A reporting framework for ecosystem-based assessment of Australian prawn trawl fisheries: a Spencer Gulf prawn trawl fishery case study

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ABBREVIATIONS

CCSA	Conservation Council of South Australia
eNGO	environmental non-government organisation
DSEWPaC	Department of Sustainability, Environment, Water, Population and Communities
EBFM	ecosystem-based fisheries management
EPBC Act	Environment Protection and Biodiversity Conservation Act (1999)(Cth)
ERAEF	ecological risk assessment of the effects of fishing
ESD	ecologically sustainable development
FHA	Fishery Habitat Area
FRDC	Fisheries Research and Development Corporation
MSC	Marine Stewardship Council
PIRSA	Primary Industries and Regions South Australia
SARDI	South Australian Research and Development Institute
SGPF	Spencer Gulf Prawn Fishery
SGWCPFA	Spencer Gulf and West Coast Prawn Fisherman's Association
TEPS	threatened, endangered and protected species

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2 EXECUTIVE SUMMARY

This Tactical Research Fund Project has been undertaken by SARDI Aquatic Sciences in response to the Spencer Gulf Prawn Fishery's (SGPF) need for an ecosystem-based reporting framework to support ongoing Marine Stewardship Council (MSC) certification. We reviewed the relevant literature to identify an appropriate reporting framework, assessed the data available for the SGPF, and its suitability for use in ecological assessment, developed a conceptual ecosystem-based assessment framework for the fishery and highlighted the research required (i.e. knowledge gaps) for full implementation. The approach developed would be of use to other prawn trawl fisheries that were seeking a transition from target-species to ecosystem-based assessments to underpin ecosystem-based fisheries management (EBFM) and ecologically sustainable development (ESD).

There is worldwide recognition of the need to move beyond single-species fisheries management to a more comprehensive understanding of the impacts on the ecosystem in which fisheries operate. ESD concepts were expanded into a global action plan at the UN Conference on Environment and Development in Rio de Janeiro in 1992 and ratified by countries including Australia, leading to the National Strategy for ESD and the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). EBFM facilitates ESD and has been recognised worldwide as having the potential to provide a mechanism for integration of ecosystem attributes into fisheries management. For EBFM to be effective, development of appropriate frameworks to integrate ecological and target species data are required.

Prawn fisheries are an important contributor to Australian fisheries production (17,000 t valued at $266 million in 2011/12; Skirtun et al. 2013). Given the evolving need to manage fisheries in a more ecologically sensitive manner, there has been increased environmental awareness of the biological impacts of trawling. Whilst these impacts are difficult to assess because of the complexity of the biological communities and frequent limited understanding of their variability, there is an opportunity to establish a framework for ecosystem-based assessment of the SGPF that could be broadly adopted across benthic prawn trawl fisheries in Australia.

The SGPF operates in Spencer Gulf in South Australia (SA), produces approximately 1,800 t of Western King prawns annually, and is the third most valuable prawn fishery in Australia ($30.3M in 2010/11) behind the Queensland East Coast Otter Trawl Fishery ($90M) and Commonwealth Northern Prawn Fishery ($62.2M).

The overall aim of this project was to develop an environmental reporting framework for Australian prawn trawl fisheries using the SGPF in SA as a case study. Our approach included (i) a review of relevant literature to identify an appropriate reporting framework; (ii) a review of data available for the SGPF, and its suitability for use in ecological assessment; (iii) development of an ecosystem-based assessment framework for the SGPF including identification and development of potential performance indicators; and (iv) the research required (i.e. knowledge gaps) to fully develop the necessary ecological performance indicators for full implementation.

Despite the substantial, diverse, often long-term data sets available for the SGPF, most of the data have been collected for stock assessment of the target species. This resulted in development of a conceptual, rather than a complete ecological assessment framework. Implementing ecological assessment in the SGPF requires further development of relevant performance indicators and reference points across each of the five key ecological components identified as important for fishery management – (i) habitats; (ii) ecosystems (ecological communities/trophodynamics); (iii) target species; (iv) non-target species including by-product and by-catch; and (v) threatened, endangered or protected species (TEPS) – and the development of a framework linking ecological and target species assessments (with decision rules to drive management decision making through the formal management plan for the fishery). While some potential performance indicators, reference points and decision rules have been developed through this project, successful implementation necessitates that these should be developed collaboratively. This process should include at least Primary Industries and Regions SA (PIRSA) Fisheries and Aquaculture, Spencer Gulf and West Coast Prawn Fishermen's Association (SGWCPFA), SARDI and the Conservation Council of SA (CCSA) and needs to recognise the considerable spatial and temporal (both inter-annual and seasonal) variation evident in the five key components across Spencer Gulf and the numerous potential impacts on the Spencer Gulf environment (e.g. other fisheries, aquaculture, shipping, harbours and wharfs, pollutants, climate change).

3 INTRODUCTION

3.1 Background

There is worldwide recognition of the need to move beyond single-species fisheries management to a more comprehensive understanding of the impacts on the ecosystem in which fisheries operate (Hilborn 2011). Following recognition of the interrelationships between continued economic and social development and the health of the environment at the 1972 United Nations (UN) Conference on the Human Environment in Stockholm, there was a substantial shift in the public perception of the potential impacts of human activities on the environment (Fletcher 2002). Release of the UN World Commission on the Environment and Development (WCED) report '(WCED 1987)' which defined sustainable development as "to meet the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987) led to a major change in international policy (Fletcher 2002).

Sustainable development concepts were expanded into a global action plan at the UN Conference on Environment and Development in Rio de Janeiro in 1992 and ratified by countries including Australia (Fletcher 2002). In 1992, the Australian and State governments agreed to endorse environmentally sustainable development, leading to the National Strategy for ecologically sustainable development (ESD; CofA 1992). The National ESD Strategy provides the major policy document for sustainable development in Australia and defines ESD as "using, conserving and enhancing the community's resources so that ecological processes, on which life depends are maintained, and the total quality of life, now and in the future, can be increased" (CofA 1992).

In Australia, all three levels of government (local, State, and Commonwealth) have agreed to implement ESD for all activities under their jurisdiction using 'whole of ecosystem' and 'bioregional approaches' based on ecosystem boundaries rather than sectoral and jurisdictional boundaries (Fletcher et al. 2011). For the past decade, the management of Australian fisheries has used an ecosystem-based approach (Fletcher et al. 2002) which was designed to meet the legislative changes and policy initiatives introduced at both the State and Commonwealth level, following proclamation of the *Commonwealth Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act 1999). The two key principles of the EPBC Act 1999 relevant to fisheries management are that (i) a fishery must be conducted in a manner that does not lead to overfishing, or for those stocks that are over-fished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover; and (ii) fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem. Requirements for ecologically sustainable management of fisheries under the EPBC Act 1999 (and other Acts) are implemented through the principles of ESD and associated risk assessments of individual fisheries, for which the processes are well described in Fletcher et al. (2002, 2005).

Ecosystem-based fisheries management (EBFM) is an operational extension of ESD and has been recognised worldwide as having the potential to provide a mechanism for integration of ecosystem attributes into fisheries management (FAO 1995, 2003; Pikitch et al. 2004). Fletcher (2006) defined EBFM as the assessment and management of all impacts and outcomes related to any commercial, recreational, charter, customary, or ‘no take’ sector operating within an ecosystem or bioregion. For EBFM to be effective, development of appropriate frameworks to integrate ecological and target-species data are required.

Prawn fisheries are an important contributor to Australian fisheries production. In 2010/11, Australian prawn fisheries were worth $266 million, placing them third in value after rock lobster ($384 million) and salmon aquaculture ($513M; Skirtun et al. 2013). In terms of volume, Australian prawn fisheries (22,537 t) were third after Australian sardine (41,319 t) and salmon aquaculture (73,989 t; Skirtun et al. 2013). Annual production of Australian trawl fisheries remained relatively stable from 2001/02 to 2011/12, with only a slight decline attributed to lower unit price (Skirtun et al. 2013). Wild-caught prawn fisheries are managed under State and Commonwealth jurisdictions with most production from Queensland, Western Australia and South Australia (Skirtun et al. 2013).

Whilst it has been recognised worldwide that there is an urgent need to manage fisheries in a more ecologically sensitive manner (Pitcher et al. 2009), and there has been increased environmental awareness on the biological impacts of trawling (Jennings and Kaiser 1998; Thrush and Dayton 2002), these impacts are difficult to assess because of the complexity of the biological communities involved and limited understanding of their variability (Messeih et al. 1991). Depending on habitat types and associated species, the environmental impacts of benthic trawl fisheries can be highly variable in nature and may require greater attention than other fishing methods due to their impact on the benthic environment, by-catch species and associated communities.

In response to Australia's growing commitment to ESD the 'National ESD Reporting Framework for Australian Fisheries' (Fletcher et al. 2002) and 'An assessment framework for ESD reporting' (Fletcher et al. 2005) were developed. Included in this framework was the acknowledgment of the broadening scope of responsibilities of management agencies and the need for a structured approach to address them. The aim of a reporting framework for environmental assessment of a fishery is to provide a logical process for identifying environmental concerns and steps to ensure strategies are implemented to manage them. An example of such an ecological risk management framework is that for Commonwealth managed fisheries (AFMA 2012).

Central to identifying environmental concerns and an effective reporting framework for ecological assessment is an ESD risk assessment. Australian fisheries management agencies have typically adopted the qualitative approach of Fletcher et al. (2002, 2005), but the ecological risk assessment of the effects of fishing (ERAEF) method (Hobday et al. 2007, 2011b) and other semi-quantitative and quantitative approaches (e.g. Stobutzki et al. 2001; Zhou and Griffiths 2008) are also used. Typically, these ESD risk assessments identify five principle components which are the effects of fishing on (i) habitats; (ii) ecosystems (ecological communities/trophodynamics); (iii) target species; (iv) non-target species including by-product and by-catch; and (v) TEPS (Fletcher et al. 2010; Hobday et al. 2011b). Evaluating the impact of fishing on target species and the ecosystem within which fishing occurs underpins ecosystem-based reporting frameworks. The two principal components are (i) a management plan with ecological and fishery performance indicators linked to decision rules through reference points; and (ii) an annual ecological assessment report which provides an evaluation of the performance of the fishery. To be effective, performance indicators, reference points, decision rules and management responses are required across all of the five key components identified above. It is also essential that the framework is regularly reviewed (e.g. every five years) to ensure currency and relevance. This broad ecological assessment approach can then support practical implementation of EBFM (Pikitch et al. 2004; Bustamante et al. 2011).

In South Australia, the *Fisheries Management Act 2007* (the Act) requires that ecological impacts be identified and assessed. The Act specifically requires that (i) current known impacts of the fishery on the ecosystem; (ii) potential impacts of the fishery on the ecosystem; and (iii) ecological factors that could have an impact on the performance of the fishery, are identified. An ESD risk assessment is required as part of fishery management plans in SA, to inform development of goals and objectives for the fishery. The ESD risk assessment report for the Spencer Gulf Prawn Fishery (SGPF) has recently been completed (PIRSA 2014a). That risk assessment identified ecological impacts which were qualitatively assessed through the ESD risk assessment framework developed by Fletcher et al. (2002). A semi-quantitative assessment of the species components identified from a 2007 by-catch survey was also done using Productivity Susceptibility Analysis (after Hobday et al. 2007, 2011b). Whilst ESD principles were followed for development of the risk assessment for the SGPF (PIRSA 2014a), EBFM provides the mechanism for implementing core ecological principles into fishery management, thereby supporting ESD. The principles of EBFM have been established for over a decade (Webb and Smith 2008), but it is only in recent years that EBFM frameworks have been developed and applied by Government agencies (e.g. for the West Coast Bioregion of Western Australia; Fletcher et al. 2010). Implementation of EBFM requires a framework for ecosystem-based assessments. This is particularly the case for benthic trawl fisheries given their low selectivity (Alverson et al. 1994), including the SGPF, despite the SGPF recently being certified by the Marine Stewardship Council. Consequently, the overall aims of this project were to (i) develop a generic framework for environmental assessment of Australian prawn trawl fisheries and, subsequently, (ii) develop a fishery-specific reporting framework using the SGPF in SA as a case study.

3.2 Overview of the South Australian Spencer Gulf Prawn Fishery

3.2.1 Description of the fishery

The SGPF operates in Spencer Gulf, SA (Figure 3-1), and is the third most valuable prawn fishery in Australia ($30.3M in 2010/11) behind the Queensland East Coast Otter Trawl Fishery ($90M) and Commonwealth Northern Prawn Fishery ($62.2M; (Dixon et al. 2013b). Compared to the West Coast and Gulf St Vincent prawn fisheries, the SGPF is the largest of the commercial prawn trawl fisheries in SA in terms of area, production and number of licences (Dixon et al. 2010). The SGPF produces approximately 1,800 t of Western King prawns annually (Figure 3-2). Commercial prawn trawling began in Spencer Gulf in 1967 (Carrick 2003). Catches and trawling intensity increased steeply over the first six years of the fishery. In 1973/74, more than 1,800 t of prawns were harvested with approximately 25,000 hrs of fishing effort. Since then, catches have remained relatively stable (~1,300-2,500 t; Dixon et al. 2013b). Fishing effort has declined from a peak of 45,786 hr in 1978/79 to 18,438 hr in 2007/08 (Dixon et al. 2013b). This effort reduction has resulted from a combination of increased fishing efficiency through co-operatively confining fishing to areas with target-sized prawns to reduce costs and maximise economic return (Currie et al. 2009).

Spatial and temporal closures are used in the management of the SGPF. Spatial closures include prohibiting trawling in waters <10 m depth, State aquatic reserves and areas that are closed by the commercial fleet on a voluntary basis. The fishery is generally closed in January and February, and from July to October each year. Gear restrictions limit vessel size and power, type and number of trawl nets towed, maximum headline length and minimum mesh size (Table 3-1). The SGPF targets a single species, Western King prawn (*Penaeus (Melicertus) latisulcatus*) and is also able to retain two by-product species (i) Balmain bug *(Ibacus* spp.) or slipper lobster; and (ii) southern calamary (*Sepioteuthis australis*). For a detailed description of the development and management history of the SGPF, see Dixon and Sloan (2007), Dixon et al. (2013b) and PIRSA (2014a,b). Management milestones are summarised in Table 3-2.

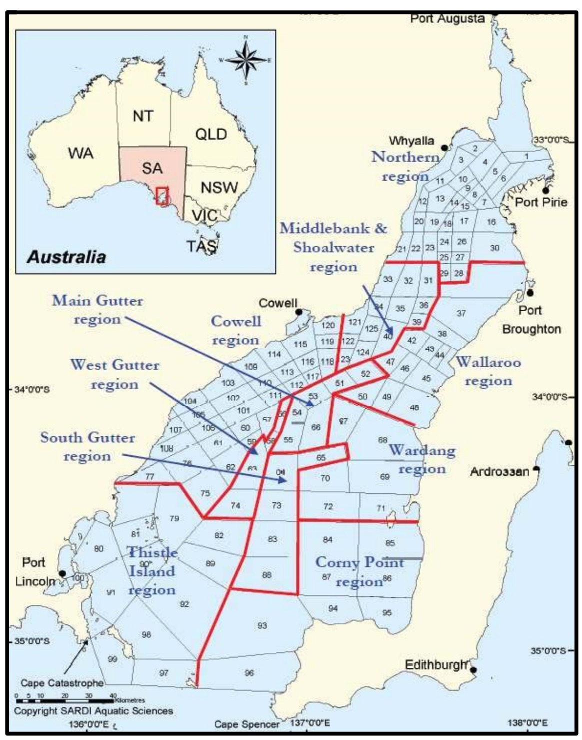

Figure 3-1 Map of the Spencer Gulf showing Spencer Gulf Prawn Fishery reporting blocks (black blocks with numbers) and regions (red blocks with names).

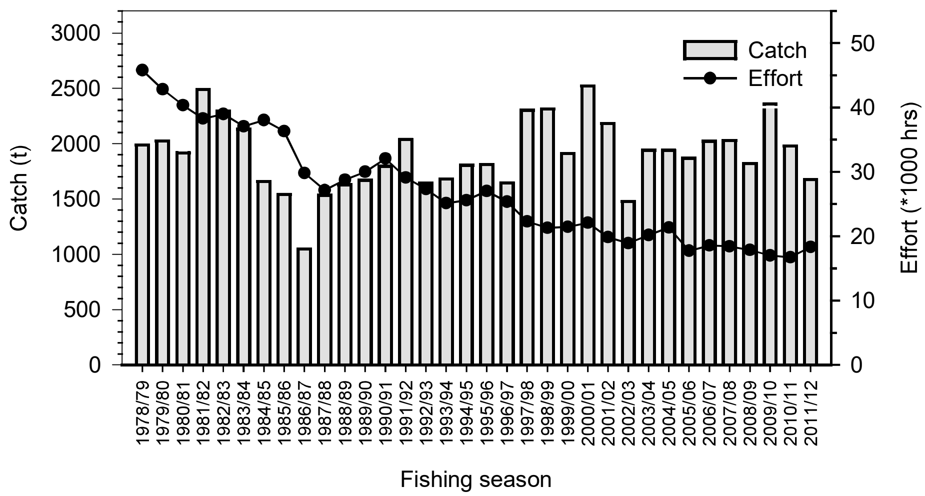

Figure 3-2 Annual catch and effort for the Spencer Gulf Prawn Fishery from 1978/79 to 2011/12.

There are generally six fishing periods within each year. Fishing occurs at night with each fishing period lasting a maximum of 14 nights from the last to first quarters of the moon in November, December, March, April, May and June. Trawl shots are generally up to 1 hr duration. Stock-assessment (fishery-independent) surveys are conducted in November, February and April to determine stock status and identify areas with high densities of target-sized prawns to inform fishing strategy development (Currie et al. 2009). Spot (fishery-dependent) surveys are also conducted at other times to identify areas of prawns that meet the size criteria of the latest fishing strategy. Fishing is then confined to those areas through a gazettal notice issued by PIRSA and fishing notices distributed by the coordinator-at-sea. A committee at sea, consisting of the coordinator at sea and several skippers, also undertakes 'real-time' management (RTM) to enhance fishing efficiency and reduce potential ecological impacts. No commercial fishing takes place until data from surveys has been analysed and the stock abundance and prawn size and spawning status are known. RTM gives the fleet the ability to adapt fishing, spatially and temporally, within the parameters of the fishing strategy, such that the fishery is managed based on the movement of prawns, their size, fishing effort and catch rates. The management committee (on land) establishes a fishing strategy with trigger limits in accordance with the management plan (PIRSA 2014b), while the committee at sea monitor all open areas, and implement changes according to the Spencer Gulf and West Coast Prawn Fisherman's Association (SGWCPFA) policies and the triggering of reference limits. This reflects the strong collaborations among all stakeholders, notably commercial fishers, managers and researchers (Hollamby et al. 2010)

Table 3-1 Current management regulations for the Spencer Gulf Prawn Fishery.

