assessment for the Effects of Fishing (ERA-EF) in other Commonwealth fisheries, as well as further measures later developed by CCAMLR to avoid significant adverse impacts to vulnerable marine ecosystems.

(c) Social and economic impacts, including effects on other commercial fishing activities and recreational fishing

Depletion versus localised depletion

Social and economic impacts of commercial fishing, as they pertain to effects on other sectors, relate mainly to the risk of reducing the availability of targeted fish stocks, reducing either the opportunity for other sectors to catch them, or the quantities or sizes of fish that other sectors may be able to catch. This can occur as a result of stock depletion, which will reduce the availability of fish to all sectors, including recreational fisheries. This needs to be dealt with by determining the long-term sustainable catches that can be taken from a resource, limiting overall catches to within these levels, and implementing appropriate sharing arrangements to apportion these sustainable catches between sectors. Ensuring the sustainability of fisheries is dealt with under Section (a)(i) above.

Reductions in availability of fished stocks to other sectors might also occur in limited areas, despite the overall stock size being maintained at sustainable levels, if fishing results in localised depletion in limited geographical areas that persists for long enough to reduce availability to other sectors in those areas. The primary factor driving the likelihood that localised depletion may occur is the rate at which the species concerned are capable of moving, to re-occupy areas from which fish have been removed by the fishery.

Localised depletion may be a problem, for example, for species such as abalone that are usually resident on individual reefs, with low movement rates to re-occupy areas depleted by over-fishing. In contrast, localised depletion has not been found for migratory species such as tunas or small pelagic fish, for which reduction in availability in particular areas has been the result of overall depletion and

resulting range contraction of the stock. FRDC-funded research has not directly investigated this question, but some insights into the likelihood of this occurring have arisen from the research below.

FRDC Project 2000-125: Implementation of an age structured stock assessment model for Sardine (Sardinops sagax) in South Australia

Research into the South Australian Sardine Fishery has provided an important insight into the dynamics of distribution patterns of the South Australian sardine resource at different stock sizes[3]. There were two disease-related mass mortality events in this resource in 1996 and 1998, as a result of which about 75% of the stock was lost each time, resulting in substantial overall depletion of this stock on both occasions. As a consequence of this stock depletion, the distribution range of the sardines (as shown by positions of catches) contracted to a small proportion of its previous range, being restricted to a small area off Port Lincoln, with disappearance of fish from much of their previously fished range.

Over the years 2001−03, the distribution range again expanded to at least three times its 2001 area as the stock rapidly recovered, with fish again becoming available in areas from which they had disappeared. This is a well-known phenomenon in over-exploited or otherwise depleted small pelagic resources, which contract to small areas of optimal or preferred habitat at low stock sizes. This can give rise to misconceptions regarding apparent 'localised depletion' in the areas from which fish have disappeared. However, this is range contraction as a result of overall stock depletion. In fact, the only place where sardines were still available after these depletion events was in the area that was then, and is still to this day, the most heavily fished area in the South Australian Sardine Fishery.

FRDC Project 2002-061: Development and evaluation of egg-based stock assessment methods for Blue Mackerel Scomber australasicus in southern Australia

From 2000 onwards, an increasing number of research projects have provided information on the relationship between distributions patterns of pelagic species, and oceanographic factors that affect their distribution. This research has primarily been concerned with determining the oceanographic conditions related to distribution of pelagic eggs and larvae, but has provided insights into environmentally driven movement of small pelagic species[4]. Knowledge of the oceanographic conditions in which eggs are likely to be found allows surveys to be planned to ensure coverage of the likely distribution area of eggs at the time of the survey, reducing the uncertainty in egg estimates and improving DEPM estimates of stock size. However, eggs occur in the vicinity in which they were spawned, and so the oceanographic factors related to egg distribution are those that favour spawning, which are therefore related to the distribution patterns of spawning adult females.

