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Assessment of the South Australian Marine Scalefish Fishery in 2016

MA Steer, AJ Fowler, R McGarvey, J Feenstra, EL Westlake, D Matthews, M Drew, PJ Rogers and J Earl

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Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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ACRONYMS

AFMA	Australian Fisheries Management Authority	**NSG**	Northern Spencer Gulf
CPUE	Catch per unit effort	**NZRLF**	Northern Zone Rock Lobster Fishery
CBCFZ	Coffin Bay Cockle Fishing Zone	**OCS**	Offshore Constitutional Settlement
Conf.	Confidential	**PRCFZ**	Port River Cockle Fishing Zone
DEPM	Daily egg production method	**PIRSA**	Primary Industries and Regions South Australia
DNA	Deoxyribonucleaic acid	**Rec.**	Recreational
DW	Disc width	**RL**	Rock Lobster
FRDC	Fisheries Research and Development Corporation	**SN**	Set net
GN	Gill net	**SL**	Shell length
GSV	Gulf St. Vincent	**SA**	South Australia
GSVPF	Gulf St. Vincent Prawn Fishery	**SARDI**	South Australian Research and Development Institute
GSVS	Gulf St. Vincent Stock	**SE**	South East
HL	Handline	**SAS**	Southern Australian Stock
HN	Hauling Net	**SGSV**	Southern Gulf St. Vincent
ITQ	Individual transferable quota	**SSG**	Southern Spencer Gulf
JG	Jig	**SZRLF**	Southern Zone Rock Lobster Fishery
KI	Kangaroo Island	**SG**	Spencer Gulf
KGW	King George Whiting	**SGPF**	Spencer Gulf Prawn Fishery
LCF	Lakes and Coorong Fishery	**SAFCOL**	The South Australian Fisherman's Co-Operative Limited
LML	Legal minimum length	**TACC**	Total Allowable Commercial Catch
LL	Longline	**TL**	Total Length
MFA	Marine Fishing Area	**WC**	West Coast
MSF	Marine Scalefish Fishery	**WCCFZ**	West Coast Cockle Fishing Zone
Misc.	Miscellaneous	**WCPF**	West Coast Prawn Fishery
NSW	New South Wales	**WA**	Western Australia
NGSV	Northern Gulf St. Vincent	**WV**	Western Victoria

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EXECUTIVE SUMMARY

This report is the first in the new series for the South Australian Marine Scalefish Fishery (MSF) that provides a description of the dynamics of the multi-species, multi-gear fleet, a comprehensive assessment of South Australia's King George Whiting stocks, and assigns stock statuses of a further 21 species or taxonomic groups that are harvested within the fishery. The report includes a summary of the taxon-specific fishing information relating to population biology; fishing access; relevant management arrangements; trends in commercial fishery statistics at the State-wide scale, biological stock or regional management units; and assessment of fishery performance.

Fleet Dynamics

This section provides a holistic view of the fishery by examining and comparing the trends in fishing effort amongst the species, the different fishing gears, amongst locations and seasons.

The dynamics of the Marine Scalefish Fishery fishing fleet have changed in recent years and many of these changes appear to relate to management arrangements. The most obvious change has been the continuous decline in fishing effort which has been perpetuated by the licence amalgamation scheme implemented in 1994 and, more recently, the two voluntary net buy-back initiatives in 2005 and 2014

Since the implementation of the licence amalgamation scheme in 1994, 399 active MSF licences have been removed, representing an overall reduction of 55.8%, and translating to a 55.6% reduction in total fishing effort.

Declines in the productivity of the premium finfish species have contributed to the diversification of the MSF fishing fleet, with many fishers switching their effort from Snapper, King George Whiting and Southern Garfish towards Southern Calamari. This recent trend indicates that Southern Calamari has been established as an opportunistic target species for commercial fishers, and has surpassed Snapper and King George Whiting as the most valuable MSF species for the first time in history.

A number of species considered in this report constitute by-product for the hauling net sector, where they are incidentally caught when fishers target more valuable species. Of these, Yellowfin Whiting, Australian Herring, Snook, Leatherjackets and Yelloweye Mullet are of medium value, with moderate market appeal. Each of these species, share similar commercial catch and effort trends, where fishing effort within the hauling net sector has been sequentially reduced.

Despite the long-term trend in declining effort, Snook and Leatherjackets have been increasingly targeted by hauling net fishers, more fishers are taking Wrasse using handlines and longlines; and there has been an increase in catches of Ocean Jackets and Western Australian Salmon over the past four years.

King George Whiting Stock Assessment

The status of the West Coast and Spencer Gulf Biological stocks were classified as '**sustainable**' whereas, the Gulf St. Vincent/Kangaroo Island biological stock was classified as '**transitional-depleting**'.

There is no indication in the high levels of handline CPUE, estimates of fishable biomass and recruitment and the declining exploitation rate to suggest that the biomass of the West Coast stock has been reduced to an extent that would impact on future levels of recruitment. As such, the classification of '**sustainable'** for this stock is retained.

The recent increases in fishery trends that are also manifested in the estimates of fishable biomass and recruitment from WhitEst suggest that the biomass of the Spencer Gulf biological stock has increased considerably since the period of decline between 2007 and 2013. This result is not consistent with the fishing pressure being too high and moving the stock in the direction of being recruitment overfished. Rather, it suggests that the biomass is at a level sufficient to ensure that future recruitment is adequate. As such, the classification for this Stock has changed from 'transitional-depleting' to '**sustainable'**.

The increase in handline CPUE since 2012 is the most positive indicator for the status of the Gulf St. Vincent/Kangaroo Island biological stock, which is consistent with a marginal increase in average recruitment over the past few years. Nevertheless, fishery catch, effort and estimated biomass have not increased sufficiently to suggest a recovery of the stock. As such, there is insufficient evidence that there has been a recovery in the biomass that would ensure adequate future levels of recruitment. The stock status of '**transitional-depleting'** that was applied in 2014 is retained.

The improved status of the King George Whiting Spencer Gulf stock compared to the previous 2014 assessment was unrelated to the management arrangements implemented in December 2016, which included a spatial closure to protect known spawning grounds and an increase in the legal minimum length, as it occurred prior to their implementation.

The main uncertainty in this stock assessment for King George Whiting relates to the relationships between fishable biomass and the estimates of the various fishery performance indicators. The

current assessment does not consider changes in 'effective' effort over time through technological advancements and the concept of the unit of fishing effort. These changes complicate interpreting fishing effort and CPUE in terms of fishable biomass. A further uncertainty relates to the poor understanding of temporal trends in catch and effort by the recreational sector. Finally, there is uncertainty about whether reproductive output in the two gulfs may have declined in recent years through targeted fishing of spawning aggregations that are located in the deep, off-shore waters of southern Spencer Gulf and Investigator Strait.

Stock Status

Overall, this report assessed the fishery performance of 22 species/taxonomic groups within South Australia's Marine Scalefish Fishery (MSF). Collectively, these taxa were considered across 34 management units, at a resolution that aligned with either the biological stock, or the State-wide or regional level. Of these, 27 (79%) stocks were classified as 'sustainable', three (9%) were 'recruitment overfished', two (6%) 'transitional-depleting', one (3%) was 'transitional-recovering', and the remaining one (3%) was undefined as there was insufficient information to assign a stock status (Table E-1).

Apart from one King George Whiting stock (Spencer Gulf) which changed from 'transitional-depleting' to 'sustainable' as a result of three consecutive years of positive recruitment, the status of King George Whiting, Snapper and Garfish stocks have remained unchanged (Table E-1).

Future Directions

Currently, the most significant gap in our knowledge in the assessment of the status of MSF fish stocks is in determining the relative contribution of the State-wide catch by the recreational fishing sector. Improving the precision of the recreational catch estimates, either through more frequent surveys or increased participation rates, will broadly benefit the assessment and subsequent management of the MSF.

Determining stock status through the weight-of-evidence approach for all the MSF stocks considered in this report has relied heavily of fishery-dependent statistics. There is a need to contemporise how the data sources are treated to determine whether they need to be adjusted or weighted to adequately reflect the changes in the fishing dynamics. This may involve exploring the relative effects of nominal increases in effective effort, sensitivity analysis of various gear types, determining whether greater influence be placed on biological metrics, or if fishery-independent data streams can be used to ground-truth model-derived estimates of biomass. For the other lower value species, there is a need to revisit whether nominal estimates of CPUE are

the most informative metric of relative abundance, as opposed to standardized, or averaged derivations of catch rates.

Table E-1. Status of South Australia's Marine Scalefish Fishery Resources in 2016.

SPECIES	STOCK	STATUS	INDICATORS
KING GEORGE WHITING	WC	Sustainable	Catch, CPUE, age structure, biomass
	SG	Sustainable	Catch, CPUE, age structure, biomass
	GSV/KI	Transitional - Depleting	Catch, CPUE, age structure, biomass
SNAPPER	SG/WC	Transitional - Depleting	Catch & Effort
	GSV	Sustainable	Catch & Effort
	WV	Sustainable	Catch & Effort
SOUTHERN GARFISH	WC	Sustainable	Catch & Effort
	NSG	Transitional - Recovering	Catch & Effort
	SSG	Sustainable	Catch & Effort
	NGSV	Overfished	Catch & Effort
	SGSV	Sustainable	Catch & Effort
	SE	Sustainable	Catch & Effort
SOUTHERN CALAMARI	STATE	Sustainable	Catch & Effort
YELLOWFIN WHITING	NSG	Sustainable	Catch & Effort
	NGSV	Sustainable	Catch & Effort
WA SALMON	WA/SA	Sustainable	Catch & Effort
AUST. HERRING	WA/SA	Sustainable	Catch & Effort
VONGOLE	WCCFZ	Sustainable	Harvest fraction, recruitment
	CBCFZ	Sustainable	Harvest fraction, recruitment
	PRCFZ	Overfished	Harvest fraction, recruitment
SNOOK	STATE	Sustainable	Catch & Effort
SAND CRABS	STATE	Sustainable	Catch & Effort
YELLOW-EYE MULLET	STATE	Sustainable	Catch & Effort
MULLOWAY	STATE	Sustainable	Catch & Effort
WHALER SHARKS	STATE	Undefined	Limited data
OCEAN JACKETS	STATE	Sustainable	Catch & Effort
BLUE-THROAT WRASSSE	STATE	Sustainable	Catch & Effort
SILVER TREVALLY	STATE	Sustainable	Catch & Effort
LEATHERJACKETS	STATE	Sustainable	Catch & Effort
GUMMY SHARK	SAS	Sustainable	Biomass
SCHOOL SHARK	SAS	Overfished	Biomass
RAYS & SKATES	STATE	Sustainable	Catch & Effort
CUTTLEFISH	STATE	Sustainable	Catch & Effort
BLACK BREAM	STATE	Sustainable	Catch & Effort

Keywords: King George Whiting, fleet dynamics, stock assessment, marine scalefish, stock status.

1. INTRODUCTION

1.1. Overview

Over the past 12 years the stock status and fishery statistics for species harvested in South Australia's Marine Scalefish Fishery (MSF) have been reported in two annual reports. The first was a comprehensive stock assessment of King George Whiting, Snapper, or Southern Garfish, which were sequentially delivered on a triennial basis. This report assessed the respective fishery at the scale of the biological stock. The second report summarised the fishery statistics for the 20 main species or taxonomic groups at the State-wide spatial scale, including assessment against the 'general' fishery performance indicators.

This report is the first in the new series for the MSF that will provide taxon-specific information on: population biology; fishing access; relevant management arrangements; trends in commercial fishery statistics at the State-wide scale, biological stock or regional management units; and assessment of fishery performance. Consequently, this report provides a comprehensive reference document to underpin the management of this complex multi-species, multi-gear fishery.

This report is partitioned into five sections. The first section, following this overview, provides an overall description of South Australia's MSF, its management arrangements, and details the indicators used to assess the performance of the species within the fishery.

Section two describes the dynamics of the commercial fleet, catch composition, and spatial and temporal trends in fishing effort.

Section three provides an assessment of South Australia's King George Whiting stocks. This assessment is based on two types of fishery performance indicators (1) the general performance indicators that relate to the long-term trends in the commercial catch and effort statistics; and (2) the biological performance indicators that consider the population size and age structure of the stocks, including annual estimates of fishable biomass, exploitation rate and recruitment.

Section four consists of a series of species-specific sections arranged in order of their descending priority, by catch, within the MSF. Each section is structured to constitute a 'stand-alone' reference. In each section the relevant biological information is presented, along with a description of the fishery, associated management regulations, interrogation of the State-wide and/or regional fishery statistics, assessment of the fishery against the general performance indicators, and a classification of stock status.

The final section, the General Discussion, synthesises the overall performance of the fishery, details emerging trends within the fishing fleet, and identifies key research priorities that will enhance the assessment of South Australia's Marine Scalefish Fishery.

1.2. Description of the Fishery

The MSF is the most complex fishery in South Australia, based on it being a multi-species, multi-gear, multi-sector fishery. Commercial fishers are permitted to take in excess of 60 marine species that include fishes, molluscs, crustaceans, annelid worms, rays, skates, and sharks. Fishery production is mainly comprised of traditional scalefish species, in particular King George Whiting (*Sillaginodes punctatus*), Snapper (*Chyrsophrys auratus*), Southern Garfish (*Hyporhamphus melanochir*) and Yellowfin Whiting (*Sillago schomburgkii*). Other species such as Southern Calamari (*Sepioteuthis australis*), Australian Herring (*Arripis georgianus*), Sand Crabs (*Ovalipes australiensis*) and Vongole (*Katelysia* spp.) are also important. Currently there are 30 types of fishing gear (or devices) endorsed in the fishery, their use differs, depending on the location of fishing and the types of species being targeted. With the exception of fishing rods and handlines, all devices must be registered on a licence before they can be used to take fish for trade or business. Within the commercial sector there are two types of licences, Marine Scalefish and Restricted Marine Scalefish. Marine Scalefish licence holders are more common. They generally have full access to scalefish species and encompass a wide variety of gear endorsements. A proportion of these licence holders have specific net endorsements and are permitted to use hauling nets and set/gill nets to target certain species. Restricted Marine Scalefish licence holders have fewer gear endorsements and are prohibited from using nets. In addition to MSF licence holders, licence holders from the Miscellaneous Fishery, the Northern and Southern Zone Rock Lobster fisheries, the Lakes and Coorong Fishery, the three prawn fisheries, the Blue Crab Fishery and Commonwealth fisheries all have some level of access.

The heterogeneous mixture of participants, fishing devices, licence conditions, policies and regulations associated with South Australia's MSF, makes the task of assessing stock status extremely challenging. This is further compounded by the highly dynamic nature of the commercial fishers who can switch their target effort between species and fish throughout State waters. The complex nature of this fishery means that there has always been considerable capacity for it to expand through the realisation of latent effort.

The recreational fishing sector also has access to many of the MSF species. It has social, cultural, and economic significance in South Australia. Most recreational fishing effort occurs in marine

waters, including estuaries, with fishers permitted to use a variety of gear types to target a variety of MSF species.

1.3. Management Arrangements

The MSF is managed by the South Australian State Government's Primary Industries and Regions South Australia (PIRSA) Fisheries and Aquaculture in accordance with the legislative framework provided within the *Fisheries Management Act 2007*, and subordinate *Fisheries Management (General) Regulations 2007*, *Fisheries Management (Marine Scalefish Fisheries) Regulations* and *licence conditions*.

The commercial MSF has undergone considerable management changes over the past 40 years that has seen the fishery restructured and limited through gear restrictions and configuration, licensing, spatial and temporal closures, and size limits. During this time there have been three notable changes that were primarily implemented to limit, and then reduce, the number of participants in the commercial sector. The first change occurred in 1977, when a freeze was imposed on the issue of new licences, which converted the commercial sector into a limited-entry fishery. This also involved a 'show cause provision' that prevented the reissue of licences to fishers if a minimum level of commercial fishing had not been met. Non-transferable Restricted Marine Scalefish licences were also created at this time to recognise part-time fishers. The second change was the licence amalgamation scheme which was introduced in 1994. This scheme is essentially a fractional licensing initiative which requires prospective fishers to purchase a certain number of points when buying a licence (see Steer and Besley 2016). The third change, implemented in 2005, was a voluntary buy-back of net fishing endorsements and subsequent spatial closures to net fishing. A similar, smaller licence buy-back scheme also occurred in 2014 in association with the implementation of the South Australian Marine Park network.

The recreational fishery is not licensed but is subjected to a range of regulations such as size, boat, bag and possession limits, restrictions on the types of gear that may be used, temporal and spatial closures, and the complete protection of some species.

1.4. Management Plan

The Fisheries Management Act 2007 describes the requirements for fisheries management plans. In 2013, the *Management Plan for the South Australian Commercial Marine Scalefish Fishery* was released. It details the management objectives of the Marine Scalefish Fishery, the strategies to achieve those objectives and monitor the performance of the fishery. It also includes harvest

strategies for key primary and secondary species and provides an increased level of certainty and transparency. The goals and objectives for the commercial Marine Scalefish Fishery are intended to capture all of the factors identified in the *Fisheries Management Act 2007* that must be balanced to pursue ecologically sustainable development, including securing the future of the commercial marine scalefish industry. The four broad goals include:

1. Ensure the Marine Scalefish Fishery resources are harvested within ecologically sustainable limits.
2. Optimum utilisation and equitable distribution of the Marine Scalefish Fishery resources.
3. Minimise impacts on the ecosystem.
4. Cost effective and participative management of the Marine Scalefish Fishery.

The *Management Plan for the South Australian Commercial Marine Scalefish Fishery* also specifies the share of the fishery to be allocated to each fishing sector, based on the existing shares at the time the management plan was requested.

1.5. Harvest Strategies

The aim of the harvest strategies for the species in the Marine Scalefish Fishery management plan is to set a process for monitoring the performance of the various species and measuring the effectiveness of the management arrangements which govern their commercial harvest. Performance indicators, operational objectives and reference points are used to determine when fishery performance warrants a review and possible changes to management arrangements.

The *Management Plan for the South Australian Commercial Marine Scalefish Fishery* has developed species specific harvest strategies for each of the four primary species and for Vongole. Harvest strategies for the remaining secondary and tertiary species have been developed to apply generally to all species. Commercial harvest strategies have not been developed for ‘Other’ species.

1.6. Fishery Performance Indicators

Four general performance indicators are used to assess the performance of a species within the MSF. These were derived from historical commercial fishery statistics from 1984 to 2016 (reference period), and include total commercial catch, and targeted effort and CPUE for specific gear types that vary amongst the taxa. Each performance indicator was assessed against the following trigger points:

1. the third highest and third lowest values of the reference period (1984 to 2016);

2. the greatest (%) inter-annual variation (+ and -) over the reference period;
3. the greatest rate of change (+ and -) over a five-year period; and
4. whether the data have decreased over the most recent five consecutive years.

Additional biological performance indicators are used in the assessment of stock of Snapper, King George Whiting and Southern Garfish. These are derived from population models that assimilate commercial, recreational and biological datasets to estimate total fishable (legal) biomass, egg production, recruitment, and exploitation rates. The limit reference points associated with these biological indicators are detailed in the harvest strategies for these species (see PIRSA 2013). Stock assessments that consider both the general and biological performance indicators are undertaken for these three species triennially. King George Whiting is assessed in this report (2017), whilst Southern Garfish and Snapper will be assessed in 2018 and 2019, respectively.

1.7. Allocation

The *Management Plan for the South Australian Commercial Marine Scalefish Fishery* also specifies the share of the fishery to be allocated to each fishing sector, based on the existing shares at the time the management plan was requested. The management plan has allocated primary and secondary species and it also provides information about managing and reviewing catch shares across the commercial sectors. Trigger levels have been developed for commercial only shares. These trigger levels include:

Primary Trigger 2 (Commercial shares only): Exceed commercial sector allocation by relevant percentage in three consecutive years or in four of the previous five years.

Primary Trigger 3 (Commercial shares only): Exceed commercial sector allocation by relevant percentage in any one year.

1.8. Stock Status Classification

A national stock status classification system was recently developed for the consistent assessment of key Australian fish stocks (Flood et al. 2014). It considers whether the current level of fishing pressure is adequately controlled to ensure that the stock abundance is not reduced to a point where the production of juveniles is significantly compromised. The system combines information on both the current stock size and the level of exploitation into a single classification for each stock against defined biological reference points. Each stock is then classified as either: ‘sustainable’, ‘transitional-recovering’, ‘transitional-depleting’, ‘overfished’, ‘environmentally limited’, or ‘undefined’ (Table 1-1). PIRSA has adopted this classification system to determine the status of all South Australian fish stocks (PIRSA, 2015).

Table 1-1. Classification scheme used to assign fishery stock status. The description of each stock status and its potential implications for fishery management are also shown (Flood et al. 2014).

	STOCK STATUS	DESCRIPTION	MANAGEMENT IMPLICATIONS
	Sustainable	Stock for which biomass (or biomass proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (i.e. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished	Appropriate management is in place
↑	Transitional–recovering	Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and the stock biomass is recovering
↓	Transitional–depleting	Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished	Management is needed to reduce fishing pressure and ensure that the biomass does not deplete to an overfished state
	Overfished	Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed

2. FISHING FLEET DYNAMICS

2.1. Introduction

Understanding the dynamics of fishers within a commercial fishery is as important for assessing status as are the population dynamics of the fish and the ecosystem that support them (Hilborn 1985). This is because the metrics of the fishers' catch and fishing effort are used as the basic input in assessing stocks.

The dynamics of a fishing fleet are essentially products of decisions made by the fishers that relate to when and where to fish, what gear to use and what species to target. These decisions can be influenced by a range of interconnected factors such as the seasonal movement and migration of the target species, weather conditions, management arrangements, and socio-economics. In order to reliably evaluate the impact of a fishing fleet on a resource, it has been argued that a thorough knowledge of the fishery is initially required, followed by a comprehensive evaluation of the spatial and temporal characteristics of the fishing activities before any reliable stock assessment and forecast models are developed for management purposes (Hilborn and Walters 1992, Mahévas et al. 2008). In most cases a detailed decomposition of fishing effort by species, fishing gear, location and season is considered to fundamentally characterise patterns of fishing activity (Hilborn and Walters 1992).

Whilst the bulk of this report is devoted to the assessment of fishery statistics for individual species to determine stock status, this section provides a holistic view of the fishery by examining and comparing the trends in fishing effort amongst the species, the different fishing gears, amongst locations and seasons. As a consequence, it reveals the dynamic nature of this fishery in terms of the changes that have occurred at different spatial and temporal scales and the relationships in trends between species.

2.2. Methods

The MSF is divided into 58 Marine Fishing Areas (MFAs) for the purpose of statistical reporting and monitoring of commercial fishing activity (Figure 2-1). All licensed fishers are required to log their fishing activities, recording specific details such as MFA fished, number of fishers on board, species targeted, species caught, weight of catch, and method of capture. This level of detail was initially recorded on a monthly basis, but since 2003 fishers have been required to provide a daily log of fishing activity. These records must be submitted monthly to SARDI Aquatic Sciences where they are entered into a database which is routinely reviewed and cross-checked to ensure that the data satisfy research needs. The current database is a compilation of catch and effort

data collected from 1983/84 to the present and provides the primary source of data used for stock assessment of the MSF species. This assessment was based on data up to 31st December 2016, thus providing a complete 33 calendar-year dataset.

The complex MSF database was restricted to a smaller, more manageable dataset that remained capable of indicating the major trends in fisher behaviour and fleet dynamics. Two main approaches were adopted to achieve this. One approach involved aggregating the data into monthly categories. This level of temporal resolution was considered appropriate, as monthly data were provided by many fishers prior to 2003 and it aligned with some of the short-term management arrangements that currently exist in this fishery (e.g. November Snapper closure). The other approach involved aggregating certain gear types into broader categories. Hauling nets, floating garfish nets, sinking and floating garfish nets, sinking mesh nets, and sinking mixed mesh nets were collectively categorised as 'hauling nets', but were differentiated from large mesh nets (>150 mm mesh size) and set gill nets (50 mm mesh size) which were considered 'set nets'. Similarly, handlines, drop lines, troll lines and fishing rods/poles in the line sector were categorised as 'handlines'.

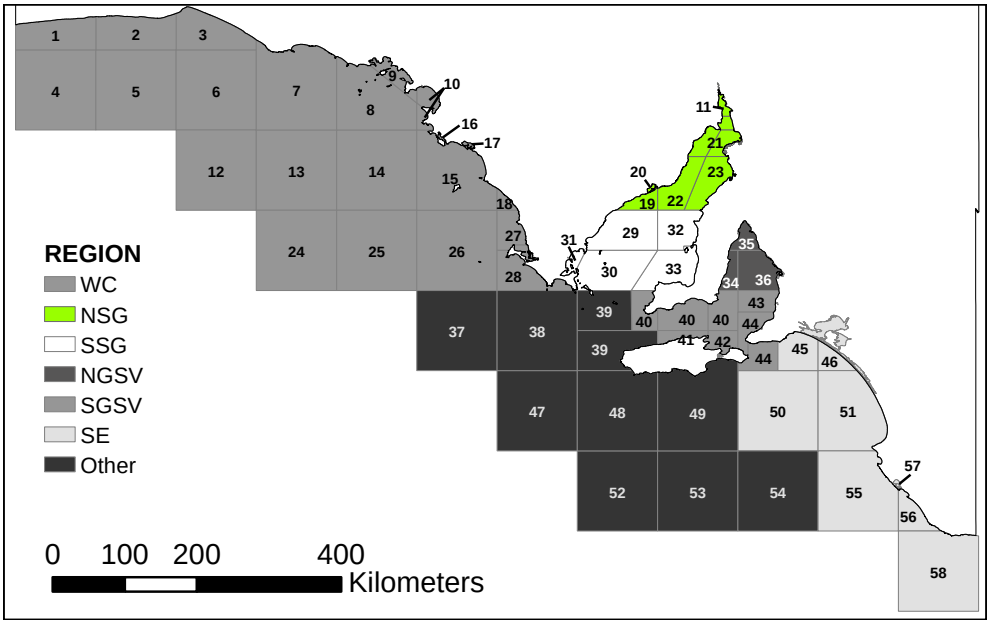

Figure 2-1. Map of the 58 Marine Fishing Areas (MFA) of South Australia's Marine Scalefish Fishery (MSF), broadly partitioned into seven regions: West Coast (WC), Northern Spencer Gulf (NSG), Southern Spencer Gulf (SSG), Northern Gulf St. Vincent (NGSV), Southern Gulf St. Vincent (SGSV), South East (SE), and Other.

2.3. Results

2.3.1. Trends in Number of Active Licences

Overall, there has been a 63.4% reduction in the number of active fishers licensed to harvest MSF species over the past 33 years, declining from 865 licences in 1984 to 316 in 2016 (Figure 2-2). The greatest reduction occurred within the Rock Lobster fisheries, as the number of active licence holders that accessed MSF species declined from 175 to 30 over the same period, representing an 82.9% reduction. The active MSF and Miscellaneous Fishery licence holders declined by 58.2% and 68.2%, respectively. The rate of decline was accelerated from 1994 due to the implementation of the licence amalgamation scheme. Two net buy-back schemes also contributed in removing active licences in 2005 and 2014 (Figure 2-2). Since the introduction of the licence amalgamation scheme the number of active licence holders has reduced at rate of approximately 15 licences.year^{-1}.

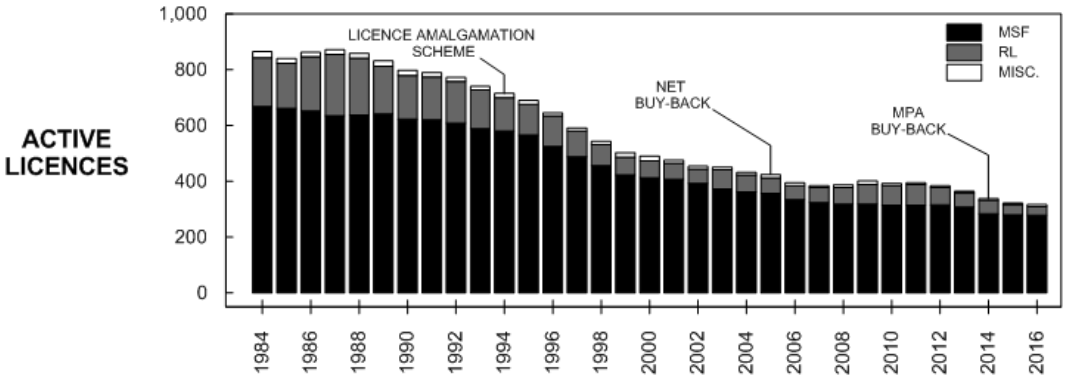

Figure 2-2. Long-term trend in the number of active licence holders that have access to the Marine Scalefish Fishery (MSF), including those from the Rock Lobster (RL) and Miscellaneous (MISC.) Fisheries.

2.3.2. Trends in Commercial Catch

Since 1984, there has been a major shift in the composition of the commercial catch within SA's MSF. This related to the removal of 'other' species catch in 2001, and was a result of the establishment of an exclusive Sardine Fishery. In the six years prior to this separation, Sardines accounted for up to 58% of the total MSF catch. Annual catches in the contemporary fishery is dominated by (>50%) the four primary species, followed by the secondary (approximately 30%), tertiary (12%), and the remaining permitted species (6%) (Figure 2-3).