Characteristic	Description
Target species	Western king prawn (*Penaeus (Melicertus) latisulcatus*)
By-product species	Balmain Bugs (slipper lobsters; *Ibacus* spp.), southern calamary (*Sepioteuthis australis*)
Fishing method	Demersal otter trawl, predominantly double rig (single rig may also be used)
Area	Waters of Spencer Gulf north of the geodesic from 34°59.12’S, 136°09.18’E (Cape Catastrophe, Eyre Peninsula) to 35°17.99’S, 136°52.84’E (Cape Spencer, Yorke Peninsula)
Depth range	≥10 m
Fishing periods	Night only – generally last quarter to first quarter of moon during Nov, Dec, Mar-Jun
Catch and effort data	Daily and monthly logbook submitted monthly
Observer program	Fishery-independent observers for stock assessment surveys, no regular program for monitoring catch composition
Management methods	Input controls: limited entry, gear restrictions, spatial and temporal closures, maximum combined headline length 29.26 m, minimum mesh size 4.5 cm, maximum vessel length 22 m, maximum vessel power 336 kW (= 450 hp)
Legislation	*Fisheries Management Act 2007*, Fisheries Management (General) Regulations 2007, Fisheries Management (Prawn Fisheries) Regulations 2006
Management plan	Yes – PIRSA (2014b)
Annual harvest strategy	Yes – PIRSA (2014b)
Consultative forums	Spencer Gulf and West Coast Prawn Fishermen’s Association Inc.
Assessments under the EPBC Act	Protected species accreditation (Part 13) – Exempt status expires 29 October 2015; Export declaration (Part 13A) – yes
Certification for sustainability	Marine Stewardship Council certification 25 July 2011; reassessment July 2016
Licences	Limited entry; restricted to 39 (transferable) in 2013/14

Table 3-2 Management history for the Spencer Gulf Prawn Fishery.

Year	Management history
1967	First commercial catch of prawns recorded.
1968	All SA waters closed to trawling except for specific managed zones for which permits are offered and all waters less than ten metres are closed to trawling.
1969	The *Preservation of Prawn Resources Regulations 1969* is introduced and vessels licensed to fish for prawns.
1971	The two Spencer Gulf fishing zones are merged to form one.
1976	Fishers operating in Anxious Bay and Coffin Bay zones on the West Coast are offered the opportunity to switch to the Spencer Gulf zone.
1981	Industry closures of the waters north of Point Lowly and adjacent to Port Broughton to trawling.
1992	Coordinator at Sea appointed and implementation of Real Time Management.
1995	The *Fisheries (Management Committees) Regulations 1995* are introduced and provide a forum for the Spencer Gulf and West Coast Prawn Fishermen’s Association to play a major role in the management of the fishery.
1998	First Management plan for Spencer Gulf Fishery introduced.
2002	Industry closure of waters adjacent to Wardang Is. to Corny Point.
2007	Second Management plan for SGPF introduced.
2011	Co-management arrangements further developed and implemented (after Hollamby et al. 2010)
2011	Marine Stewardship Council (MSC) certification of fishery
2012	SGWCPFA Committee at Sea authorised to maintain fishing activities at sea.
2014	Third Management plan for SGPF introduced (PIRSA 2014b).

3.2.2 Legislative framework

National

Since the introduction of the Intergovernmental Agreement on the Environment in 1992 (which included the description of ESD principles, the conservation of biological diversity and ecological integrity, intergenerational equity and the precautionary principle) and the implementation of the EPBC Act 1999, Australian fisheries management objectives have broadened considerably and now explicitly include principles of ESD. The Australian Government defined ESD in the National Strategy as 'using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased' (National Strategy for ESD, 1992, p.6). The principles of ESD have been incorporated into fisheries legislation and management frameworks throughout Australia. The two key principles of the EPBC Act 1999 are that (i) a fishery must be conducted in a manner that does not lead to overfishing, or for those stocks that are over-fished, the fishery must be conducted such that there is a high degree of probability the stock(s) will recover; and (ii) fishing operations should be managed to minimise their impact on the structure, productivity, function and biological diversity of the ecosystem.

South Australia

The *Fisheries Management Act 2007* provides for the conservation and management of the aquatic resources of SA, the management of fisheries and aquatic reserves, the regulation of fishing and the processing of aquatic resources, the protection of aquatic habitats, aquatic mammals and aquatic resources and the control of exotic aquatic organisms and disease in aquatic resources; and for other purposes. Object 1 of the Act is to protect, manage, use and develop the aquatic resources of the State in a manner that is consistent with ESD: (i) protect the aquatic resources of the State from over-exploitation; (ii) aquatic habitats are to be protected and conserved; and (iii) aquatic ecosystems and genetic diversity are to be maintained and enhanced. The Act also requires that ecological impacts be identified and assessed, specifically (i) current known impacts of the fishery on the ecosystem; (ii) potential impacts of the fishery on the ecosystem; and (iii) ecological factors that could have an impact on the performance of the fishery (PIRSA 2014b). The three prawn fisheries in South Australia are managed by Primary Industries and Regions South Australia (PIRSA) under the legislative framework provided by the Act and specific regulations in the *Fisheries Management (General) Regulations 2007* and

Fisheries Management (Prawn Fisheries) Regulations 2006 which are subordinate to the Act.

In 2014, the management plan for the SGPF (PIRSA 2014b) was implemented under the *Fisheries Management Act 2007* to provide a strategic policy framework for the ecologically sustainable management of the fishery. The management plan aims to achieve outcomes consistent with broader Government objectives for the management of the marine environment. Policy drivers addressed by the management plan include (i) the National Strategy for ESD; (ii) the precautionary principle, as set out in the Intergovernmental Agreement on the Environment (1982); and (iii) the EPBC Act 1999. To achieve this, the management plan provides a formal harvest strategy for the fishery that includes decision rules that guide harvest strategy development for each fishing period within each season (PIRSA 2014b).

3.2.3 Reporting requirements

Under the prescribed regulations*,* licence holders in the SGPF are required to provide daily and monthly catch and effort data to SARDI Aquatic Sciences through logbook returns. Data provided in the logbook returns includes licence information, date(s), number of shots, fishing location (i.e. block number), trawl start and end time (providing trawl duration), trawl depth, GPS location of the mid-point of three trawl shots per night (first, middle (approximately 4^{th}), last), trawl speed, a count of the number of prawns from a 7 kg sample (termed bucket count), frozen catch by size grade, catch processed in brine, retained by-product and water temperature. As part of the requirement under the EPBC Act 1999, licensed fishers must also report any interactions of their fishing activity with threatened, endangered and protected species (TEPS) to PIRSA Fisheries and Aquaculture and the Commonwealth's Department of the Environment. Since 2007, licence holders have reported interactions of their fishing activity with TEPS to PIRSA Fisheries and Aquaculture using the 'Wildlife Interaction Identification Guide and Logbook' which are recorded against the corresponding catch and effort logbook number. Both forms are returned to SARDI Aquatic Sciences for collation and reporting purposes.

3.2.4 Current initiatives to reduce ecological impact

Since inception, the SGPF has implemented management practices that have substantially moderated the ecological impact of this fishery on Spencer Gulf, thereby contributing towards the principals of ESD and EBFM. Two of these – the hopper system and closed areas – were established to directly reduce impacts of the fishery on the ecology of Spencer Gulf. Other initiatives, implemented to improve prawn quality (and thus price) and/or fishing efficiency have indirectly reduced the impact of this fishery. These include ‘crab bags’, improved net designs and effort reduction.

The hopper system enables the total catch to be maintained in a ‘wet well’ with continuous water flow that efficiently separates by-catch from prawns. This system is supported by the use of ‘crab bags’, which contain the macro faunal by-catch. Collectively, these (i) prevent small by-catch species from being crushed; and (ii) enable the larger by-catch to be immediately returned to the marine environment, thereby likely improving the survival rates of the majority of species, particularly crabs, large fish, rays and sharks.

There are two areas that have been permanently closed to prawn trawling by the SGWCPFA. These are located at Wardang Island (established 2002) and Port Broughton (established 1981; see Table 5-2). Both were established to protect the benthic environment, including complex sponge beds, and juveniles of commercially important species, with the former also providing substantial protection to syngnathids. Two additional closures have been implemented seasonally since 1981 (Point Lowly and Cowell). These areas support sensitive benthic and syngnathid populations, along with typically being dominated by small prawns.

Although net size and mesh are controlled through regulation, the most effective nets have the foot line bouncing on or ‘tickling’ the muddy habitats. Development of lighter chains, which have replaced heavier designs that dug into the sea floor, allows them to be rigged to tumble across the muddy substrate. This reduces the volume of by-catch. In addition, periodic evaluation of the effectiveness of by-catch reduction devices has been undertaken (e.g. Dixon et al. 2014; Kennelly 2014).

Several initiatives have combined to reduce fishing effort (Table 5-2), which has substantially reduced the fishery’s potential impact on the Spencer Gulf environment. These include (i) fishing strategies concentrating fishing activity into areas with target-sized prawns, based on fishery-independent and spot surveys; (ii) relatively short trawl-shot duration; and (iii) long-term reductions in the number of nights fished. Notably, the number of nights fished has reduced from ~240 in the 1970s to ~50 since the 2000s.

3.2.5 Spencer Gulf Environment

Bathymetry and physical oceanography

Spencer Gulf and Gulf St Vincent are two of the largest marine incursions into continental Australia (Richardson et al. 2005). Shallow water depths, a high tidal range and highly saline waters support unique benthic habitats with a close relationship between the distribution patterns of sediments, benthic fauna and water depth (Richardson et al. 2005; Figure 3-3).

Spencer Gulf displays strong geographic differences in depth, temperature and salinity. Depth ranges to 60 m in the south of the gulf. There is a large gradient in temperature and salinity from north to south (Richardson et al. 2005), that also varies temporally. Spencer Gulf is classified as an inverse estuary because salinity increases towards the head of the Gulf due to high summer evaporation rates and minimal freshwater input. For example, mean annual salinity towards the head of the Gulf is typically ~45 ppt salinity (Nunes and Lennon 1986; Nunes Vaz et al. 1990), approximately 10 ppt above adjacent oceanic salinity levels.

In northern Spencer Gulf, water temperatures vary considerably with an average of 12^{o}C in mid-winter to 28°C in mid-summer (Nunes and Lennon 1986). Sea surface temperatures (SSTs) become gradually cooler from northern to southern Spencer Gulf and are considerably cooler in the adjacent open ocean (Dixon et al. 2010). Overall, SSTs in Spencer Gulf are lower (12-24°C) and more variable than in parts of tropical Australia which support commercially important *P. latisulcatus* fisheries such as Broome and Shark Bay in Western Australia (Nunes and Lennon 1986).

Key oceanographic features of Spencer Gulf are the Port Lincoln Boundary Current, which flows northward along the western coast and has a general clockwise water circulation (Figure 3-4). A high density current of saline water flows out of the Spencer Gulf (Bonaparte's Tongue) in autumn (Figures 3-5, 3-6), when water temperatures cool and higher salinity water at the head of the Gulf becomes too dense to maintain stability in the water column. This high density saline water then sinks and flows out of the Spencer Gulf (source Richardson et al. 2005).

Sedimentology

Spencer Gulf is a region of warm-temperate, heterozoan carbonate deposition. There are no permanent rivers bringing fresh water or terrigenous sediments to the Gulf. Low siliciclastic input and shallow water depths promote deposition of diverse heterozoan carbonates with large variations in grain size. The remains of bryozoans, rhodoliths (coralline algae nodules), bivalves and gastropods form gravels, which may also produce sands when broken down further by abrasion and bioerosion. Small benthic foraminifera, delicate bryozoans, articulated corallines and echinoids initially generate sand grains. Mud is created by the comminution of fragile components such as thin crustose corallines and articulated bryozoans.

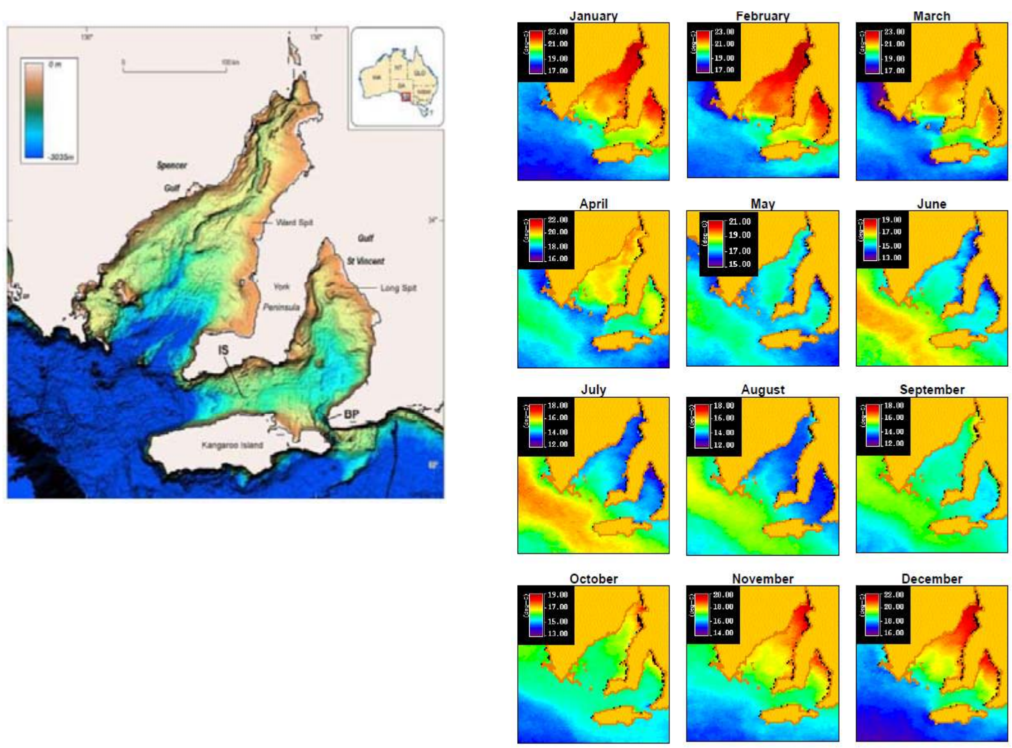

Figure 3-3 Bathymetry of Spencer Gulf (source Richardson et al. 2005, left panel) and average monthly sea surface temperature (SST °C) throughout the Spencer Gulf and Gulf St. Vincent. IS = Investigator Straight; BP = Backstairs Passage, between 2002-2007 (right panels, source: Tanner and Volkman 2009).

Spencer Gulf sediments can be divided into four main facies: (i) mollusc, coralline, benthic Foraminifera gravel, sand, and mud; (ii) coralline (rhodolith) gravel; (iii) bivalve mud; and (iv) skeletal sand and gravel (James and Bone 2011). The distribution of these facies is affected by complex oceanographic conditions (Figure 3-7).

Sediments in Spencer Gulf are predominantly sand and mud, with seagrass common at depths of <10 m (Dixon et al. 2010). The south-western corner of the mouth of the Gulf is dominated by rhodolith gravels, particularly around bathymetric highs where currents bring in oceanic marine waters from the shelf that scour the seafloor. Deeper parts of the south-eastern Gulf are dominated by skeletal sand and gravel. Seagrass meadows in the shallow coastal areas of the Gulf are associated with mollusc, coralline, benthic foraminiferan gravel, sand, and mud facies. The seafloors of the northern and central Gulf are dominated by muddy bivalve deposits because high salinities restrict the growth of other organisms (e.g. corallines, bryozoans, and echinoids).

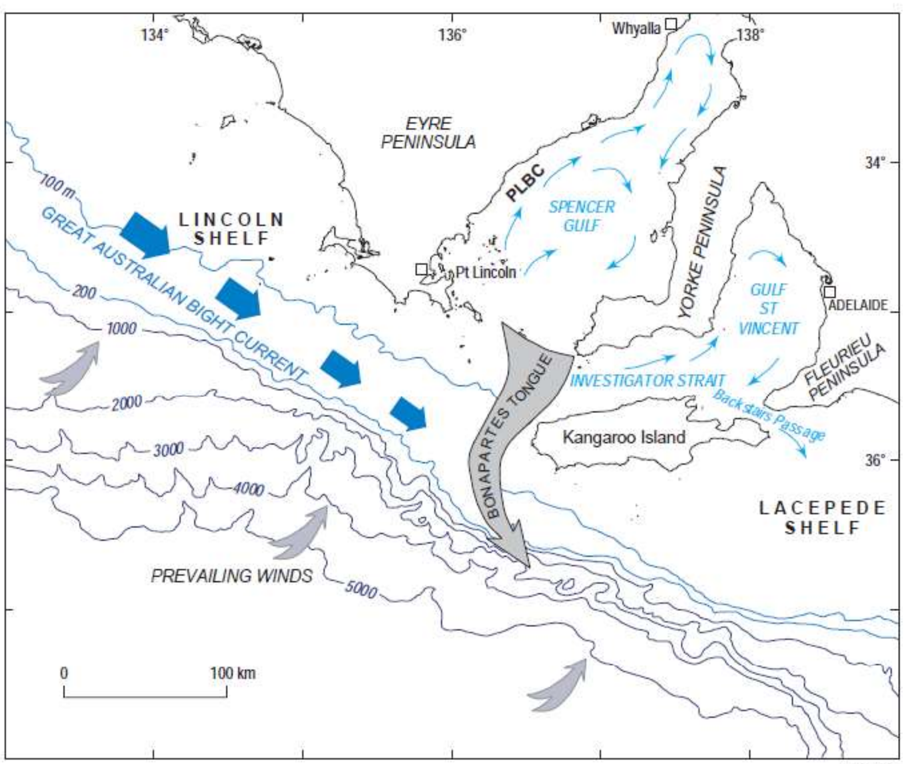

Figure 3-4 Key oceanographic features of Spencer Gulf and Gulf St. Vincent. In Spencer Gulf, light blue arrows (gross net flow) show the Port Lincoln Boundary Current (PLBC) which flows northwards along the western coast and the overall clockwise circulation. Large grey arrow shows high density saline water (Bonaparte's Tongue) which flows out of Spencer Gulf in the austral autumn (source Richardson et al. 2005).