Modelling of the relationships between oceanographic parameters that might serve as predictors of egg occurrence found that the factors with the strongest relationships with egg abundance off eastern and southern Australia were latitude, sea surface temperature (SST) and salinity. The highest densities of eggs were sampled in water with SST between 18°C and 20.5°C and salinities between 35.35 and 35.5 parts per thousand (ppt), indicating that fish are choosing water masses of a preferred temperature, occurring in particular areas, in which to spawn. SST varies rapidly and substantially, seasonally and inter-annually, across these areas, as a result of seasonal cycles of cold upwelling (causing localised high plankton productivity), wind and current driven surface transport and subsequent warming. Pelagic species respond rapidly to these changes, with distribution patterns changing to follow water masses of preferred temperature (for spawning) or productivity (for feeding). This rapid and continual movement in response to oceanographic conditions results in fish moving to follow preferred water masses, substantially reducing the risk of localised depletion occurring.

Seafood CRC Project 2013-746: Optimising the size and quality of Sardines through real-time harvest monitoring

This project provided further information on the potentially rapid, environmentally induced, movement of small pelagic species. Whereas previous research into the environmental predictors of sardine distribution focussed on factors related to distributions of eggs, to improve the planning of DEPM surveys, this project extended this work to understanding how oceanographic conditions affect the distribution of juvenile and adult sardines[45]. In part, this research was designed to assist industry to set up a real-time predictive system to reduce catches of juvenile fish, and optimise chances of finding adult fish. Predictive models showed that the oceanographic factors that are most closely related to distribution of juvenile and adult sardines are sea surface temperature (SST), depth and chlorophyll-*a* concentration (productivity).

Juvenile and adult sardines were found to have different preferred habitats, with juvenile sardines being more likely to be found in shallow water less than 35 m depth with SST less than 17°C or greater than 22°C. Juvenile sardines (which are filter feeders on phytoplankton) also showed a preference to be in areas of very low or very high phytoplankton biomass at chlorophyll-*a* concentrations below 0.25 µg/l or above 1.65 µg/l. In contrast, adult sardines (which are mainly particulate feeders taking zooplankton) are more likely to be present in waters between 40 m and 85 m depth with SST ranging from approximately 17.5 to 21°C and low phytoplankton biomass at chlorophyll-*a* concentrations below 0.45 µg/l. Distributions of SST and chlorophyll-*a* vary substantially between years as a result of changes in wind patterns and upwelling intensity (see Figure 4). Seasonal and inter-annual changes in the distribution of preferred temperature and chlorophyll-*a* habitat for sardines result in substantial and rapid changes in the distribution patterns of fish as they move to occupy constantly shifting areas of preferred temperature and productivity (see Figure 5).