Total catch of primary species peaked at 2,089 t in 2001 and has since declined to a record low of 1,222 t in 2016, representing a 41.5% decline over 16 years (Figure 2-3). Prior to 1999, the

composition of catch of the primary species was relatively stable, where annual King George Whiting catch accounted for approximately 40%, followed by Southern Garfish (30%) Snapper (20%) and Southern Calamari (15%). Since then, the relative proportion of King George Whiting and Garfish catch has declined below 25% and 15%, respectively, whereas annual catches of Snapper and Calamari have increased, particularly from 2007 onwards (Figure 2-3).

The total annual catch of secondary species remained above 1,000 from 1984 to 2006, peaking at 2,025 t in 1995 (Figure 2-3). Western Australian Salmon and Australian Herring, collectively accounted for most (up to 74%) of the catch up to 2002. From 2002 until 2009, the annual catch of Vongole substantially increased, accounting for up to 34% of the catch of secondary species at its peak in 2007. Total annual catch has since declined to a low of 670 t in 2012 (Figure 2-3).

School and Gummy Sharks were the dominant tertiary species harvested in the fishery from 1984 to the mid-1990s (Figure 2-3). Annual catches of Leatherjackets and Oceanjackets emerged during the early 1990s peaking above 900 kg in 1991, since 2006 annual catches have rarely exceeded 100 kgs (Figure 2-3).

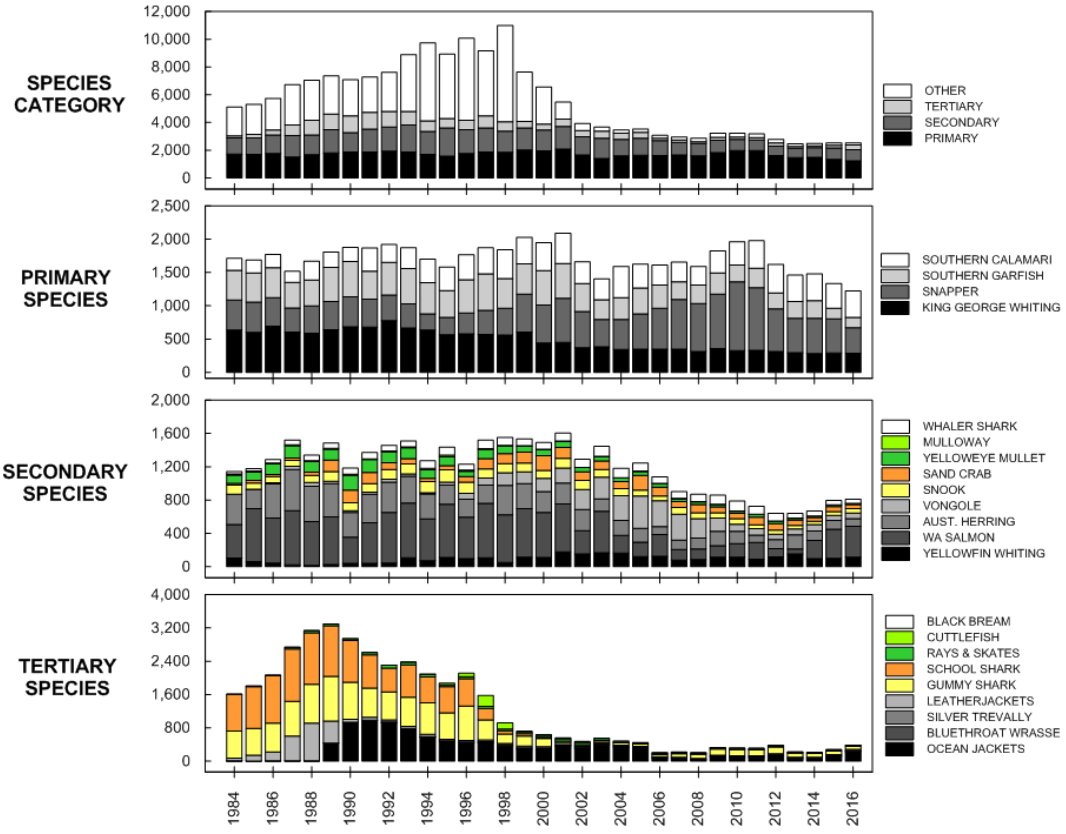

Figure 2-3. Long-term trend in total catch (t) in the commercial Marine Scalefish Fishery, presented for the secies considered in this report in order of priority.

2.3.3. Trends in Fishing Effort

Species

Annual estimates of total fishing effort in the commercial MSF peaked at 137,333 fisher-days in 1992 (Figure 2-4). This peak represented an 18.8% increase in annual effort since 1984, after which, there was a 59.3% reduction in effort, which declined to 55,837 fisher-days in 2016. This decline, which occurred at a relatively consistent rate of approximately 3,227 fisher-days.year^{-1}, was influenced by the licence amalgamation scheme and subsequent net buy-back initiatives.

Up until 2015, most (>75%) of the fishing effort was targeted to a particular species. In 2016, 28.1% of the effort was non-specific, with fishers identifying 'any target' within their catch returns. This level of 'non-specific' reporting was the highest on record. Of the reported targeted effort, the four primary species have consistently accounted for the greatest proportion (approx. 62%), of which King George Whiting has historically dominated (approx. 40%). Since 2011, there has been a distinct shift in fishing activity, as fishers have directed targeted effort away from King George Whiting and Snapper towards Southern Calamari. The relative proportion of effort targeted towards Southern Calamari has increased above 20%, representing a doubling in fishing effort since the late 1990s and 2000s (Figure 2-4).

The secondary species attracted approximately 5% of the total fishing effort. The distribution of targeted effort amongst these species has changed over the past 33 years. Historically, Western Australian Salmon, Snook and Yelloweye Mullet attracted the most effort during the mid-1980's accounting for approximately 70% of targeted effort directed at secondary species. Fishers increasingly targeted Sand Crabs from the late 1980s, and Vongole became a prominent target from 2002 onwards, accounting for up to 15% and 40% of secondary species effort, respectively. In each instance these increases were associated with management initiatives that supported the development of the fisheries. Similarly, Whaler Sharks became noticeably targeted over the past 15 years, accounting for up to 12% of the secondary species fishing effort (Figure 2-4).

Less than 3% of the State-wide fishing effort was targeted towards the nine tertiary species considered in this report. There were a few periods of notable expansion for some 'niche' tertiary species such as School Sharks, Leatherjackets, Ocean Jackets and Cuttlefish. Targeted effort for each of these species doubled over short (<5 years) periods but did not persist. In recent years, Ocean Jackets and Gummy Sharks have accounted for the majority (>75%) of fishing effort amongst the nominated tertiary species.

The remaining 40 permitted species accounted for approximately 6% of the State-wide total targeted effort in 2016.

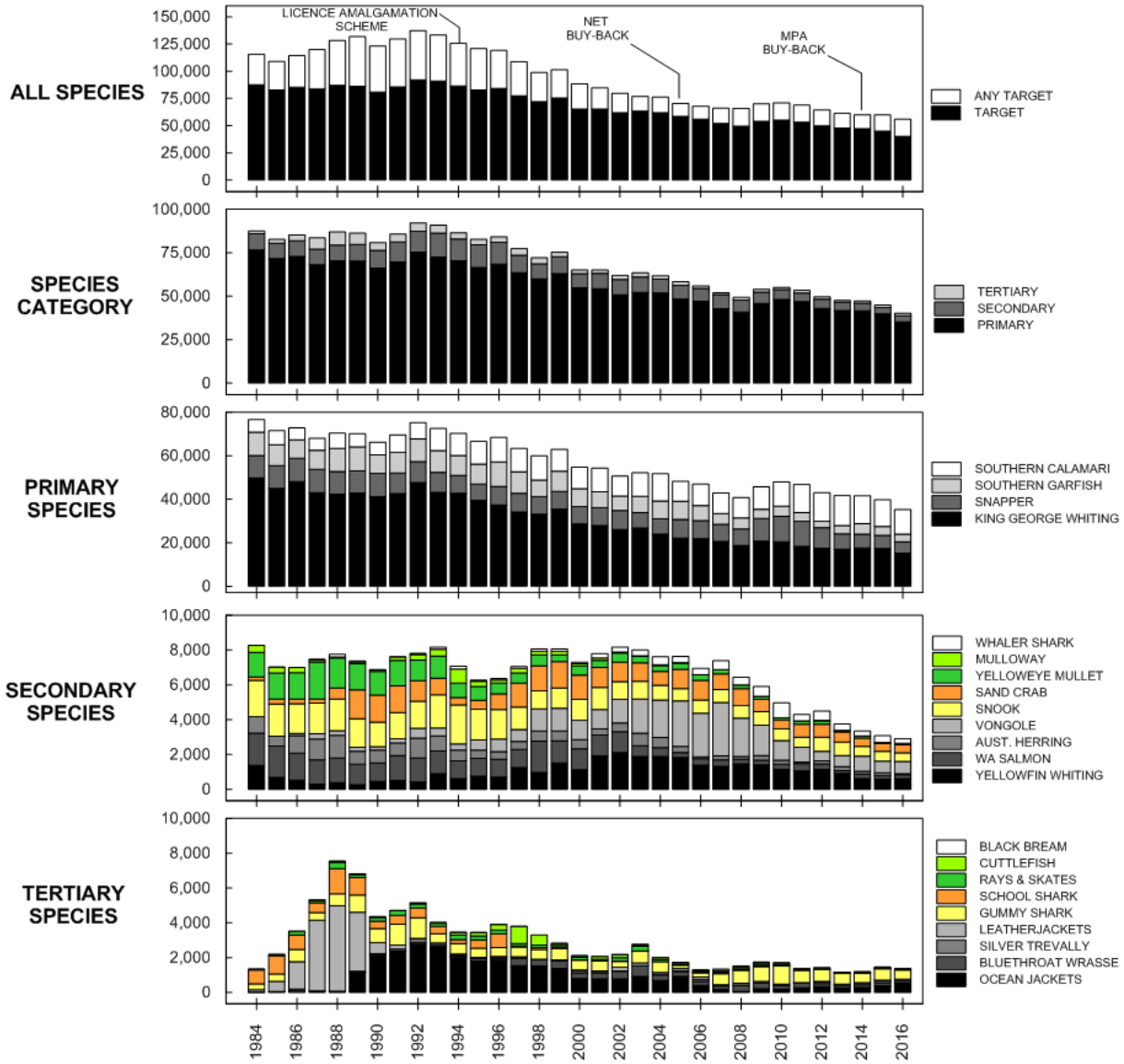

Figure 2-4. Total effort (fisher-days) in the commercial Marine Scalefish Fishery partitioned into targeted and non-targeted 'any target' effort (top) and into species-specific targeted effort.

Gear

Hauling nets and handlines have consistently been the dominant gear type within the fishery, collectively accounting for >60% of the total fishing effort within the fishery (Figure 2-5). The proportionate use of set nets has declined from 16% in 1987 to 1% in 2016, with the greatest reduction occurring throughout the late 1990s and early 2000s, in response to the State-wide

netting review and associated restrictions. The relative use of squid jigs has steadily increased from 1994 as the Southern Calamari fishery evolved from a bait resource to a priority species within the MSF, and has further increased from 2011 onwards to account for approximately 20% of the State-wide total fishing effort. The proportionate use of longlines doubled throughout the mid-2000s, and has since accounted for approximately 12% of the total fishing effort.

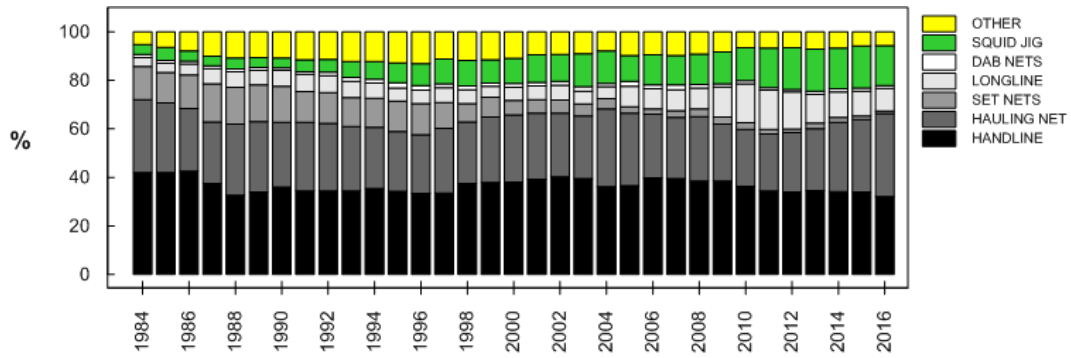

Figure 2-5. Gear usage (% of total fishing effort) within the commercial Marine Scalefish Fishery (MSF).

Location

Historically, the spatial distribution of fishing effort was widespread with most of the State MFAs registering some level of fishing activity (Figure 2-6). Fishing effort was most intense in the northern gulfs and near major regional ports such as Ceduna (MFAs 8, 9, 10), Coffin Bay (MFAs 27, 28), Port Lincoln (MFAs 30, 31) and Beachport (MFAs 55, 56, 57). Since 2001, fishing effort has largely contracted to within the gulfs, as fishing intensity around the regional centres has diminished to relatively low levels (< 4,000 fisher-days.year^{-1}) (Figure 2-6). Of the regional centres, only Port Lincoln and Ceduna have maintained some consistent fishing activity. The northern gulfs have continued to account for most of the fishing effort, but this has also declined over the past 33 years, from an average of >40,000 fisher-days.year^{-1} during the 1980s and 1990s to <29,000 fisher-days.year^{-1} since 2005. Average annual fishing effort within MFAs 19 and 29 in southern Spencer Gulf was below 500 fisher-days.year^{-1} over the last three years (2014 to 2016), declining to the lowest level recorded for this area (Figure 2-6).

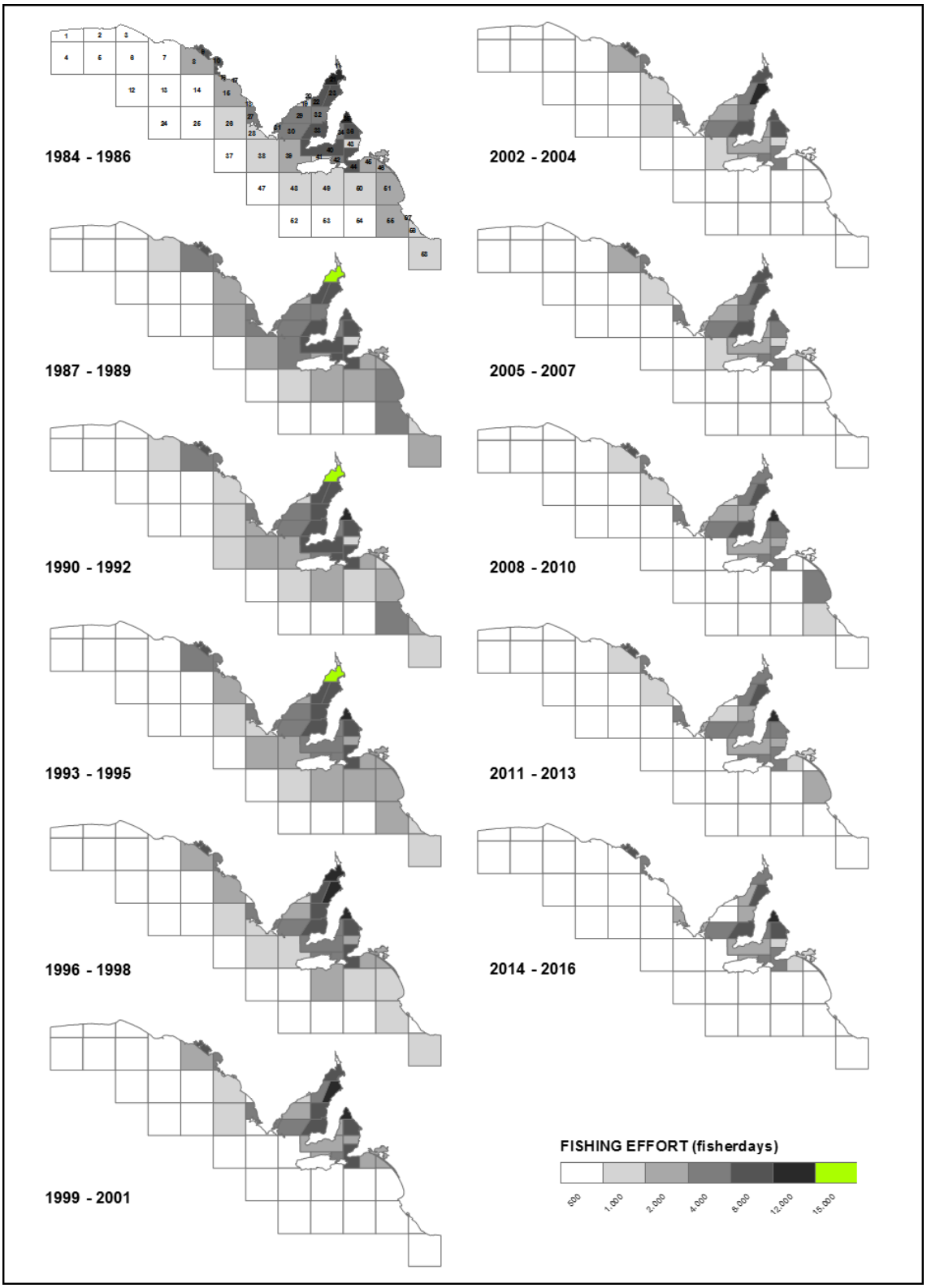

Figure 2-6. Spatial and temporal distribution of fishing effort (fisher-days) averaged over triennia from 1984 to 2016 in the Marine Scalefish Fishery (MSF).

Season

The high diversity of target species within the MSF provides fishers with considerable flexibility (Figure 2-7). Among the four primary species, monthly targeted fishing effort for King George Whiting peaked above 2,000 fisher-days in July, and although this species was targeted throughout the year its fishing activity remained highest during winter. Conversely targeted effort for Southern Garfish was highest during late summer, peaking at 670 fisher-days in February. The seasonal pattern of fishing activity for Southern Calamari and Snapper was similar, where they both maintained relatively high levels of fishing effort throughout the year, peaking in autumn and again in late spring (Figure 2-7).

Targeted effort for most of the remaining species peaked during the warmer spring and summer months and maintained some level of fishing activity throughout the year. Yellowfin Whiting, Bluethroat Wrasse, Silver Trevally and, to a lesser extent, Black Bream were the only species that displayed a distinct winter peak in fishing activity (Figure 2-7).

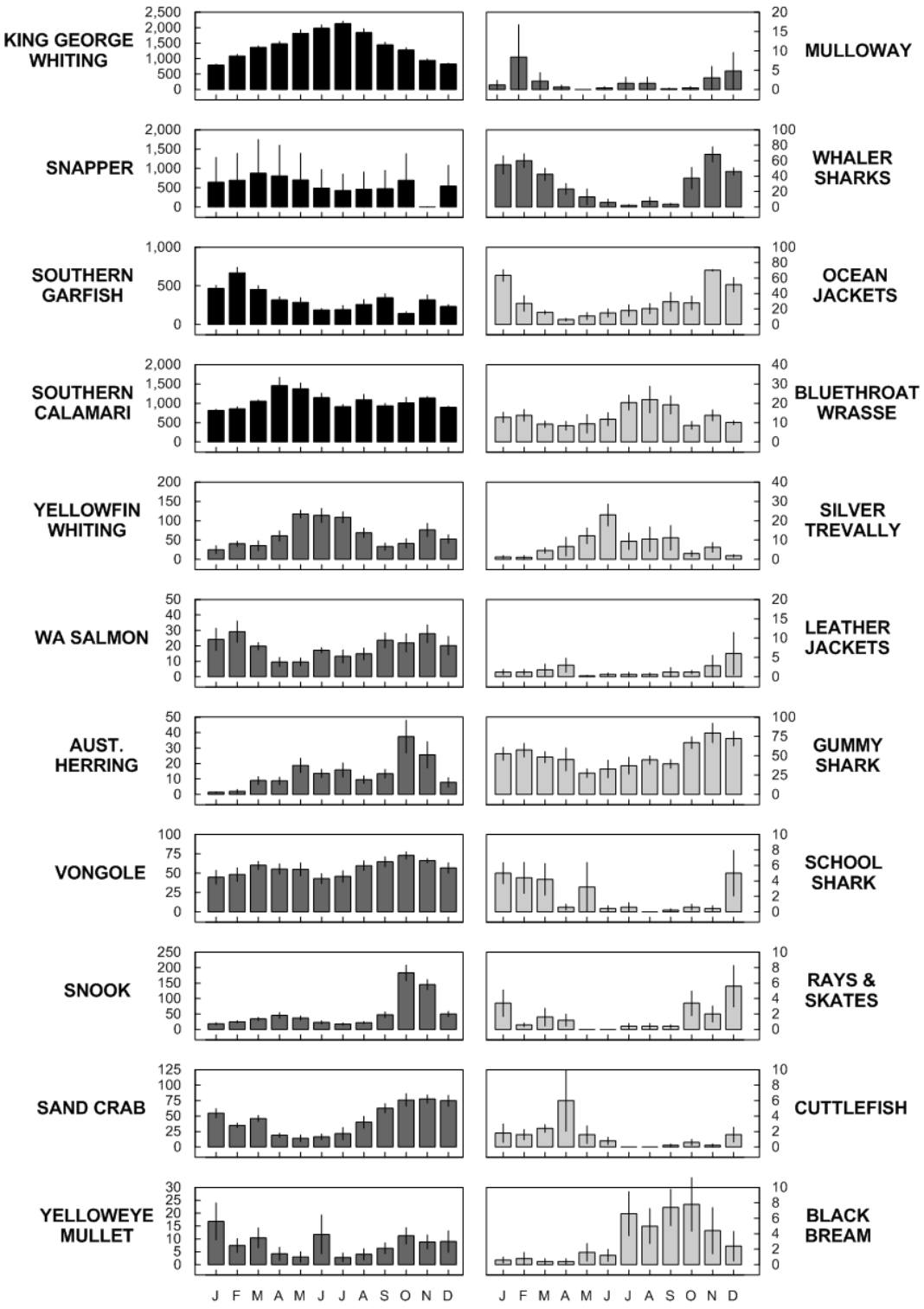

Figure 2-7. Monthly pattern of targeted fishing effort (fisher-days averaged (± se) from 2011 to 2016) for each of the 22 species/taxa assessed in this report. The different shade denote species category; primary (black), secondary (dark grey), teritary (light grey).

2.4. Discussion

The dynamics of the Marine Scalefish fishing fleet have changed in recent years and many of these changes appear to relate to management arrangements. The most obvious change has been the continuous decline in fishing effort which has been perpetuated by the licence amalgamation scheme implemented in 1994 and, more recently, the two voluntary net buy-back initiatives in 2005 and 2014. Since their implementation, these management arrangements have successfully reduced the number of active licence holders by 63.4%, which has translated to a 59.3% reduction in fishing effort. This has manifested in a spatial contraction of effort across the State, with fishing effort virtually disappearing from most regional centres outside the gulfs and the fishery becoming almost exclusively confined to gulf waters and a few protected bays west of Eyre Peninsula. Most of the fishing effort within the MSF was targeted, although a greater proportion of fishers in 2016 were non-specific in their target species indicating that they are either becoming more general in their fishing activity or are not specifically recording a target species in their catch returns.

Collectively, the fishery's four primary species accounted for the greatest proportion (62%) of targeted effort, of which King George Whiting has historically dominated. Since 2011, there have been declines in targeted effort for Snapper, King George Whiting and Southern Garfish as a consequence of a range of management arrangements (i.e. spatial closures, closed seasons, netting restrictions, catch limits). Conversely, targeted effort for Southern Calamari has steadily increased. This species has effectively become a year-round opportunistic target for many fishers, possibly to offset the loss of access to the other primary species. The increasing trend in the relative use of squid jigs also reflects this shift in behaviour amongst the fishing fleet.

The ephemeral periods of increased fishing activity for other secondary and tertiary species, such as Ocean Jackets, Western Australian Salmon and Snook also highlights the dynamic capacity of the MSF fishing fleet. Given the declining fishing activity observed for some of the primary species, current fishers may have greater incentive to target an increased diversity of 'under-utilised' species and synchronise their fishing activity to the species' patterns of seasonal abundance. Despite this, the diversity of secondary and tertiary species targeted by the fishing fleet has diminished in recent years.

3. KING GEORGE WHITING STOCK ASSESSMENT

3.1. Introduction

King George Whiting (*Sillaginodes punctatus*) is one of the most valuable, coastal marine finfish species of southern Australia. It occurs in coastal and shelf waters, distributed from Sydney (NSW), around the southern coastline, and to Perth in Western Australia (WA) (Kailola et al. 1993). The species is particularly significant in South Australia (SA), the geographic centre of its distribution, where abundances and fishery productivity are highest.

King George Whiting has a complex life history that involves ontogenetic changes in habitats that are linked by movement at different life history stages (Fowler and Jones 2008). In SA, spawning by King George Whiting occurs during autumn and early winter at off-shore reefs, shoals and mounds in relatively deep water in exposed localities that experience medium/high wave energy (Fowler et al. 2000a, b, 2002). The eggs and larvae are advected throughout a prolonged pre-settlement duration to nursery areas in shallow, protected bays located in the northern gulfs or bays of the west coast and Kangaroo Island (Fowler and Short 1996, Fowler et al. 2000b). Juvenile fish grow and develop in the vicinity of these nursery areas. When they reach approximately three-years of age, they undertake significant movement southwards if in the gulfs or otherwise off-shore, and ultimately replenish the populations of older fish on the spawning grounds (Fowler et al. 2000b, 2002). Such movement results in a significant ontogenetic shift from relatively protected shallow waters that support extensive meadows of seagrass to more exposed, deeper water and reef habitat. As a consequence, population size and age structures of King George Whiting vary geographically (Fowler et al. 2000a). The northern gulfs and inshore bays support populations with only a few age classes, whereas in the south the populations involve multiple age classes with fish up to around 20 years of age. The spawning grounds and nursery areas for King George Whiting can be separated by up to several hundred kilometers. As such, the processes of larval advection and adult movement are significant obligate steps that link the different life history stages and their preferred habitats (Fowler et al. 2002).

The stock structure for King George Whiting throughout its range in southern Australia remains unresolved due to uncertainty about the extent of connectivity amongst regional populations and the lack of clear phylogeographic genetic structure (Haigh and Donnellan 2000). A recent genetic study did indicate that the SA and Victorian populations were genetically similar, but were distinct from those in Western Australia and also in Tasmania (Jenkins et al. 2016). The similarity in genotypes between SA and Victoria are consistent with the results from hydrodynamic modelling and otolith chemistry analyses which indicate the Victorian populations may be replenished from

spawning grounds located in SA, through the eastward advection of eggs and larvae (Jenkins et al. 2000, 2016). The genetic homogeneity of the SA regional populations indicate that there must be at least a small degree of mixing between them. Nevertheless, for stock assessment and management purposes three stocks are recognised based largely on the locations of and connectivity between nursery areas and spawning grounds (Fowler et al. 1999, 2000b). These stocks are: west coast of Eyre Peninsula (WC); Spencer Gulf (SG); and Gulf St. Vincent / Kangaroo Island (GSV/KI) (Fowler and McGarvey 2000, Fowler et al. 2014).

3.1.1. Fishery

King George Whiting is a 'primary' species of SA's Marine Scalefish Fishery (PIRSA 2013), that is heavily targeted by both the commercial and recreational sectors (Fowler et al. 2014). Several life history stages are targeted: young, immature adults in the northern gulfs; the immature fish as they travel southwards; and mature adults on the spawning grounds. As such, during their ontogenetic development, the fish run the gauntlet of fishing lines and nets that are used to target them in different habitats. Because of this, SA's King George Whiting fishery is described as a 'gauntlet' fishery.

Three different commercial fisheries have access to SA's King George Whiting stocks, i.e. the Marine Scalefish Fishery (MSF), and the Northern Zone and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) (PIRSA 2013). Historically, this species was the most valuable for the commercial sector, but since 2007/08 its total value fell below that of Snapper and more recently below that of Southern Calamari. Nevertheless, King George Whiting remains the highest value species by weight. The main gear types used in the commercial fishery to target it are handlines, hauling nets and gill nets. For the recreational sector, this is an iconic species that is heavily targeted with hook and line, principally from boats.

3.1.2. Harvest Strategy

When the commercial Management Plan was developed (PIRSA 2013), the three King George Whiting stocks were classified as 'sustainably fished' (Fowler et al. 2011). As such, the primary objective of the harvest strategy that it contained was to maintain this positive status and fishery performance. Nevertheless, in the subsequent stock assessment (Fowler et al. 2014), the status of the two gulf stocks, i.e. SG and GSV/KI changed to 'transitional-depleting'. In response, the recent focus has been to recover the status of these two stocks, whilst maintaining the sustainable status of the West Coast Stock. To this end, significant management changes were implemented in December 2016.