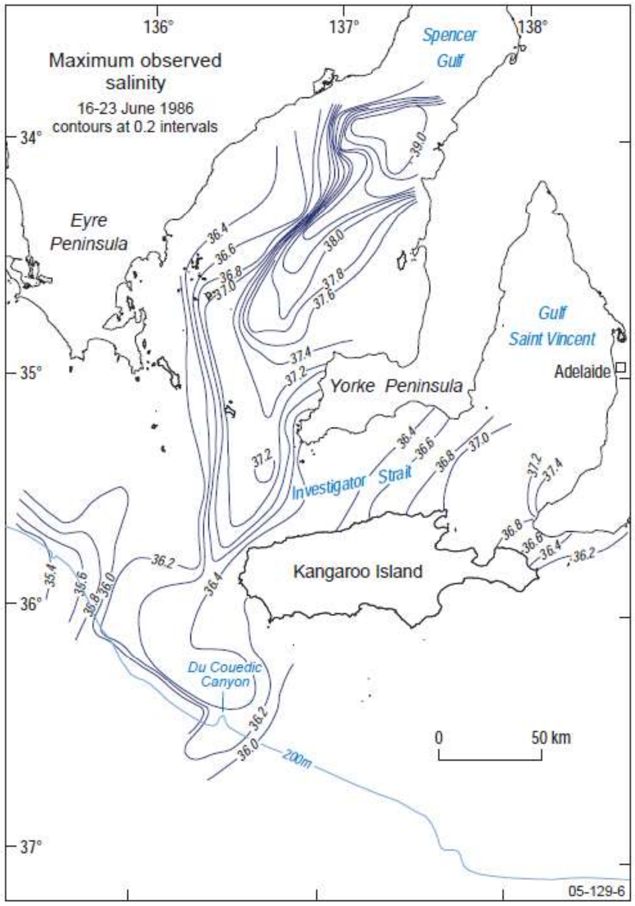

Figure 3-5 Aerial view of isohaline contours (maximum salinity) and Bonaparte's Tongue in southern Spencer Gulf during the austral autumn (source Richardson et al. 2005).

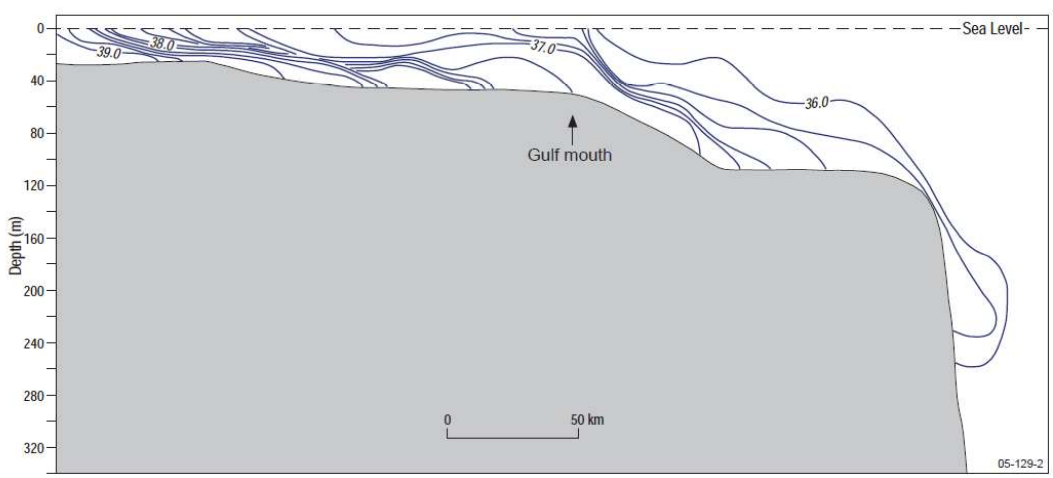

Figure 3-6 Profile of southern Spencer Gulf during the austral autumn showing isohaline contours (maximum salinity) and hypersaline bottom currents indicating Bonaparte's Tongue (source Richardson et al. 2005).

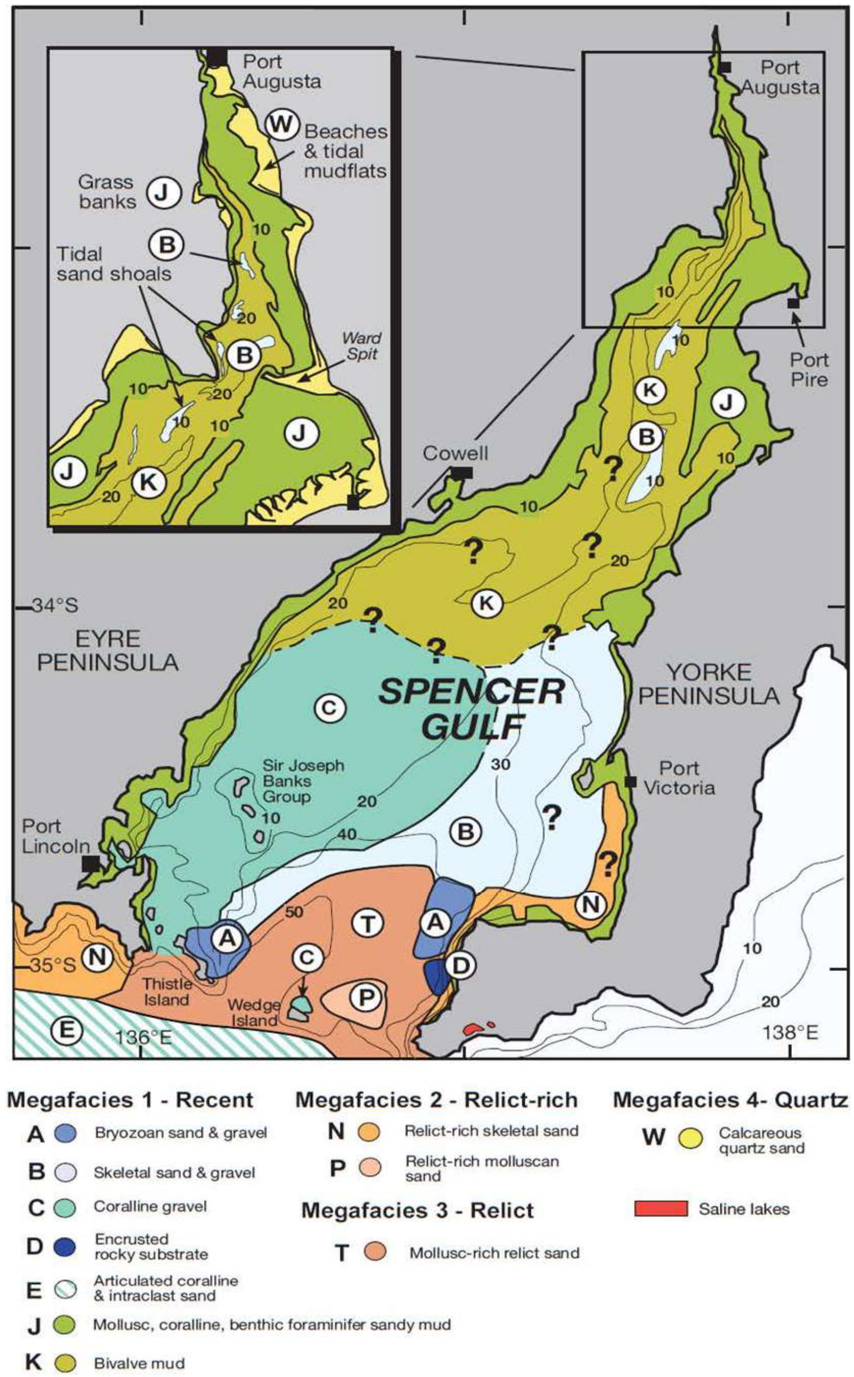

Figure 3-7 Sedimentology of Spencer Gulf (main map). Detailed surface sediment facies and environments in northern Spencer Gulf (insert, top left) (James and Bone 2011).

Relationships between bathymetry, physical oceanography, sedimentology and Western King prawns

In South Australia, juvenile Western King prawns occur predominantly on inter-tidal sand- and mud-flats, generally located between shallow seagrass beds and mangroves (Kangas and Jackson 1997; Tanner and Deakin 2001). In Spencer Gulf, seagrass habitats are common at depths <10 m where trawling does not occur (Currie and Sorokin 2010a). Juvenile abundance is significantly greater in the mid-intertidal zone compared to lower and upper zones of the Gulf (Roberts et al. 2005).

Dixon et al. (2013b) divided the Spencer Gulf coastline into Fisheries Habitat Areas (FHA 20, 23, 25-37, Thorny Passage to Formby Bay) following Bryars (2003). Of 12 identified habitat types, 'tidal flats' and 'mangrove forests' were assessed as appropriate juvenile prawn habitat. The percentage of coast (by length) that comprised juvenile habitat was estimated from the FHA maps and satellite images for two definitions of juvenile habitat (tidal flat only, combination of tidal flat and mangrove forest) (Bryars 2003; Dixon et al. 2013b). Juvenile habitat comprised 992 km (51%) of the Spencer Gulf coastline when all tidal flats were considered, and 245 km (25%) when only areas with adjacent tidal flats and mangrove forests were considered (Dixon et al. 2013b). The largest areas of juvenile prawn nursery habitat occurred in far northern Spencer Gulf, Germein Bay and False Bay (Dixon et al. 2013b). These results were supported by previous studies of juvenile prawn abundance in Spencer Gulf (Roberts et al. 2005). Dixon et al. (2013b) postulated that production in South Australia's prawn fisheries was related to the area of juvenile habitat.

3.3 Project approach

The overall aims of this project were to develop a generic framework for ecological assessment of Australian trawl fisheries and, subsequently, to develop a fishery-specific reporting framework using the Spencer Gulf Prawn Fishery (SGPF) in South Australia (SA) as a case study. To achieve these we first reviewed relevant literature to identify an appropriate generic reporting framework. Once the generic framework was established, we reviewed the literature and data available for the SGPF to develop an ecological reporting framework to inform ecological assessment for this fishery. This included identification and development of potential performance indicators and an outline of the research required (i.e. knowledge gaps) for full implementation of an ecological reporting framework for this fishery.

4 OBJECTIVES

1. Develop a reporting framework for environmental assessment of Australian trawl fisheries following the principles of ecosystem-based fisheries management;

By using the Spencer Gulf Prawn Trawl Fishery as a case study:

2. Collate and analyse existing data/information to address the environmental impacts of prawn trawling on: benthic habitats; trophodynamics; target species; and non-target species including by-catch/by-product and threatened, endangered and protected species;
3. Integrate existing data on trawl tracks using GIS to produce a continuous contour map representing the ecological foot-print of prawn trawl activities in Spencer Gulf;
4. Identify and prioritise future research to support ecosystem-based fisheries management.

5 METHODOLOGY

5.1 Ecological assessment framework

A review of the available literature, including relevant legislation, was conducted to develop a conceptual reporting framework. The key literature included the EPBC Act 1999, 'National ESD Reporting Framework for Australian Fisheries: The 'How To' Guide for Wild Capture Fisheries' (Fletcher et al. 2002), 'An assessment framework for ESD reporting' (Fletcher et al. 2005), the ecological risk management framework for Commonwealth managed fisheries (Hobday et al. 2007, 2011b; AFMA 2012), and alternative semi-quantitative and quantitative approaches (e.g. Stobutzki et al. 2001; Zhou and Griffiths 2008; Astles et al. 2009) including the regional assessment and planning tools developed in Western Australia (Fletcher et al. 2010; Fletcher et al. 2011). This approach was taken to ensure the developed generic framework was consistent with the ecosystem approach to fisheries (FAO 2003) and similar to that applied to ESD assessments in Australia. It was supplemented by reviewing information on the potential environmental impacts of Australian trawl fisheries (e.g. Svane 2003; 2005; Svane et al. 2007; 2008; 2009; Currie et al. 2009; 2011; Currie and Sorokin 2010a,b), and other projects that have developed ecological performance indicators for trawl (Bustamante et al. 2011; Piasente et al. 2012) and finfish (Goldsworthy et al. 2011; Hall and Wise 2011) fisheries.

5.2 Spencer Gulf Prawn Fishery case study

The SGPF was chosen as a case study for the development of a fishery-specific reporting framework. Relevant data and information were obtained from the previous and current management plans, stock assessments, published literature, SARDI databases, grey literature and student projects. This search included identification and summation of the data/information available for the fishery and its suitability for yielding performance indicators for ecosystem-based assessment of the SGPF. The example performance indicators identified were used to convert the conceptual reporting framework for ecological assessment of prawn trawl fisheries to a potential, more specific framework for the SGPF.

5.2.1 Scope of this study

The spatial extent of this study was constrained to the area of Spencer Gulf in SA where the SGPF operates (i.e. Cape Catastrophe, Eyre Peninsula, 34^{o}59.12'S, 136^{o}09.18'E to Cape Spencer, Yorke Peninsula, 34^{o}17.99'S, 136^{o}52.84'E; Figure 3-1). Excluded were the two areas where prawn trawling is prohibited: (i) waters <10 m depth; and (ii) aquatic reserves which have prohibitions on fishing. Locations of these reserves are described in the Act.

The study considered contributions of the fishery to ecological wellbeing which included (i) retained species; (ii) non-retained species; and (iii) the general ecosystem. Specifically, the scope of the ecological assessment encompasses and comprises the five ecological assets (components) identified in the ESD risk assessment and the supporting ecological risk assessment of the effects of fishing (ERAEF; PIRSA 2014a). Thus, this ecological assessment framework spans the potential impacts of the SGPF on (i) habitats; (ii) the ecosystem (ecological communities and trophodynamics); (iii) target and non-target species; (iv) by-product and by-catch and; (v) TEPS. This is consistent with the ecological values and objectives of the SGPF from PIRSA (2014b) which are outlined in Table 5-1.

Table 5-1 Ecological values and objectives relevant to the Spencer Gulf Prawn Fishery.

Value	Objectives
Habitat	Ensuring that impacts on habitat forming species kept at acceptable levels (Fletcher et al. 2010) Management plan Goal 3. Protect and conserve aquatic resources, habitats and ecosystems. 3c. Fishery impacts on benthic habitat and associated species are sustainable (PIRSA 2014b)
Ecosystem	Ensuring that any impacts on ecosystem structure and function are kept at acceptable levels (Fletcher et al. 2010) Management plan Goal 3. Protect and conserve aquatic resources, habitats and ecosystems (PIRSA 2014b).
Target Species	Keeping biomass levels above levels where recruitment could be affected (Fletcher et al. 2010) Management plan Goal 1. Future prawn biomass is maintained above sustainable levels (PIRSA 2014b)
Non-target species	Keeping biomass levels above levels where recruitment could be affected (Fletcher et al. 2010) Management plan Goal 3. Protect and conserve aquatic resources, habitats and ecosystems. 3a. Fishery impacts on by-product and by-catch species are sustainable; 3b. Fishery impacts on TEPS are sustainable (PIRSA 2014b)

5.2.2 Data and information sources

Data and information for ecological assessment of the SGPF were obtained from numerous sources. These included (i) historical catch, effort and fishing-location data from commercial logbooks provided by fishers to SARDI; (ii) the management plan for the SGPF (PIRSA 2014b) and stock assessment reports (e.g. Dixon et al. 2013b); (iii) estimates of retained weights of non-target species (i.e. southern calamary and Balmain bug; after Roberts and Steer 2010); (iv) prawn (and by-product) distribution, abundance and population length structure from fishery-independent surveys; (v) interactions of the SGPF with TEPS reported by fishers via the TEPS logbook to SARDI (after Tsolos and Boyle 2013); and (vi) estimates of by-catch from fishery-independent surveys (Dixon et al. 2005b; Svane 2003; Svane et al. 2007; Currie et al. 2009). Collectively, these sources were used to identify the data and information available for ecological assessment of the SGPF.

5.2.3 Data analysis and information synthesis

5.2.3.1 Habitat

In the absence of data and information on the composition and distribution of habitat types across Spencer Gulf in waters >10 m depth (e.g. sediment type, bottom cover, sessile species), we used the location and intensity of fishing effort as an index of the potential impact of the SGPF on the Spencer Gulf habitats. Using ArcGIS software, the point density interpolation method was used to map (i) annual trawl intensity (hr/km^2) for each fishing season from 2002/03 to 2011/12; and (ii) mean annual trawl intensity (hr/km^2) for the combined fishing seasons of 2002/03-2006/07, 2007/08-2011/12 and 2002/03-2011/12 from the fishing location (i.e. GPS location at the mid-point from approximately 30% of annual trawl shots) provided by fishers in the commercial logbooks. The first two time periods were selected to undertake five-year comparisons while the entire 10-year period was selected as an historic baseline because fishing effort was relatively stable from 2002/03 to 2011/12 (Table 5-2). GPS coordinates that were either on land or within the 0-10 m depth stratum (where trawling is prohibited) were treated as errors and removed from the dataset using ArcGIS software. This resulted in an 18% reduction of the number of shots from the original GPS data. To confirm remaining GPS coordinates reflected fishing location, the resultant maps were qualitatively evaluated against reported catch and effort data and validated by commercial fishers.