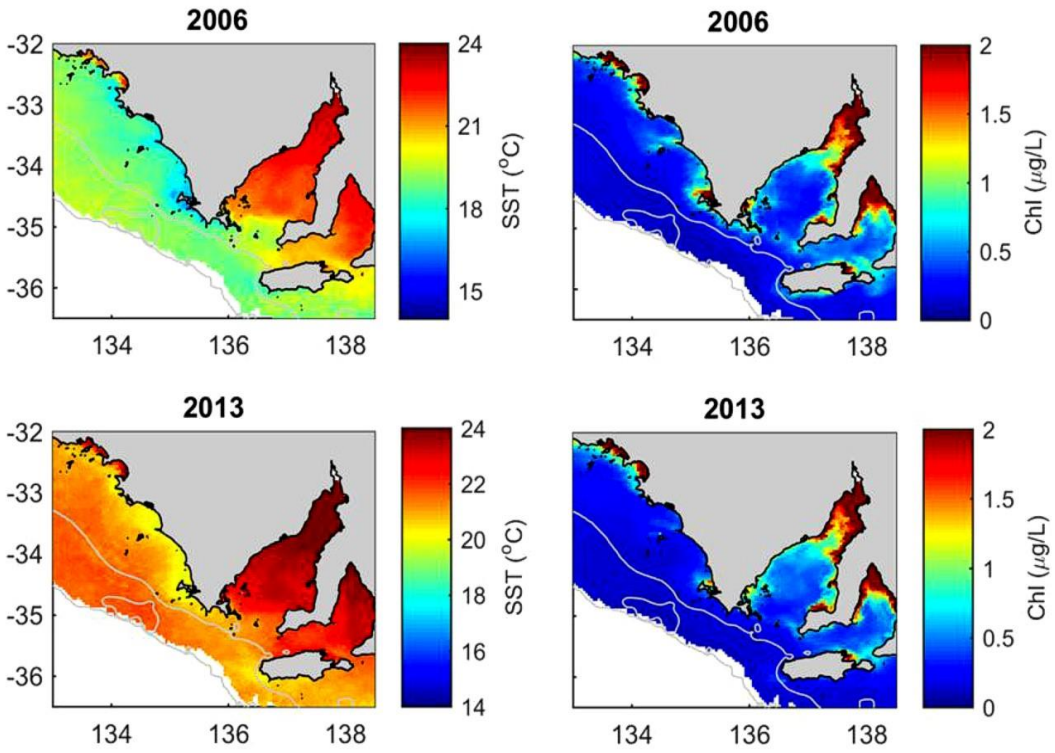

Figure 4. Comparison between the February-March average distributions of sea surface temperature (left) and chlorophyll-a concentration (right) in 2006 and 2013.

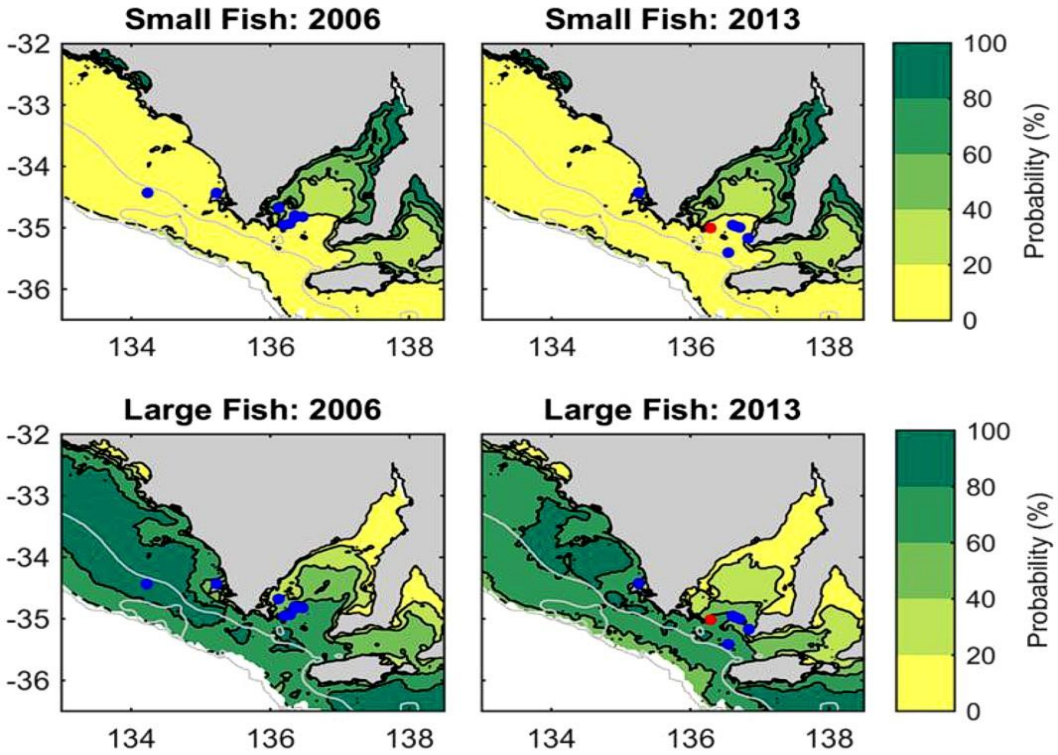

Figure 5. Comparison of the predicted probability (%) of preferred habitat for juvenile (top) and adult (bottom) sardines in 2006 and 2013, estimated from the distribution of February-March average SST and chlorophyll-a concentration in those years. Habitat maps are overlaid with the locations of juvenile (red dots) and adult (blue dots) fish caught by commercial vessels over this period).