3.1.3. Management Regulations

Regulations for managing South Australia's King George Whiting fishery involve a complex suite of input and output controls (PIRSA 2013). For the commercial sector, the principal means of effort control is 'limited entry', and the number of licence holders operating in the MSF has declined considerably over time. Furthermore, there is a complexity of regulations that apply to the gears that are used to take King George Whiting. These restrict the numbers of handlines and hooks that can be legitimately used, and for hauling nets and gill nets involve gear specifications and spatial and temporal restrictions. The take of the recreational sector is managed through size, bag and boat limits and spatial restrictions.

The management regulations for King George Whiting were recently enhanced following the transitional depleting status that was assigned to the two stocks in the South Australian gulfs (Fowler et al. 2014), and the ensuing extensive review of management arrangements that took place throughout 2016. The changes that were implemented in December 2016 were: (1) an increase in legal minimum length (LML) from 310 to 320 mm TL for all waters east of longitude 136°E, whilst the LML remains 300 mm in West Coast waters; (2) a State-wide reduction in the recreational bag limit from 12 to 10 legal-sized fish per person, with the boat limit reduced from 36 to 30 fish per boat; and (3) introduction of a spatial spawning closure in Investigator Strait and southern Spencer Gulf from 1st to 31st May that was first implemented in 2017. Furthermore, a possession limit of either 72 fish or 10 kg of fillets or 36 fish and up to 5 kg of fillets exist for recreational fishers.

3.2. Methods

3.2.1. Data Sources

The data sources considered in this stock assessment were: commercial fishery statistics; recreational fishery data; and population size and age structures from market measuring. These data were considered at the State-wide scale, at the scale of the three stocks or at the regional population level, as appropriate.

The commercial fishery data for King George Whiting were extracted from the commercial Marine Scalefish Fisheries Information System for the 33-year period of 1984 to 2016. These data were aggregated to provide annual totals at the State-wide and stock levels. For total catch, the three main gear types (handlines, hauling nets and gillnets) were differentiated. With respect to effort and CPUE, only the data for handlines are considered as the recent low levels of effort in the net sector have reduced the value of the data from this sector as fishery performance indicators

(PIRSA 2013). There are two components of fishing effort, i.e. targeted and untargeted effort. The former relates to when the fishers intentionally targeted King George Whiting, whilst the latter refers to effort directed at other species that produced catches of King George Whiting, or where fishing was untargeted. For handlines, total effort was estimated from targeted effort that was scaled up by the proportional additional catch that was taken by untargeted effort (Fowler et al. 2014). This allowed estimation of annual estimates of handline CPUE.

To provide information on population structure, King George Whiting from regional commercial catches have been sampled at the SAFCOL fish market in Adelaide as well as by occasional sampling trips to Kangaroo Island and the West Coast of Eyre Peninsula. This market sampling involves a two-stage sampling protocol (Fowler et al. 2014). In short, fishery catches were accessed at the market from which numerous fish were measured to obtain size information. From these, a random sub-sample was taken for further biological analysis. The sampled fish were measured for total length (TL) and weighed individually, sexed and stage of reproductive development was determined. The fish were then dissected for removal of the otoliths that were later used to determine fish age using an established ageing protocol (Fowler and Short 1998, Fowler et al. 2014). Subsequently, regional estimates of annual size and age structures were generated.

3.2.2. 'WhitEst' Fishery Model

Stock assessments for King George Whiting use a computer fishery model, WhitEst, which is a dynamic, spatial, age- and length-structured model that was developed in an FRDC-funded project (Fowler and McGarvey 2000). It was used here to integrate all input data from 1984 to 2016 to generate estimates of output parameters that were used as biological performance indicators and interpreted in terms of fishery status. The data sources that were used as input to the WhitEst model were: 1. monthly totals for commercial catch (kg) and effort (fisherdays); 2. market samples of the commercial catch giving proportions by age and sex in different spatial cells for most months through the sampling periods of September 1994 to June 1997, July 2004 to June 2007, July 2008 to December 2010, October 2011 to September 2013, October 2014 to September 2016; 3. Monthly estimates of recreational catch (fish numbers) and effort (fisherdays); 4. information on movement by King George Whiting in the two gulfs, based on results from tag-recapture studies undertaken in the 1960s, 1970s, and 1980s (Jones et al. 1990, Fowler et al. 2002).

WhitEst runs on a monthly time step, accounting for seasonal movement and temporal variation in exploitation levels. The model employs the slice-partition method to describe population

numbers by age and length (McGarvey et al. 2007). It is fitted to monthly catches, conditional upon the effort in fisherdays required to take each catch. Commercial catch and effort data are analysed and modelled separately for the four gear types (handline, hauling net, gill net and all other gears combined) and three target types (targeting King George Whiting, targeting other species, and not targeting any other species), as reported in monthly commercial catch returns. Estimates of recreational catch and effort are based on the results from three telephone/diary surveys undertaken in 2000/01, 2007/08 and 2013/14 (Jones and Doonan 2005, Jones 2009, Giri and Hall 2015). The estimation of monthly and annual totals were determined through interpolation for the intervening years. The handling of recreational fishery data to achieve this is complicated and the details of analytical procedures are provided in Appendices 1 to 4, whilst fits of the model to data are presented in Appendix 5.

The model divides the fishery into six spatial cells. These include the West Coast and the northern and southern regions of the two gulfs. A sixth cell is located offshore from the West Coast where spawning is considered to occur but from where catches are low. This spatial structure takes into account the annual summer migrations from inshore nursery areas in the northern gulfs to the spawning areas in the southern gulfs and offshore from the West Coast.

WhitEst integrates the input data sets and undertakes maximum likelihood estimation of three principal performance indicators; recruitment, legal-size population biomass and exploitation rate. Biomass and exploitation rate are calculated monthly. Annual estimates of biomass are computed as the mean of the monthly model estimates in each year. Exploitation rate is the fraction of biomass harvested annually and is calculated as the sum across all gear and target types of monthly model catches in each calendar year divided by (year average) legal biomass. Recruitment for each annual cohort is estimated as numbers of approximately 2 year olds. In the recruitment time series graphs, the year shown is the year each cohort has fully entered the fishable stock and is principally targeted in the fishery as 3 year olds.

3.2.3. Assessment of Fishery Performance

Two sets of fishery performance indicators were considered for the King George Whiting fishery at the State-wide and stock spatial scales (PIRSA 2013), i.e. the general and biological performance indicators (Table 3-1). The general fishery performance indicators considered were; total catch, targeted handline effort, and targeted handline CPUE. The time series of data from 1984 to 2016 for the three indicators were calculated. Then, the value for 2016, was compared using the trigger reference points (Table 3-1), calculated for the ‘reference period’, i.e. the historical data time series back to 1984 (PIRSA 2013).

There are four biological performance indicators: fishable biomass; harvest fraction; recruitment; and age structure (Table 3-1; PIRSA 2013). The first three are time-series of output parameters from 'WhitEst', whilst the age structures are catch proportions by age from market sampling. The estimates of output parameters were considered for the three stocks. The status of each of the three King George Whiting stocks was classified based on the national reporting system using a weight-of-evidence approach (Flood et al. 2014).

For assessment of catch shares amongst the commercial fisheries, the total catches reported in 2016 were compared against their allocations and associated triggers reference points (Table 3-2).

Table 3-1. Fishery performance indicators and trigger reference points used to assess fishery performance as specified in the Management Plan (PIRSA 2013). The type of indicator and whether a primary or secondary one is also indicated. G – general; B – biological.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT
TOTAL CATCH	G	3rd Lowest / 3rd Highest
	G	Greatest % interannual change (+/-)
	G	Greatest 5 year trend
	G	Decrease over 5 consecutive years
TARGET HANDLINE EFFORT	G	3rd Lowest / 3rd Highest
	G	Greatest % interannual change (+/-)
	G	Greatest 5 year trend
	G	Decrease over 5 consecutive years
TARGET HANDLINE CPUE	G	3rd Lowest / 3rd Highest
	G	Greatest % interannual change (+/-)
	G	Greatest 5 year trend
	G	Decrease over 5 consecutive years
FISHABLE BIOMASS	B	3 year av. is +/- 10% of previous year
HARVEST FRACTION	B	> 28% (int. standard)
RECRUITMENT	B	+/- 10% of average of previous 5 years
AGE COMPOSITION	B	Change in long-term or previous 5 years

Table 3-2. Allocation percentages and trigger limits for SA's King George Whiting commercial fishery. Fishing sectors are; MSF = Marine Scalefish, SZRL = Southern Zone Rock Lobster, NZRL = Northern Zone Rock Lobster.

COMMERCIAL ALLOCATION	MSF 98.10%	SZRL n/a	NZRLF 1.90%
TRIGGER 2	n/a	0.50%	2.97%
TRIGGER 3	n/a	0.75%	3.96%

3.3. Results

3.3.1. Commercial Fishery Statistics

State-wide

There has been a long-term declining trend in total commercial catch of King George Whiting, which involved a 64% decrease from the highest catch of 776 t recorded in 1992 to the lowest of 281 t recorded in 2014 (Figure 3-1). By 2016 it had increased marginally to 287 t. In comparison, the annual estimates of catch from the recreational sector of 382 t in 2000/01, 324 t in 2007/08 and 367 t in 2013/14 were relatively consistent.

Handlines have always been the dominant gear which, between 1984 and 1999, produced catches of around 400 $t.yr^{-1}$ (Figure 3-1). Subsequently, handline catch fell by 43.2% from 431 t in 1999 to 245 t in 2016. The catch by hauling nets has fallen by 87% from the record of 266 t in 1992 to only 35 t in 2016. The total State-wide gillnet catch has always been less than 50 $t.year^{-1}$, and fell to 7 t in 2016. The value of the annual commercial catch of King George Whiting has varied considerably over time (Figure 3-1). It ranged from $3.6 million in 2005 to $5.5 million in 2003, and was $4.6 million in 2016.

Handline effort on King George Whiting declined from 30,732 fisherdays in 1992 to 11,495 fisherdays in 2016, i.e. a reduction of 62.6% over 24 years (Figure 3-1). This declining trend relates at least partly to the reduction in number of licence holders in the commercial fishery. Between 1984 and 2016, the number who reported taking King George Whiting fell from 645 to 237, and those targeting them from 591 to 208 (Figure 3-1). The rate of decline accelerated after 1994 when the licence amalgamation scheme was introduced and again in 2005 through the net buyback.

The estimates of State-wide handline CPUE have been variable, but have trended upward over time, although divisible into several time periods (Figure 3-1). It increased from 1984 to 1991, but

then declined over several years to 1995. It then increased considerably until 1999, after which there was a noticeable decline to 2002. Subsequently, handline CPUE has gradually increased to the highest recorded level in 2016.

The State-wide commercial catches are divisible into those from the three component stocks, which have all declined over time (Figure 3-2). Through the 1980s and 1990s, the SG Stock provided the highest catches. Through the 2000s, they fell below those of the WC Stock, which has continued to produce the highest catches. Those from the GSV/KI Stock have always been the lowest of the three stocks.

Seasonal variation in catches of King George Whiting have been a consistent feature (Figure 3-2). They have generally been higher through the cooler months and lower during summer. In 2016, the commercial catch was dominated by that from the MSF Fishery, with a relatively small contribution from the NZRLF (Figure 3-2). In 2013/14, the recreational sector accounted for 58.1% of the total catch, i.e. a considerably higher percentage than that of the commercial fishery (Giri and Hall, 2015).

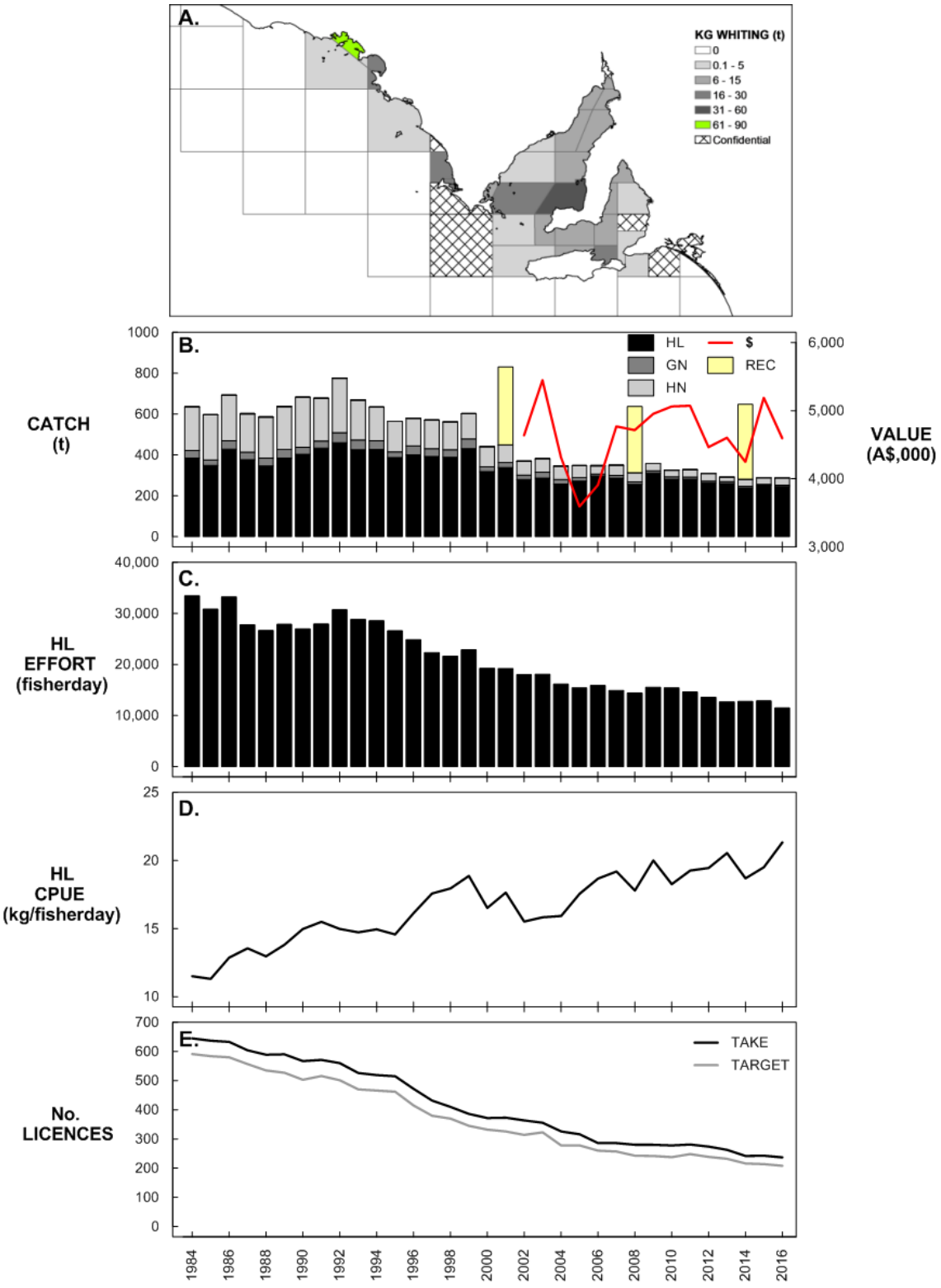

Figure 3-1. King George Whiting. (A) Catch distribution for 2016; Long-term trends in : (B) total catch for the main gear types (handline, hauling net, gill net), estimated recreational catch and gross production value; (C) Long-term total effort for handline; (D) total catch per unit effort for handline; and (E) the number of active licence holders taking or targeting the species.

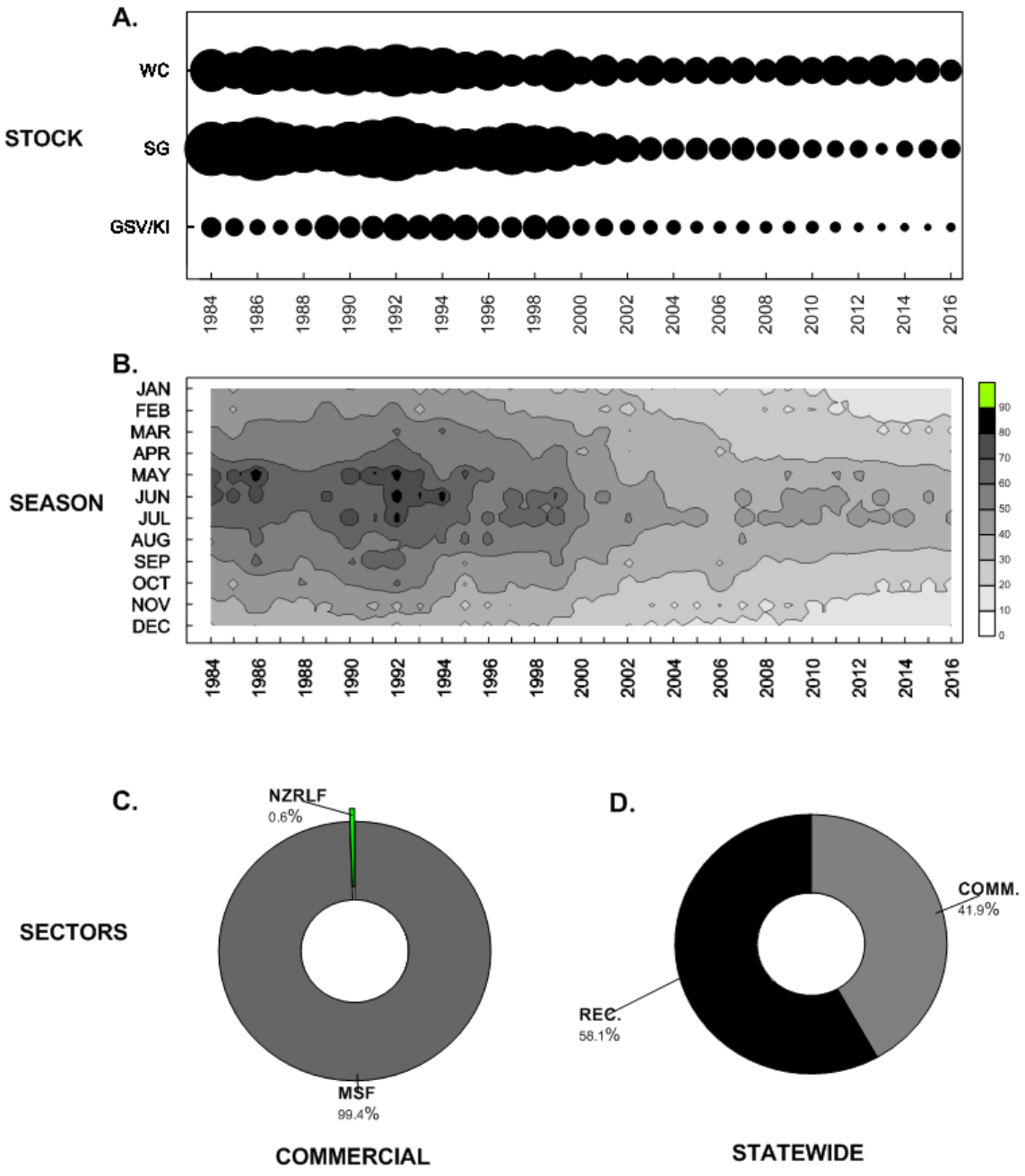

Figure 3-2. King George Whiting. Long-term trends in the annual distribution of catch among biological stocks (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

West Coast Stock

Annual commercial catches for this stock increased between 1984 and 1992 when the maximum of 283 t was taken (Figure 3-3). From then, total catch gradually declined by 53% to only 134 t in 2002. Subsequently, it increased to 172 t in 2013, before falling to 124 t in 2016, which was the lowest ever recorded. Total effort declined regularly from 17,544 fisherdays in 1984 to 5,099 fisherdays in 2016.

In all years, handlines were the dominant gear whose catches dropped from the high of 218 t in 1999 to 123 t in 2016 (Figure 3-3). Handline effort has declined relatively consistently from the maximum of 15,738 fisherdays in 1984 to the lowest of 5,045 fisherdays in 2016. In contrast, handline CPUE has increased considerably in several multi-year steps. It increased between 1987 and 1992 before declining considerably to 1995. It increased again to 1999 before falling from 20.8 to 15.6 kg.fisherday^{-1} in 2002. Subsequently, CPUE increased to the highest recorded value of 25.1 kg.fisherday^{-1} in 2013. Although it dropped considerably in 2014, it has recovered to the second highest level of 24.4 kg.fisherday^{-1} in 2016. The number of fishers taking and targeting King George Whiting from the WC Stock with handlines have both declined considerably between 1984 and 2016 (Figure 3-3). The former fell from 194 to 84, whilst the latter declined from 193 to 82.

The model-estimated values of fishable biomass have gradually increased over time, particularly between 1984 and 1999 and again between 2008 and 2016 (Figure 3-3). The general increasing trend in biomass reflects a long-term increasing trend in recruitment, although interrupted by occasional declines. Furthermore, there has been a long-term decreasing trend in exploitation rate which relates to the decline in fishing effort, reflecting the declining number of commercial fishers. The recent age structures for the populations in the bays of the West Coast remain dominated by the 2+ and 3+ age classes.

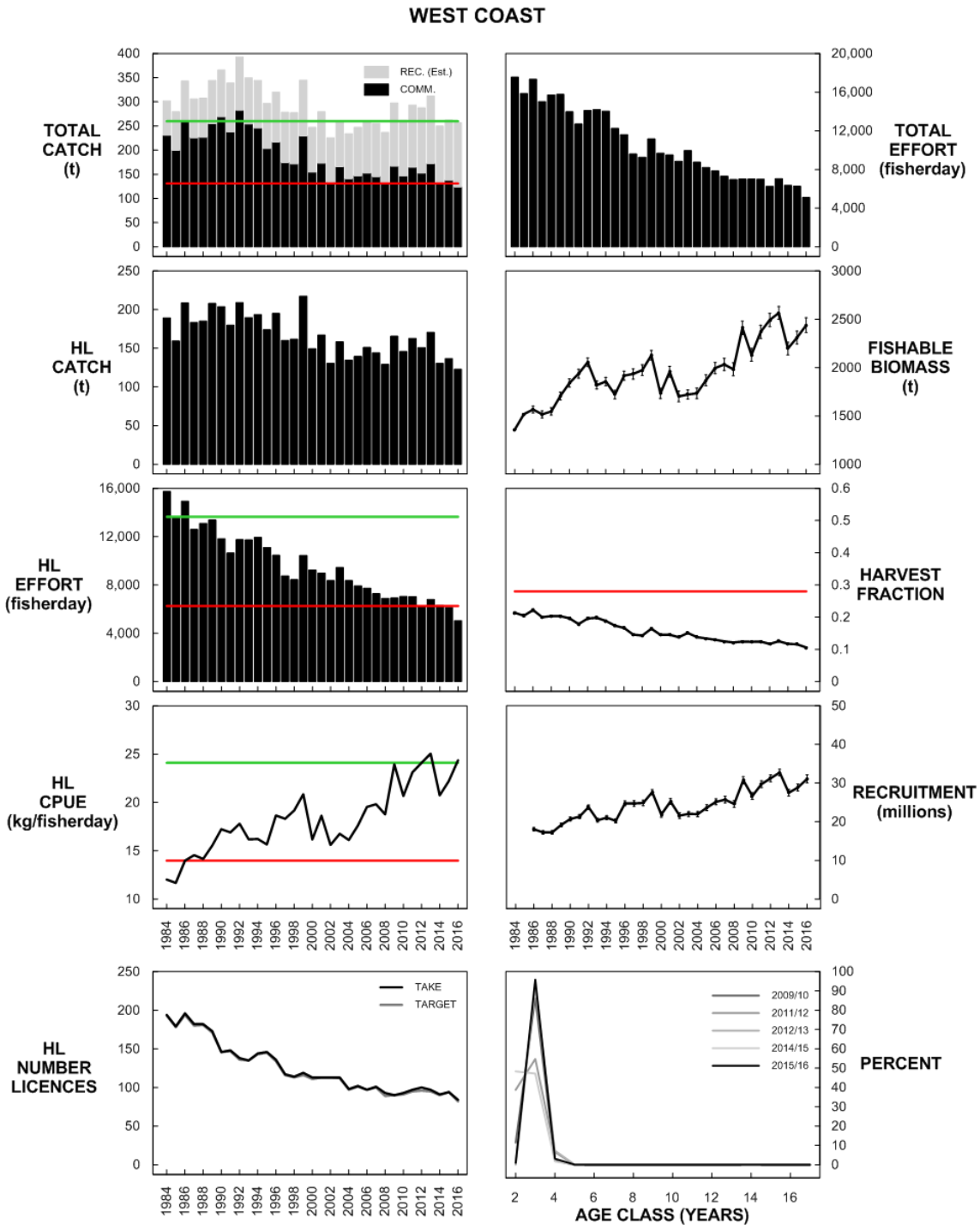

Figure 3-3. Key outputs used to assess the status of the West Coast King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2009/10 to 2015/16. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-1.

Spencer Gulf Stock

Total commercial catch of King George Whiting from Spencer Gulf varied cyclically between 1984 and 1997 (Figure 3-4). From the latter year until 2004, it declined by 57.1% and then to 2013 declined by a further 44.8% to the lowest ever recorded amount of 70.6 t. From 2013 to 2016, total catch increased to 107.8 t. There has been a long-term decline in total fishing effort from 24,411 fisherdays in 1984 to 5,788 fisherdays in 2016.

Total handline catch has been considerably lower through the 2000s then through the 1980s and 1990s (Figure 3-4). It was lowest at 57 t in 2013 before increasing by 48% to 85 t in 2016. Handline fishing effort was variable between 1984 and 1992, before declining by 57.8% by 2004. It was then relatively stable for several years, until declining in 2013 to the lowest level of 3,414 fisherdays, but has since increased by 17.9% to 4,024 fisherdays in 2016. Handline CPUE showed a long-term increase although with clear cyclical variation for which the cycles typically involved several years when catch rates increased quickly, followed by a number of years when they declined. From 2003 to 2007, catch rate increased by 33.1% from 15.4 to 20.5 kg.fisherday^{-1}. However, from 2007 to 2013, there was the longest period of decline during which it dropped by 18.0% to 16.8 kg.fisherday^{-1}. Nevertheless, between 2013 and 2016, it increased again, attaining the highest recorded level of 21.0 kg.fisherday^{-1}. The number of licence holders who took King George Whiting with handlines fell from 237 in 1984 to 106 in 2016 (Figure 3-4), whilst those targeting it fell from 233 to 104.

The estimates of fishable biomass from WhitEst have been cyclical, reflecting periods of increase and decline, but nevertheless have shown a long-term increase (Figure 3-4). Whilst the estimates declined marginally between 2007 and 2012, since then they have increased to the highest estimated level in 2016. Overall, the increasing trend in biomass reflects a long-term decline in exploitation rate relating to the declining numbers of fishers and their total effort. The estimates of recruitment have been variable, but shown no long-term trend. Recruitment was lowest between 2002 and 2004, but since then has increased considerably. The age structures remain dominated by the younger age classes, although with some older age classes still represented in the catches.

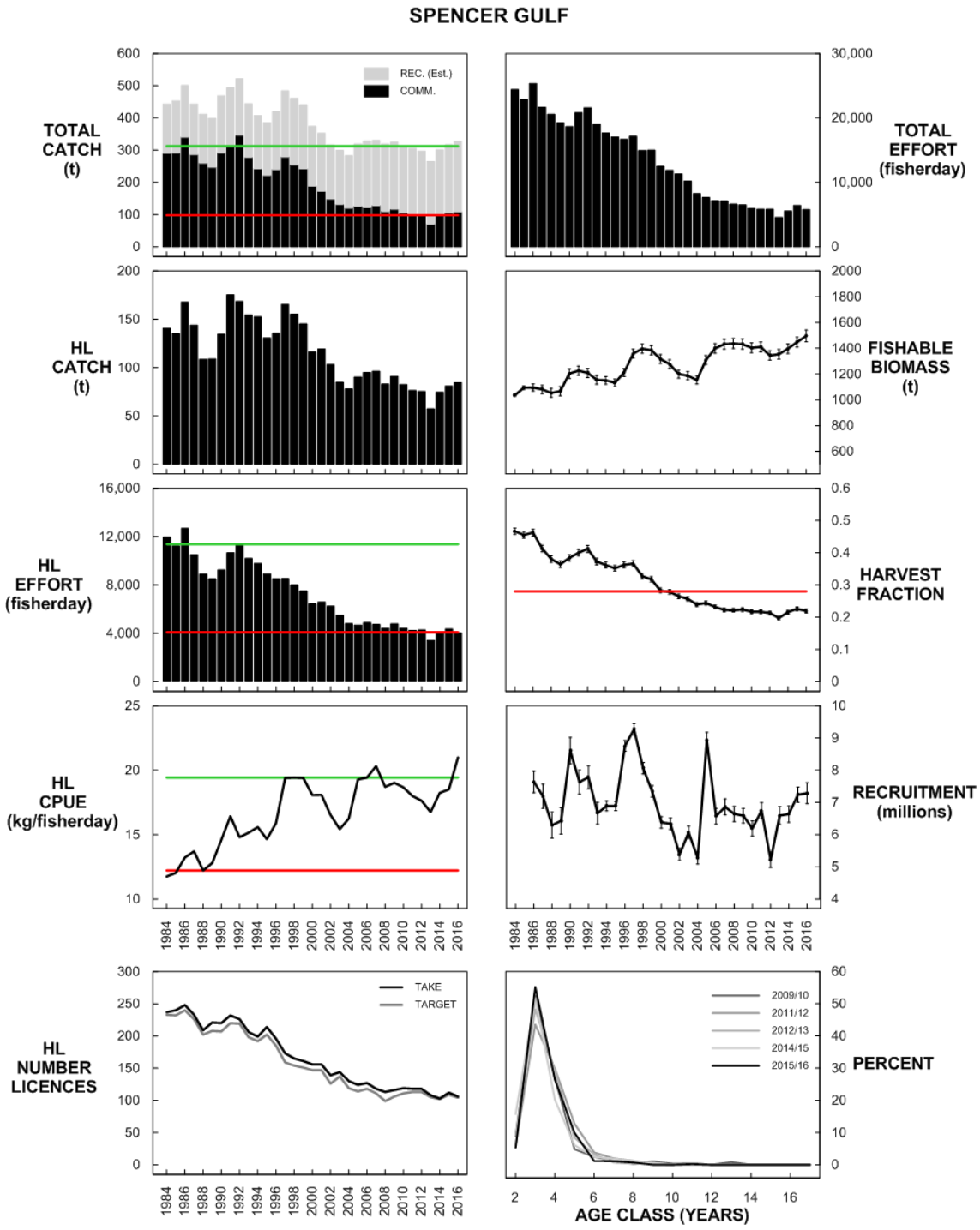

Figure 3-4. Key outputs used to assess the status of the Spencer Gulf King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2009/10 to 2015/16. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-1..