The filtered data were used to determine the trawling intensity categories of 'no fishing', and 'low', ‘medium' and 'high' 'intensity'. Trawl path polygons were constructed from the width of the trawl (i.e. 19.45 m, which assumes a net spread factor of 0.75; after Carrick 1996), and the distance trawled (determined from trawl speed and duration). As there was no information available on direction of the trawl paths, all trawl shots were assumed to have a north-south orientation. For each given period, the sum of the areas of all polygons multiplied by a scaling factor [(total number of trawl shots)/(number of shots with GPS coordinates)] provided an estimate of the cumulative area trawled. The actual area of the gulf trawled requires that the overlap of trawl shots is taken into account. Thus, using the Dissolve Tool in ArcGIS, all trawl path polygons were combined into a single, multi-part polygon, the area of which was multiplied by the scaling factor to calculate the area fished. Effort data were aggregated into four levels of trawl intensity (i) no fishing; (ii) low (0.1-1 h.km^2); (iii) medium (1.001-10 h.km^2); (iv) and high (>10 h.km^2). To prevent potentially spurious GPS data from biasing the spatial extent of 'low' intensity trawling, areas with very low trawling intensities (< 0.1 hr/km^2) were included in the 'no fishing' category. This threshold was increased for the five (< 0.5 hr/km^2) and 10-year (< 1.0 hr/km^2) distribution maps to account for cumulative effects. This resulted in a more representative distribution of trawling undertaken by the fishery. These spatially resolved effort data were used to quantify two potential performance indicators for ecological assessment. These were (i) area of high trawl intensity; and (ii) percentage of the area of no and low trawl intensity subsequently trawled. In addition, data on the abundance of habitat forming, by-catch species (after Currie et al. 2009) were overlaid onto the 10-year maps of trawl intensity with the medium and high trawl intensity areas combined.

Subsequently, reported fishing effort from commercial logbooks was used to determine the effort in each fishing block over the period 1990/91 to 2012/13. While these data lack the spatial resolution of the GPS data, they enable the time series of information on fishing location to be extended.

5.2.3.2 Ecosystem

Data relating to the interaction between the SGPF and Spencer Gulf ecosystem were difficult to obtain and primarily restricted to those from the fishery-independent by-catch study undertaken in 2007 (Currie et al. 2009). The analyses of these data and identification of any potential performance indicators is described in the remaining components of Section 6.2.3.

5.2.3.3 Target species

Data and information on the catch, effort and catch-composition data, fishery-independent surveys, biology of Western King prawns and stock assessment and management of the target species were obtained from the management plan for the fishery (Dixon and Sloan 2007) and stock assessments. Data are synthesised, integrated and analysed regularly in publically-available stock assessments for the SGPF (e.g. Dixon et al. 2013b), that inform management arrangements for the sustainable use of this resource underpinned by the guidelines in the management plan for the fishery (PIRSA 2014b), so they have not been reproduced in this report. Rather, a summary of the available data and information are provided in Section 7.

5.2.3.4 Non-target species: by-product and by-catch

By-product

There are three sources of by-product (i.e. southern calamary and Balmain bug) data for the SGPF. These are (i) logbook data provided by commercial fishers; (ii) abundance estimates from the single by-catch survey in 2007 (Currie et al. 2009); and (iii) abundance estimates from the study of by-product in the SGPF (samples from November 2008, February 2009 and March 2009; Roberts and Steer 2010). Logbooks include estimates of the catch of the two permitted by-product species. These data, which were available from 2002/03 to 2011/12, were aggregated by fishing season to determine the total annual catches of each species (after Roberts and Steer 2010). These long-term data were used to quantify two potential performance indicators for ecological assessment. These were (i) mean annual catch of southern calamary; and (ii) mean annual catch of Balmain bug. Subsequently, abundance estimates of southern calamary and Balmain bug from Currie et al. (2009) and Roberts and Steer (2010) were overlaid onto the 10-year map of trawl intensity with the medium and high trawl intensity areas combined. Whilst this provided a visual representation of the spatial overlap between prawn trawl intensity and the abundance of by-product species during four time periods, the limited time series of the by-product abundance data prevented identification of any additional potential performance indicators for ecological assessment.

By-catch

The primary sources of data on by-catch in the SGPF are Svane et al. (2007) and Currie et al. (2009). As by-catch in the SGPF potentially comprises many species (Currie et al. 2009), species-specific analyses in this report were constrained to giant cuttlefish, blue swimmer crabs and King George whiting. The first of these is an iconic species and the last two are commercially important. Abundance estimates for these three species from Currie et al. (2009) were overlaid onto the 10-year map of trawl intensity with the medium and high trawl intensity areas combined. Whilst this provided a visual representation of the spatial overlap between prawn trawl intensity and the abundance of by-catch species, the limited time series of the by-catch abundance data prevented identification of any additional potential performance indicators for ecological assessment. Data from Svane et al. (2007) were spatially limited and, consequently, omitted from these analyses.

5.2.3.5 Non-target species: threatened, endangered and protected species (TEPS)

The primary data on interactions of the SGPF with TEPS are derived from the logbooks provided by commercial fishers (since 2009/10) and fishery-independent surveys (2007; 2010/11-2012/13). The logbook data were aggregated by fishing season to determine the total annual TEPS interactions (after Tsolos and Boyle 2013), and the interaction locations were overlaid onto the 10-year map of trawl intensity with the medium and high trawl intensity areas combined, to provide a visual representation of the spatial overlap between prawn trawl intensity and TEPS interactions. The fishery-independent survey data were used to quantify syngnathid catch rates spatially (i.e. by fishing region) and temporally. The analyses were restricted to this species group because over 99% of TEPS interactions involve syngnathids (Currie et al. 2009).

6 RESULTS AND DISCUSSION

6.1 Information available for ecological assessment of the SGPF

There are substantial, diverse, often long-term data sets available for the SGPF (Table 6-1). Whilst most of the data have been collected for stock assessment of the target species, there have also been several studies that directly or indirectly provide data to support an environmental assessment of the SGPF against the remaining four key components. For example, studies have quantified levels of (i) by-product; (ii) by-catch; and (iii) interactions with TEPS. Several research projects have been conducted to obtain information on the impacts of prawn trawling in Spencer Gulf, including the fates and consequences of discarded by-catch (Svane 2003, 2005; Svane et al. 2007, 2008; Currie et al. 2009), and the impacts of trawling on benthic habitats and species assemblages (Svane et al. 2009). Nevertheless, there are few data and limited information for ecological assessment of the SGPF against the component ‘ecosystem’. This deficiency is being addressed in two ways (i) an FRDC-funded project (FRDC 2011/205) that is developing an ecosystem model for Spencer Gulf; and (ii) repeating the gulf-wide, 2007 by-catch survey (after Currie et al. 2009), which will provide a platform for inter-annual comparisons. Both of these will be informed by the studies of Carrick (1997), Svane (2003) and Svane et al. (2007).

The recent ESD risk assessment and ERAEF for the SGPF (PIRSA 2014a) used the qualitative method of Fletcher et al. (2002). The target species (Western King prawn) was medium risk, by-product species Balmain bug and southern calamary were low risk and by-catch species (collectively) were high risk. Regardless of their risk ranking, the species components of the SGPF were assessed further in the ERAEF (Hobday et al. 2007, 2011b). Following stakeholder consideration, across all retained and non-retained components, 23 out of 195 species were assessed further for the purposes of considering management arrangements to mitigate risks These were categorised as high risk species, or low/medium risk species where there were strong divergent views, uncertainty in the information considered by a stakeholder panel or a species of special interest (PIRSA 2014). For example, blue swimmer crabs were considered a species of interest due to their high abundance in the by-catch and their importance to the commercial blue swimmer crab fishery that operates in Spencer Gulf. For 20 of these 23 species, management arrangements were considered to be sufficient to mitigate any potential risk to those species (PIRSA 2014). The exceptions were (i) tiger pipefish; (ii) coastal stingaree; and (iii) giant cuttlefish (PIRSA 2014) for which mitigation strategies were developed.

Table 6-1 Summary of data and information available to inform ecological assessment of the Spencer Gulf Prawn Fishery. FD/FI=Fishery dependent/independent, O=Other).

Ecological component	Study Type	Data	Description	Source
Habitat	Spatially resolved catch effort data	FD	~30% of SGPF trawl shots provide Lat/Long locations	SARDI Fisheries – Information Services
	By-catch survey	FD	Summary of by-catch distribution and abundance	Carrick (1997)
	By-catch survey	FD	Summary of by-catch distribution and abundance 1994-2002	Dixon et al. (2005b)
	By-catch survey	FD	Summary of by-catch distribution and abundance	Svane et al (2007)
	By-catch survey	FI	Habitat forming species	Currie et al. (2009)
	By-catch survey	FI	Distribution and diversity of sponges in Spencer Gulf	Sorokin and Currie (2009)
	Bathymetry/oceanography	O	Physical environmental variables	Richardson et al. (2005)
	Sedimentology	O	SG seafloor sediment composition	James and Bone (2011) O'Connell (2014); O'Connell et al (in press).
Ecosystem (ecological communities and trophodynamics)	By-catch survey	FI	Habitat forming and community structure	Currie et al. (2009)
	By-catch survey	FI	Benthic macro-biota composition & distribution in Spencer Gulf	Currie et al. (2011)
	By-catch survey	FI	Environmental gradients in demersal fish distribution & trophodynamics in Spencer Gulf	Currie and Sorokin (2010b) Currie and Sorokin (2010a)
	Trophic group differentiation	O	C:N isotope ratios	Svane et al. (2007)
	Trophodynamic modelling	O	Ecosystem model of Spencer Gulf - initiative	Gillanders et al. (FRDC 2011/205)
	Trophodynamic modelling	O	GAB Ecosystem model	Goldsworthy et al. 2013
Target species	Catch and effort data	FD	SARDI Fisheries – Information Services	Dixon et al. (2013b)
	Survey (target species)	FI	SGPF stock assessment surveys	Dixon et al. (2013b)
	Fisheries biology	O	Biological data	Dixon et al. (2013b)
	Stock Assessment	FD	Catch/effort data, catch composition	Carrick (2003); Carrick and McShane (1998); Carrick and Williams (2000, 2001); Dixon et al. (2005a, 2007, 2009, 2010, 2012, 2013b); Dixon and Hooper (2008);
Non-target species: by-product	Catch/effort data	FD	SARDI Fisheries – Information Services	Roberts and Steer (2010)
	By-product survey	FD	Biological data	Roberts and Steer (2010)
	By-catch survey	FI	By-catch surveys to inform SGPF risk assessment	Currie et al. (2009)
	By-catch survey	FI	Prawn fishery by-product and by-catch	Svane et al. (2007)
Non-target species: By-catch	By-catch survey	FI	Prawn fishery by-catch	Carrick (1997)
	By-catch survey	FI	Prawn fishery by-catch and discards	Currie et al (2009)
	By-catch survey	FI	Monitoring & assessment of by-catch & discards	Dixon et al. (2005b)
	Catch composition	FD	Catch/effort data, catch composition	Dixon et al. (2013b)
	By-catch & lab. experiments	O	Fate & consumption of by-catch Impacts of trawling on macro-flora & fauna	Svane et al. (2008); Svane et al. (2009)
Non-target species: TEPS	TEPS logbook	FD	SARDI Fisheries – Information Services (TEPS interactions report)	Tsolos and Boyle (2013)
	By-catch survey	FI	Prawn fishery by-catch and discards	Currie et al. (2009)
	Survey (target species)	FI	SGPF stock assessment	Dixon et al. (2013b)
	By-catch survey	FI	Taxonomy of Syngnathids in Spencer Gulf	Sorokin et al. (2009)

6.1.1 Habitat

Data and information for ecological assessment against the component 'habitat' were available from (i) logbook catch and effort data (SARDI); (ii) by-catch surveys (Carrick 1997, Svane 2003; Dixon et al. 2005b, Svane et al. 2007, Currie et al. 2009); (iii) sponge distribution and diversity (Sorokin and Currie 2009); (iii) Spencer Gulf bathymetry and oceanography (Richardson et al. 2005); and (iv) sedimentology of Spencer Gulf (James and Bone 2011; O'Connell 2014; O'Connell et al. in press; Table 6-1).

Spatial distribution of fishing effort

The spatial distribution of fishing effort was used to map trawl intensity for each fishing season (2002/03 to 2011/12; Figure 6-1) and the three combined fishing season periods of 2002/03-2006/07, 2007/08-2011/12 and 2002/03-2011/12 (Figure 6-2) according to four trawl-intensity categories (no fishing; low, medium and high intensity). The maps show that trawl intensities were generally consistent among fishing seasons and, consequently, the maps of the aggregated fishing seasons were similar to those of the individual fishing seasons (Figures 6-1, 6-2). Most trawling occurred north of Corny Point in mid- to upper-Spencer Gulf with the highest trawl intensities adjacent to Wallaroo. Medium trawl intensities occurred around the high intensity region adjacent Wallaroo and also in southern Spencer Gulf, adjacent Corny Point. Notably, however, these maps fail to capture the reduction in fishing effort in the northern, more ecologically sensitive, areas of Spencer Gulf from 1999/2000 that are evident in Figure 6-3, but for which no GPS data were available. The total area available to the SGPF for prawn trawling (excluding waters <10 m depth) is 1,619,119 ha (1,619 km^2), which represents 72% of the total area of Spencer Gulf below the high-water mark (2,236 km^2). From 2002/03 to 2011/12, and based on point-density interpolation of GPS data, the total area of medium (estimated range: 219,819-310,356 ha) and high (estimated range: 27,713-46,575 ha) intensity trawling were relatively stable, while the percentage of the available trawling area that was not fished ranged from 34-52% (Tables 6-2, 6-3; Figures 6-1, 6-2). There was a slight increasing trend in the area of low intensity trawling during this period (estimated range: 513,719-674,025 ha). Notably, over the decade from 2002/03 to 2011/12, high intensity trawling was estimated to have occurred over no more than 3% of the available trawl area (Table 6-3).

Table 6-2 Estimated total area (ha) of the Spencer Gulf exposed to four levels of trawl intensity from 2002/03 to 2011/12.

	Trawling intensity areas (ha)				
Time period	**No fishing**	**Low**	**Medium**	**High**	**Total**
2002/03	611,481	672,131	299,406	33,100	1,616,119
2003/04	566,763	701,238	310,356	37,763	1,616,119
2004/05	671,038	640,544	257,963	46,575	1,616,119
2005/06	848,181	501,906	225,425	40,606	1,616,119
2006/07	689,450	659,269	229,844	37,556	1,616,119
2007/08	784,788	513,719	280,919	36,694	1,616,119
2008/09	791,531	560,238	219,819	44,531	1,616,119
2009/10	637,956	695,569	253,881	28,713	1,616,119
2010/11	683,344	674,025	227,069	31,681	1,616,119
2011/12	555,019	769,056	252,431	39,613	1,616,119
2002/03-2006/07	315,588	1,008,231	255,275	37,025	1,616,119
2007/08-2011/12	357,675	972,744	250,631	35,069	1,616,119
2002/03-2011/12	**220,088**	**1,106,263**	**253,300**	**36,469**	**1,616,119**

Table 6-3 Estimates of area (% total area) of Spencer Gulf trawled by the SGPF for four categories of trawl intensity from 2002/03-2011/12.

	Trawling intensity areas (% of total)			
Time period	**No fishing**	**Low**	**Medium**	**High**
2002/03	38	42	19	2
2003/04	35	43	19	2
2004/05	42	40	16	3
2005/06	52	31	14	3
2006/07	43	41	14	2
2007/08	49	32	17	2
2008/09	49	35	14	3
2009/10	39	43	16	2
2010/11	42	42	14	2
2011/12	34	48	16	2
2002/03-2006/07	20	62	16	2
2007/08-2011/12	22	60	16	2
2002/03-2011/12	**14**	**68**	**16**	**2**

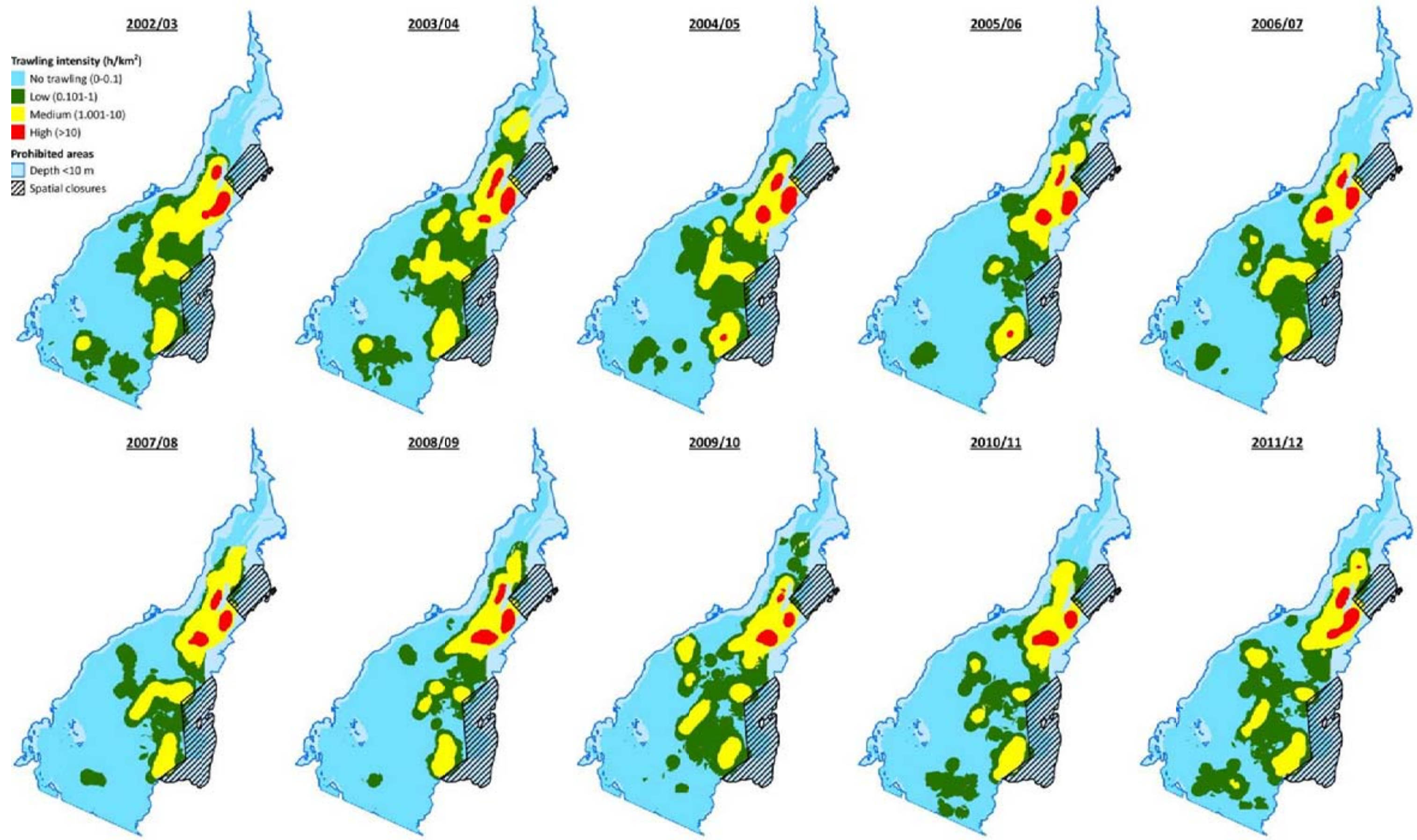

Figure 6-1 Map of Spencer Gulf with annual trawl intensity contours from 2002/03 to 2011/12. Hashed areas represent voluntary closures within the SGPF.