FRDC Project 2013-028: Review and update of harvest strategy settings for the Commonwealth Small Pelagic Fishery - Single species and ecosystem considerations

Atlantic ecosystem modelling work[15] confirmed earlier ecosystem modelling results[16], finding that predators in the southern Australian pelagic ecosystem have low dietary dependence on the species harvested in the SPF, and that depletion of these species, individually or in combination, has only minor impacts on other parts of the ecosystem, including predator species. None of the key higher trophic level predators in southeast Australia, including a seals, penguins and tunas, were found to have a high dietary dependence on these species. Recommended maximum exploitation rates tailored to the individual productivity rates of the four SPF target species were also shown in ecosystem and population models to prevent stock depletion and maintain pelagic populations at or above depletion levels of 50% of unfished biomass.

Environmentally-driven movement of small pelagic species

As has been found in other upwelling ecosystems supporting substantial abundance of small pelagic species, FRDC funded research into the environmental drivers of pelagic fish distribution has shown that small pelagic species exhibit rapid movement and flexible distribution patterns, related to remaining within preferred water masses for feeding or spawning. This capability for rapid movement and redistribution greatly reduces the risk that fishing in any one area can lead to persistent localised depletion, provided that overall biomass is maintained at levels required for functioning of the ecosystem concerned.

6. Science Quality Assurance

In September 2012, Minister Ludwig, then Minister for fisheries, announced a review of Commonwealth fisheries legislation, following attention placed on Commonwealth fisheries, particularly the SPF, throughout August and September 2012. The resulting 'Borthwick Review' report, released in March 2013, identified potential improvements to make Commonwealth fisheries more sustainable, and meet industry and community expectations into the future. They key focus of the review related to aspects of the *Fisheries Management Act 1991* and *Fisheries Administration Act 1991*, and to AFMA's role as independent authority responsible for the management of Commonwealth fisheries, but the review did make some mention of requirements for science to inform this management.

In confirming that AFMA should remain the independent authority responsible for management of Commonwealth fisheries, Mr Borthwick emphasised that current governance, and the established process for the AFMA Commission to remain distinct from government allows, decisions to be made against objective criteria based on science, economic and other relevant analysis. Submissions by stakeholders noted the importance of peer review of science, and the importance of greater transparency, availability and understanding of the science used to inform fisheries management, to provide improved public understanding and trust that fisheries decisions are based on objective criteria and on scientific and economic analysis.

In response to the outcomes of the Borthwick review, and to wider calls for transparent processes to review and assure quality of science, the FRDC commissioned work to develop a *Science Quality Assurance Standard*, similar to such standards and guidelines adopted in the United Kingdom, European Union, Canada, United States and New Zealand.

FRDC Project 2014-009 - Development of guidelines for quality assurance of Australian fisheries research and science information

This project was initiated to develop a standard and guidelines for the peer review and quality assurance of research and scientific information intended or likely to inform fisheries and related environmental policy and management decisions. Based on a comprehensive review of national and international best practices for science quality assurance, this study will provide a draft standard and guidelines, including key principles for science quality, implementation guidelines and performance monitoring for science quality assurance processes[46]. An agency-specific plan for implementation of the science quality assurance key principles and quality assurance processes has been developed for AFMA, to illustrate how the Standard could be implemented in other jurisdictions.

A science quality assurance standard helps ensure that scientific evidence and information, and the process whereby the quality of this information is reviewed and ensured, is transparent, reliable and trusted by participants, stakeholders, government and the public. Such a standard contributes directly to a number of the FRDC strategic objectives, including promoting natural resource sustainability, providing a trusted basis for resource access and resource allocation and improving community and consumer support.

7. Appendix 1: Scientific Names of Cited Fish Species

List of standard common and scientific names of the fish species referred to in the text. Common fish names used are as specified in the Australian Fish Names Standard: www.fishnames.com.au.