Gulf St. Vincent / Kangaroo Island Stock

Total commercial catch from this stock has been consistently lower than for the other two stocks (Figure 3-2) and has varied through several different periods (Figure 3-5). After declining between 1984 and 1988, it increased to the record level of 147.3 t in 1992. Subsequently, it declined to the lowest annual catch of 46.3 t in 2015. Total effort has shown similar variation and between 1992 and 2016 declined from 14,252 to 4,035 fisherdays.

Handline catch largely accounted for the variation in total catch, being highest between 1992 and 1995 before declining to the lowest level of 32 t in 2013. It has subsequently increased by 19% to 38 t in 2016. Handline fishing effort reached its highest level of 7,655 fisherdays in 1992 (Figure 3-5). It subsequently declined by 54.5% to 3,484 fisherdays in 2000 and then remained relatively flat to 2009, after which there was further decline to 2,345 fisherdays in 2015, before increasing marginally in 2016. Between 1984 and 2007, handline CPUE was variable but nevertheless increased by 65.8% (Figure 3-5). Over the following five years, it declined by 20% to the low value of 12.7 kg.fisherday^{-1} in 2012. It has subsequently increased by 22% over several years to 15.5 kg.fisherday^{-1} in 2016. The numbers of licence holders who captured or targeted King George Whiting with handlines have declined considerably. In 1984, a total of 134 fishers took King George Whiting, which fell to 53 in 2016 (Figure 3-5). The numbers who targeted this species with handlines fell from 131 to 50.

The estimates of fishable biomass from WhitEst showed a long-term increase between 1984 and 2009, but then declined considerably to 2012 (Figure 3-5). Subsequently, the biomass estimates have stabilized and increased marginally. The decline reflected a period of declining recruitment rates between 2004 and 2010, which have subsequently increased between 2010 and 2016. The exploitation rate has gradually declined over time, reflecting declining numbers of fishers and fishing effort. The age structures remain dominated by fish in the 3+ to 6+ age classes with some representation in older age classes.

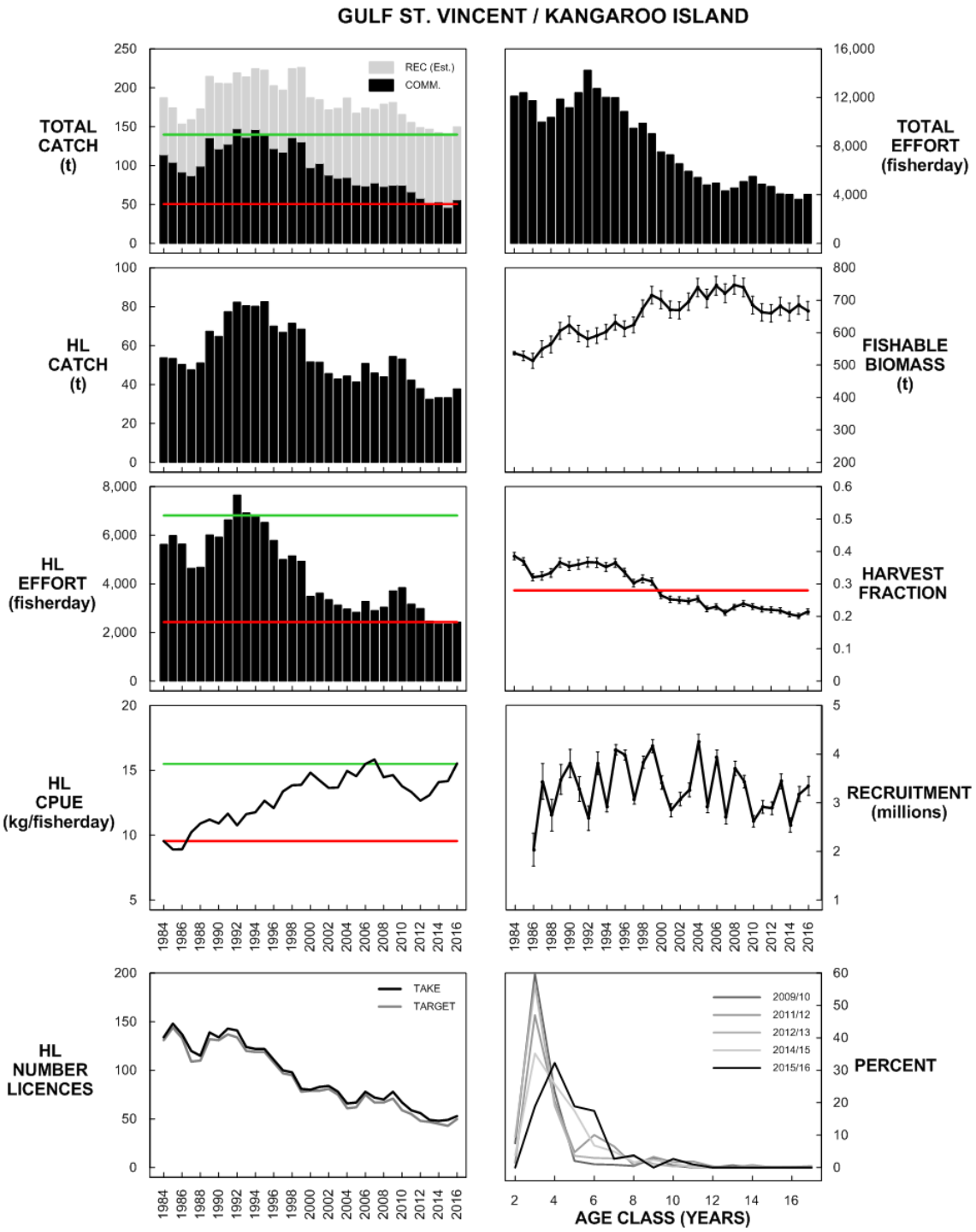

Figure 3-5. Key outputs used to assess the status of the Gulf St. Vincent/Kangaroo Island King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2009/10 to 2015/16. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-1.

3.3.2. Fishery Performance

The catch data from the three commercial sectors from 2016 were compared against their allocations using Triggers 2 and 3 as reference points. The Southern Zone Rock Lobster breached Trigger 2 reference points from 2012 until 2015, exceeding its commercial sector allocation by >0.5% for four consecutive years (Table 3-3). No other commercial sectors exceeded their respective Trigger reference points.

The general fishery performance indicators were assessed for 2016 at both the State-wide and stock spatial scales. A total of 10 breaches of trigger reference points were recorded (Table 3-4). At the State-wide scale and for the West Coast Stock, the breaches for 2016 related to low catches, the lowest targeted handline effort, but high estimates of handline CPUE. The results were similar for the SG and GSV/KI Stocks except that increases in catch since 2013 meant that trigger reference points for total catch for both stocks were not activated.

For the biological performance indicators, five trigger reference points were breached (Table 3-4). At the State-wide scale and for the WC and SG Stocks, the average annual estimates of biomass between 2014 and 2016 were considerably above the long-term averages. Note that only for the GSV/KI Stock was this trigger reference point not activated. For both the SG and GSV/KI Stocks, the estimates of recruitment in 2016 were greater than 10% above the averages from the previous five years.

Table 3-3. Results from consideration of commercial catches of King George Whiting by fishery against their allocation percentages and trigger reference points. Fishing sectors are; MSF = Marine Scalefish, SZRL = Southern Zone Rock Lobster, NZRL = Northern Zone Rock Lobster. Green colour – allocation not exceeded, red colour – allocation trigger activated.

COMMERCIAL ALLOCATION	MSF 98.10%	SZRL n/a	NZRLF 1.90%
TRIGGER 2	n/a	0.50%	2.97%
TRIGGER 3	n/a	0.75%	3.96%
2012	97.80%	2.10%	0.10%
2013	97.20%	2.80%	-
2014	98.90%	1.10%	-
2015	98.80%	1.20%	-
2016	99.40%	0.60%	-

Table 3-4. Results from the assessment of the general (G) and biological (B) fishery performance indicators against their trigger reference points at the State-wide and stock spatial scales for King George Whiting.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE	WC	SG	GSV/KI
TOTAL CATCH	G	3rd Lowest / 3rd Highest	2nd LOWEST	LOWEST	×	×
	G	Greatest % interannual change (+/-)	×	×	×	×
	G	Greatest 5 year trend	×	×	×	×
	G	Decrease over 5 consecutive years	×	×	×	×
TARGET HANDLINE EFFORT	G	3rd Lowest / 3rd Highest	LOWEST	LOWEST	2nd LOWEST	3rd LOWEST
	G	Greatest % interannual change (+/-)	×	×	×	×
	G	Greatest 5 year trend	×	×	×	×
	G	Decrease over 5 consecutive years	×	×	×	×
TARGET HANDLINE CPUE	G	3rd Lowest / 3rd Highest	HIGHEST	2nd HIGHEST	HIGHEST	2nd HIGHEST
	G	Greatest % interannual change (+/-)	×	×	×	×
	G	Greatest 5 year trend	×	×	×	×
	G	Decrease over 5 consecutive years	×	×	×	×
FISHABLE BIOMASS	B	3 year av. is +/- 10% of previous year	16.7% ABOVE	21.7% ABOVE	15.7% ABOVE	×
HARVEST FRACTION	B	> 28% (int. standard)	×	×	×	×
RECRUITMENT	B	+/- 10% of average of previous 5 years	5.6% ABOVE	3.6% ABOVE	12.3% ABOVE	11.7% ABOVE
AGE COMPOSITION	B	Change in long-term or previous 5 years	×	×	×	×

3.4. Discussion

3.4.1. Context of this Assessment

In the early 2000s there was considerable concern about the sustainability of the South Australian King George Whiting fishery (McGarvey et al. 2003). It was apparent from several indicators that the abundances of each of the three South Australian stocks had declined considerably between 1999 and 2002. This concerning status prompted a review of the management of the fishery through 2004 that culminated in significant changes that were implemented on the 1st October 2004. Since then each triennial stock assessment has provided the opportunity to assess stock status following these management changes. The first three of these assessments indicated considerable recovery in the status of the three stocks (McGarvey et al. 2005, Fowler et al. 2008; 2011). In fact, based on the assessment in 2011, all three South Australian stocks were assigned the status of 'sustainable' in the national stock status report in 2012 (Kemp et al. 2012). However, in the most recent stock assessment that was undertaken in 2014, the classifications assigned to the two gulf stocks were less positive (Fowler et al. 2014, Hamer et al. 2016). Based on data collected up to December 2013, the SG Stock was classified as transitional depleting, based on declining trends over the previous seven years in total commercial catch, handline effort and CPUE, as well as estimated biomass. The GSV/KI Stock was also classified as 'transitional-

depleting' because of declining trends in catch, effort and CPUE between 2007 and 2012, as well as a high exploitation rate. Furthermore, for issues associated with 'effective' effort that are discussed below, it was considered that the declining trends for both stocks may have under-estimated the real declines in biomass (Fowler et al. 2014).

As the current stock assessment only considered data that were collected up to the end of December 2016, there was no opportunity for the new management changes to have impacted on the populations that would be evident in the results of this stock assessment. Nevertheless, this assessment did provide opportunity to assess whether the declines in the stocks of both gulfs up to 2013 had continued through the years of 2014 to 2016.

3.4.2. Determination of Stock Status

The status of each of the three South Australian King George Whiting stocks was classified using the recently-developed, national stock status classification system (Flood et al. 2014). The assignment of status used a weight-of-evidence approach based on the fishery performance indicators and associated trigger reference points that are specified in the Management Plan (PIRSA 2013). These include four general performance indicators from the commercial fishery statistics and four biological indicators that are based either on outputs from the WhitEst model or on the population age structures.

The fishery performance indicators are based on several sets of data. The most complete and informative data used to assess stock status for King George Whiting are the trends in commercial catch, effort and CPUE (PIRSA 2013), with trends in handline CPUE considered the best indicators of relative biomass. Nevertheless, there are several reasons why the relationships between fishery statistics, even including handline CPUE, and fishable biomass must be interpreted cautiously. Since data on fishing effort were first recorded in this fishery from July 1983, advancements in fishing gear, power of vessels, electronic equipment and the use of social media have significantly improved the capacity of fishers to find and catch fish. Nevertheless, the data on fishing effort that were used to calculate CPUE in this assessment have not been corrected for this long-term increasing 'effective' effort. A further complication is that the unit of fishing effort used in this assessment, i.e. 'a fisherday' is a relatively coarse measure that contains no information about numbers of hours fished, or travelling times and distances. Yet, it is highly likely that these aspects of fishing practices have also changed in association with the technological changes between the early 1980s and the late 2000s. The final factor that can influence the relationship between CPUE and the biomass of King George Whiting also relates to fisher behaviour as well as to the multi-species nature of the fishery. Fishers can direct their

fishing effort away from King George Whiting to target other species, depending on relative levels of abundance as well as market influences. In such cases, the variation in effort on King George Whiting is independent of its fishable biomass. Overall, the changes in 'effective' effort and fisher behaviour over time must have had a long-term impact on the relationship between CPUE and fishable biomass.

The second set of data used as indicators of stock status are population age structures (PIRSA 2013). King George Whiting in South Australia are not distributed evenly with respect to size and age (Fowler and McGarvey 2000, Fowler et al. 2000a). Some populations primarily involve small, young fish, whilst others support broader age and size distributions. The latter form the spawning aggregations during the reproductive season (Fowler et al. 1999), which are supplemented by annual movement of small, young adults from inshore areas (Fowler et al. 2002). The different size and age distributions of fish in different regions are the culmination of a complexity of life history and demographic processes. As such, the regional estimates of population structure provide indicators of stock status (PIRSA 2013). Market sampling for King George Whiting has been undertaken across the State during each financial year of 2006/07, 2008/09, 2009/10, 2011/12, 2012/13, 2014/15 and 2015/16. The age distributions from recent years were considered against historical data.

The computer fishery assessment model 'WhitEst' integrated the commercial and recreational fishery data with the biological data to provide annual estimates of the output parameters of recruitment, fishable biomass and annual exploitation rate. These represent the biological fishery performance indicators that were considered in determining stock status (PIRSA 2013). As with the trends in commercial fishery statistics, the temporal trends in the output parameters from the model should also be interpreted cautiously with respect to the extent that they depict real trends in the populations and fishery. This is because the estimates of output parameters are strongly influenced by the quality of the input data to the model. The data from the commercial sector are subject to the issues of concern about interpretation that primarily relate to technology changes and fisher behaviour that were discussed above. Furthermore, there is considerable uncertainty about the time-series of catch and effort data from the recreational sector. These primarily relate to the few empirical data available and the complexity in analytical procedures and their underlying assumptions required to provide estimates for the intervening years. This is the case despite this sector recently accounting for >50% of the total catch of King George Whiting across the State.

3.4.3. Stock Status

West Coast Stock

This Stock includes the populations of King George Whiting that inhabit all the bays and offshore areas of Eyre Peninsula. In 2014, it was classified as sustainable. Through the 2000s it consistently contributed the highest proportion of total State-wide catch of the three stocks. Nevertheless, through 2014 to 2016, catches and effort were at their lowest levels reflecting a marginal decline in the number of commercial license holders through this period. The question is whether these declines are sufficient to warrant a change to the classification of the Stock.

From 2014, handline CPUE was variable but nevertheless in 2016 increased to the second highest level yet recorded. Estimated levels of recruitment from WhitEst were also variable, but remained high. The estimates of biomass also increased through this period, indicating that the considerable drop that occurred in 2014 was not maintained. Since 1984, the estimates of exploitation rate have been downward, reflecting the long-term decline in commercial effort, due to the decrease in number of license holders operating in the fishery. By 2016, the exploitation rate was falling towards 10% of the fishable biomass, which is considerably lower than the trigger reference point. The age structures from the West Coast bays remained dominated by the 2+ to 4+ age classes (Fowler et al. 2014), which meant there was no obvious change.

The levels of catch and effort have declined since 2013. Nevertheless, even with a cautious interpretation of the fishery performance indicators, there is no indication in the high levels of handline CPUE, estimates of fishable biomass and recruitment and the declining exploitation rate to suggest that the biomass has been reduced to an extent that would impact on future levels of recruitment. As such, the classification of **sustainable** for this Stock is retained.

Spencer Gulf Stock

This Stock extends throughout the entire northern and southern regions of Spencer Gulf. The period of 2007 to 2013 was one of considerable decline for this Stock, as evident in the trends in catch, handline effort and handline CPUE that were also manifested in the time-series of fishable biomass and recruitment from WhitEst (Fowler et al. 2014). This culminated in the status of transitional-depleting. However, the year 2013 represented the lowest point in these downward trends. From 2014 to 2016, the fishery statistics all increased considerably, consistent with a recovery in the fishable biomass. The question is whether this recovery was sufficient to warrant a change in stock status.

From 2013 to 2016, catch, effort, and CPUE for handlines increased by 48%, 18% and 25%, respectively. These are substantial changes in the context of the declining trends between 2007 and 2013. They suggest considerable increases in recruitment and biomass after 2013, which are evident in the trends in output parameters from the WhitEst model. Particularly for recruitment, the downward trend in the model output from 2005 to 2012 was arrested, and since then there has been a year-to-year increase to 2016, with recruitment in the latter year considerably above the average of the previous five years. Whilst there was a marginal increase in exploitation rate from 2014 to 2016, which related to the increase in fishing effort, it remained considerably lower than historical levels and the trigger reference point. Southern Spencer Gulf is one of the State's few regions that supports a broad age structure and in 2016 there was no evidence that this age structure had become truncated.

The recent increases in fishery trends that are also manifested in the estimates of fishable biomass and recruitment from WhitEst suggest that the biomass of this population has increased considerably since the period of decline between 2007 and 2013. Such variable biomass appears typical for this Stock, which is evident in the cyclical variation in the temporal trends in fishery statistics. These indicators suggest that the population is subject to recruitment variation that impacts on population biomass and fishery productivity over cycles that last for a number of years. This result is not consistent with the fishing pressure being too high and moving the stock in the direction of being recruitment overfished. Rather, it suggests that the biomass is at a level sufficient to ensure that future recruitment is adequate. As such, the classification for this Stock is changed to **sustainable**.

Gulf St. Vincent / Kangaroo Island Stock

The GSV/KI Stock is distributed throughout Gulf St. Vincent, Investigator Strait and around Kangaroo Island. Like SG, this Stock also experienced a significant downturn during the period of 2007 to 2012 that culminated in the status of transitional depleting (Fowler et al 2014). Nevertheless, since then, there has been some recovery in fishery statistics consistent with a recent increase in biomass. The question is whether this recovery has been sufficient to warrant a change in stock status.

The extent of changes in the handline fishery statistics between 2013 and 2016 were: 16.7% increase in catch; a reduction of 1.6% in effort; and an 18.3% increase in CPUE. In general, these changes were moderate compared with those for the SG Stock. The changes in the output parameters from the WhitEst model were also moderate. Although the downward trend in estimated biomass from 2008 to 2012 was arrested, nevertheless there was only marginal

increase to 2016. Furthermore, for recruitment, there was evidence of a downward trend between 2004 and 2010, but there has been no substantial increase since then. The low and marginally declining exploitation rates from 2009 to 2015, reflect the relatively low levels of fishing effort.

The increase in handline CPUE since 2012 is the most positive indicator for the status of this Stock, which is consistent with a marginal increase in average recruitment over the past few years. Nevertheless, fishery catch, effort and estimated biomass have not increased sufficiently to suggest a recovery of the Stock. As such, there is insufficient evidence that there has been a recovery in the biomass that would ensure adequate future levels of recruitment. As such, the stock status of **transitional-depleting** that was applied in 2014 is retained here.

3.4.4. Assessment Uncertainties

The main uncertainty in this stock assessment for King George Whiting relates to the relationships between fishable biomass and the estimates of the various fishery performance indicators. The primary data used as indicators and which underpin the estimation of the biological indicators by WhitEst are the commercial fishery statistics. In a general sense it is expected that the parameters of catch, effort and CPUE are influenced by the biomass of King George Whiting. Nevertheless, there are other factors relating to fisher behaviour and technological advancements that also influence these relationships. Fishers can change their fishing effort between different target species and also move between regions of the fishery in order to pursue better financial gain. Furthermore, with changes in 'effective' effort over time through technological advancements, the concept of the unit of fishing effort, i.e. a 'fisher-day' has changed over time. These changes over short and long time scales complicate interpreting fishing effort and CPUE in terms of fishable biomass.

A further significant uncertainty relates to the poor understanding of temporal trends in catch and effort by the recreational sector. It is apparent from the three State-wide telephone/diary surveys undertaken through the 2000s (Jones and Doonan 2005, Jones 2009, Giri and Hall 2015), that this sector accounts for a significant proportion of the total catch of King George Whiting. The estimates of recreational catch and effort used in the WhitEst model were interpolated from the limited data available from the telephone/diary surveys undertaken in 2000/01, 2007/08, and 2013/14. In reality, it is unlikely that such interpolated values provide satisfactory time series of estimates of recreational catch and effort. In addition, the estimates of catch and effort from the telephone/diary surveys are very imprecise. Yet, the estimated time series of recreational catches are likely to have had considerable impact on the output parameters from WhitEst. They may

have affected the recent trends in model-estimated biomass that were considerably less than those in the estimates of commercial CPUE.

Finally, there is uncertainty about whether reproductive output in the two gulfs may have declined in recent years. These may have been impacted by the targeted fishing of spawning aggregations that are located in the deep, off-shore waters of southern Spencer Gulf and Investigator Strait. In recent years, such places have become accessible to commercial and recreational fishers due to technological developments in fishing boats and electronic equipment. The fishing of such aggregations may have disrupted the spawning activity and reduced egg production in such areas. Whilst the recent upturn for the SG Stock allays this concern somewhat, the long-term declining recruitment trend in GSV/KI remains a concern. The new spatial spawning closure that incorporates most of Investigator Strait and part of southern Spencer Gulf is designed to relieve the fishing pressure on these fishing areas and to provide opportunity for some fish to spawn uninterrupted.

3.4.5. Future Work

The most significant requirement to better assess the status of SA's King George Whiting stocks would be to attain better estimates of recreational catch and effort. Since more than half of the total catch is taken by this sector, these catches dominate exploitation levels, especially for the GSV/KI Stock. Better and more frequent recreational catch data would directly improve the comparison of shares and biological performance indicators from the WhitEst model.

Consideration should also be given to collecting more refined data on fishing effort from the commercial sector. The commercial fishery will undergo significant structural reform over the next five years. This will provide opportunity to review and revise the process of data collection on catch and effort from the fishery, including a revision of the commercial logbook. As such, consideration can be given to developing informative measures of commercial fishing effort that will provide more meaningful estimates of CPUE with respect to their relationship with fishable biomass. Furthermore, this will also provide the opportunity to consider whether there are any cost-effective fishery independent performance indicators that could be used.

There is currently an FRDC-funded project underway for King George Whiting in South Australia (FRDC Project 2016/003) that will improve the stock assessment process. The project will provide estimates of the biomass of the spawning stock using the daily egg production method (DEPM) that will then be used to ground-truth the WhitEst model. The project is based on egg surveys throughout the southern gulfs and Investigator Strait. As such, it will provide refined spatial

information on egg production to be used to assess whether the spatial spawning closure has been located correctly. An associated PhD project is considering the relationships between spawning grounds and nursery areas, thereby providing empirical evidence for the spatial scale over which the life history operates.

4. STOCK STATUS OF KEY MARINE SCALEFISH SPECIES

4.1. Introduction

Assessing the status of fish stocks can be challenging, particularly for lower value stocks that have limited data to inform quantitative assessments. In these situations, a weight-of-evidence approach is required to support stock determination (Flood et al. 2014). With the exception of three primary MSF species (King George Whiting, Snapper and Southern Garfish) that have supporting sophisticated computer models capable of integrating fishery-dependent and independent information to inform stock status, determining the status of the remaining species relies on the interpretation of fishery-dependent catch and effort data. Additional information about the species' stock structure, biology and management arrangements can contribute to the decision-making process.

This section of the report uses a weight-of-evidence approach to determine the stock status of 21 MSF species or taxonomic groups that are distributed across the 'Primary', 'Secondary' and 'Tertiary' species categories, as defined in the Management Plan (PIRSA 2013). For each species or taxon, the relevant biological information is presented, along with a description of the fishery; associated management regulations; interrogation of the fishery statistics at either the biological stock, State-wide or regional scale; assessment of the fishery against the general performance indicators; and a classification of stock status.

4.2. Method

Commercial catch and effort data are the primary data considered in this section. The appropriate data for each taxon were extracted from the SARDI Aquatic Sciences' commercial Marine Scalefish Fisheries Information System which includes data from the Marine Scalefish, Northern and Southern Zone Rock Lobster Fisheries. Data on Snapper catches by the Lakes and Coorong Fishery (LCF) and by-product of Southern Calamari by SA's prawn fisheries are also included. The data were extracted from a 33-year time series from 1984 to 2916 and were aggregated at either the biological stock, State-wide, or regional scale to provide annual estimates of catch and effort for the main gear types (Table 4-1). The presentational of data was limited by constraints of confidentiality, i.e. data could only be presented for years when summarised from five or more fishers. Estimates of recreational catch obtained from three telephone/diary surveys (Henry and Lyle 2003, Jones 2009, Giri and Hall 2015) were also presented.

The performance of each stock was assessed by comparing the general performance indicators for 2016, against the trigger reference points calculated from the historical data (see Section 1.5).

Table 4-1. List of MSF categories and species/taxa considered in this section, the scale of their stock boundary, main gear types, and the resolution of catch and effort data (whether its targeted or total).

CATEGORY	SPECIES/TAXON	STOCK	GEAR	TARGETED OR TOTAL
PRIMARY	SNAPPER	Biological	Handline, Longline	Targeted
	SOUTHERN GARFISH	Biological	Hauling Net, Dab Net	Targeted
	SOUTHERN CALAMARI	State-wide & Regional	Squid Jig, Hauling Net	Targeted
SECONDARY	YELLOWFIN WHITING	Biological	Hauling Net	Targeted
	WA SALMON	State-wide	Hauling Net	Targeted
	AUST. HERRING	State-wide	Hauling Net	Targeted
	VONGOLE	Biological	Cockle Rake	Total
	SNOOK	State-wide	Hauling Net	Targeted
	SAND CRAB	State-wide	Crab Net	Targeted
	YELLOWEYE MULLET	State-wide	Hauling Net	Total
	MULLOWAY	State-wide	Handline, Set Net	Total
	WHALER SHARKS	State-wide	Longline	Targeted
TERTIARY	OCEAN JACKETS	State-wide	Fish Trap	Targeted
	BLUETHROAT WRASSE	State-wide	Handline	Total
	SILVER TREVALLY	State-wide	Handline	Total
	LEATHERJACKETS	State-wide	Hauling Net	Total
	GUMMY SHARK	State-wide	Longline	Targeted
	SCHOOL SHARK	State-wide	Longline	Total
	RAYS & SKATES	State-wide	Hauling Net, Longline	Total
	CUTTLEFISH	State-wide	Squid Jig	Total
	BLACK BREAM	State-wide	All	Total

4.3. Results

4.3.1. SNAPPER (*Chrysophrys auratus*)

Biology

Snapper (*Chrysophrys auratus*) is a large, long-lived, demersal, finfish species that is a member of the family Sparidae. It is broadly distributed throughout the Indo-Pacific region including Australia, where its extensive distribution includes the coastal waters of the southern two thirds of the continental mainland as well as northern Tasmania (Kailola et al. 1993). Throughout this distribution, Snapper occupy a diversity of habitats from shallow bays and estuaries to the edge of the continental shelf across a depth range of at least 200 m. The stock structure for Snapper in Australian waters is complex, as there are considerable differences in the spatial scales over which populations are divisible into separate stocks (Fowler et al. 2016a; 2017). A recent otolith chemistry study has indicated that the South Australian population involves three stocks (Fowler 2016, Fowler et al. 2017). The Western Victorian Stock (WVS) is a cross-jurisdictional stock that extends westward from Wilsons Promontory, Victoria into the south eastern waters of South Australia (SE). The remaining State waters of SA are divisible into the Spencer Gulf / West Coast Stock (SG/WCS) and Gulf St. Vincent Stock (GSVS) (Fowler 2016a, Fowler et al. 2017).