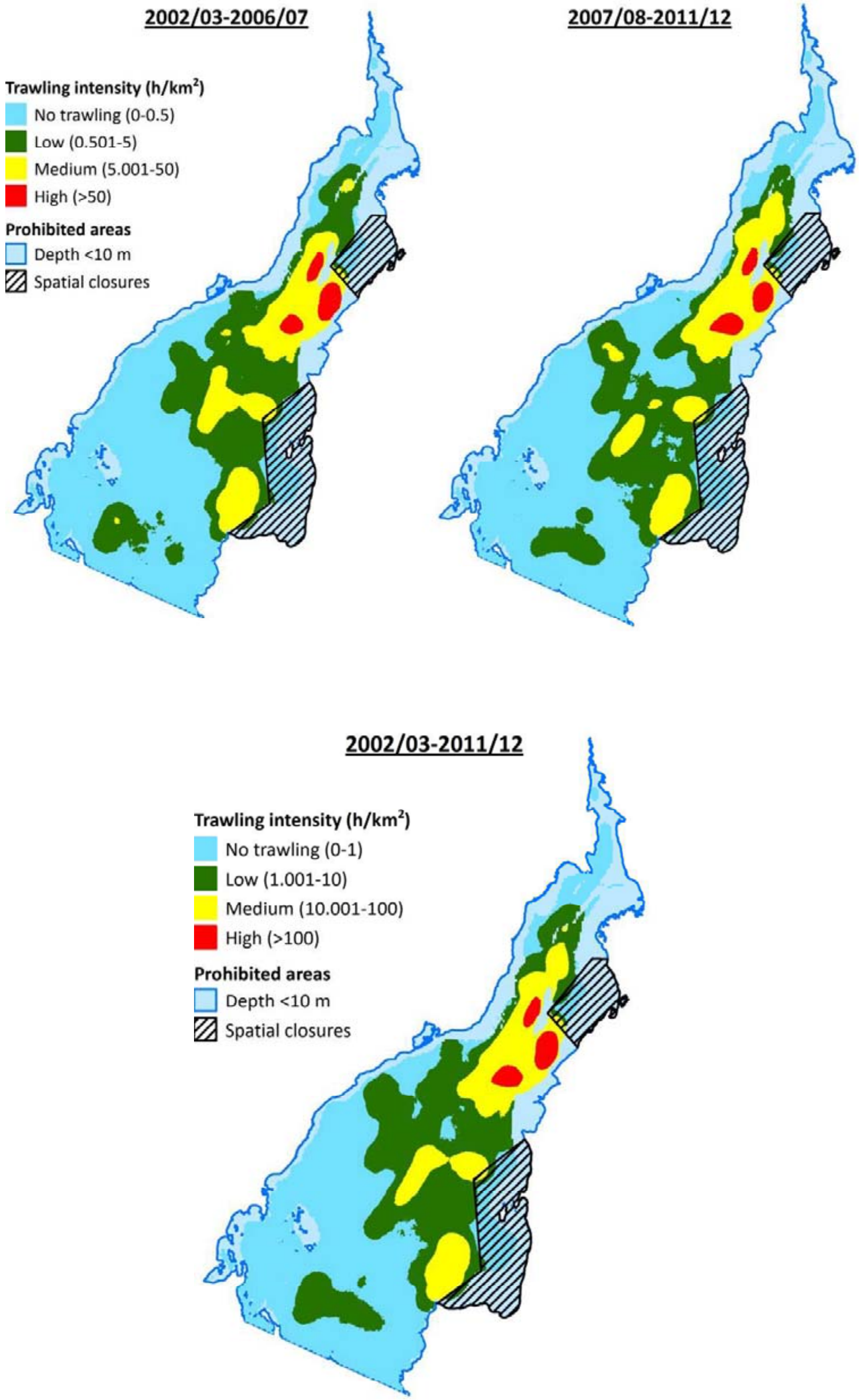

Figure 6-2 Map of Spencer Gulf with cumulative trawl intensity contours for three time periods (i) 2002/03-2006/07; (ii) 2007/08-2011/12 and (iii) 2002/03-2011/02. Hashed areas represent voluntary closures within the SGPF.

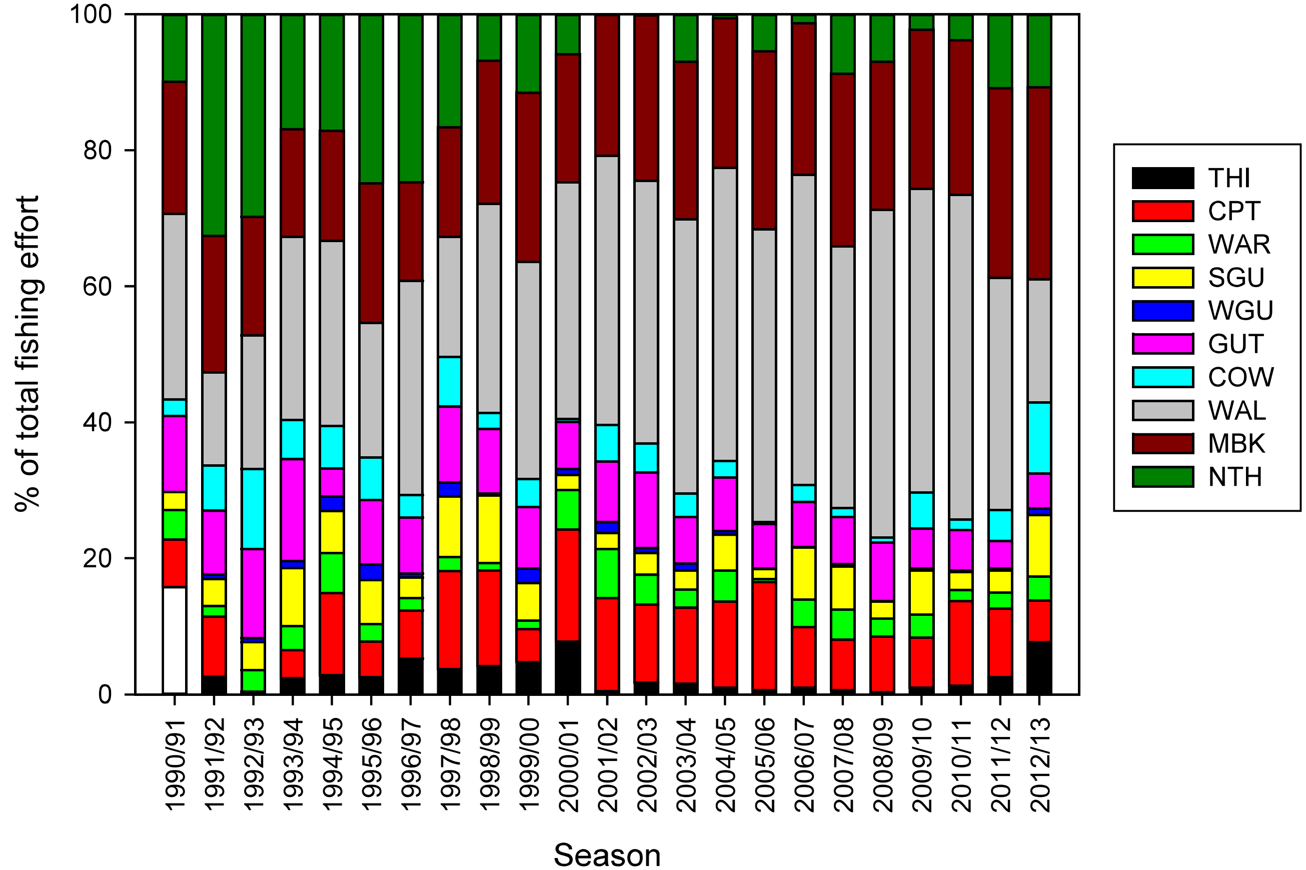

Figure 6-3 Spatial distribution of fishing effort from 1990/91 to 2012/13. COW – Cowell, CPT – Corny Point, GUT – Gutter, MBK – Middle Bank, NTH – North, SGU – South Gutter, THI – Thistle, WAL – Wallaroo, WAR – Wardang and WGU – West Gutter. Refer Figure 3-1 for location.

Spatial distribution of habitat-forming species

Species obtained as by-catch in the SGPF provide habitats for other species. These include the Porifera (sponges), Urochordata (sea squirts), Cnidaria (soft corals), Bryozoa (lace corals), Rhodophyta (red algae), Phaeophyta (brown algae), Magnoliophyta (seagrass) and Chlorophyta (green algae; PIRSA 2014a) species groups. Maps showing the spatial distribution of these 'habitat-forming' species groups from the 2007 by-catch survey (Currie et al. 2009) are shown in Figure 6-4. Spatial distribution and abundance varied considerably among phyla and prawn trawling intensity (Table 6-4; Figure 6-4). For example, sponges yielded the highest biomass estimates (4,007 g/ha), particularly in northern (top 120 km) and southern (bottom 80 km) Spencer Gulf with smaller estimates of biomass in the middle of Spencer Gulf. This species group was also substantially more common in the low-intensity prawn trawl areas (6,546 g/ha), when compared with the combined high and medium-intensity prawn trawl areas (941 g/ha). In contrast, seagrass by-catch (dominated by *Posidonia* wrack) was limited and generally restricted to a few sample locations in the north-eastern part of Spencer Gulf.

6.1.2 Ecosystem

Data and information on the potential impact of the SGPF on the component 'ecosystems', are very limited (Table 6-1). However, this is currently being addressed through several initiatives. First, an FRDC-funded project (FRDC 2011/205) is developing an ecosystem model for Spencer Gulf, which will provide a tool for evaluating potential ecosystem consequences from extractive and other uses of Spencer Gulf. This model is synthesising much of the available information for Spencer Gulf, including analyses of gut contents and the use of stable isotope methods, to determine the diet and trophic level of key species (Svane et al. 2007), and the 2007 by-catch survey (Currie et al. 2009). Second, the FRDC-funded hydrodynamic and biogeochemical model for Spencer Gulf (Middleton et al. 2013) may yield information on physical and chemical processes in the water column which may also affect the benthic community. Third, the 2007 by-catch survey was repeated in 2013. Direct comparison of these two surveys may facilitate analyses of temporal ecosystem shifts.

6.1.3 Target species

There are substantial data and information sources for ecological assessment of the component 'target species' (Table 6-1). These include (i) long-term, catch and effort data; (ii) estimates of prawn abundance and population structure from fishery-independent surveys; and (iii) a comprehensive understanding of the fisheries biology of Western King prawns. As these data are synthesised, integrated and analysed regularly in publically-available stock assessments for the SGPF (e.g. Dixon et al. 2013b) that inform management arrangements for the sustainable use of this resource underpinned by the guidelines in the management plan for the fishery (Dixon and Sloan 2007), these have not been reproduced in this report.

Table 6-4 Mean biomass (g/ha) of habitat forming by-catch species (from Currie et al. 2009) aggregated by areas of differing trawl intensities (10-year average trawl intensity, 2002/03 to 2011/12) (i) voluntary spatial closures; (ii) no trawling (0 hrs); (iii) low (0.001-1 hr/km^2) and (iv) combined medium and high (>1 hr/km^2).

	Mean biomass (g/ha)				
Species group	**Spatial closures**	**No trawling**	**Low**	**Med + High**	**Total area**
Seagrass wrack	379	4	587	114	357
Sponges	1109	3460	6546	941	4007
Urochordates	103	49	380	103	236
Algae	451	340	137	787	395
Bryozoans	249	403	356	13	239
Cnidarians	529	958	104	15	188

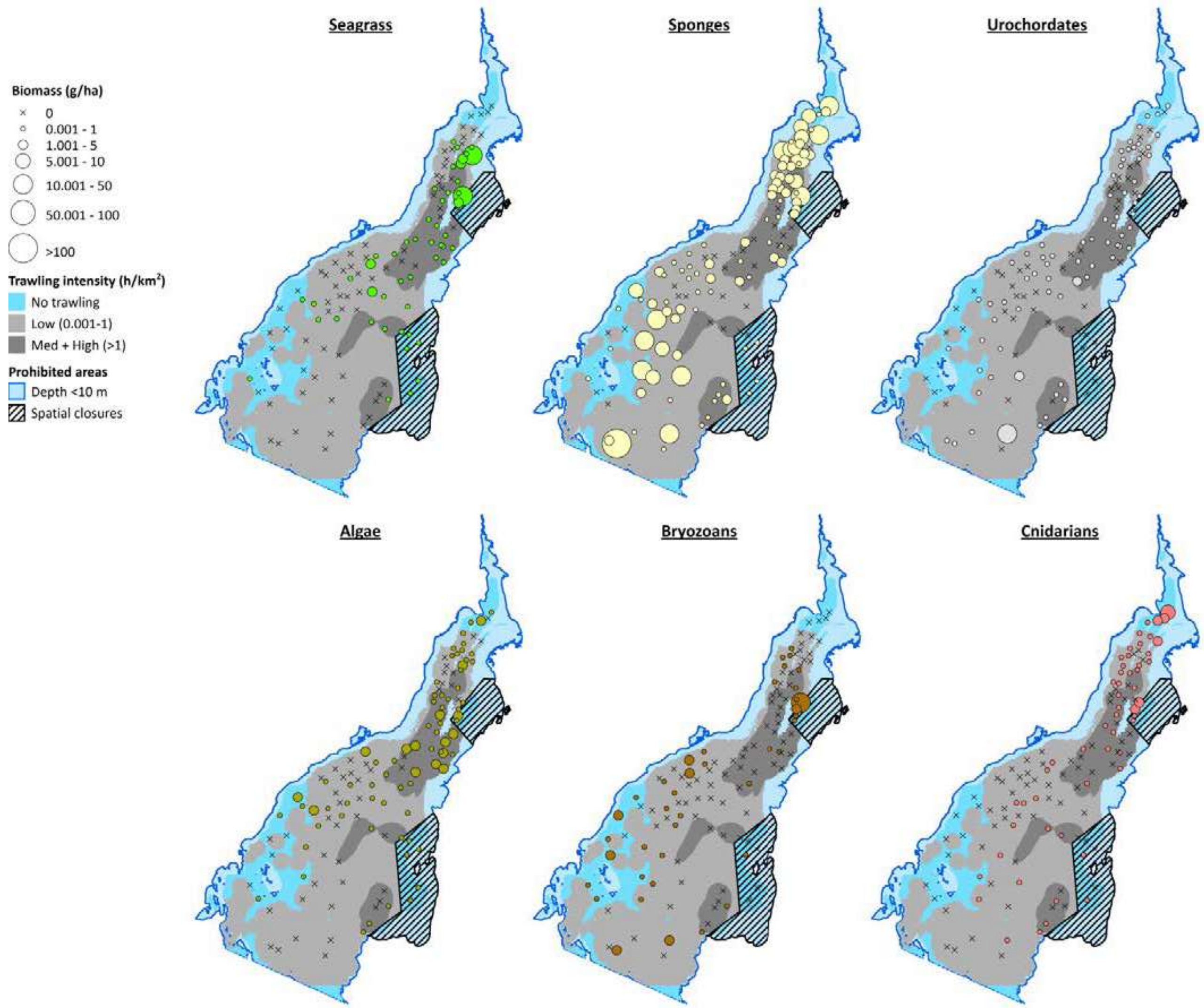

Figure 6-4 Spatial distribution of habitat forming species groups from the 2007 by-catch survey (Currie et al. 2009) overlaid on trawl intensity contours (10-year average trawl intensity, 2002/03 to 2011/12).

Catch, effort and catch-composition data

Licence holders in the SGPF have provided detailed daily catch and effort data to SARDI Aquatic Sciences through logbook returns. The data provided include licence information, date(s), shot number, fishery reporting block (Figure 3-1), trawl start/end time (duration), trawl depth, fishing location (GPS), trawl speed, bucket counts, catch by size grade, brine catch, retained by-product and water temperature. Data are available from 1988/89 to 2012/13. Additional historical catch data, notably (i) total annual catch and effort from 1968-1973; and (ii) monthly data from 1973-1988, are available from South Australian Fishing Industry Council annual reports (Dixon et al. 2012). These data provide information on the catch and effort history of the fishery (Figure 3-2), temporal trends in commercial catch rates, and the spatial distribution of catch and effort (Dixon et al. 2013b).

Fishery-independent surveys

Fishery-independent surveys (FIS; see Dixon et al. 2013), using industry vessels with independent observers, have been conducted before, during and toward the end of each fishing season to inform the fishing strategy and for subsequent assessment of fishery performance against performance indicators prescribed in the management plan (Dixon and Sloan 2007). These surveys have comprised 30 minute trawls at fixed sites, with the distance trawled dependent on trawl speed. Data collected during surveys have included total catch, trawl time, trawl distance, trawl direction, bucket count and water temperature. Length-frequency data provide sex-specific length distribution, sex ratio, and mean-prawn-weight data. In addition, egg production is estimated (November survey only) and a recruitment index (February survey only) generated.