Common Name	Scientific Name
Australian Anchovy	*Engraulis australis*
Australian Sardine	*Sardinops sagax*
Blue Grenadier	*Macruronus novaezelandiae*
Blue Mackerel	*Scomber australasicus*
Common Jack Mackerel	*Trachurus declivis*
Cuttlefish	*Sepia* sp.
Gould's Squid	*Notodarus gouldi*
King Gar (Saury)	*Scomberesox saurus*
Patagonian Toothfish	*Dissostichus eleginoides*
Pink Ling	*Genypterus blacodes*
Redbait	*Emmelichthys nitidus*
Silver Warehou	*Seriolella punctata*
Southern Bluefin Tuna	*Thunnus maccoyii*
Southern Calamari	*Sepioteuthis australis*

8. Appendix 2: FRDC-Funded Project Time Lines

FRDC Project	Abbreviated Project Title	Duration
		1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
Small Pelagic Fishery		
1998-130	A collaborative investigation on the usage and stock assessment of bait fishes in southern and eastern Australian waters	
2000-125	Implementation of an age structured stock assessment model for Sardine in South Australia	
2002-061	Development and evaluation of egg-based stock assessment methods for Blue Mackerel in southern Australia	
2002-236	Optimising at-sea post-harvest handling procedures for the Australian Sardine	
2003-072	Trophodynamics of the GAB: assessing the need for an ecological allocation in the SA pilchard fishery	
2004-039	Evaluation of egg production as a method of estimating spawning biomass of Redbait off the east coast of Tasmania	
2005-031	Establishing ecosystem-based management for the South Australian Sardine fishery	
2008-023	Trophodynamics of small pelagic fishes in the southern Australian ecosystem	
2009-021	Movement patterns and stock structure of Australian Sardine off South Australia and the east coast	
2013-028	Review and update of harvest strategy settings for the Commonwealth Small Pelagic Fishery	
2013-053	Summer spawning patterns and preliminary DEPM survey of Jack Mackerel and Australian Sardine off the east coast	
2013-063	Benchmarking Australia's small pelagic fisheries against world's best practice	
2013-064	Small Pelagic Research Coordination Program	
2014-022	Developing a rapid molecular identification technique to improve egg production based fish biomass assessments	final 2017
2014-026	Improving the precision of estimates of egg production and spawning biomass obtained using DEPM	
2014-033	Egg distribution, reproductive parameters and spawning biomass of Blue Mackerel, Australian Sardine and Tailor	
2014-046	Technical workshop to explore options for mitigating marine mammal interactions in the Small Pelagic Fishery	
2015-035	Establishment of trigger limits for key marine mammal species that overlap with the Commonwealth Small Pelagic Fishery	

FRDC Project	Abbreviated Project Title	Duration
		1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016
South East Scalefish and Shark Fishery - Blue Grenadier Fishery		
1997-115	Modelling the population dynamics of high priority SEF species	
2000-102	Spawning and reproductive biology of Blue Grenadier in south-eastern Australia and off Western Tasmania	
2001-008	Assessment of seal–fishery interactions in the winter Blue Grenadier fishery off west Tasmania	
2003-044	Development of a sustainable industry-based acoustic observation system for Blue Grenadier	
2005-006	The influence of environmental factors on recruitment and availability of fish stocks in south-east Australia	
2006-028	Implementation of a Fishery Independent Survey for the Southern and Eastern Scalefish and Shark Fishery	
2007-030	Use of otolith chemistry to assess the stock structure of blue grenadier in the Commonwealth Trawl and GAB fisheries	
Macquarie, Heard and McDonald Island Toothfish Fisheries		
2000-109	Stock Assessment and Management Strategy Evaluation for Sub-Antarctic Fisheries	
2006-042	Demersal fishing interactions with marine benthos in the Australian EEZ of the southern ocean	
2008-046	Evaluating gear and season specific age-length keys to improve stock assessments for Patagonian Toothfish	
2010-064	The spawning dynamics of Patagonian Toothfish in the Australian EEZ at Heard Island and the McDonald Islands	
2013-013	Development of robust assessment methods and harvest strategies for Toothfish fisheries in the Southern Ocean	final 2017
National Fisheries Status Reports		
2011-513	Status of key Australian fish stocks reports 2012 - the inaugural process of production and lessons learned	
2012-513	Status of key Australian fish stocks reports - review of the 2012 reporting process and planning for future reports	
2014-030	Status of key Australian fish stocks (SAFS) reports 2014 and beyond	
2015-034	Status of Australian Fish Stocks (SAFS) reports 2016, and further development of the SAFS production and dissemination system	
Science Quality Assurance		
2014-009	Development of guidelines for quality assurance of Australian fisheries research and science information	

9. Appendix 3: References Cited

Listed in the order in which they are cited in the text

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