The recent otolith chemistry study was also informative about the demographic processes responsible for the replenishment of the three SA stocks. It indicated that each stock depends on recruitment into a primary nursery area: Port Phillip Bay (PPB), Victoria for the WVS; Northern Spencer Gulf (NSG) for the SG/WCS; and Northern Gulf St. Vincent (NGSV) for the GSVS (Fowler 2016). For the SE region, Snapper abundance varies episodically, as fish of a few years of age move westwards over hundreds of km from PPB (Fowler et al. 2017). This relates to strong year classes in PPB, and as such is likely to be a density dependent process related to inter-annual variation in recruitment. The populations of Snapper that occupy the two northern gulfs are independent and self-recruiting. They also experience inter-annual variability in recruitment of 0+ fish, as a consequence of variable larval survivorship (Fowler and Jennings 2003). Each is an important nursery area that acts as a source of emigration that replenishes regional populations in adjacent coastal waters. NSG is the source region for Southern Spencer Gulf (SSG) and most likely also for the West Coast of Eyre Peninsula (WC), whilst NGSV is the source for SGSV. As such, regional population dynamics for SA's populations are primarily driven by temporally variable recruitment and subsequent emigration of fish from source to adjacent regional populations.

Fishery

Snapper is an iconic fishery resource in each mainland State of Australia (Kailola et al. 2003). In recent years, South Australia (SA) has been the dominant State-based contributor to the national total catches of both the commercial and recreational sectors (Fowler et al. 2016a, b). SA's Snapper fishery is geographically extensive and encompasses most of the State's coastal marine waters from the far West Coast of Eyre Peninsula to the SE, although the highest abundances and fishery catches have generally been in Spencer Gulf (SG) or Gulf St. Vincent (GSV).

Snapper is a primary target species of the commercial and recreational sectors of SA (PIRSA 2013). License holders from four different commercial fisheries have access to the fishery, i.e. the Marine Scalefish Fishery (MSF), the Northern Zone and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) and the Lakes and Coorong Fishery (LCF) (PIRSA 2013). Their main fishing gear types for targeting Snapper are handlines and longlines, since using hauling nets to take Snapper was prohibited in 1993. Snapper is a favourite species of local and inter-state recreational fishers, many of whom target the large trophy fish that can be abundant in SA's coastal waters. Recreational fishers target Snapper using rods and lines, primarily from boats, although jetty and land-based catches do occur. In the recent stock assessment, the contributions to total catch by the commercial and recreational sectors were 62% and 38%, respectively (Giri and Hall 2015, Fowler et al. 2016b).

The spatial structure of SA's Snapper fishery has experienced considerable change since 2007 (Fowler et al. 2016a). Historically, the highest catches and catch rates were made in SG, but these declined considerably, whilst contemporaneously those in NGSV and the SE increased to unprecedented levels (Fowler et al. 2016a). These changes reflected independent demographic processes relating to recruitment and adult migration that occurred for each of the three SA stocks (Fowler 2016, Fowler et al. 2017). From about 2011 onwards, the changes caused considerable concern about the management of the fishery that ultimately resulted in several levels of action: numerous management changes were implemented to limit commercial catches; whilst several FRDC-funded research projects were undertaken to identify the demographic processes responsible for the observed spatial changes (FRDC 2012/020, Fowler 2016), and to develop a fishery independent index of fishable biomass (FRDC 2014/019, Steer et al. 2017).

The harvest strategy for Snapper outlined in the current Management Plan (PIRSA 2013) reflects the changes and concerns about the challenges for fishery management since 2007. The harvest strategy involved a watching brief until the two FRDC funded projects (FRDC 2012/020, FRDC 2014/019) were completed. As such, it did not include explicit decision rules with respect to

responses to fishery status. It proposed that the review of the Management Plan and harvest strategy that is scheduled for 2018 take into consideration what should be our enhanced understanding of the biology and population dynamics of Snapper that will result from these two projects. Then, the aim should be to provide greater certainty for sustainable management by developing a harvest strategy that involves explicit decision rules about management responses to fishery status that are based on the enhanced understanding of the biology and fishery.

Management Regulations

Regulations for the commercial sector of South Australia's Snapper fishery involve a suite of input and output controls (PIRSA 2013). The four commercial fisheries with access to Snapper each have limited-entry, i.e. the numbers of fishers who can target Snapper have been limited for many years. There is a legal minimum length of 380 mm total length (TL), whilst there are also several gear restrictions. Snapper cannot be taken with fish traps, whilst the use of all nets, including hauling nets and large mesh gill nets for targeting Snapper has been prohibited since 1993. From December 2012, the number of hooks on set lines was reduced from 400 to 200 for fishers operating within SG and GSV, but remains at 400 for other regions. There is also a 50 kg bycatch trip limit for the Commonwealth-managed Southern and Eastern Scalefish and Shark Fishery. Commercial handline fishers are limited with respect to the numbers of handlines and hooks per line that can be legitimately used. Also, a daily commercial catch limit of 500 kg was introduced for all South Australian waters. In December 2016, this daily commercial catch limit was further reduced due to on-going concerns about stock status for the three South Australian Snapper stocks (Fowler et al. 2016a). For the SG/WC Stock, it was reduced to 200 kg with a limit of two days per trip. For the waters of GSV and also the SE region, the limit was reduced to 350 kg. For the former region, a trip limit of two days was set, whilst for the latter the limit of five days was set.

For the recreational sector, the minimum legal length of 380 mm TL as well as bag and boat limits apply. In December 2016, bag and boat limits were reduced in response to the recent changes in spatial structure and stock status (Fowler 2016, Fowler et al. 2016a). Up until this time, the bag and boat limits differed geographically. However, from the review of the recreational fishery in 2016 (PIRSA 2016), the bag limit of 5 and boat limit of 15 fish for the size range of 380 - 600 mm TL, and bag limit of 2 fish and boat limit of 6 fish for fish >600 mm TL now apply for all State waters. For the Charter Boat sector, the bag and boat limits are currently similar to those of the general recreational sector, with a further complication relating to number of passengers on board.

When the number exceeds six passengers, the catches are limited to 1 fish per day for those >600 mm TL, and either 3 or 5 for the 380 – 600 mm TL, depending on location.

Since 2000, the management regime for Snapper has involved at least one seasonal closure per year for both fishing sectors. From 2003 to 2011, this was a month-long fishery closure throughout November. From 2012, the seasonal closure was extended for several weeks until 15th December for all fishing sectors. Furthermore, in 2013, five Snapper spawning spatial closures were implemented in the northern gulfs to extend the duration of protection of important spawning aggregations until the 31st January, thereby conferring protection for most of the reproductive season. The four spatial closures in NSG and one in NGSV are circular with a 4-km radius from a fixed point.

Commercial Fishery Statistics

State-wide

Estimates of total State-wide commercial catch of Snapper show cyclical variation, with the cycles typically encompassing several years (Figure 4-1). Since 2003, i.e. the year that produced the minimum catch at the start of the most recent cycle, State-wide catch increased to a record level of 1,035 t in 2010, before declining by more than 63% to 382 t in 2016. Historically, handlines were the most significant gear type, and their catches largely accounted for the cyclical variation in total catch until 2008. However, longline catch increased marginally between 2005 and 2008, before increasing considerably until 2010 when it became the dominant gear type. Both longline and handline catches have declined since 2010.

There was a long-term, gradual declining trend in targeted commercial fishing effort between the mid-1980s and 2008 (Figure 4-1). This was followed by a period of elevated fishing effort between 2009 and 2012 that related to the increase in longline effort. However, since 2011, longline effort has declined, complementing the on-going, long-term declining trend for handline effort. As such, in 2016, targeted fishing effort was the historically lowest yet recorded. State-wide handline CPUE showed cyclical variation, superimposed on a long-term increasing trend. However, since 2007 it has decreased considerably, concomitant with the emerging dominance of longline fishing. Longline CPUE increased considerably between 2004 and 2015, before declining marginally in 2016.

The number of fishers from across all four commercial fisheries who reported taking Snapper, declined consistently from 403 in 1984 to 244 in 2000. It then stabilised for a number of years before again declining from 2010 onwards. Between 2010 and 2016, it fell from 260 to 167 fishers.

The number of commercial fishers who targeted Snapper varied similarly and fell from 201 to only 141 in 2016.

In 2016, the commercial catch was dominated by the MSF which contributed >99% of the reported catch (Figure 4-2). Small catches were reported by the NZRLF and SZRLF, with none reported by the LCF.

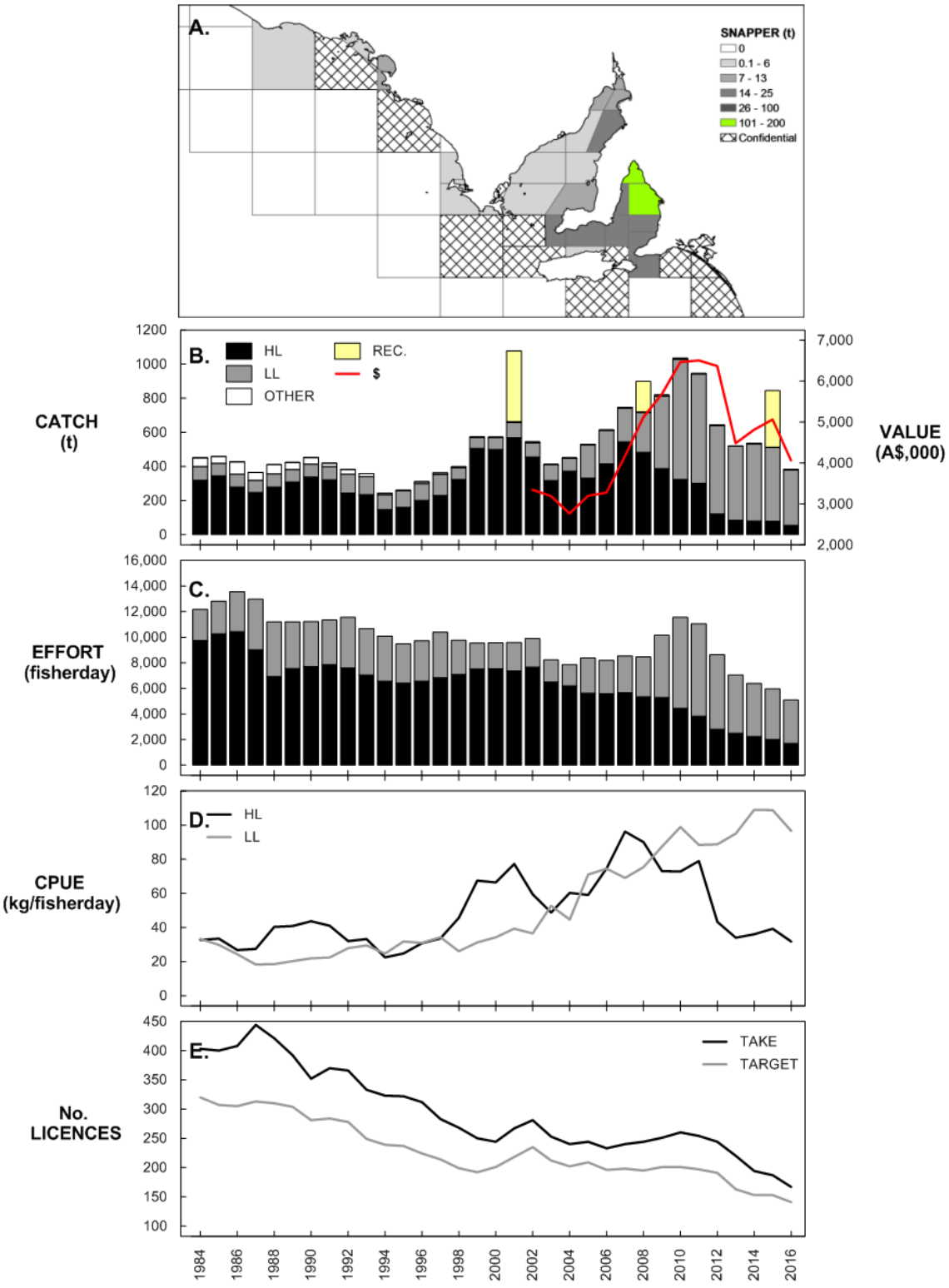

Figure 4-1. Snapper. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for the main gear types (handline and longline) and gross production value; (C) Long-term total effort for handline and longline; (D) total catch per unit effort for handline and longline; and (E) the number of active licence holders taking or targeting the species.

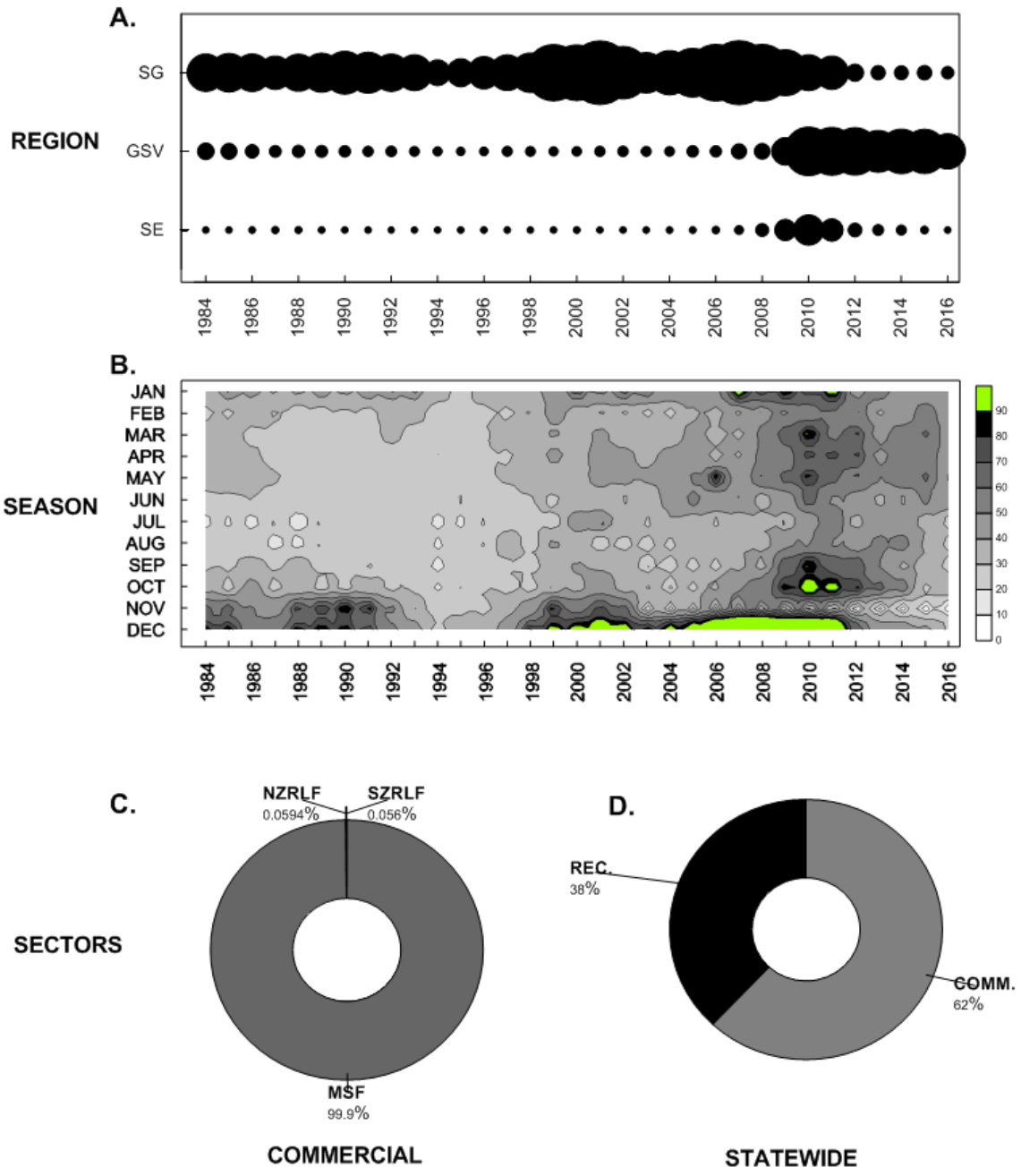

Figure 4-2. Snapper. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Regional

The relative contributions of the three stocks to total State-wide annual catches have changed considerably over time, indicating a significant change in the spatial structure of the fishery. The SG/WC Stock provided the highest annual catches up to 2009, after which they declined and fell to their lowest levels between 2012 and 2016 (Figure 4-2). The catches from the GSV Stock were very low until around 2004. They then increased gradually for a few years before accelerating between 2007 and 2010. This stock became and has subsequently remained the main contributor to the State-wide catch up to 2016. The catches from the South East region also increased dramatically between 2007 and 2010, but have declined back to a low level in 2016.

Spencer Gulf / West Coast Stock

Annual catches from the SG/WC Stock have varied cyclically with peaks in 1990, 2001 and 2007. The latter produced the highest catch of 616.6 t (Figure 4-3). Relatively low catches were recorded in 1994 and 2003, whilst from 2007 to 2012 annual catches fell considerably. Particularly low catches were recorded in each year from 2012 to 2016, with the latter year producing the lowest ever catch for this stock of 66.3 t. Total effort that produced Snapper catches has also declined regularly, dropping from the high of 11,726 fisher-days in 1986 to only 1,629 fisher-days in 2016.

Targeted handline catches have also varied cyclically over time. The highest of 516.1 t was taken in 2001, which fell to the lowest of only 29.8 t in 2016 (Figure 4-3). Targeted handline effort increased between 1984 and 2002 to the highest level of 5,138 fisher-days. Since then, it has declined to the lowest of 612 fisher-days in 2016. Targeted handline CPUE has varied cyclically, but also shown a long-term increasing trend. Nevertheless, it peaked in 2007 at 138.2 kg.fisherday^{-1}, but then declined steeply in 2012 to 64.6 kg.fisherday^{-1}, before decreasing even further to 48.7 kg.fisherday^{-1} in 2016. The number of license holders taking and targeting Snapper declined slowly through the 1980s and 1990s but the rates of decline increased through the 2000s. Those taking Snapper with handlines fell from 206 to 94 between 1984 and 2016, whilst those targeting fell from 170 to 69.

Targeted longline catch for the SG/WC Stock was relatively flat from 1984 to 2004. It then increased and peaked at 154.1 t in 2005 before declining again. By 2016, it had fallen to only 30.6 t. Targeted LL effort has also declined considerably since 1997 when it peaked at 2,578 fisher-days. By 2016, it had fallen to 610 fisher-days. Targeted LL CPUE peaked between 2004 and 2011, with the highest at 99.4 kg.fisherday^{-1} in 2006. By 2016, it had dropped to 50.1

kg.fisherday^{-1}. The numbers of fishers taking and targeting Snapper with longlines have declined steadily from 1988 to 2016. Those taking Snapper fell from 116 to 45 and those targeting it fell from 99 to 39 (Figure 4-3).

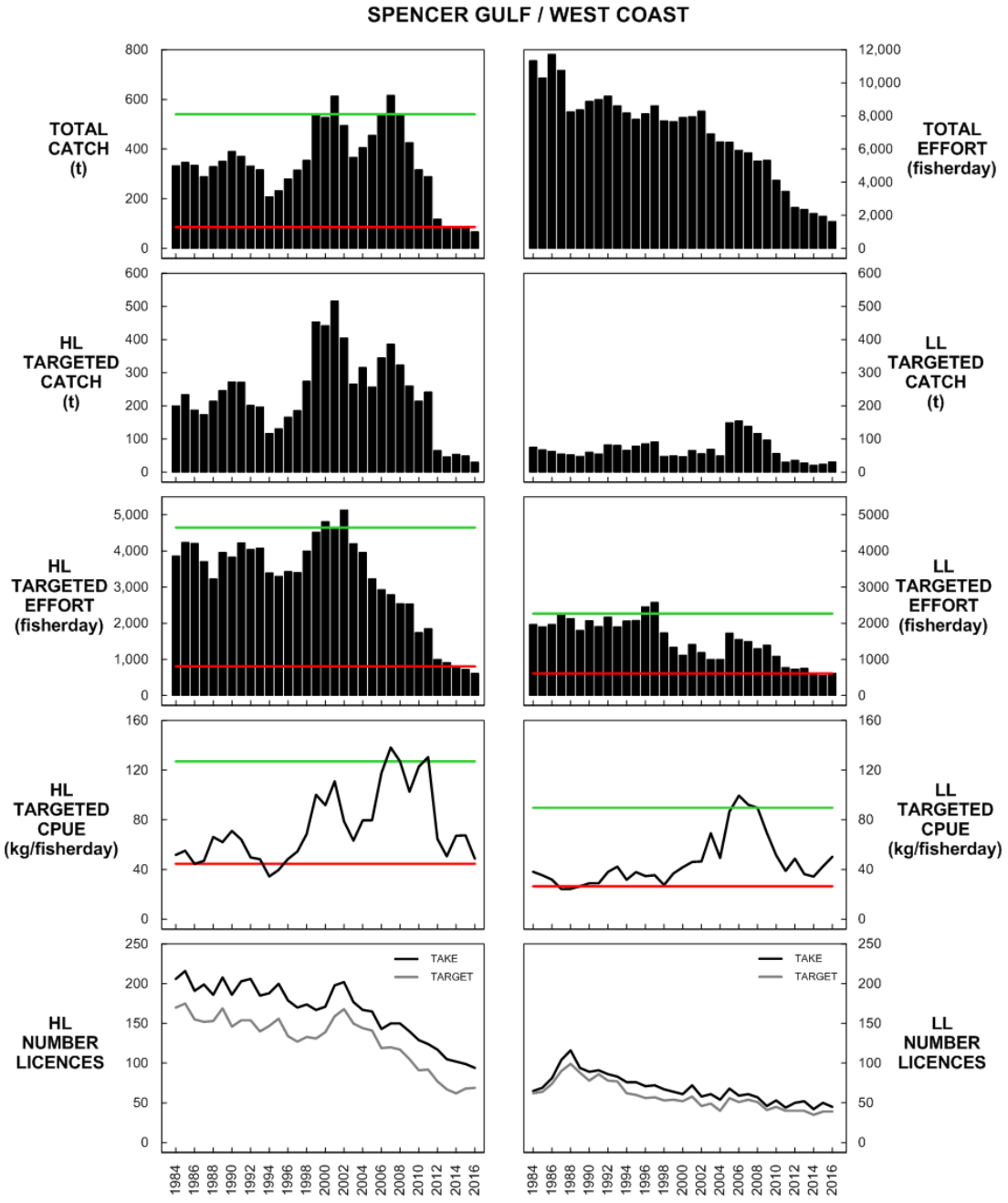

Figure 4-3. Key fishery statistics used to inform the status of Snapper in Spencer Gulf/West Coast. (Left) Trends in total catch, handline targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with handlines. (Right) Trends in total effort; longline targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with longlines. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Gulf St. Vincent Stock

Historically, the GSV Stock produced relatively low catches from 1984 to 2006. However, from then to 2010 total catch increased exponentially culminating in the record catch of 454.1 t (Figure 4-4). This has subsequently declined to 311.0 t in 2016. Total effort declined from 1984 to 2004 before increasing to the record level of 4,498 fisher-days in 2011. Since then, it has gradually declined to 3,303 fisher-days in 2016.

Targeted HL catch has generally remained relatively low for this stock despite the high effort levels during the early 1980s (Figure 4-4). Targeted HL CPUE remained moderate even between 2006 and 2016, when effort was highest. The LL fishery for the GSV Stock has largely accounted for the recent rapid increase in catches. Between 2008 and 2015, targeted LL catch increased from 46.7 $t.yr^{-1}$ to 388.2 $t.yr^{-1}$. This increase was associated with a 334.1% increase in longline fishery effort from 657 to 2,852 fisher-days. This has dropped back to 2,534 fisher-days in 2016. Longline CPUE demonstrated a long-term increase primarily between 2000 and 2010, when it peaked at 145.7 $kg.fisherday^{-1}$. It has subsequently declined to 114.6 $kg.fisherday^{-1}$ in 2016. The numbers of LL fishers who took and targeted Snapper peaked in 2012 and declined to considerably lower numbers in 2016 (Figure 4-4).

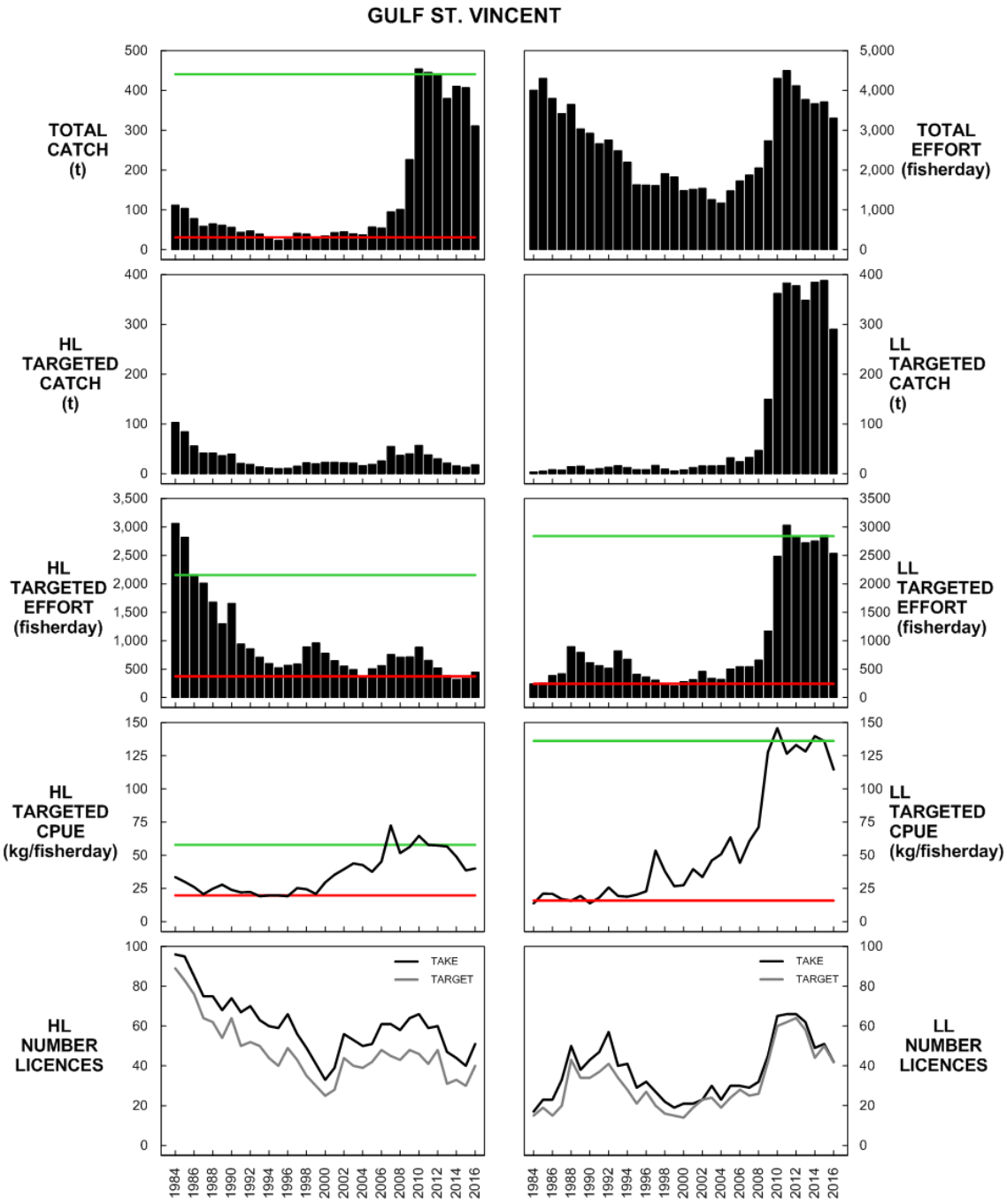

Figure 4-4. Key fishery statistics used to inform the status of Snapper in Gulf St. Vincent (Left) Trends in total catch, handline targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with handlines. (Right) Trends in total effort; longline targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with longlines. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

South East

Historically, the SE region has produced only marginal catches of Snapper (Figure 4-5). However from 2006 to 2010 there was an exponential increase that culminated in a record catch of 261 t in 2010. Since then, it has fallen consistently and in 2016 total catch was only 3.5 t. Recent total effort varied in a similar way, reaching a peak in 2010 before dropping to a very low level in 2016.

Targeted HL catch in the SE has always been low (Figure 4-5). There was a minor increase from 2006 to 2009, which has subsequently declined. Such catches reflect low but variable fishing effort, which peaked at 316 fisher-days in 2007. Targeted HL CPUE was generally <20 kg.fisherday^{-1}, but increased from 2003 and was highest from 2006 to 2009. The numbers of HL fishers who took and targeted Snapper peaked in 2009, and have subsequently declined to just a few.