Abundances of juvenile prawns have been monitored annually by undertaking directed surveys in key juvenile prawn habitat in the northern reaches of Spencer Gulf. Initially, five sites were sampled (see Roberts et al. 2005), but this has been rationalised to two sites in recent years (Port Pirie and False Bay). Methods are well described in Roberts et al. (2010). Briefly, a stern-towed, ‘jet net’ enables sampling of the sand-mud substrate to a depth of approximately 5 cm. In conjunction with historical surveys (Carrick, 1996; Roberts *et al*, 2005), linking estimates of juvenile prawn abundance with the fishery-independent surveys that are focussed on adult prawns across the fishing grounds, may yield a predictive index of recruitment to the fishable biomass.

Biology of Western King prawns

The biology of the target species, Western King prawns (*Penaeus* (*Melicertus*) *latisulcatus*) is well described in Dixon et al. (2013b). Information available encompasses distribution and taxonomy, stock structure, reproductive biology including size at maturity and fecundity, growth rates, natural mortality estimates and movement patterns.

Stock assessment and management

There have been twelve assessments of the prawn resource that supports the SGPF (Carrick and McShane 1998; Carrick and Williams 2000, 2001; Carrick 2003; Dixon and Hooper 2008; Dixon et al. 2005a, 2007, 2009, 2010, 2012, 2013b; Noell et al. 2014). Stock assessments synthesise information available for the fishery, assess the status of the resource, and comment on the performance of the fishery with respect to biological performance indicators and reference points. From 2004, stock assessments have also documented the biology and management of Western King prawn and, since 2007, assessments have explicitly addressed the suite of performance indicators prescribed in the relevant management plan (Dixon and Sloan 2007). More recent assessment reports have also undertaken spatial and temporal analyses to link survey data with subsequent commercial catches.

The new management plan for the fishery (PIRSA 2014b) is a comprehensive document describing the evolution of the SGPF, the legislative and regulatory framework and the management arrangements, including the first ecological performance indicators (Table 6-5). While this approach reflects a preliminary outcome from this project, there is a need to review these performance indicators and reference points to ensure their quantification and linkage to decision rules in subsequent management plans for the fishery.

6.1.4 Non-target species: by-product and by-catch

Non-target species comprise by-product and by-catch. By-product species are not targeted, but may be retained. Two species, southern calamary and Balmain bug, are permitted by-product in the SGPF. In contrast, by-catch comprises species that are incidentally caught during prawn trawling, which must be discarded. By-catch of TEPS is considered in Section 6.2.1.5.

By-product

The primary data and information sources for ecological assessment of the component 'by-product' comprises (i) estimates of annual catch determined from logbook data provided by commercial fishers; (ii) abundance estimates from the gulf-wide by-catch survey in 2007 (Currie et al. 2009); and (iii) abundance estimates from the study on by-product in the SGPF (Roberts and Steer 2010; Table 6-1).

Table 6-5 ESD risk areas, performance indicators and limit reference points for the Spencer Gulf Prawn Fishery (PIRSA 2014b).

ESD risk addressed	Performance indicator	Limit reference point
Fishing impacts on target species	Average adult prawn catch rate from three SASs each season	Average adult prawn catch rate ≥ 68.2 kg/hr (2.5 lb/min).
Fishing impacts on target species	Recruitment index (square root of the number of juvenile prawns (males <33 and females <35 mm CL) captured per nautical mile trawled following Carrick (2003)).	<35
	Mean egg production.	<500 million eggs/trawl-hour
Research knowledge	Commercial catch and effort.	Mean commercial catch rate > 80kg/hr. Logbook records provided by all fishers for 100% of fishing nights.
	Fishery independent surveys conducted.	Fishery surveys conducted sufficient to inform annual fishery status assessments.
	Strategic research plan.	Research plan updated annually.
Impacts on trophic structure / by-catch	By-catch and by-product catch rate (number/hectare) from by-catch surveys.	EBFM reporting undertaken regularly.
	Long-term by-catch reporting and monitoring measures developed where appropriate.	Appropriate reference points identified in EBFM project report developed and considered for long term monitoring.
	Technology for reducing impacts of fishing activity on by-catch species sustainability adopted where appropriate.	Technology for reducing impacts of fishing activity on by-catch species sustainability adopted where appropriate
	EBFM report.	EBFM report completed.
	ESD risk assessment report reviewed in life of the plan.	ESD risk assessment reviewed in life of plan.
TEPS	Interaction rate for TEPS (number of interactions per fishing day reported in wildlife interaction logbooks).	Interaction rates for TEPS from wildlife interaction logbooks and SASs monitored annually.
	Number of TEPS/hectare reported in EBFM reports.	TEPS number/ hectare monitored and reported in EBFM reports regularly.
	Closed areas maintained.	Area closures for reducing fishery impacts on sygnathids included in fishing strategies where appropriate.
	Industry codes of practice followed where developed.	Where developed, Industry codes of practice are communicated to fishing fleet and adopted.
Broader environment / habitat disturbance	Annual fishery footprint relative to maximum annual fishing footprint maximum.	Fishing footprint does not change by more than 2% from historic maximum annual fishing footprint.
Impacts on trophic structure / removal of/damage to organisms by fishing	Closed areas maintained.	Closed areas maintained in fishing strategies.

Reported annual catches of southern calamary from the SGPF were relatively stable from 2002/03 to 2011/12 and ranged from 21.1 to 30.9 t (Figure 6-5). These catches were lower than that estimated (~90 t) by Roberts and Steer (2010), suggesting that substantial quantities of southern calamary are caught, but not retained. In contrast, catches of Balmain bug have shown greater variability among fishing seasons when compared to southern calamary. Catches increased yearly from a minimum in 2001/02 (1.1 t) until a peak in 2008/09 (7.2 t), after which they displayed subsequent declines over the last two years (Figure 6-6), likely due to the minimum legal size introduced in 2011. Maps showing the spatial distribution of these by-product species from the 2007 by-catch survey (Currie et al. 2009) and by-product surveys in 2008/09 (Roberts and Steer 2010) are shown in Figure 6-7. Notably, while spatial distribution and abundance varied between species and among levels of prawn trawling intensity (Table 6-6; Figure 6-7), they were largely similar across survey periods (Figure 6-7). Southern calamary were widespread, with the highest densities occurring from the middle to northern Spencer Gulf, across both low and medium-high trawling intensity areas. Densities of Balmain bug were highest in northern Spencer Gulf and in the deeper waters in the middle and southern parts of the Gulf.

By-catch

The primary data and information for ecological assessment of the SGPF against the component 'by-catch' are the gulf-wide survey undertaken in 2007 (Currie et al. 2009) and other, less spatially-representative surveys, undertaken opportunistically since the late 1990s (Carrick 1997; Dixon et al. 2005b; Svane et al. 2007; Currie et al. 2009; Dixon et al. 2013b; Table 6-1). Currie et al. (2009) identified that ecological communities were similar across areas with historically different levels of trawl intensity. Consequently, trawl-related differences in community structure were small in comparison to those associated with latitude (i.e. north-south gradient; Currie et al. 2009).

By-catch, caught incidentally in the SGPF, comprises approximately 400 species, half of which comprised different species of vegetation (Currie et al. 2009). Consequently, analyses in this report were constrained to TEPS (Section 6.2.1.5), giant cuttlefish, and two species representative of important commercial fisheries (blue swimmer crabs and King George whiting).

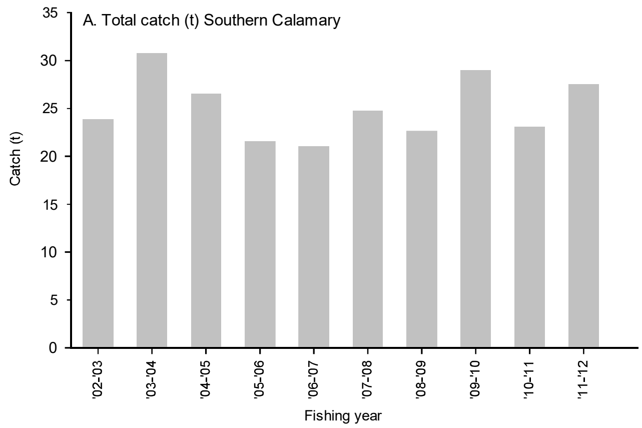

Figure 6-5 Retained catches of southern calamary by the SGPF from 2002/03 to 2011/12.

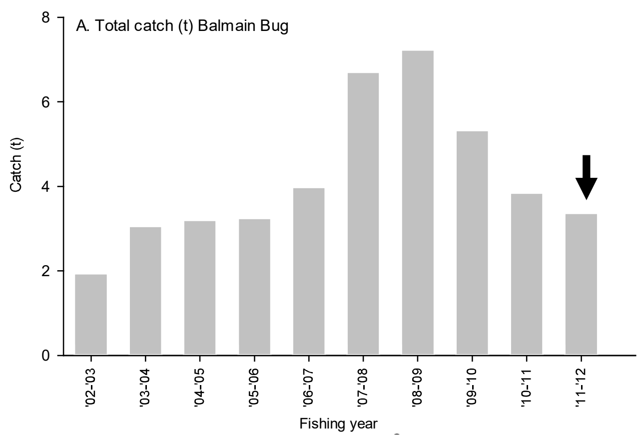

Figure 6-6 Retained catches of Balmain bug from the SGPF from 2002/03 to 2011/12. Black arrow indicates size limit introduction.

Table 6-6 Mean abundance (no./ha) of the by-product species southern calamary and Balmain bug (from Currie et al. 2009) aggregated by areas of differing trawl intensities (10-year average trawl intensity, 2002/03 to 2011/12) (i) voluntary spatial closures; (ii) no trawling (0 hrs); (ii) low (0.001-1 hr/km^2) and (iii) combined medium and high (>1 hr/km^2).

	Mean biomass (g/ha)				
Species	**Spatial closures**	**No trawling**	**Low**	**Med + High**	**Total area**
Southern calamary	28.65	14.92	10.19	14.72	13.40
Balmain bug	4.98	1.81	1.01	0.65	1.23

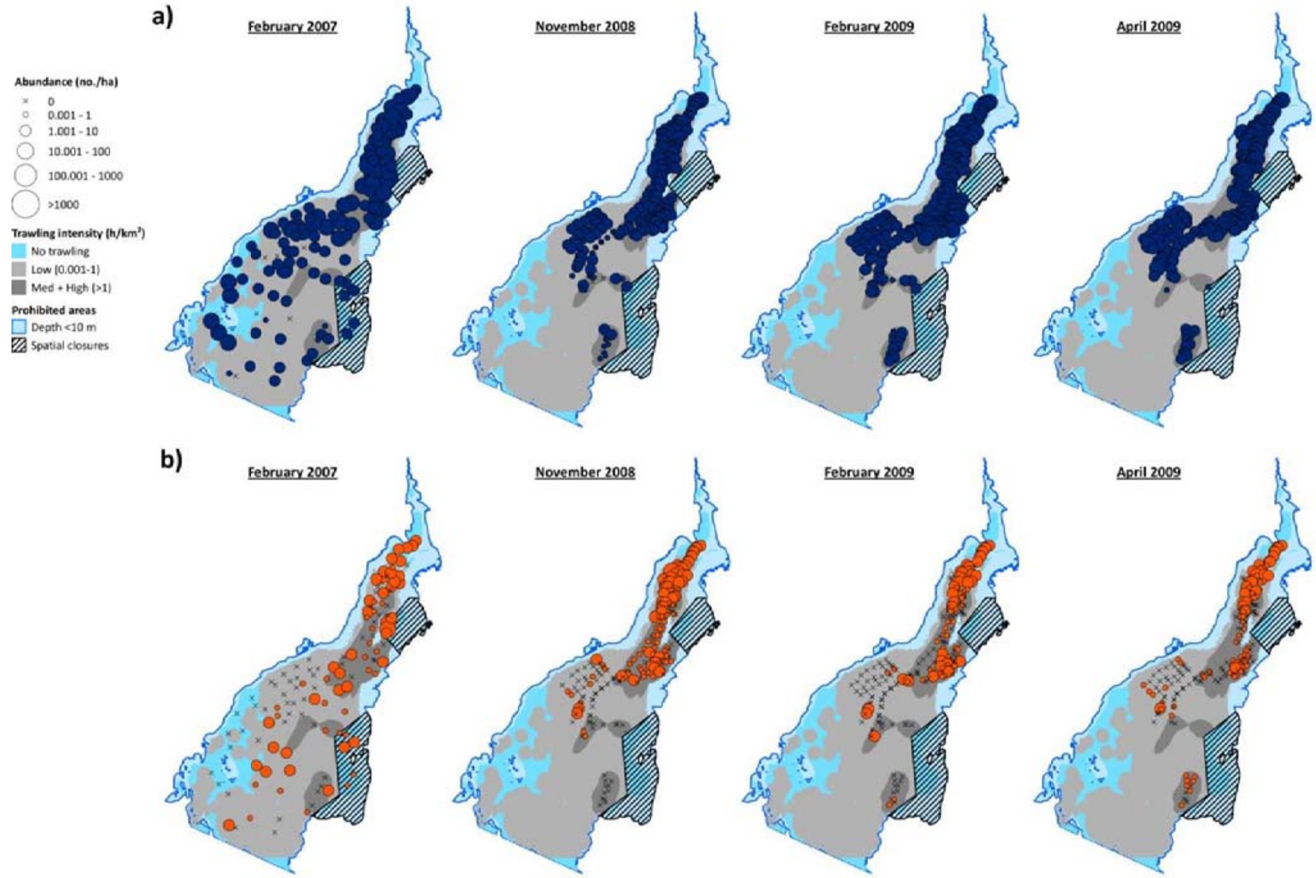

Figure 6-7 Distribution and abundance of the by-product species southern calamary (a, top) and Balmain bug (b, bottom) from the by-catch survey in 2007 (Currie et al. 2009) and by-product survey in 2008/09 (Roberts and Steer 2010) overlaid on areas of differing trawl intensities (10-year average trawl intensity, 2002/03 to 2011/12).

The spatial distribution of these by-catch species from the 2007 by-catch survey (Currie et al. 2009) are shown in Figure 6-8. Notably, distribution and abundance varied among species and levels of prawn trawling intensity (Figure 6-8). For example, giant cuttlefish densities were highest in northern Spencer Gulf, although individual samples with high abundance were obtained throughout the gulf. Blue swimmer crabs were more commonly sampled from northern Spencer Gulf.

6.1.5 Non-target species: threatened, endangered and protected species

Over recent years, the data and information available for ecological assessment of the SGPF against the component 'TEPS' has increased substantially. These data are now available because, since July 2007, licence holders have reported interactions with TEPS through the 'Wildlife Interaction Identification and Logbook' form returned to SARDI Aquatic Sciences. Thus, most of the data and information for TEPS comprises logbook data that are regularly aggregated to a data summary in publically-available reports (e.g. Tsolos and Boyle 2013; Table 6-1). Additional data are also available from Svane (2003), the gulf-wide by-catch survey in 2007 (Currie et al. 2009) and fishery-independent surveys since November 2009.

The annual total number of reported TEPS interactions increased from zero in 2008/09 to ~135 interactions in 2011/12 (Figure 6-9 A; Tsolos and Boyle 2014). These patterns were also evident in the number of interactions per 1000 trawl hours (Figure 6-9 B) and as a proportion of catch (Figure 6-9 C). While these trends may reflect an increasing interaction rate, it is more likely they reflect an increase in reporting rate following an education program. During this period the proportion of animals returned to the water alive was estimated to have changed from 100% in 2009/10 to ~50% in 2011/12 (Figure 6-9 A), indicating reduced survival. The causes for this are unclear, but may partly reflect the difficulty in rapidly determining the state in which Syngnathids are released. Spatial distribution and interaction frequency varied substantially among years and levels of prawn trawling intensity (Figure 6-10).

Syngnathids, including tiger pipefish, Macleays crested pipefish, brushtail pipefish, spotted pipefish, bigbelly seahorse, leafy seadragon and common seadragon, dominate the TEPS by-catch in the SGPF (Currie et al. 2009; Tsolos and Boyle 2014). Mean abundance of syngnathids varies temporally (Table 6-7; Figures 6-11, 6-12, 6-13) and spatially (Figures 6-11, 6-12, 6-13), but few clear trends are evident. Non-syngnathid TEPS interactions in the SGPF are rare, with one great white shark, one pinniped and three flutemouths recorded since 2007/08, all of which were released alive (Tsolos and Boyle 2014).

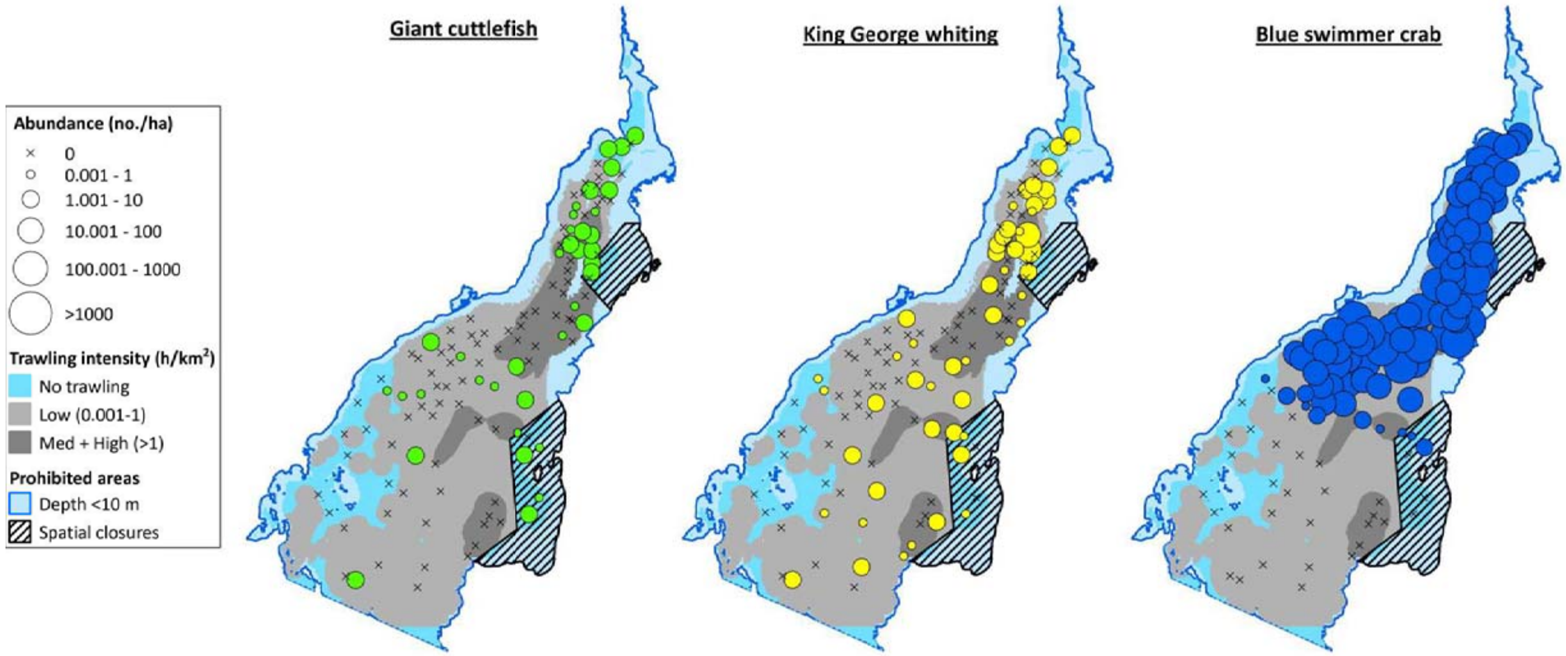

Figure 6-8 Distribution and abundance of giant cuttlefish, King George whiting and blue swimmer crabs from the by-catch survey in 2007 (Currie et al. 2009) overlayed on areas of differing trawl intensities (10-year average trawl intensity, 2002/03 to 2011/12).