Targeted LL catches were always less than several tonnes.yr^{-1} up to 2007 after which there was a rapid increase to the maximum level of 239 t in 2010 (Figure 4-5). Subsequently it has declined to only 3 t in 2016. There was a considerable increase in targeted longline effort, which peaked in 2010 at 2,614 fisher-days, but which has subsequently declined to only 92 fisher-days in 2016. Targeted CPUE also increased dramatically from 2007 to 2010, peaking at 91.5 kg.fisherday^{-1} before declining to 32.7 kg.fisherday^{-1} in 2016. The number of LL fishers who took and targeted Snapper increased dramatically from 2005 and peaked in 2010 before declining to low numbers in 2016.

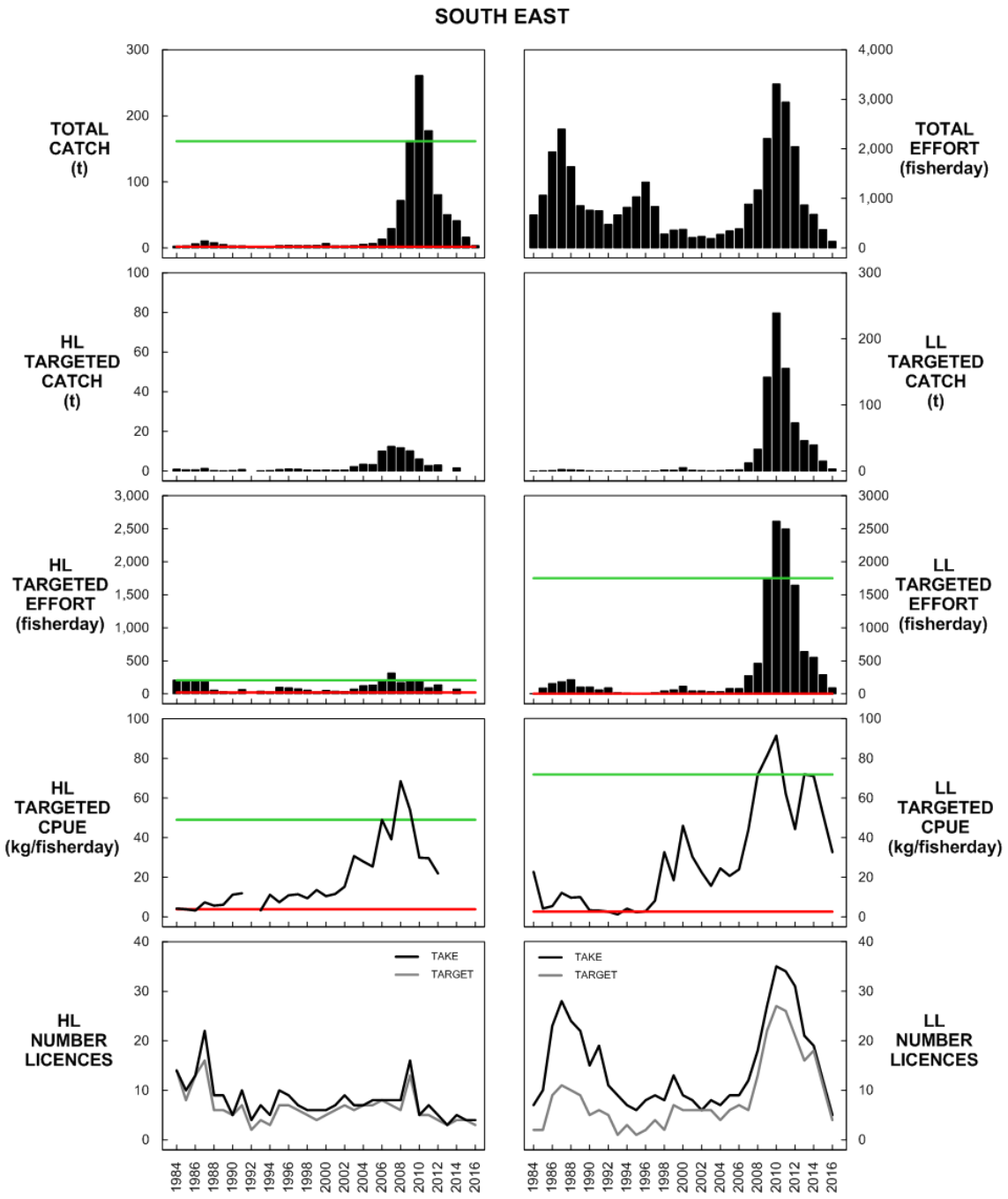

Figure 4-5. Key fishery statistics used to inform the status of Snapper in the South East. (Left) Trends in total catch, handline targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with handlines. (Right) Trends in total effort; longline targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Snapper with longlines. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Fishery Performance

The catch data from the four commercial fisheries from 2016 were compared against their allocations using Triggers 2 & 3 as reference points (Table 4-2). No trigger reference points were exceeded. The general fishery performance indicators were assessed for the SG/WC Stock, GSV Stock and the SE regional population. There were six breaches of trigger reference points, four of which were for the SG/WC Stock (Table 4-3). In 2016, total catch was the lowest recorded, whilst there had been five years of declining handline effort to the lowest recorded level. Also, targeted longline effort was the 3rd lowest. There were no breaches for the GSV Stock. For the SE in 2016, total catch had been declining for five years, whilst handline effort was low.

Table 4-2. Comparisons of percentages of commercial catch of Snapper taken by the fisheries, with their allocations and trigger limits specified in the Management Plan (PIRSA 2013). MSF – Marine Scalefish, SZRL – Southern Zone Rock Lobster, NZRL – Northern Zone Rock Lobster, LCF – Lakes and Coorong. Green colour – allocation not exceeded, red colour – allocation trigger activated.

COMMERCIAL ALLOCATION	MSF 97.50%	SZRL 1.78%	NZRLF 0.68%	LCF 0.04%
TRIGGER 2	n/a	2.68%	1.30%	0.75%
TRIGGER 3	n/a	3.58%	2.00%	1.00%
2012	97.30%	2.30%	0.30%	0.10%
2013	96.40%	3.10%	0.40%	0.10%
2014	98.90%	0.70%	0.10%	0.20%
2015	99.40%	0.50%	0.20%	-
2016	99.90%	0.10%	0.10%	-

Table 4-3. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the biological stock level for Snapper.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	SG/WCS	GSVS	SE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	LOWEST	×	×
	G	Greatest % interannual change (+/-)	×	×	×
	G	Greatest 5 year trend	×	×	×
	G	Decrease over 5 consecutive years	×	×	✓
TARGET HANDLINE EFFORT	G	3rd Lowest / 3rd Highest	LOWEST	×	LOWEST
	G	Greatest % interannual change (+/-)	×	×	×
	G	Greatest 5 year trend	×	×	×
	G	Decrease over 5 consecutive years	✓	×	×
TARGET HANDLINE CPUE	G	3rd Lowest / 3rd Highest	×	×	×
	G	Greatest % interannual change (+/-)	×	×	×
	G	Greatest 5 year trend	×	×	×
	G	Decrease over 5 consecutive years	×	×	×
TARGET LONGLINE EFFORT	G	3rd Lowest / 3rd Highest	3rd LOWEST	×	×
	G	Greatest % interannual change (+/-)	×	×	×
	G	Greatest 5 year trend	×	×	×
	G	Decrease over 5 consecutive years	×	×	×
TARGET LONGLINE CPUE	G	3rd Lowest / 3rd Highest	×	×	×
	G	Greatest % interannual change (+/-)	×	×	×
	G	Greatest 5 year trend	×	×	×
	G	Decrease over 5 consecutive years	×	×	×

Stock Status

Spencer Gulf / West Coast Stock

In the last stock assessment in 2016, the SG/WC Stock was assigned the status of transitional-depleting (Fowler et al. 2016a, b). This status reflected that the biomass in the three component management units of NSG, SSG and the WC were declining, based on decreasing trends in commercial catches, effort and CPUE. This broad-scale decline in biomass was related to poor recruitment into the main nursery area in NSG since 1999, which meant that emigration rates to SSG and the WC had been low for all age classes throughout the 2000s (Fowler et al. 2016b). Whilst it was evident that the biomass of the SG/WC Stock had declined, it was uncertain whether the stock was recruitment overfished, even though recruitment was below average throughout the 2000s. This is because regional exploitation rates had declined considerably due to reductions in commercial fishing effort. Furthermore, considerable management changes were implemented between 2012 and 2016, to reduce exploitation and to increase reproductive output and recruitment.

The fishery performance indicators presented here for the SG/WC Stock suggest that in 2016 the stock status may have deteriorated further than in 2015. Total catch, handline catch and handline effort fell to their lowest levels, whilst handline CPUE fell to its lowest since 1996. These declines in 2016 were generally small but all parameters were already at historically low levels. The question is whether the declines were sufficient to warrant changing the stock status to recruitment overfished.

In contrast to the declines in the handline fishery statistics in 2016, those for longlines increased marginally. The most significant was for longline CPUE that increased by 18.1%. As such, these increases largely off-set the declines in the handline sector, suggesting that the fishable biomass had remained approximately the same as in 2015. As such, the status of **transitional-depleting** is maintained for this stock. It is acknowledged that it could take some considerable time for any benefits of the considerable management changes that have been implemented since 2012 to be manifested in the populations. Nevertheless, if the general performance indicators, particularly handline and longline CPUE, do decline further in 2018 it will be necessary to change the status to recruitment overfished.

Gulf St. Vincent Stock

The GSV Stock involves the two regions of NGSV and SGSV. In 2016, this stock was assigned the status of ‘sustainable’. This reflected the strong performance of the fishery in NGSV from

about 2008 onwards that was indicative of an increase in biomass that related to the recruitment of numerous strong year classes to the population throughout the 2000s. This high biomass sustained the highest ever catches taken from any SA region through the history of the fishery. SGSV supported a much lower biomass through this time, but also showed evidence of an increase in biomass up to 2012.

The fishery statistics for the GSV Stock for 2016 showed considerable declines, indicating that the high catches over recent years have begun to reduce the high biomass. Total catch was considerably lower than the record catches taken in 2010, 2011 and 2012. Longlines were the main gear used to fish this stock, and longline catch, effort, CPUE and numbers of fishers all declined in 2016. As such, based on these indicators should the stock status be changed to transitional depleting?

Despite the declines in fishery performance indicators discussed above, the levels of these fishery statistics in 2016 still remained very high compared to historical levels, which resulted in no breaches of trigger reference points. It is expected that the considerable management changes made between 2012 and 2016 will limit fishery catches. As such, it appears that there remains sufficient spawning stock biomass to maintain average recruitment levels into the future, and so the status of **sustainable** is maintained.

Western Victorian Stock

The SE population of Snapper is part of the larger Western Victorian Stock. This regional population is sustained through emigration of adult fish from the main nursery area located approximately 600 km to the east in Port Phillip Bay, Victoria (Fowler et al. 2017). In 2016, the stock was assigned the status of ‘sustainable’, reflecting strong fishery performance in PPB and recent above-average recruitment of Snapper to this nursery area (Hamer et al. 2016). These results suggest that the stock is not overfished nor is the current level of fishery performance likely to cause it to become overfished. Despite the very low recent catches, effort and CPUE recorded for the fishery in the SE, it is part of the larger **sustainable** stock.

4.3.2. SOUTHERN GARFISH (*Hyporhamphus melanochir*)

Biology

The geographic distribution of Southern Garfish (*Hyporhamphus melanochir*) extends from Shark Bay in Western Australia, along the southern coast of mainland Australia and up the east coast to Eden in southern New South Wales, as well as the surrounding waters of Tasmania (Kailola 1993, Noell and Ye 2008). Throughout its distribution this schooling species occurs in sheltered bays and shallow, inshore, marine waters to depths of approximately 20 m. They are particularly abundant throughout the gulf regions of South Australia.

Spatial and temporal analysis of gonadosomatic indices indicated that Southern Garfish have an extended spawning season that spans approximately six months (from October to March) and within this season only a small proportion (10 – 20%) of the population are in spawning condition at any given time (Giannoni 2013). This indicates that reproductive activity within the population is asynchronous, consequently the extended spawning season is sustained by a series of small pockets of spawning activity. The estimated size at maturity ($L_{50\%}$) for female Southern Garfish in South Australia is 215 mm TL, which is equivalent to the mean age of 17.5 months (Ye et al. 2002).

There have been attempts to find Southern Garfish eggs in the field (Ling 1958, Noell 2003). In northern GSV, samples of a variety of seagrass species, including *Zostera muelleri, Posidonia sinuosa, P. angustifolia, Amphibolis antarctica* and *Heterozostera tasmanica* were collected and examined for adhering Southern Garfish eggs. However, no eggs were found.

During the 1990s, a total of 2,079 Southern Garfish were sampled from commercial catches in South Australia and successfully aged for a study on age and growth (Ye et al. 2002). There were seven age classes that contributed to the commercial catches (0+ to 6+ years), however, the catches were dominated (89%) by one- and two-year-old fish. Less than 2% were from 4+ to 6+ age classes. A more recent study which compared the size and age structures of the fishery with that of the 1950s indicated that historically the fishery was once dominated by 4+ and 5+ Southern Garfish, but over numerous years of exploitation the fishery has become considerably truncated to consist of primarily one- and two-year-old Southern Garfish (Fowler and Ling 2010).

In 2009, a study adopted a combined approach to delineate potential Southern Garfish sub-populations, and determine the extent of mixing within South Australia's coastal waters, through the integration of multiple otolith-based techniques (Steer et al. 2009a). Spatial differences in otolith chemistry (trace elements and stable isotopes) and morphometrics indicated that there

were several groups of Garfish that had spent significant parts of their lives in different environments and that there was some level of restriction that prevented complete mixing among the regions (Steer et al. 2009b, Steer et al. 2010; Steer and Fowler 2015). At least five regional divisions were identified. Three of these were clearly defined as they exhibited negligible levels of inter-regional mixing: The West Coast; Northern Spencer Gulf; and South-Western Spencer Gulf. The remaining two, however, were less distinct: Northern Gulf St. Vincent and Southern Gulf St. Vincent, but demonstrated a level of population structuring that would regard them as separate as a precautionary management measure. A concurrent study examining the spatial variation in parasite abundance in Southern Garfish inferred a similar population structure (Hutson et al. 2011). This level of population structuring was sufficient to suggest that the historical management framework of two discrete, gulf-specific, stocks should be restructured to align with these five smaller, semi-discrete, regional units.

Fishery

Southern Garfish is a significant inshore fishery species of southern Australia, with fisheries in Victoria, Tasmania, South Australia and Western Australia. Historically, the national commercial catch for this species has been dominated by that from South Australia where the catch has usually exceeded 400 t per annum, with an approximate value of $1.8 million (Econsearch 2014). This species is also a popular target amongst South Australian recreational anglers (Jones 2009).

In South Australia, licence holders from four different commercial fisheries have access to Southern Garfish within their respective fishery areas. These are the Marine Scalefish Fishery, Northern Zone Rock Lobster Fishery, Southern Zone Rock Lobster Fishery, and Lakes and Coorong Fishery. The Southern Garfish fishery is principally located in Spencer Gulf and Gulf St. Vincent (Figure 1.1) and managed as part of the multi-species, multi-gear MSF through a series of input and output controls. Commercial fishers typically target Southern Garfish using hauling nets and dab nets. Hauling net fishers account for the majority (~90%) of the commercial catch even though their fishing activities are restricted by regulation to waters <5 m deep.

Recreational fishers are permitted to use dab nets but predominantly use traditional hook and line as they fish from boats and shore-based platforms throughout the State. In 2013/14, this sector took an estimated 870,147 Southern Garfish, equating to an estimated catch of 79.2 t (Giri and Hall 2015).

Management Regulations

The commercial MSF has undergone considerable management changes over the past 40 years that has seen the fishery restructured and limited through gear restrictions and configuration, licensing, spatial and temporal closures, and size limits. Although most of these management changes have been generic in nature there have been a few that have largely impacted the Southern Garfish fishery. The most notable of these have been a series of net fishing spatial closures. Areas closed to netting were first implemented on the West Coast in 1958 and were subsequently followed by a depth-delimited ban in the early 1970s when net fishers were restricted to operate in coastal waters <5 m deep. Further netting closures were implemented in 1983, 1994, 1995, 1997 and 2005. In addition, deep water netting exemptions for a few commercial operators were revoked in 2006. These closures have significantly restricted the commercial Southern Garfish hauling net fishers to relatively small areas within the northern gulfs. Currently, it is estimated that net fishers in Northern Gulf St. Vincent have access to 465 km^2 of fishable area, which is approximately 55% less than the 1,028 km^2 available in Northern Spencer Gulf.

In 2001, the legal minimum length (LML) for Southern Garfish was increased from 210 mm to 230 mm total length (TL). This increase was made to ensure that at least 50% of Southern Garfish at that size would be reproductively mature and therefore had the opportunity to spawn at least once (Ye et al. 2002). Despite this increase, no corresponding changes to the mesh size regulations for hauling nets were implemented. Reductions in the recreational bag and boat limits were also implemented in 2001.

A specific harvest strategies for Southern Garfish was developed as part of the Management Plan for the South Australian Commercial Marine Scalefish Fishery which was released in October 2013 (PIRSA 2013). Although no specific management arrangements were prescribed in the Management Plan to achieve these targets, a range of tools were identified and an adaptive management approach outlined to consider the management arrangements needed to meet the targets over time. These included gear modifications, spatial and temporal closures, and effort/catch management (PIRSA 2013). Through collaborative research and consultation amongst PIRSA, SARDI and the commercial fishing industry it was agreed that a combination of effort and gear-based management strategies should be adopted to reach the operational targets. Furthermore, it was agreed that these strategies should be dynamic and altered in response to the status of the fishery. Initially, two 20-day seasonal closures that alternated between the gulfs were implemented in 2012. The duration of these closures were subsequently increased to 38

days in 2013, 40 days in 2014, and 60 days in 2016. Similarly, the minimum regulated mesh size of the pocket component of the hauling nets was sequentially increased from 30 mm to 32 mm in 2013 and to 35 mm in 2017. Furthermore, the LML of Southern Garfish for commercial fishers was increased from 230 mm to 250 mm in 2015. In 2016 the recreational bag and limit of Southern Garfish was halved from 60 and 180 fish to 30 and 90 fish. The LML, for recreational fishers, remains at 230 mm.

Commercial Fishery Statistics

State-wide

The total commercial catch of Southern Garfish was 155.2 t in 2016, combined across all gear types, including both targeted and untargeted catch, and was worth approximately A$1.6 million (Figure 4-6). This was the second consecutive year when catches dropped below 164 t, and is the lowest on record. The hauling net sector has traditionally dominated total catch, having consistently accounted for approximately 90% of the State-wide harvest since 1984 (Figure 4-6). Catches in this sector varied between 325 t and 500 t from 1984 to 2002, averaging 413 $t.yr^{-1}$, before declining to approximately 130 $t.yr^{-1}$ in 2016. The dab net sector accounts for most of the remaining catch (~10%). This sector yielded higher than average catches throughout the 1990s (~62 $t.yr^{-1}$) compared to the last decade when catches rarely exceeded 30 $t.yr^{-1}$ (Figure 4-6).

Combined fishing effort for Southern Garfish for the hauling net and dab net sectors has steadily declined from a peak of 17,776 fisher-days in 1984 to a low of 4,770 fisher-days in 2012 (Figure 4-6). This represents a 73.2% decrease over 28 years declining at a rate of 474 $fisher\text{-}days.year^{-1}$. This decline can largely be attributed to a consistent reduction in hauling net effort. Since then fishing effort has slightly increased, rising 5% to 4,988 fisher-days in 2016. This trend was consistent for both gear types.

Catch rates have remained relatively high in the hauling net sector from 2005 to 2014 averaging 55.5 $kg.fisherday^{-1}$, which was 11.1 $kg.fisherday^{-1}$ more than the average catch rates of the preceding decade (Figure 4-6). Catch rate has since declined to 35.5 declining $kg.fisherday^{-1}$ in 2015 and 34.4 $kg.fisherday^{-1}$ in 2016. Dab net catch rates displayed a long-term increasing trend from 1984 to 2002, rising from 20.2 $kg.fisherday^{-1}$ in 1984 to a peak of 58.6 $kg.fisherday^{-1}$ in 2001 (Figure 4-6). This increase was not sustained as it dropped to 31.9 $kg.fisherday^{-1}$ in 2007. Contemporary catch rates in the dab net sector have increased to 49.6 $kg.fisherday^{-1}$ in 2016.

Two management strategies have reduced the number of licence holders in South Australia's MSF. The first was the licence amalgamation scheme implemented in 1994, which has

contributed significantly to the long-term decline in the number of commercial fishers who land Southern Garfish. The second was the 2005 net buy-back. These two strategies have contributed to the 57% reduction in the number of commercial fishers landing Southern Garfish from 1995 to 2011 (Figure 4-6). The relative proportion of commercial fishers that nominated Southern Garfish as their specific target has remained relatively consistent at 75% of fishers landing Southern Garfish throughout the last 20 years.

Regional

Most of the State-wide catch of Southern Garfish has historically been landed in the NGSV and NSG (Figure 4-7). Catches from the WC, SSG and SGSV were considerably reduced from 2005 onwards as a result of the implementation of a suite of netting closures.

From 1984 to 1999, most Southern Garfish were landed during autumn (Figure 4-7). This was followed by two years during which high catches uncharacteristically peaked in mid-winter (July/August). Since then, overall monthly catches have declined considerably from the regular 40 t harvests during autumn, to 10 t to 30 t monthly catches spread from January to August (Figure 4-7).

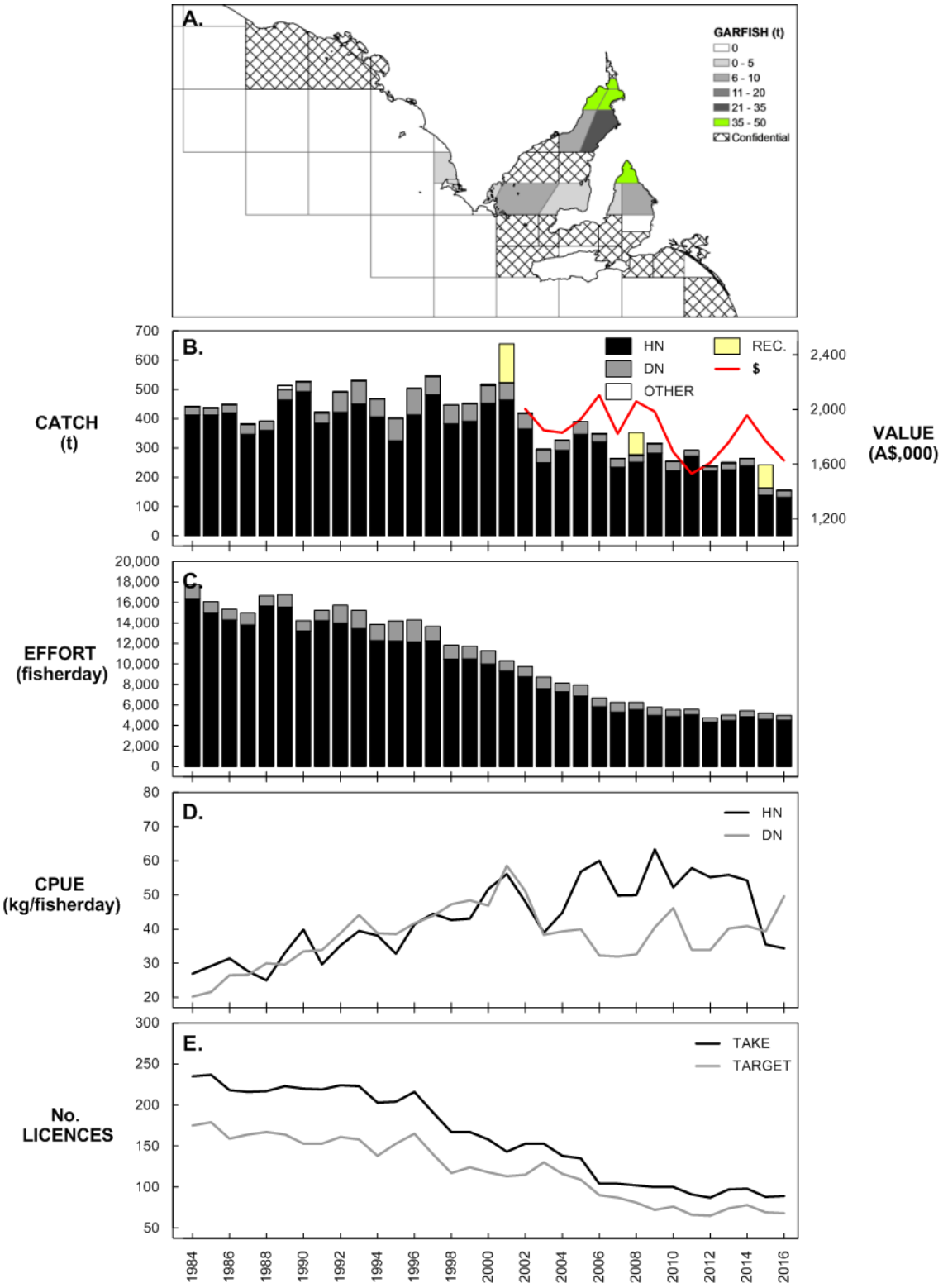

Figure 4-6. Southern Garfish. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for the main gear types (hauling and dab nets) and gross production value; (C) Long-term total effort for hauling and dab nets; (D) total catch per unit effort for hauling and dab nets; and (E) the number of active licence holders taking or targeting the species.

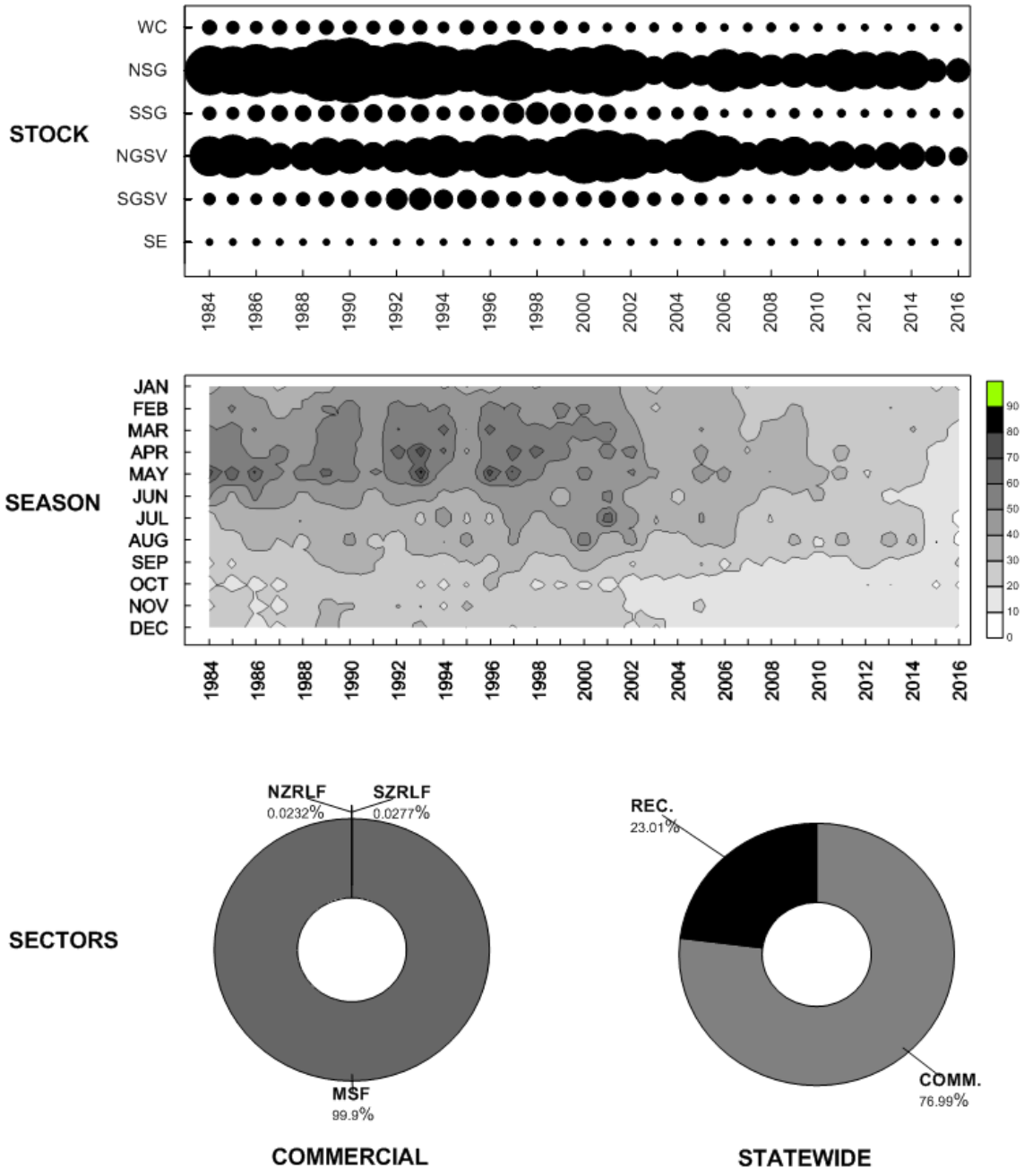

Figure 4-7. Southern Garfish. Long-term trends in the annual distribution of catch among biological stocks (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascrtained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

West Coast

From 1984 to 1999, the annual commercial catch of Garfish from the West Coast accounted for approximately 7% of the State's catch. This has since declined to <3% in 2016 and has been driven by a continuous reduction in hauling net effort through the implementation of commercial netting restrictions (Figure 4-8). Annual Garfish catch peaked at 37.2 t in 1992 of which hauling net sector landed 86%. Over the past three years, catches have remained below 5 t, falling to the lowest recorded level of 1.3 t in 2013, before increasing by to 4.4 t in 2015. Total fishing effort has declined 92% since 1984, with fishers expending 89 days catching Garfish in 2016, a level similar to the previous six years.

Dab nets emerged as the dominant gear type in 2006, and in 2016 this sector accounted for the majority of the total targeted catch in this region (Figure 4-8). The targeted catch rates in the hauling net sector peaked at 77.1 kg.fisher-days^{-1} in 1999. Since 2005 less than five hauling net fishers have operated in this region per year. Targeted catch rates in the dab net sector have ranged from 16.7 - 54.3 kg.fisher-days^{-1}, with the most recent etimate of 49.8 kg.fisher-days^{-1} being the second highest on record. Approximately 12 dab netters have been taking Garfish in this region over the past three years.

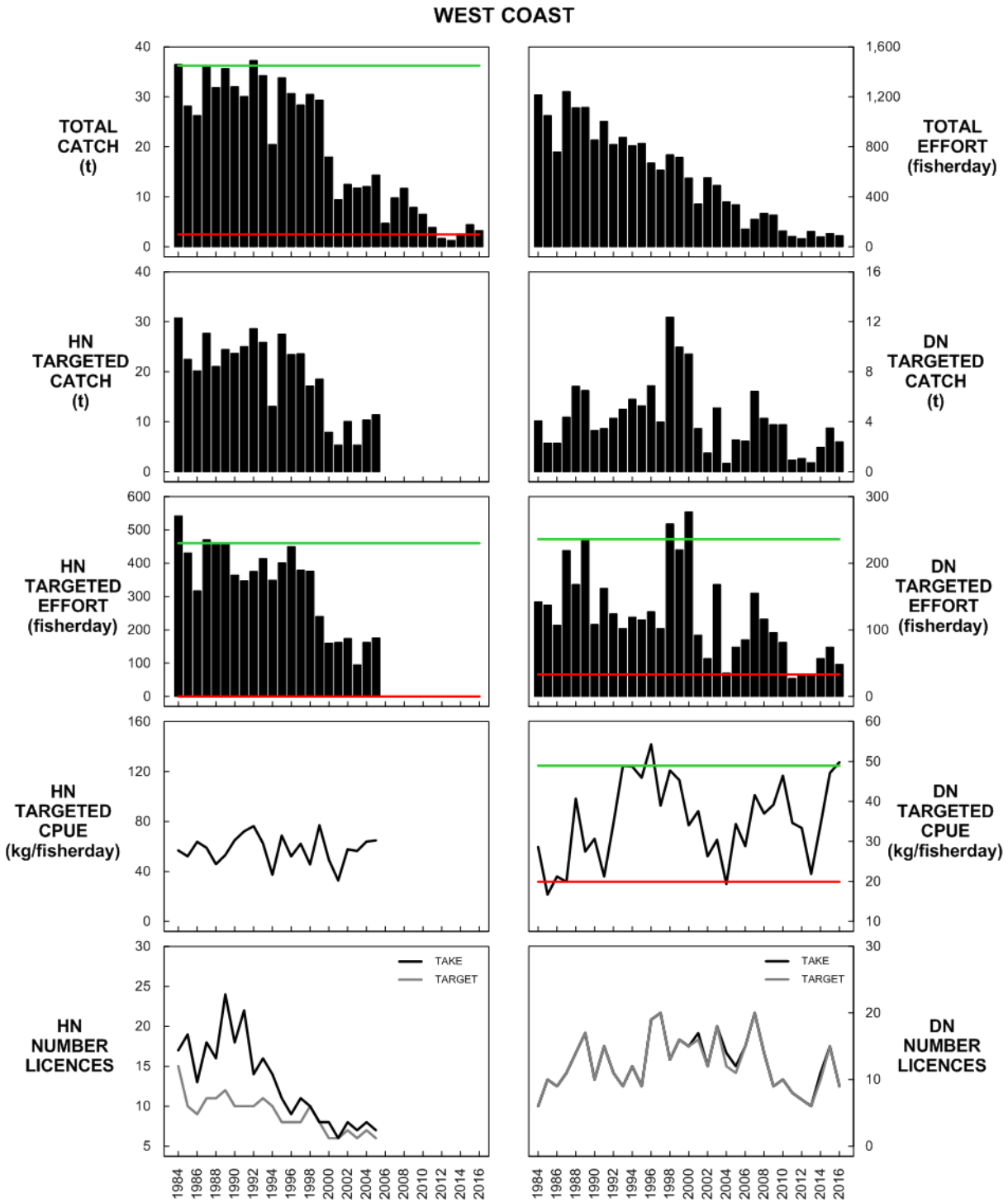

Figure 4-8. Key fishery statistics used to inform the status of the West Coast stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Northern Spencer Gulf

Northern Spencer Gulf has been the most productive fishing ground for Southern Garfish in South Australia since 1984. The highest recorded catch was 271.4 t in 1990 and the lowest 78.4 t in 2015 (Figure 4-9). There was a relatively rapid decline in catch from 1997 to 2003, during which it dropped 61% from 250 t to 98 t. Annual catches exceeded 160 t twice since 2003 (2006 and 2011) and remained relatively stable at approximately 145 t from 2012 until 2014, before dropping below 80 t in 2015 and 2016. There has been a long-term trend of decreasing fishing effort in this region, declining from a peak of 7,500 fisher-days in 1988 to 2,129 fisher-days in 2012, at a rate of approximately 215 fisher-days.yr^{-1}. This trend has been driven by the hauling net sector, which has consistently contributed to >95% of the fishing activity. Catch rates for target hauling net fishers trended upwards from 2003 rising from 44.7 kg.fisherday^{-1} to 129.9 kg.fisherday^{-1} in 2012, representing a 190% increase over nine years. Catch rates have subsequently fallen to 68.6 kg.fisher-days^{-1} in 2016 (Figure 4-9). Few dab net fishers (<13) have historically targeted Southern Garfish in this region each year, catching on average 36.4 kg.fisherday^{-1}. There has been a slight increase in the number of hauling net fishers catching Southern Garfish over the past two years, of which approximately 60% specifically targeting them.

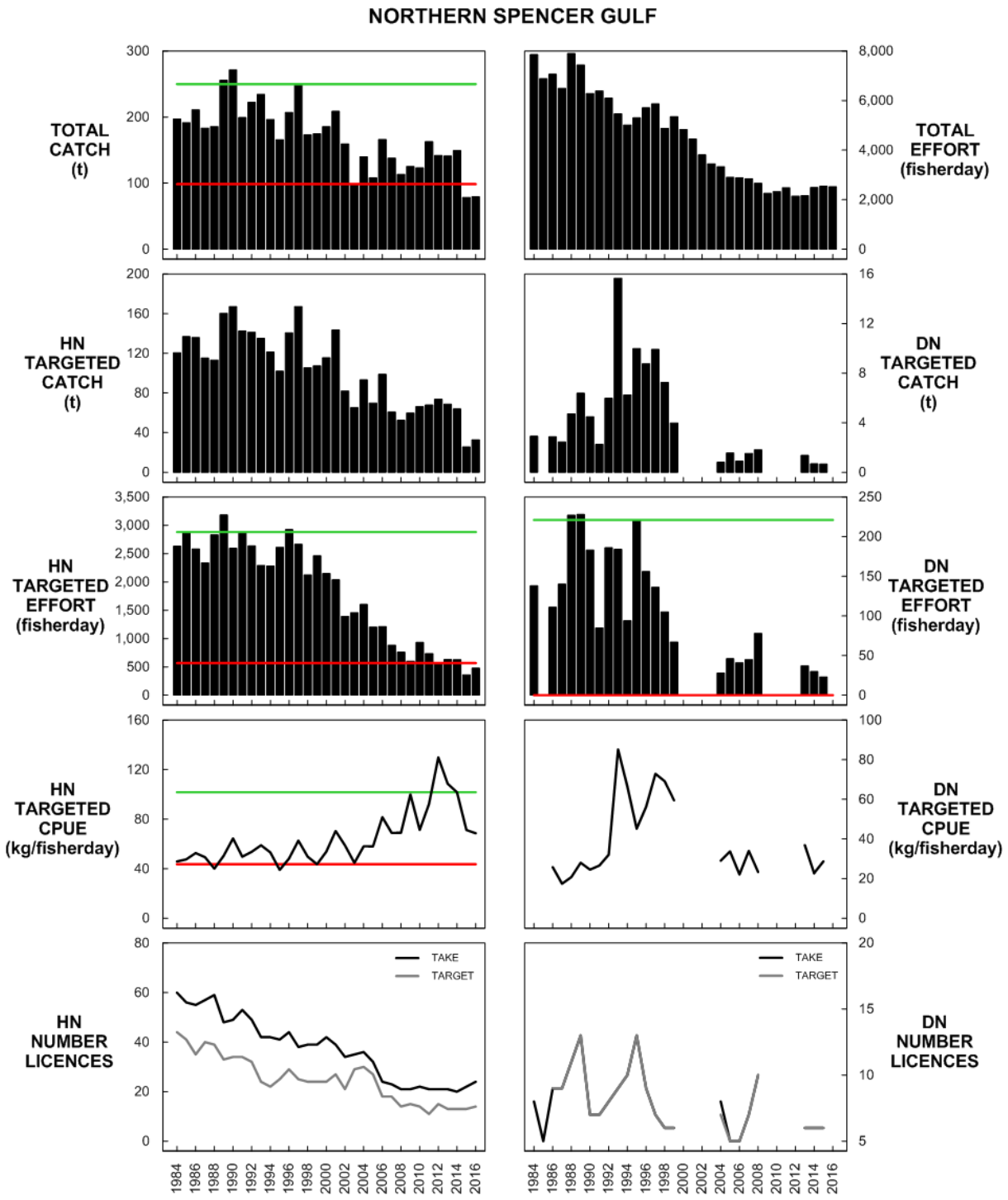

Figure 4-9. Key fishery statistics used to inform the status of the Northern Spencer Gulf stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Southern Spencer Gulf

Large areas of Southern Spencer Gulf have been closed to commercial hauling net fishing since 2005, and as a result the relative contribution of this region to the State-wide catch has decreased from approximately 10% up to 2005 to 3% over the past decade (Figure 4-10). Approximately half of the hauling net fishers who operated in this region specifically targeted Southern Garfish. This sector historically accounted for approximately 30% of the total catch which peaked at 71.2 t in 1998. However, it has been considerably eroded through spatial restrictions imposed in 2005 to become almost exclusively fished by the dab net sector. Total catch of Southern Garfish in this region has not exceeded 15 t since 2009 (Figure 4-10). Targeted dab net effort remained relatively stable at approximately 120 fisher-days from 2011 to 2014, before increasing above 230 fisher-days in 2015 and 2016. Targeted dab net CPUE peaked at 55.6 kg.fisher-days^{-1} in 2010, dropping to 38.5 kg.fisher-days^{-1} in 2012 before returning to 52.4 kg.fisher-days^{-1} in 2016 (Figure 4-10). Most dab netters (>90%) have specifically recorded Southern Garfish as their fishing target.

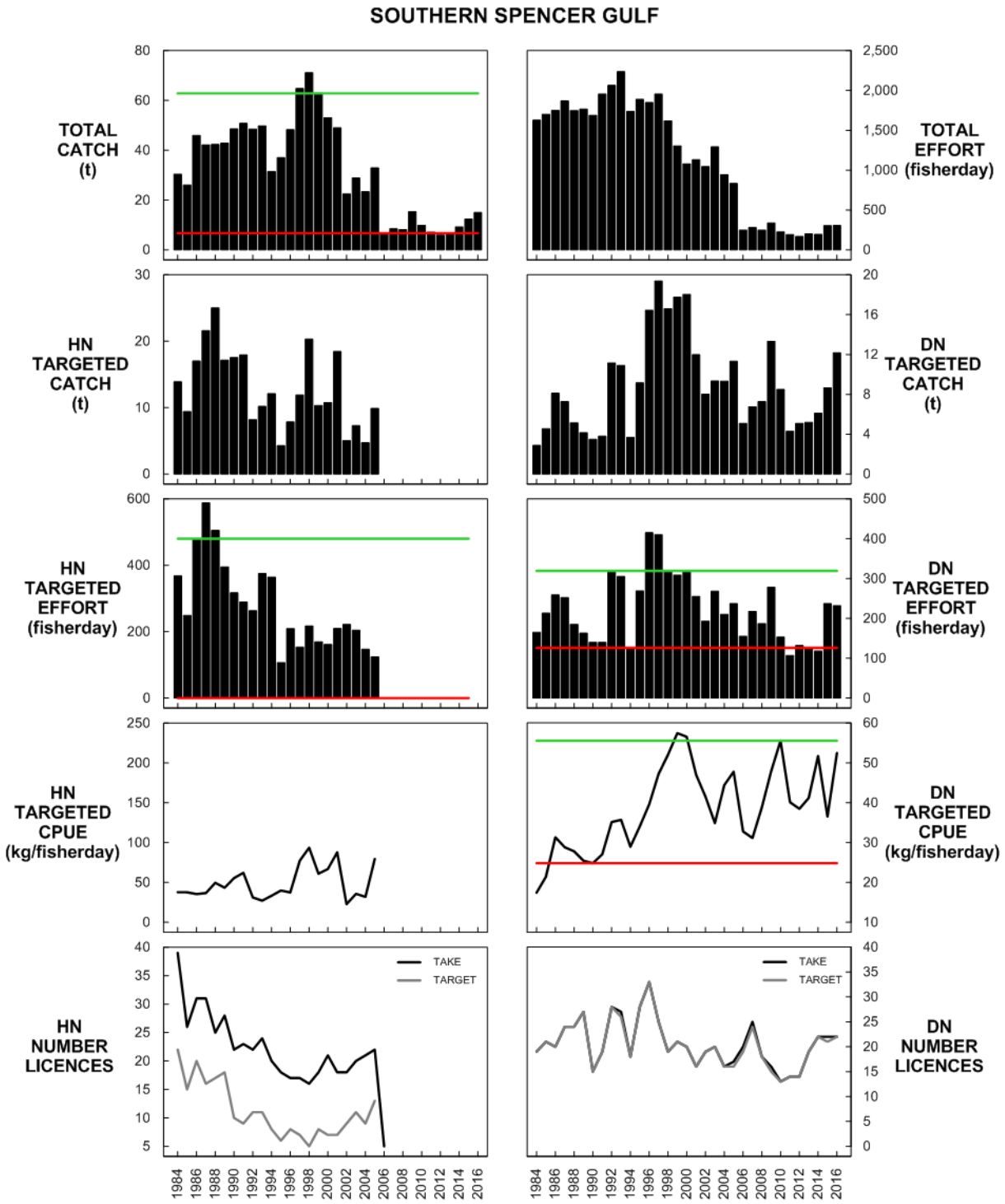

Figure 4-10. Key fishery statistics used to inform the status of the Southern Spencer Gulf stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Northern Gulf St. Vincent

Northern Gulf St. Vincent is the second most productive region in the State, accounting for ~35% of the State's annual catch. Annual catches have exceeded 200 t twice in the past 31 years; 221.4 t in 2000 and 209.6 t in 2005, before consistently declining to a record low of 53.3 t in 2016 (Figure 4-11). This represents a 74.5% decline over 12 years. This decline corresponded with a 62.9% decline in hauling net targeted effort and a 46% reduction in targeted CPUE. Conversely levels of annual targeted catch and effort in the dab net sector have increased, consistently exceeding 5 t and 115 fisher-days over the past four years, respectively. This level of dab net activity has not occurred since 2006. Targeted catch rates in this sector have also remained relatively high (> 40 kg.fisher-days^{-1}) over the same period (Figure 4-11).

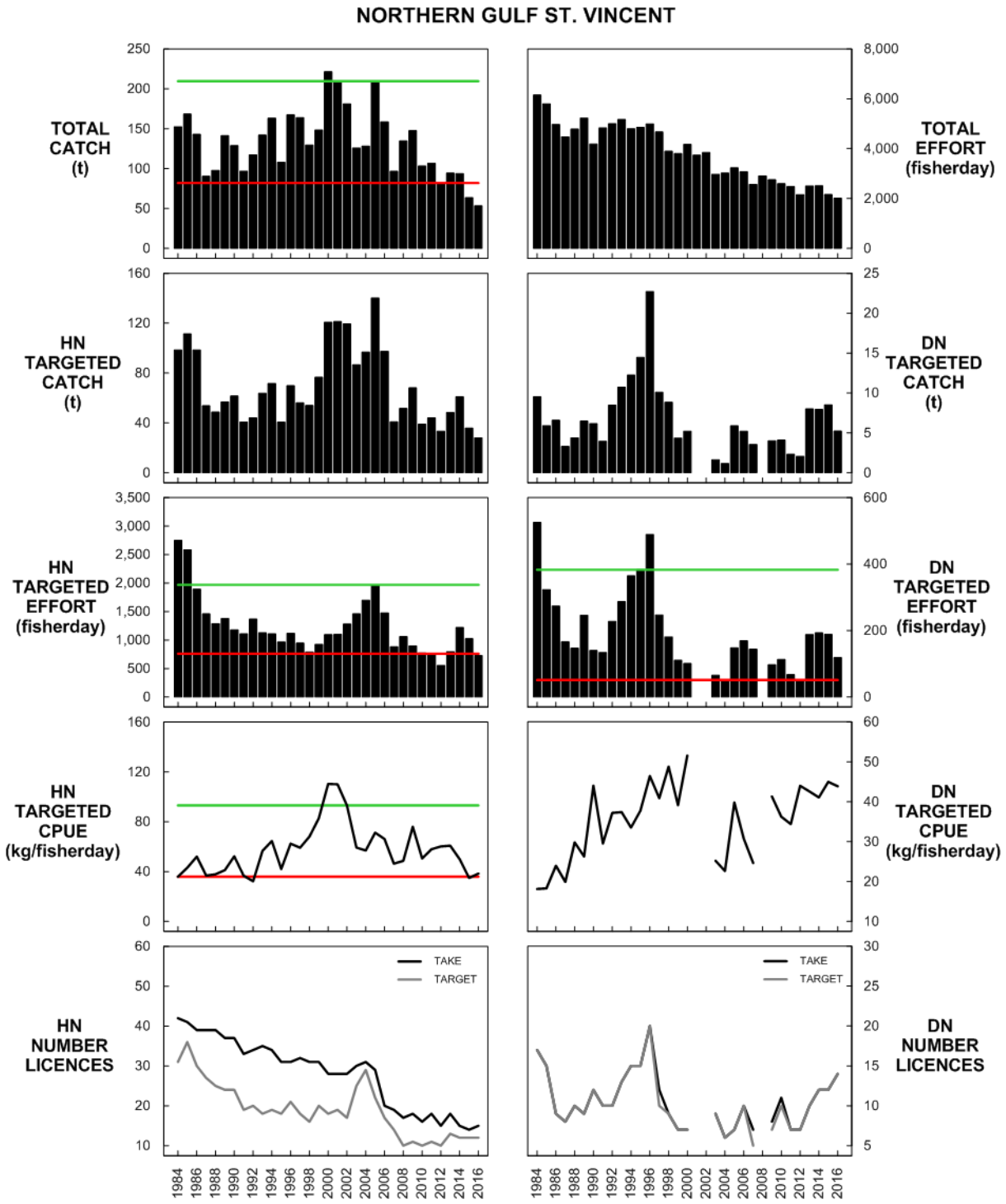

Figure 4-11. Key fishery statistics used to inform the status of the Northern Gulf St. Vincent stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Southern Gulf St. Vincent Stock

The relative contribution of the commercial Southern Garfish catch from this region to the annual State-wide total has rarely exceeded 10%. Annual catches steadily increased from 24 t in 1984 to 70 t in 1993 with both the hauling net and dab net sectors contributing equally (Figure 4-12). From 1993, the contribution of Southern Garfish catch by the hauling net sector declined as a result of a steady reduction in effort (Figure 4-12). From 2005 onwards the dab net sector accounted for >75% of annual commercial fishing effort in this region as the implementation of netting restrictions virtually removed all hauling net activity from the region. Targeted dab net effort has also recently declined, dropping from 558 fisher-days in 2005 to a record low of 39 fisher-days in 2015 and again in 2016. Consequently, total catches in this region have remained <6t over the past four years. Catch rates within the dab net sector have increased over this time period, increasing 40%, from 48 to 67 kg.fisher-days^{-1} (Figure 4-12).

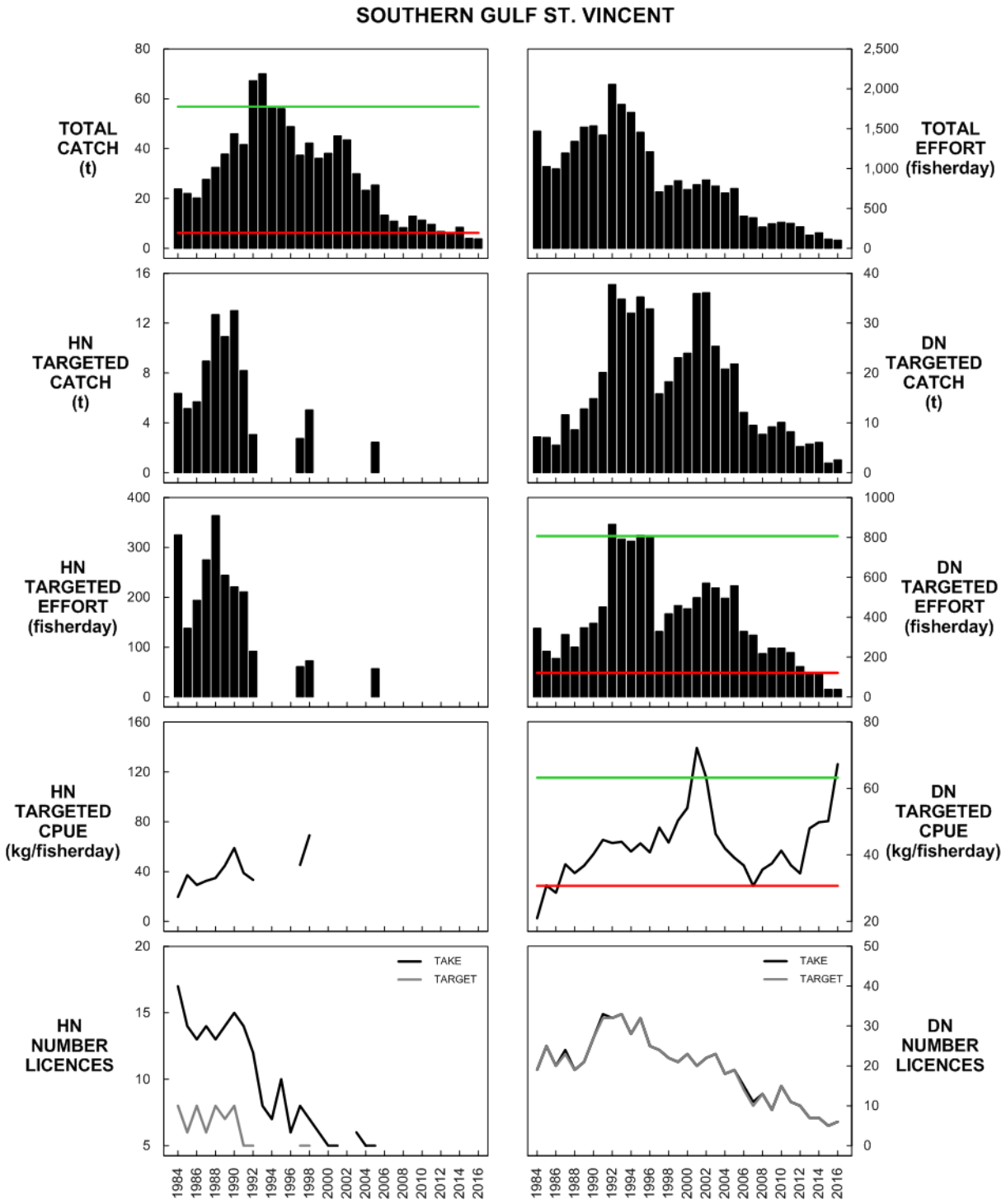

Figure 4-12. Key fishery statistics used to inform the status of the Southern Gulf St. Vincent stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

South East

A negligible amount of Southern Garfish is landed by the commercial sector in the South East, with the annual State-wide contribution rarely exceeding 0.3%. Total catch and effort has remained below 1 t and 40 fisher-days per year since 2003, respectively (Figure 4-13).

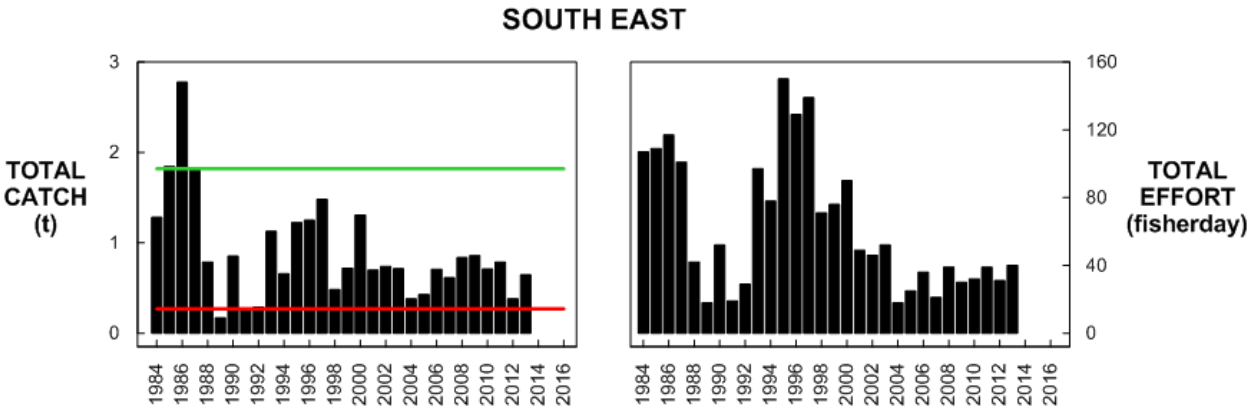

Figure 4-13. Key fishery statistics used to inform the status of the South Eastern stock of Southern Garfish. (Left) Trends in total catch; (Right) Trends in total effort. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Fishery Performance

The relative contributions to the total State-wide catch from the three commercial fisheries have been relatively stable over the past five years. In 2016, neither Trigger 2 nor Trigger 3 was breached (Table 4-4). One minor exception was SZRLF which exceeded 0.2% in 2013, however it was not large enough to breach the prescribed trigger limit.

The general performance indicators were assessed at the biological stock level. There were 10 breaches of trigger reference points across the six stocks (Table 4-5). In 2016, low catches breached the lower limit reference points in NGSV, SGSV and NSG. NSG and NGSV also recorded the second lowest estimates of target hauling net effort in 2016. Dab net effort was the lowest recorded for SGSV, however their respective catch rates were high, registering the second highest CPUE and interannual change, as well as the greatest increasing trend over the last five years. Dab net catch rates in 2016 were also the highest on record for the West Coast.

Table 4-4. Results from consideration of commercial catches of Southern Garfish by fishery against their allocation percentages and trigger reference points. MSF = Marine Scalefish, SZRL = Southern Zone Rock Lobster, NZRL = Northern Zone Rock Lobster. Green colour – allocation not exceeded, red colour – allocation trigger activated.

COMMERCIAL ALLOCATION	MSF 99.79%	SZRL 0.16%	NZRLF 0.05%
TRIGGER 2	n/a	0.75%	0.75%
TRIGGER 3	n/a	1.00%	1.00%
2012	99.86%	0.11%	0.04%
2013	99.72%	0.25%	0.03%
2014	99.89%	0.11%	0.01%
2015	99.89%	0.11%	0.01%
2016	99.95%	0.03%	0.02%

Table 4-5. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the biological stock spatial scales for Southern Garfish.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	WC	NSG	SSG	NGSV	SGSV	SE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×	2nd LOWEST	×	LOWEST	LOWEST	
	G	Greatest % interannual change (+/-)	×	×	×	×	×	
	G	Greatest 5 year trend	×	×	×	×	×	
	G	Decrease over 5 consecutive years	×	×	×	×	×	
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest		2nd LOWEST		2nd LOWEST		
	G	Greatest % interannual change (+/-)		×		×		
	G	Greatest 5 year trend		×		×		
	G	Decrease over 5 consecutive years		×		×		
TARGET HAULING NET CPUE	G	3rd Lowest / 3rd Highest		×		×		
	G	Greatest % interannual change (+/-)		×		×		
	G	Greatest 5 year trend		×		×		
	G	Decrease over 5 consecutive years		×		×		
TARGET DAB NET EFFORT	G	3rd Lowest / 3rd Highest	×		×	×	LOWEST	
	G	Greatest % interannual change (+/-)	×		×	×	×	
	G	Greatest 5 year trend	×		×	×	×	
	G	Decrease over 5 consecutive years	×		×	×	×	
TARGET DAB NET CPUE	G	3rd Lowest / 3rd Highest	HIGHEST		×	×	2nd HIGHEST	
	G	Greatest % interannual change (+/-)	×		×	×	2nd HIGHEST	
	G	Greatest 5 year trend	×		×	×	HIGHEST	
	G	Decrease over 5 consecutive years	×		×	×	✓	

Stock Status

West Coast Stock

A negligible amount of Southern Garfish is landed by the commercial sector on the West Coast, with its contribution to the State-wide total rarely exceeding 2%. The implementation of commercial netting restrictions in this region has contributed to the continuous reduction in hauling net effort since the late 1950s (Steer et al. 2016). In the absence of hauling net fishing, the current level of exploitation of Southern Garfish in the West Coast is unlikely to cause the biological stock

to become recruitment overfished. On this basis the West Coast Southern Garfish stock is classified as **sustainable**.