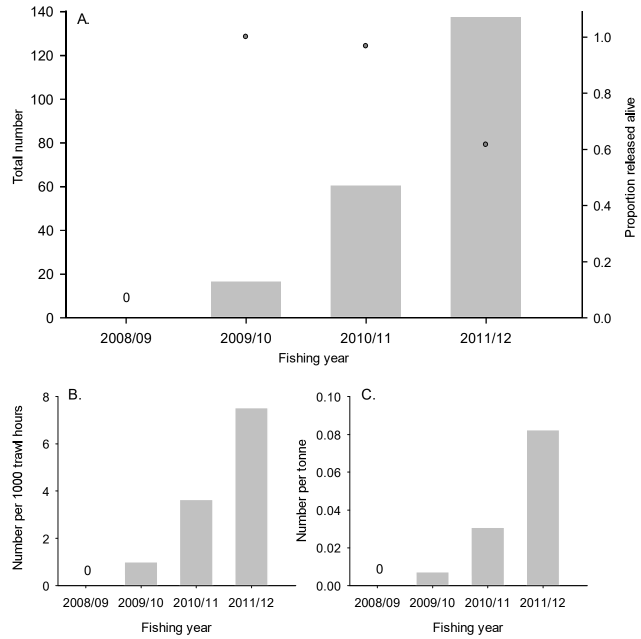

Figure 6-9 A. Annual total number of TEPS caught (bars) and the proportion released alive (dashed line) from the SGPF since 2007; B. number of TEPS caught per thousand hours of effort and; C. number of TEPS caught per tonne of reported prawn catch in the SGPF.

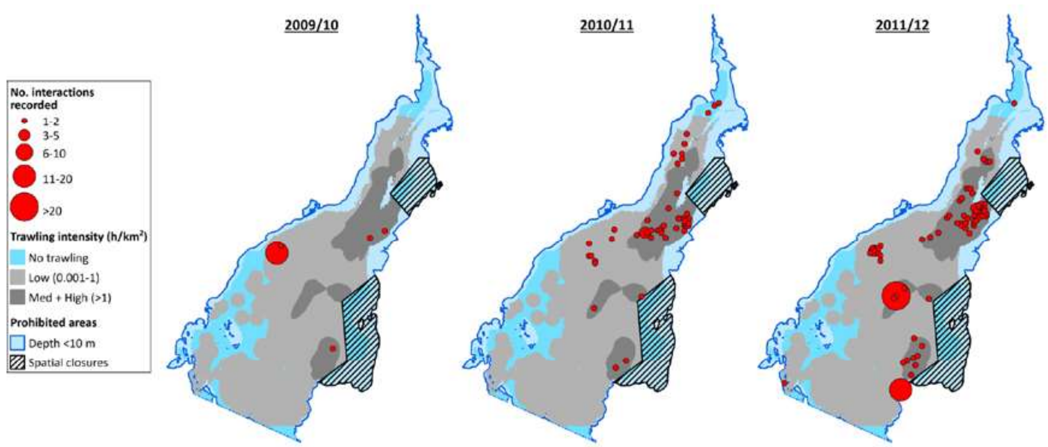

Figure 6-10 Distribution and total reported number of TEPS (bubble size, total no./trawl shot), in 2009/10, 2010/11 and 2011/12 (Wildlife Interaction Logbooks), overlaid on areas of differing trawl intensity (10-year average trawl intensity, 2002/03 to 2011/12). Note: the number and location of survey sites differs through time.

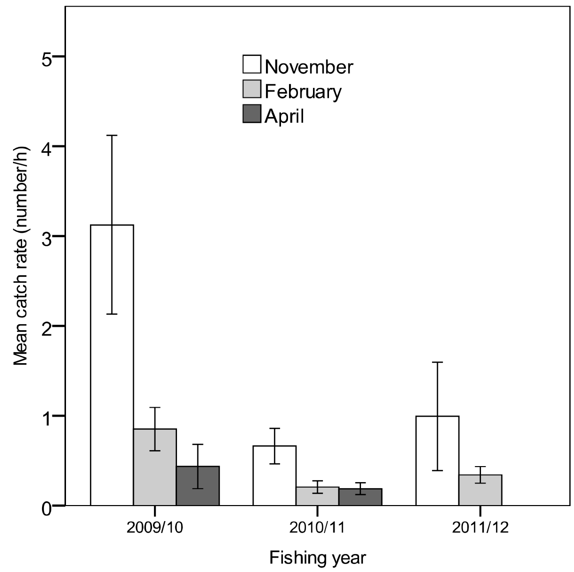

Figure 6-11 Comparison of the standardised catch rate of syngnathid species (all species) across years and months from FI surveys. Error bars represent +/- 1 standard error of the mean.

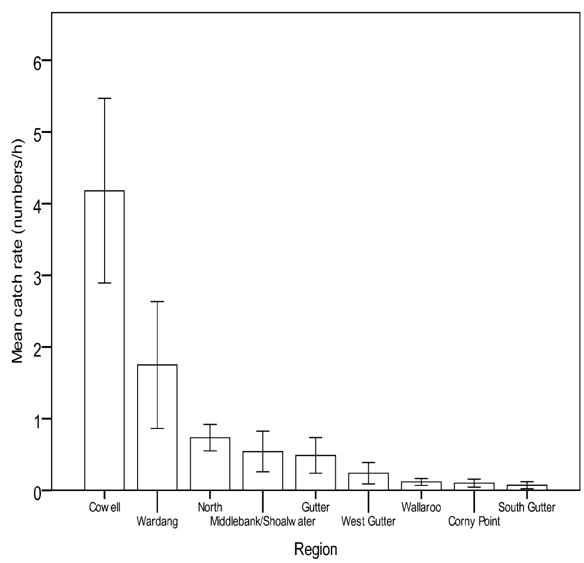

Figure 6-12 FI survey data - Comparison of the standardised catch rate for syngnathid species (all taxa) from FI surveys within Spencer Gulf averaged over three fishing years. Error bars represent +/- 1 standard error of the mean.

Table 6-7 The abundance (±SE) of syngnathids captured and released during fishery-assessment surveys in November, February and April of 2010, 2011 and 2012 (no data available for April 2012).

	Mean abundance (no./h trawled)			
Survey	**No fishing**	**Low**	**Med + High**	**Total area**
Nov-09	9.71 ± 6.41	6.51 ± 2.40	0.40 ± 0.22	3.05 ± 0.97
Feb-10	2.29 ± 1.19	0.72 ± 0.30	0.24 ± 0.14	0.49 ± 0.15
Apr-10	0.00 ± 0.00	1.31 ± 0.88	0.10 ± 0.06	0.56 ± 0.34
Nov-10	0.00 ± 0.00	1.18 ± 0.35	0.65 ± 0.33	0.83 ± 0.24
Feb-11	0.57 ± 0.57	0.15 ± 0.08	0.15 ± 0.07	0.16 ± 0.06
Apr-11	2.40 ± 1.22	0.14 ± 0.07	0.22 ± 0.08	0.26 ± 0.07
Nov-11	0.00 ± 0.00	0.00 ± 0.00	0.56 ± 0.32	0.33 ± 0.19
Feb-12	0.00 ± 0.00	0.18 ± 0.09	0.03 ± 0.03	0.09 ± 0.04

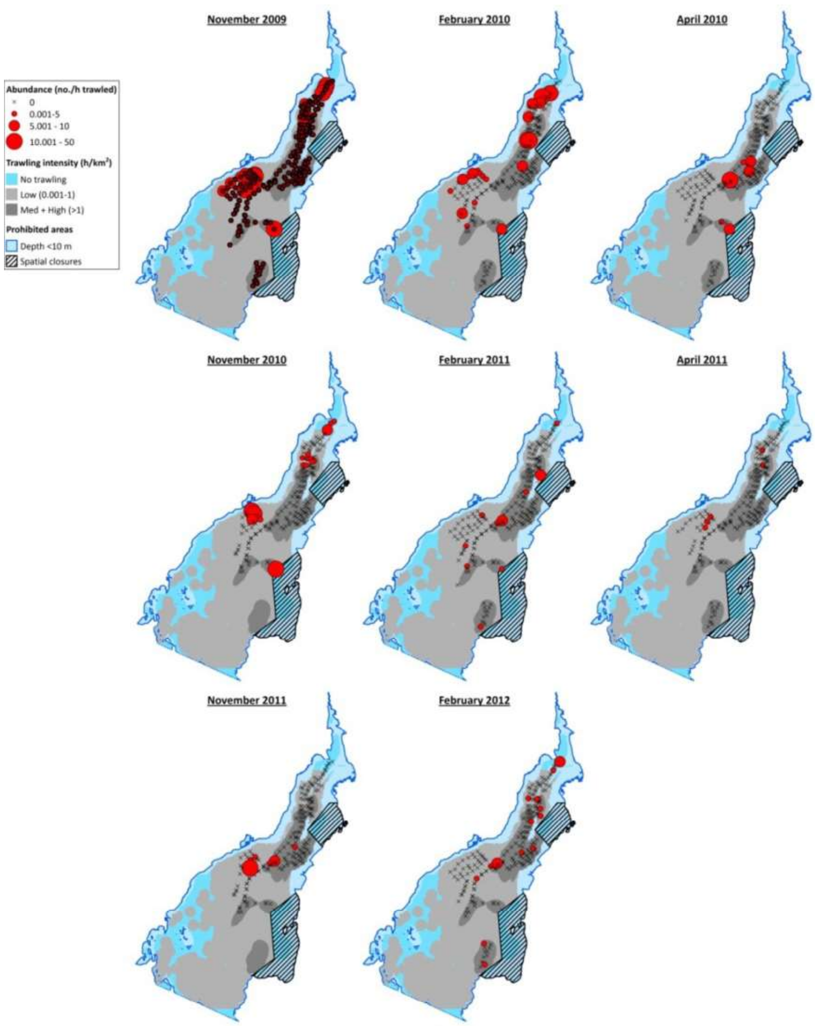

Figure 6-13 Distribution and abundance of syngnathids in Spencer Gulf from fishery assessment surveys during 2009 to 2012, overlayed on the areas of differing trawl intensity (10-year average trawl intensity, 2002/03 to 2011/12).

6.2 Implementing ecosystem-based assessment in the SGPF

Implementation of ecological assessments in the SGPF requires an operational plan (e.g. FAO 2011) with the key steps to include (1) identification of relevant performance indicators and reference points across each of the five key components – (i) habitats; (ii) ecosystem (ecological communities/trophodynamics); (iii) target species; (iv) non-target species including by-product and by-catch; and (v) TEPS; (2) development of a framework linking annual ecological and stock assessments with decision rules to drive management decision making embedded in the management plan for the fishery (Figure 6-14; Table 6-8; Table 6-9); and considering an appropriate time period for review. Whilst these performance indicators, reference points and the reporting framework should be developed collaboratively, involving at least PIRSA Fisheries and Aquaculture, SGWCPFA, SARDI Aquatic Sciences and the CCSA, analyses of the data and information available for the SGPF undertaken in this report provide guidance and direction to support this process. These analyses also highlight where data are currently inadequate to formulate these performance indicators.

When generating performance indicators and reference points, and determining the management decisions following ecological assessments against them, there are several factors that need consideration. First, there is considerable spatial and temporal (both inter-annual and within season) variation evident in the five key components across Spencer Gulf. Consequently, it is important to explicitly consider this variability when evaluating the robustness of performance indicators and reference points. Second, the uncertainty in the available data and robustness of the selected performance indicators should be acknowledged. For example, the degree to which the periodic reporting of fishing location data (i.e. GPS) influences the spatial distribution of high-, medium- and low-intensity trawling areas requires formal evaluation. Third, it is necessary to recognise that the Spencer Gulf environment is potentially impacted by a range of diverse activities including fisheries (e.g. abalone, blue swimmer crab, snapper, sardine), other aquatic industries (e.g. aquaculture, shipping, harbours, wharfs), pollutants (e.g. from coastal industries) and weather (e.g. climate change; Steer et al. 2013). As undertaking an ecological assessment of the SGPF may yield performance indicator values outside of the established reference points, it will be important to evaluate whether this reflects an impact from the SGPF, another factor on the Spencer Gulf environment or a cumulative effect (FRDC project 2011/205). The need for this evaluation is likely to be greatest for those performance indicators related to by-product, by-catch and TEPS.

Implementation of bioregional plans (Fletcher et al. 2010) in support of ecosystem based management (Webb and Smith 2008) and/or integrated ocean management may yield a long-term, integrated approach to resolving this issue.

6.2.1 Habitat

There are several potential performance indicators for assessing the component 'habitat' (encompassing habitat forming and sessile species) including (i) area of high-intensity trawling; (ii) expansion of high-trawling intensity into areas of Spencer Gulf with historically low levels of trawl intensity; and (iii) increases/continued trawling effort in areas of Spencer Gulf that have either not been trawled or received only low levels of trawl intensity (i.e. overlap; Table 6-2). There are, however, several difficulties with these approaches.

Firstly, there are several different ways in which these performance indicators could be calculated, and it is not yet evident which method may be the most appropriate. For example, for the area of high trawling intensity, it may be appropriate to use the data from 2002/03 to 2011/12 to determine suitable reference points. The largest area of high-intensity fishing, 46,600 ha in 2004/05, could be used as an upper limit reference point. In contrast, development of a performance indicator based on an expansion of high-intensity trawling into those areas of the Gulf across which trawl effort has been traditionally much lower is more difficult because of the alternative estimation methods. Secondly, none of these performance indicators captures the overlap of prawn trawling with different habitat types (e.g. yet-to-be identified rare, important or sensitive) or the degree to which different trawled habitats are able to 'recover'. Consequently, while it is likely that development of performance indicators for the key component 'habitat' will need to consider these current deficiencies, one of the key limitations will probably be the availability of suitable data (but see Hobday et al. 2011a; James and Bone 2011; O'Connell 2014; O'Connell et al. in press; Table 6-1). If these data were to become available, this would alleviate the need to use the location and intensity of fishing effort as an index of the potential impact of the SGPF on the Spencer Gulf habitats. Thirdly, the use of each of these approaches is influenced by (i) fishing location (GPS) not being recorded for each trawl shot; (ii) data selection rules applied to eliminate likely spurious data; (iii) definition of no and low trawling intensity; and (4) challenge of identifying the extent of fishery overlap with environmental variables and associated long-term impact given the ecological dynamics of the species/habitats involved and the methods used by the fishery. The degree to which periodic reporting of fishing location affects interpretation of these potential performance indicators is poorly understood. While it is unlikely that the high-intensity trawl areas would be affected by reporting frequency, the low-intensity trawl areas (strongly influenced by reporting frequency), which may contain some of the more ecologically sensitive areas of Spencer Gulf, could change substantially. It is also not clear if the recording of fishing location occurs systematically, or is biased to the recording of GPS positions when vessels move among areas. There are also problems with the accuracy of the data. For example, numerous reported fishing locations occur on land, in waters shallower than 10 m where prawn trawling is prohibited, or sporadically across Spencer Gulf outside of established trawl areas. In addition, to account for the potential bias on the spatial extent of 'low' intensity trawling, areas with very low trawling intensities were included in the 'no fishing' category. While this likely resulted in a more representative distribution of trawling undertaken by the fishery, as validated by commercial fishers and the catch distribution data, the spatial extent of trawling in Spencer Gulf is strongly influenced by the definitions of no and low trawling. Consequently, the uncertainty associated with these data and their use needs to be resolved for the utility of these potential performance indicators to be fully evaluated. One way to do this would be to have the fishing fleet record the start, centre and finish GPS points for an entire fishing run and then to use bootstrapping techniques to examine the sources of error around the current data. This approach, and the elimination of current errors, would be facilitated by adoption of the integrated electronic catch and effort log currently pending.

6.2.2 Ecosystem

Based on the available data and information, it was not possible to identify any potential performance indicators for ecological assessment against the component 'ecosystem'. There are, however, several approaches underway that are likely to yield suitable performance indicators. These include the current FRDC-funded project that is developing a trophodynamic model for Spencer Gulf (FRDC 2011/205) and direct comparisons between the 2007 and 2013 gulf-wide by-catch surveys.

Whilst rapid assessments such as the ratio of prawn catch to by-catch may be suitable, alternative performance indicators such as (i) species richness indices; (ii) mean trophic level; and (iii) fishery-in-balance models (Hall and Wise 2011; Hobday et al. 2011a) are more likely to be suitable for ecological assessment against the component 'ecosystem'. However, each of these methods requires a time series of species-specific abundance (numbers or weights) data, with such data currently available only for 2007 (Currie et al. 2009).

Broad indicators of diversity, such as species richness, evenness and dominance, may provide a convenient summary of changes in catch species assemblages over time (Hall and Wise 2011). Because species richness indices may be affected to varying extents by the most, or least, abundant species, Hill's numbers which uses a suite of indices to account for limitations and biases in using a single index (Hill 1973), has proven useful for estimating species richness and diversity for investigating fishery impacts on fish assemblages (Rice 2000; Ferguson et al. 2013).

Whilst broad indicators of diversity may indicate changes in species assemblages, they do not provide an indication of the nature of the change. Additionally, such indices are sensitive to sample size and spatial/temporal trends may be affected by changes in catch per unit effort (CPUE), fishing effort (Hall and Wise 2011) and the hydrodynamics of Spencer Gulf (Middleton et al. 2013). For this reason, other ecosystem-based indicators developed for use with fishery data, such as mean trophic level, mean maximum length and fishery-in-balance (Pauly et al. 1998; Christensen 2000; Pauly and Palomares 2005; Zhang et al. 2009; Ramos et al. 2011) indices may provide more robust performance indicators for ecosystems (Hall and Wise 2011). For example, mean trophic level has been explored (management simulations) as a performance indicator to inform ecological assessment of the Northern Prawn Fishery (Bustamante et al. 2011).

6.2.3 Target species

Given that the indicators for assessing performance of the SGPF are prescribed in the management plan (PIRSA 2014b), it was considered both inappropriate and beyond the scope of this project to consider alternative performance indicators for ecological assessment against the component 'target species'.

6.2.4 Non-target species: by-product and by-catch

By-product

The most obvious potential performance indicator for assessing the component 'by-product' is total annual catch (Table 6-8), for which it may be appropriate to use the reported catch data from 2002/03 to 2011/12 to determine suitable reference points (e.g. maximum annual catch as an upper limit reference point; Figures 6-5, 6-6). However, use of this performance indicator may be influenced by several factors including only the retained catch being reported. For example, if all the calamary catch was retained (e.g. due to a change in price), then reported catches would increase without any potential impact on the population. In addition, implementation and/or changes to minimum legal sizes can influence catch levels. Consequently, ‘external’ influences on performance indicators need to be considered during development and implementation. It is also likely to be necessary to develop a by-product performance indicator based on the relative abundance of southern calamary and Balmain bugs, perhaps supported by data obtained from fishery-independent surveys. This approach would also need to consider seasonal variations in abundance that are evident in the current data (Roberts and Steer 2010; Figures 6-5, 6-6).

By-catch

Based on the available data and information, one of the most suitable potential performance indicators for ecological assessment against the component ‘by-catch’ is likely to be temporal change in bycatch species composition. Current application is, however, limited because spatially-resolved data on by-catch are only currently available from the 2007 (Currie et al. 2009) and 2013 (SARDI unpublished data) by-catch surveys and suitable performance indicators are likely to require a long-term data set (>5 replicates). In addition, there is a need to consider developing species-specific performance indicators, particularly for iconic (e.g. giant cuttlefish), any high-risk and other commercially-important (e.g. snapper, King George whiting, blue swimmer crabs) species. These performance indicators will also require long-term data, although the large number of current projects focussed on giant cuttlefish in Spencer Gulf (e.g. FRDC 2011/054, 2013/010, 2013/032 and 2013/052) may yield suitable performance indicators for this species in the short-term. For the remainder, suitable approaches could include (1) determining the validity of using ‘fishery footprint’ as a proxy for ecological assessment against the component ‘by-catch’; (2) increasing the frequency of the gulf-wide by-catch survey (e.g. biennially/triennially, based on a cost-benefit analysis) to reduce the overall time period required to establish a baseline – followed by less frequent surveys (e.g. every 5 years); (3) developing daily and/or fishery-independent (i.e. the three stock assessment surveys) reporting systems for the iconic, any high-risk and other commercially-important species. The latter would help to resolve the current limitation on the seasonality of the data and once available, should be evaluated for their suitability as indicator species for the broader by-catch assessment.

Table 6-8 Potential (denoted in *italics*) ecological performance assessment for the Spencer Gulf Prawn Fishery: performance indicators, reference points and associated data requirements. * indicates current management plan (PIRSA 2014b).

Objectives, performance indicators and reference points				Data requirements / availability		
Risk component	**Operational objective**	**Performance indicator**	**Performance measure/limit reference point**	**Source**	**Potential reference periods**	**Required Frequency**
Habitat	Fishery impacts on benthic habitat and associated communities are minimised	*Area of high intensity fishing*	*>46,600 ha*	*CE logbook*	*2002/03 to 2011/12*	*Annual*
		New trawl area fished (% of total area fished)	*>5% increase from previous year*			
		Changed trawling effort in low/no trawl areas (overlap)	*>1% increase from previous year*			
		% rare/sensitive/slow recovery habitats trawled	*>1%*			
		Ratio discards:target	*Increasing trend*	*By-catch survey; stock assessment survey*	*2006/07 and 20012/13*	*Annual*
Ecosystem	Fishery impacts on ecosystem, including trophic interactions and bycatch are minimised	*Species assemblage trophic metrics* *By-catch species composition* *Catch (t) or catch rate (kg/hr) of high-risk, iconic and/or commercially important species*	*To be determined*	*By-catch survey; stock assessment survey* *CE logbook*	*2006/07 and 20012/13*	*Annual*
Target species*	Maintain ecologically sustainable prawn biomass	Catch rate (kg/hr)	>68.2 kg/hr (adults)	Stock assessment survey	N/A – value specified in management plan	Three surveys per year
	Future prawn biomass is maintained above sustainable levels		>35 (recruit index)			
By-product Eastern Balmain bug	Fishery impacts on by-product species are sustainable	*Catch (t)*	*>7 t Balmain bug*	*CE logbook; stock assessment survey*	*2002/03 to 2011/12*	*Annual; three surveys per year*
Southern calamary		*Catch (t)*	*>30 t Southern calamary*			
TEPs *Pinnipeds (all)* *Cetaceans (all)* *Turtles (all)* *Sharks (Great white shark, Grey nurse shark)* *Sea snakes (all)* *Syngnathids(all)* *Finfish (all listed)*	Fishery impacts on TEPs are sustainable	Catch (number)	*Great white shark, Grey nurse shark, pinnipeds, cetaceans, turtles: ≥1/season* *Sea snakes: ≥10/season* *Finfish (≥10/season)* *Syngnathids: ≥1/hour trawled*	*TEPs reporting*	*2008/09 to 2011/12*	*Annual*

Table 6-9 Potential (denoted in italics) ecological performance assessment for the Spencer Gulf Prawn Fishery: analysis of data and performance indicator robustness and potential management responses. * indicates current management plan (PIRSA 2014b).

ESD Risk (EBFM component)	Operational objective	Performance indicator	Performance measure/limit reference point	Evaluation	Robustness	Fisheries Management response	Comments and action	External drivers
Habitat	Fishery impacts on benthic habitat and associated communities are minimised	*Area of high intensity fishing*	*>46,600 ha*	*~30% catch has spatial data*	*Moderate-High*	*Area closures – redistribution of spatial catch*	*Need to increase % reporting spatial data*	*Environmental impacts, other fisheries, heavy industry, agriculture*
		New trawl area fished (% of total area fished)	*>5% increase from previous year*					
		Changed trawling effort in low/no trawl areas (overlap)	*>1% increase from previous year*					
		% rare/sensitive/ slow recovery habitats trawled	*>1%*					
		Ratio discards:target	*Increasing trend*	*Few years data: by-catch survey*	*Low*	*Area/time closure, BRDs (+ evaluation)*	*Develop time-series of data to provide robust PI*	-
Ecosystem	Fishery impacts on ecosystem, including trophic interactions and bycatch are minimised	*Species assemblage trophic metrics* *By-catch species composition* *Catch (t) or catch rate (kg/hr) of high-risk, iconic and/or commercially important species*	*TBA*	*Few years data: by-catch survey*	*TBA*	*TBA*	*Develop time-series of data to provide robust PI*	*Impacts from heavy industry, agriculture*
Target species*	Maintain ecologically sustainable prawn biomass	Catch rate (kg/hr)	>68.2 kg/hr (adults)	Stock assessment survey	High	TACC and location of fishing informed by results of stock assessment survey	Further develop time-series of data	Impacts from heavy industry, agriculture
	Future prawn biomass is maintained above sustainable levels		>35 (recruit index)					
By-product Eastern Balmain bug Southern calamary	Fishery impacts on by-product species are sustainable	*Catch (t)*	*>7 t Balmain bug*	*Longer time-series needed*	*Moderate*	*Area/time closure, BRDs (+ evaluation)*	*Develop time-series of data to provide robust PI*	*Environmental impacts, other fisheries, heavy industry, agriculture* *Increasing abundance of by-product species*
			>30 t Southern calamary					
TEPs *Pinnipeds (all)* *Cetaceans (all)* *Turtles (all)* *Sharks (Great white shark, Grey nurse shark)* *Sea snakes (all)* *Syngnathids(all)* *Finfish (all listed)*	Fishery impacts on TEPs are sustainable	*Catch (number)*	*Great white shark, Grey nurse shark, pinnipeds, cetaceans, turtles: ≥1/season* *Sea snakes: ≥10/season* *Finfish (≥10/season)* *Syngnathids: ≥1/hour trawled*	*Longer time-series needed*	*Moderate*	*Area closures to reduce fishery impacts are considered in developing harvest strategies where appropriate.* *Time closures* *BRDs (+ evaluation)* *Industry codes of practice*	*Further development and evaluation of BRDs*	*Environmental impacts, other fisheries, heavy industry, agriculture* *Increasing abundance of TEPs species*

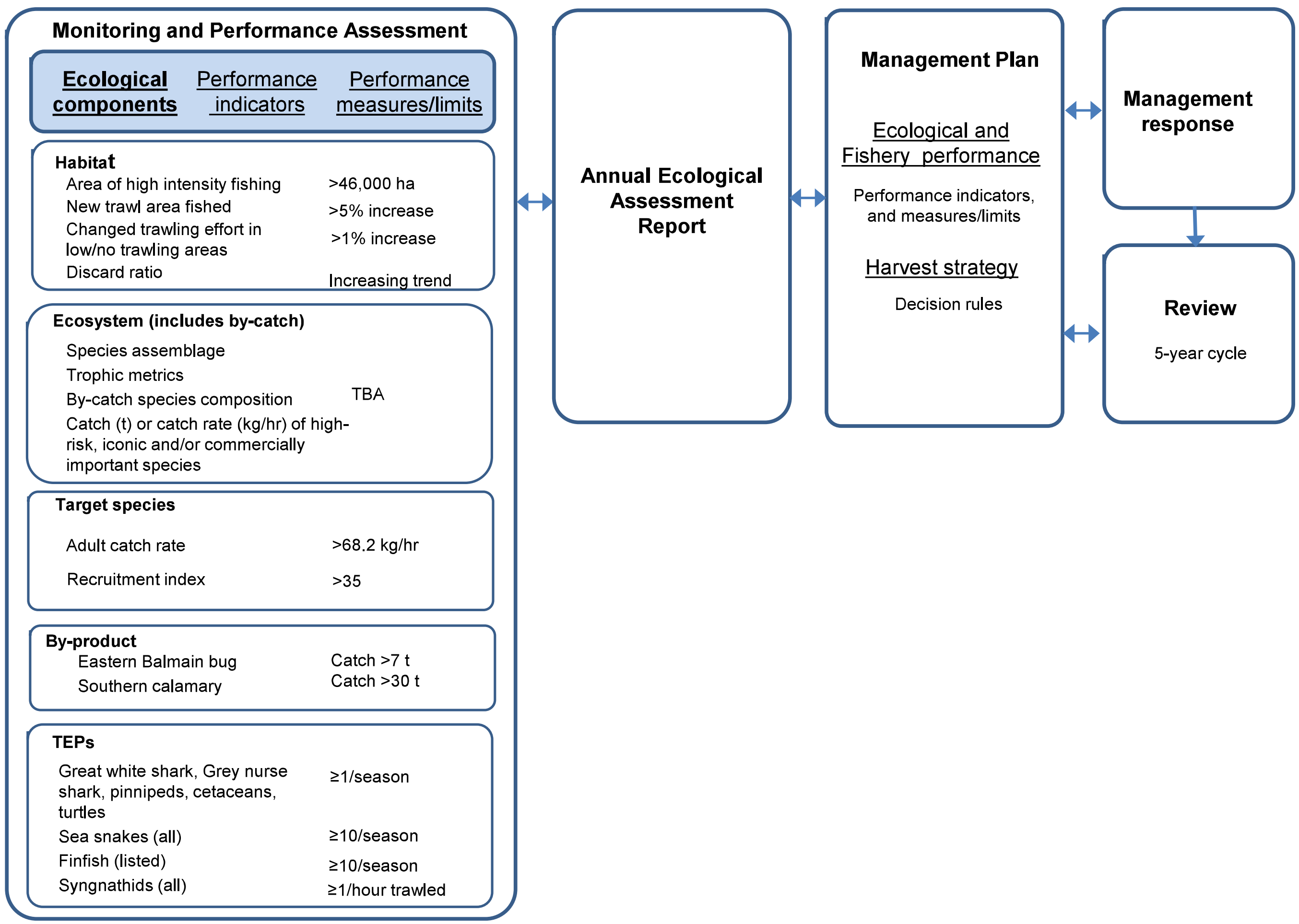

Figure 6-14 Schematic showing the key components of an ecosystem based reporting framework for the Spencer Gulf Prawn Fishery, including indicative performance indicators and reference points.

6.2.5 Non-target species: TEPS

As with by-product, the most obvious potential performance indicator for assessing the component 'TEPS' is the number of interactions per fishing season. For those species with which the SGPF has historically had little interaction, such as pinnipeds, cetaceans and turtles (i.e. 'large-bodied' TEPS), an upper limit of one interaction per year may provide a suitable reference point. In contrast, a different approach is likely to be required for syngnathids which dominate the TEPS by-catch in this fishery. For example, it may be more appropriate to use a performance indicator linking the reported interactions and fishing effort (e.g. number per hr trawled), or to use the stock assessment surveys as the data source for this component. However, use of such an abundance-based measure needs to consider spatial and temporal variability in the catch rates of syngnathids (see Table 6-7; Figures 6-11, 6-12, 6-13).

7 CONCLUSION

This FRDC Tactical Research Fund Project had four objectives: (i) develop a reporting framework for environmental assessment of Australian trawl fisheries following the principles of ecosystem-based fisheries management; and then, using the SGPF as a case study, to (ii) collate and analyse existing data/information to address the environmental impacts of prawn trawling on: benthic habitats; trophodynamics; target species; and non-target species including by-catch/by-product and threatened, endangered and protected species; (iii) integrate existing data on trawl tracks using GIS to produce a continuous contour map representing the ecological foot-print of prawn trawl activities in Spencer Gulf; and (iv) identify and prioritise future research to support ecosystem-based fisheries management. These objectives have been achieved through a review of the relevant literature to identify an appropriate reporting framework, assessment of the data available for the SGPF, and its suitability for use in ecological assessment, GIS mapping of fishing effort and development of a conceptual ecosystem-based assessment framework for the fishery including identification and development of potential performance indicators, reference points and decision rules. The approach developed here would be of use to other prawn trawl fisheries that were seeking a transition from target-species to ecosystem-based assessments, perhaps initially through a national workshop. The tool developed here will assist EBFM and ESD, and satisfy a MSC certification condition.

8 IMPLICATIONS

This project has yielded a conceptual framework and some indicative performance indicators, reference points and decision rules to support ecosystem-based assessment of the SGPF. However, the overall costs of implementing ecosystem-based assessment of the SGPF are unknown, but could be substantial.

There is an opportunity for this approach to be further developed and implemented in conjunction with the next management plan review. However, despite considerable data for the fishery, there were several ESD risk components for which data were limited, impeding performance indicator identification. Consequently, implementation will require data that are currently unavailable and analyses that were beyond the scope of this study. For example, if a change in 'fishery footprint' is an inappropriate surrogate measure, it may be necessary to (1) increase the frequency of the gulf-wide by-catch survey (e.g. biennially/triennially) to reduce the overall time period required to establish a baseline – followed by less frequent surveys (e.g. every 5 years); and/or (2) develop daily and/or fishery-independent (i.e. the three stock assessment surveys) reporting systems for the iconic, any high-risk and other commercially-important species.

9 RECOMMENDATIONS

It is recommended that the data (and their associated limitations), potential performance indicators and the conceptual ecological assessment framework developed in this project for the SGPF be further developed in a collaboration among PIRSA Fisheries and Aquaculture, SGWCPFA, SARDI Aquatic Sciences, and the CCSA over the next five years and be considered for incorporation into future management plans for the SGPF. This will almost certainly require collection of additional data and conduct of a cost-benefit analysis. The need for these data, and cost-effective methods to obtain them should be formally considered as part of this implementation strategy.

10 FURTHER DEVELOPMENT

The management plan for the SGPF has recently been revised (PIRSA 2014b). The framework for ecosystem-based assessment of the SGPF outlined in this report (Section 6) can be further developed and considered for inclusion in future management plans for the fishery. This would likely be aided through a national workshop to evaluate reporting and analytical frameworks to support management decisions across bottom trawling fisheries.

11 Extension and Adoption

During the course of this project, there have been numerous discussions with stakeholders. For example, the draft report was presented to the Research Sub-committee of the SGWCPFA in January 2014 which includes the CCSA, and the Management Committee in March 2014. Subsequently, the Research Sub-committee and Management Committee were provided copies of the draft report for their comments which were included in subsequent versions. This report has been widely distributed (see Appendix 13.4) with recipients including the Australian Council of Prawn Fisheries, South Australian Spencer Gulf, Gulf St Vincent and West Coast prawn fisheries, Northern Prawn fishery, prawn fisheries of Western Australia and the MSC assessors.

12 Project Materials Developed

The primary output from this project is this final report. Other minor outputs include copies of presentations provided to the SGWCPFA and MSC assessors.

13 APPENDICES

13.1 Intellectual property

This research is for the public domain. The report and any resulting manuscripts are intended for wide dissemination and promotion. All data and statistics presented conform to confidentiality arrangements.

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