Northern Spencer Gulf Stock

From the stock assessment in 2016, the NSG stock of Southern Garfish was assigned the status of 'transitional-recovering' (Steer et al. 2016). This status reflected that long-term management changes had resulted in a reduction in the exploitation rate below the operational target of 60%; sustained increases in egg production and fishable biomass; and improved recruitment. Management measures (i.e. further increases in mesh size and LML) were also implemented to continue to promote stock recovery. These additional measures included a 40-day seasonal closure in 2015 and a 60-day closure in 2016. These closures contributed to reductions in targeted hauling net catch, effort and catch rates over the last two years. Based on the fishery statistics presented here up to December 2016 for NSG in association with the most recent management arrangements there is no evidence of any change in the status of this stock. A full stock assessment for Southern Garfish is scheduled for 2018 when the fishery will be assessed against the modelled biological performance indicators. Until then, this stock will remain classified as **transitional-recovering**.

Southern Spencer Gulf Stock

Large areas of Southern Spencer Gulf have been closed to hauling net fishing, with the most recent closure being implemented around southern Yorke Peninsula in 2005. Consequently, the hauling net sector has been effectively removed from this region and, as such, it has become predominantly fished commercially by dab netters. Although fishing effort and catch rates in the dab net sector have increased over the past two years, they have remained within the general performance trigger reference points. This stock is classified as **sustainable**.

Northern Gulf St. Vincent Stock

In the most recent stock assessment the NGSV stock of Southern Garfish was classified as 'recruitment overfished' (Steer et al. 2016). This classification was based on negative breaches in fishable biomass and recruitment against the trigger reference points; persisting low rates of egg production; relatively high exploitation rates coupled with increased effort and declining catch rates. Like NSG, the hauling net sector has had two seasonal closures (40 days in 2014 and 60 days in 2106) which contributed to declines in targeted hauling net catch, effort and catch rates. Based on the fishery statistics presented here up to December 2016, in association with the most recent management arrangements, there is no evidence of any change in the status of this stock.

A full stock assessment for Southern Garfish is scheduled for 2018 when the fishery will be assessed against the modelled biological performance indicators. Until then, this stock will remain classified as **overfished**.

Southern Gulf St. Vincent Stock

Prior to 1993, the commercial catch of Southern Garfish from southern Gulf St. Vincent was equally shared between the hauling net and dab net sectors. Since then, the hauling net sector declined as a function of a steady reduction in fishing effort. In 2006, dab nets became the dominant gear type. Hauling nets were removed from his region by implementation of the voluntary net buy-back scheme and spatial netting closures in 2005. Prior to this management restructure, the commercial Southern Garfish catch from this region rarely exceeded 10% of the State-wide harvest, however, after its implementation this was reduced to <5%. The history of this regional fishery and its current status is almost identical to SSG, characterised by relatively low levels of fishing activity and commercial catch and extensive netting closures. Over the last two years targeted dab net effort has declined to the lowest levels on record, however their associated catch rates have remained relatively strong. On this basis the SGSV stock remains classified as **sustainable**.

South East Stock

Like the West Coast, a negligible amount of Southern Garfish is landed by the commercial sector in the South East, with the State-wide contribution rarely exceeding 0.3%. The current level of exploitation of Southern Garfish in the South East is unlikely to cause the biological stock to become recruitment overfished. On this basis the South East Garfish stock is classified as **sustainable**.

4.3.3. SOUTHERN CALAMARI (*Sepioteuthis australis*)

Biology

Southern Calamari is endemic to southern Australian and northern New Zealand waters. In southern Australia, it ranges from Dampier in Western Australia to Moreton Bay in Queensland, including Tasmania. It inhabits coastal waters and bays, usually in depths of less than 70 m (Winstanley et al. 1983).

The life-history of Southern Calamari is typical of most squid species where they 'live-fast and die-young', exhibiting rapid growth and a sub-annual life-span (Jackson 2004). In South Australia, adults and juvenile Southern Calamari are predominantly found in shallow, inshore waters, whereas the deeper, offshore waters are occupied by sub-adults. Such spatial segregation is common in squid species, as is having offshore nursery and inshore spawning grounds (Sauer 1995). The distribution and abundance patterns of adult Southern Calamari in South Australia's gulfs tend to conform to a seasonal, systematic pattern consistent amongst years (Triantafillos 2001). Adult abundance typically increases for six months to a peak and declines for the remainder of the year. The timing of these peaks vary among regions and tend to follow an anti-clockwise progression around the gulfs, starting in the south-east during late spring and concluding along the western coasts during late winter. Seasonal patterns in water clarity, associated with the prevailing winds, appear to drive this progression as Calamari seek the relatively protected leeward shores to spawn (Triantafillos 2001; Steer et al. 2007). Spawning occurs throughout the year, consequently supplying a continuous 'conveyor-belt' of recruits to the population.

The biological stock structure across the distribution of Southern Calamari is complex and potentially dynamic. One study used allozyme markers to identify three genetic types with overlapping distributions and possible stocks off Western Australia, South Australia, New South Wales and Tasmania (data are not available for Victoria) (Triantafillos 2004). In contrast, another study using microsatellite markers found little genetic differentiation between seven study sites in Western Australia, South Australia, Victoria and Tasmania (Smith et al. 2015). It also identified Tasmania as a possible important site for gene flow. Life history dynamics, and studies of movement and statolith microchemistry in Tasmania also suggest some localised biological stock structuring (Pecl et al. 2011). For the purpose of this assessment South Australia's Southern Calamari is considered to comprise a single stock, however, the catch and effort data will be interrogated at the regional scale to explore the dynamics of this fishery at a greater resolution.

Fishery

In South Australia, the Calamari resource is shared by three sectors. Adults are targeted by commercial licence holders and recreational fishers on the inshore spawning grounds, while juveniles and sub-adults are incidentally caught by commercial prawn trawlers operating in the deeper (>10 m), offshore, gulf waters. The commercial prawn trawling fleet are permitted to retain and sell Southern Calamari as by-product.

Recreational fishers also fish from jetties, breakwaters and other shore-based platforms. Most of the catch is landed by hand jigs, however commercial fishers are also licensed to use hauling nets, gill nets and dab nets. Daily boat and bag limits apply to the recreational sector. In 2013/14, this sector took an estimated 473,803 Southern Calamari, equating to an estimated catch of 154.9 t (Giri and Hall 2015).

Management Regulations

As far back as 1992, there were fishery management concerns about the increasing popularity of Calamari fishing by both recreational and commercial fishers and the potential vulnerability of the spawning stocks (Marine Scalefish White Paper 1992). There were also reports of the illegal sale of Calamari. These concerns resulted in the implementation of recreational bag and boat limits in 1995 (i.e. 15 per bag/45 per boat per day) and have remained unchanged. Currently, input controls such as spatial and temporal closures and gear restrictions (minimum mesh size (30 mm) and lengths (600 m)) apply to the net sector, however these are generic measures rather than being specific to Calamari. Restrictions currently prevent netting in all metropolitan waters and in waters greater than five meters deep, as well as in numerous bays and marine protected areas. The jigging sector dominates the Southern Calamari fishery and is permitted in most State waters, with the exception of several aquatic reserves. In 2004, a full-time cephalopod fishing closure was implemented in False Bay, northern Spencer Gulf, to protect the annual spawning aggregation of the Giant Australian Cuttlefish, *Sepia apama*. It is not known whether this spatial closure inadvertently provides some regional protection for spawning Calamari.

Commercial Fishery Statistics

State-wide

The total reported commercial catch of Southern Calamari, combined across all fisheries, in 2016 was 443.76 t and has remained relatively stable (>350 t) over the last six years (Figure 4-14). Of this, Calamari by-product pooled across all three prawn fisheries has consistently accounted for <10 % since it was first reported in 2004. The estimated production value of this fishery has

increased from approximately A$1.9 million in 2001/02 to a peak of A$5.1 million in 2011/12. Since then it has remained above A$3.6 million per year, and in 2016 was the most valuable MSF species at A$4.7 million.

Prior to 1992, the jig and hauling net sectors of the MSF contributed equally to annual catches. Since then, jigs have become the preferred gear type and have generally accounted for approximately 70% of the annual catch. Total fishing effort combined for both jig and hauling net fishers has remained relatively stable over the past 12 years, ranging between 11,461 fisher-days in 2008 to 14,487 fisher-days in 2011. In 2016, 13,494 fisher-days were expended catching Southern Calamari within the MSF. Catch rates have gradually increased over the past 33 years for both gear types, at a rate of approximately 0.5 kg.fisherday.year^{-1}. With the exception of 2016, catch rates for jig fishers have been approximately 50% higher than for hauling net fishers. Since the implementation of the licence amalgamation scheme in 1994, the number of licence holders taking Southern Calamari has declined from 355 to 221, representing a 37% reduction over 22 years. The number of licence holders specifically targeting Calamari has remained relatively stable, averaging approximately 215 licences per year (Figure 4-14).

Regional

Southern Calamari is caught throughout the State with the majority landed within the gulfs (Figure 4-15). Catches have notably increased in NSG, SSG and NGSV since 2008, with all three regions accounting for similar proportions of the State-wide commercial total. Although, Calamari can be caught throughout the year, they tend to peak during late spring and late autumn. In 2016, the commercial catch of Calamari was dominated by the Marine Scalefish fishers (89.1%), whilst the Prawn fishery accounted for 10.5%, and Southern and Northern Zone Rock Lobster fishers accounted for the remaining <1% (Figure 4-15). In 2013/14 the recreational sector accounted for 30.2% of the State-wide catch of Calamari.

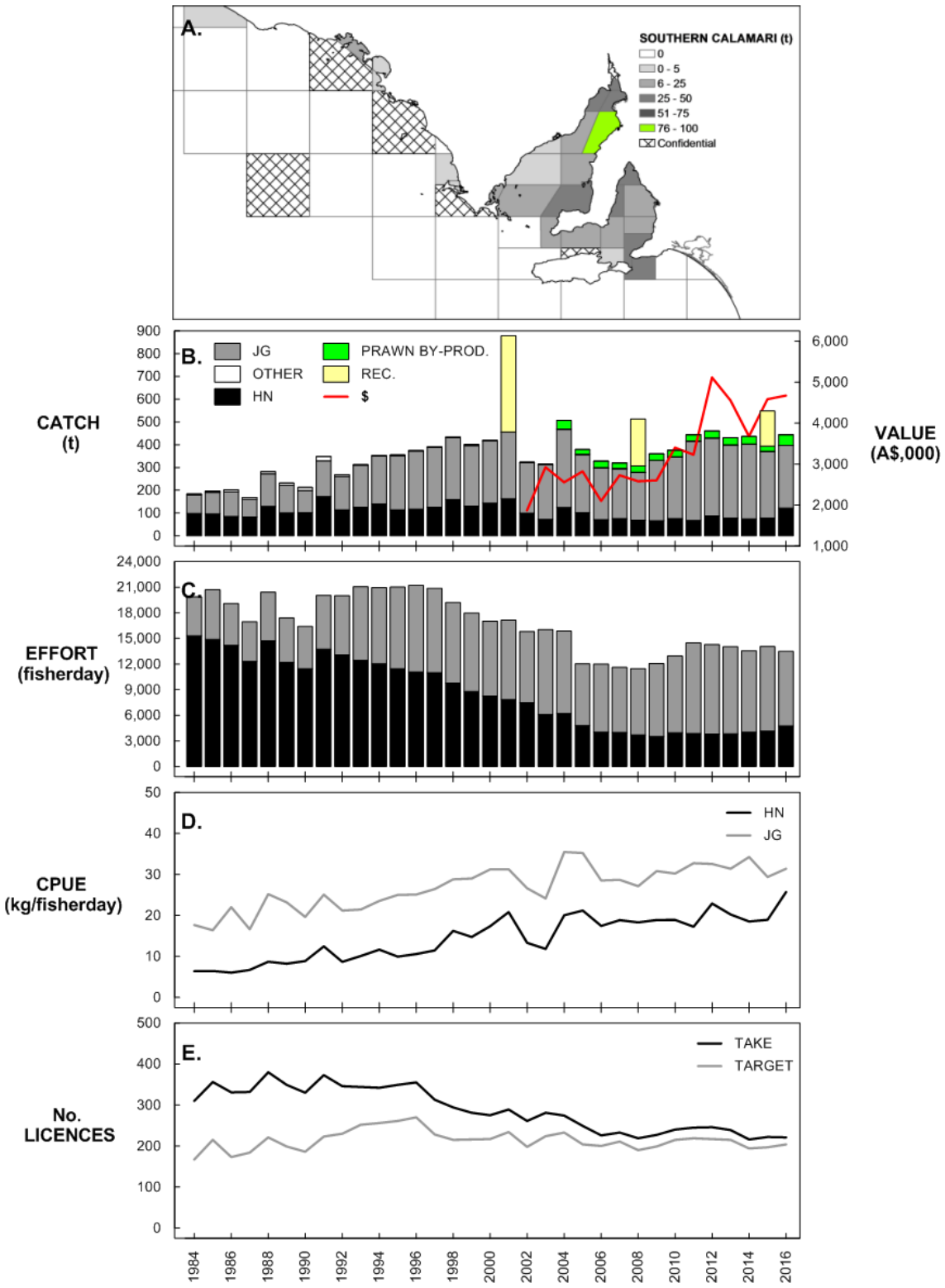

Figure 4-14. Southern Calamari (A) Catch distribution for 2016; Long-term trends in: (B) total catch for the main gear types (squid jig, hauling net, prawn bycatch) and gross production value; (C) Long-term total effort for squid jigs and hauling nets; (D) total catch per unit effort for squid jigs and hauling nets; and (E) the number of active licence holders taking or targeting the species.

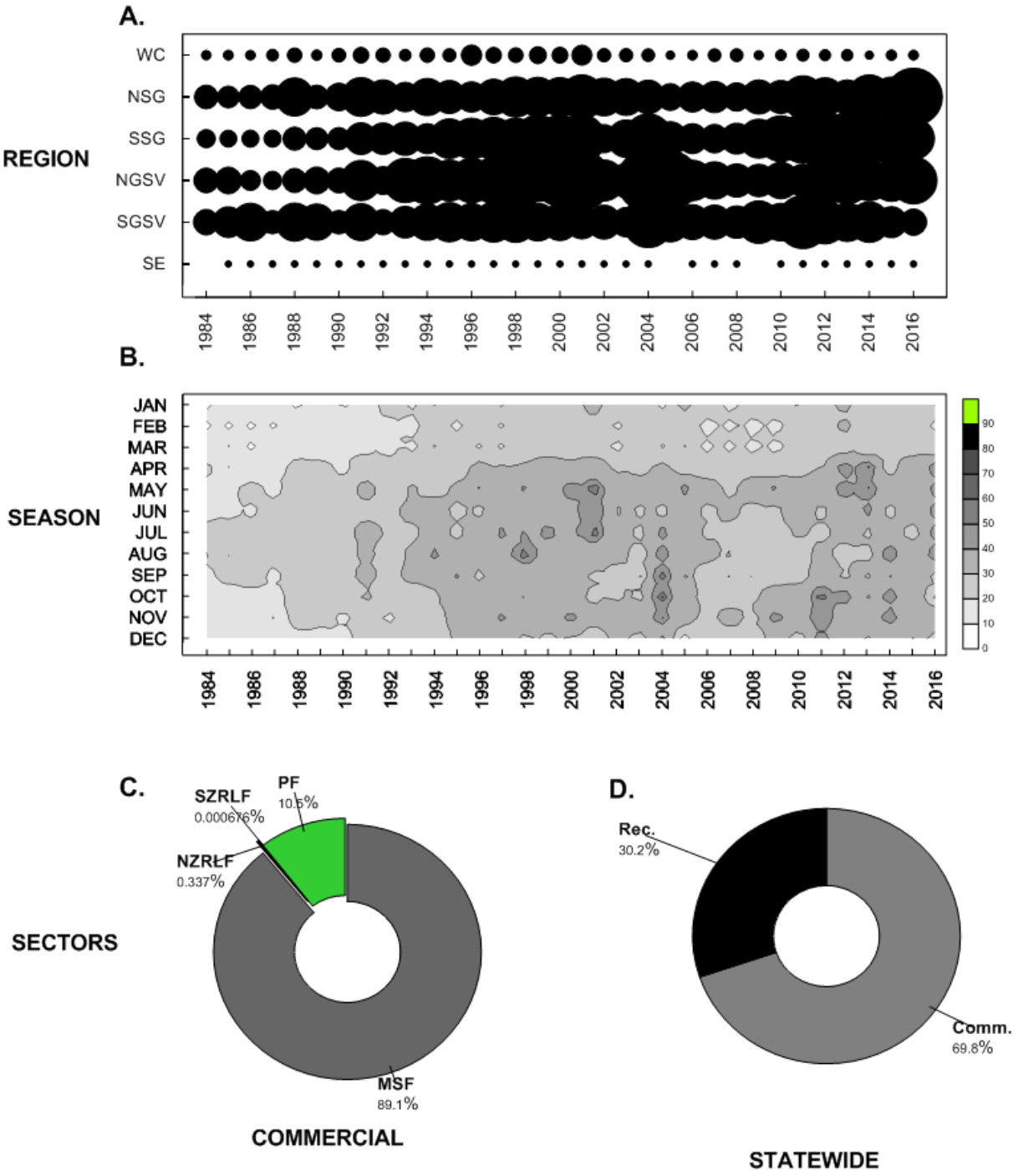

Figure 4-15. Southern Calamari. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

West Coast

The annual commercial catch of Southern Calamari from the West Coast has rarely exceeded 10% of the State's catch (Figure 4-16). Total catches have declined from a peak of 36.2 t in 2001 to 5.2 t in 2014. Annual catch has remained around 10 t over the past two years. Total effort in this region has also declined from a historic peak of 1,872 fisher-days in 1988 to 283 fisher-days in 2009, decreasing at rate of 60.7 fisher-days.year^{-1} over 22 years. Effort levels have remained below 450 fisher-days.year^{-1} since 2014. Almost all (>98%) of the fishing for Southern Calamari in this region has been targeted by the jig sector as there are negligible areas that are available for hauling net fishers. With the exception of a steep decline in 2014, targeted catch rates have remained >20 kg.fisherday^{-1} since 2006. The number of fishers targeting Southern Calamari has ranged from 33 to 55 over the past decade (Figure 4-16).

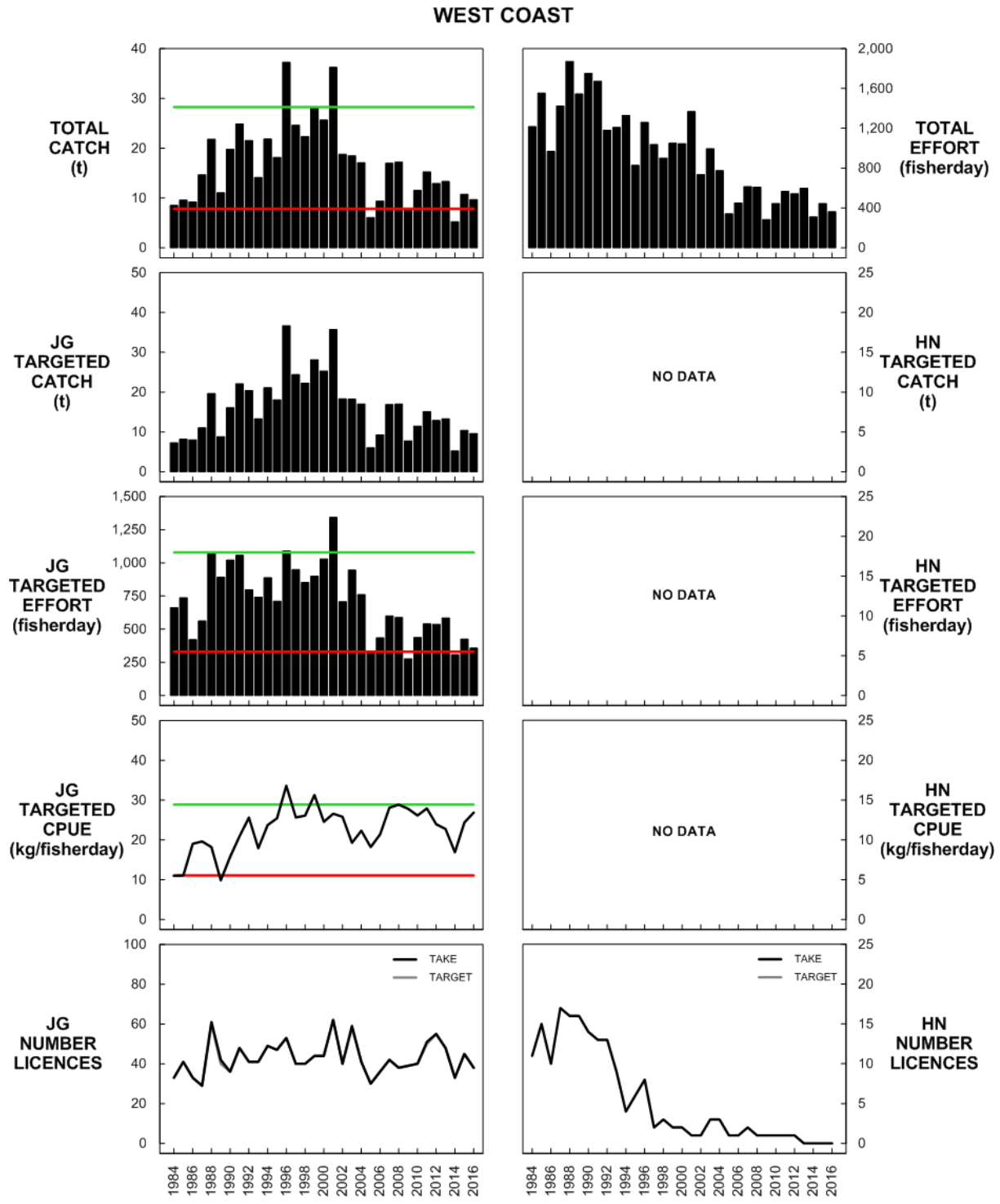

Figure 4-16. Key fishery statistics used to inform the status of Southern Calamari in the West Coast. (Left) Trends in total catch, squid jig targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with jigs. (Right) Trends in total effort; hauling net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with hauling nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Northern Spencer Gulf

Total catch of Southern Calamari in Northern Spencer Gulf has typically accounted for approximately 25% of the State's catch. The 2016 annual catch of 135 t was the highest on record, increasing from the previous year by 52.9% (Figure 4-17). Of this, targeted jig catch accounted for 40.5% and targeted hauling net catch 7.5%. The targeted hauling net catch for this year was uncharacteristically high, exceeding 10 t for the first time, where historically catches in this sector have rarely exceeded 3 t per year. Targeted jig and hauling net effort were relatively high in 2016, registering 1,665 and 134 fisher-days, respectively. Targeted jig catch rates have peaked above 37 kg.fisherday^{-1} twice over the last six years, with 2016 yielding a slightly lower catch rate of 32.8 kg.fisherday^{-1}. Targeted catch rates in the hauling net sector peaked at 75 kg.fisherday^{-1} in 2016, more than double the annual catch rate of previous years. The number of licence holders targeting Southern Calamari using jigs has declined from a recent peak of 45 fishers in 2011 to 34 in 2016, whereas the numbers of hauling net fishers targeting Calamari has remained relatively stable over the past decade, ranging from 20 to 24 fishers per year.

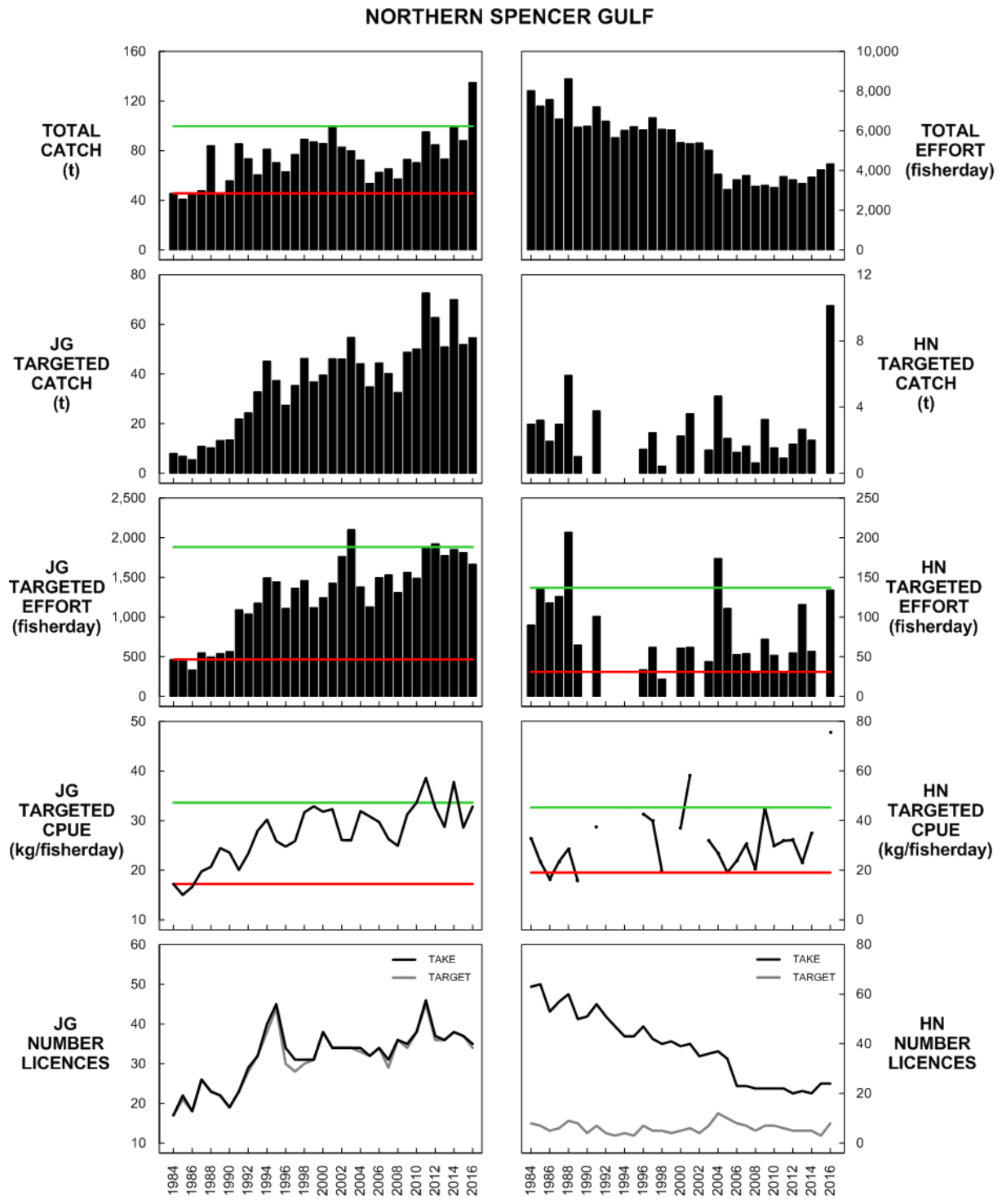

Figure 4-17. Key fishery statistics used to inform the status of Southern Calamari in the Northern spencer Gulf. (Left) Trends in total catch, squid jig targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with jigs. (Right) Trends in total effort; hauling net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with hauling nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Southern Spencer Gulf

Total catch of Southern Calamari in Southern Spencer Gulf has accounted for approximately 30% of the State's catch. It peaked at 122 t in 2012 and declined to 93 t in 2016, dropping below 100 t for the first time in eight years (Figure 4-18). Total effort levels followed a similar trend, rising to the most recent peak of 3,749 fisher-days in 2012 before subsiding to 2,917 fisher-days in 2016. Like the WC, almost all (>98%) of the fishing for Southern Calamari in this region has been targeted by the jig sector as there are negligible areas that are available for hauling net fishers. Catch rates in this sector peaked at 36.3 kg.fisherday^{-1} in 2013 and has since remained above 28 kg.fisherday^{-1}. The number of licence holders using jigs to target Southern Calamari in this region has remained relatively stable since 1992, averaging approximately 87 licences per year (Figure 4-18).

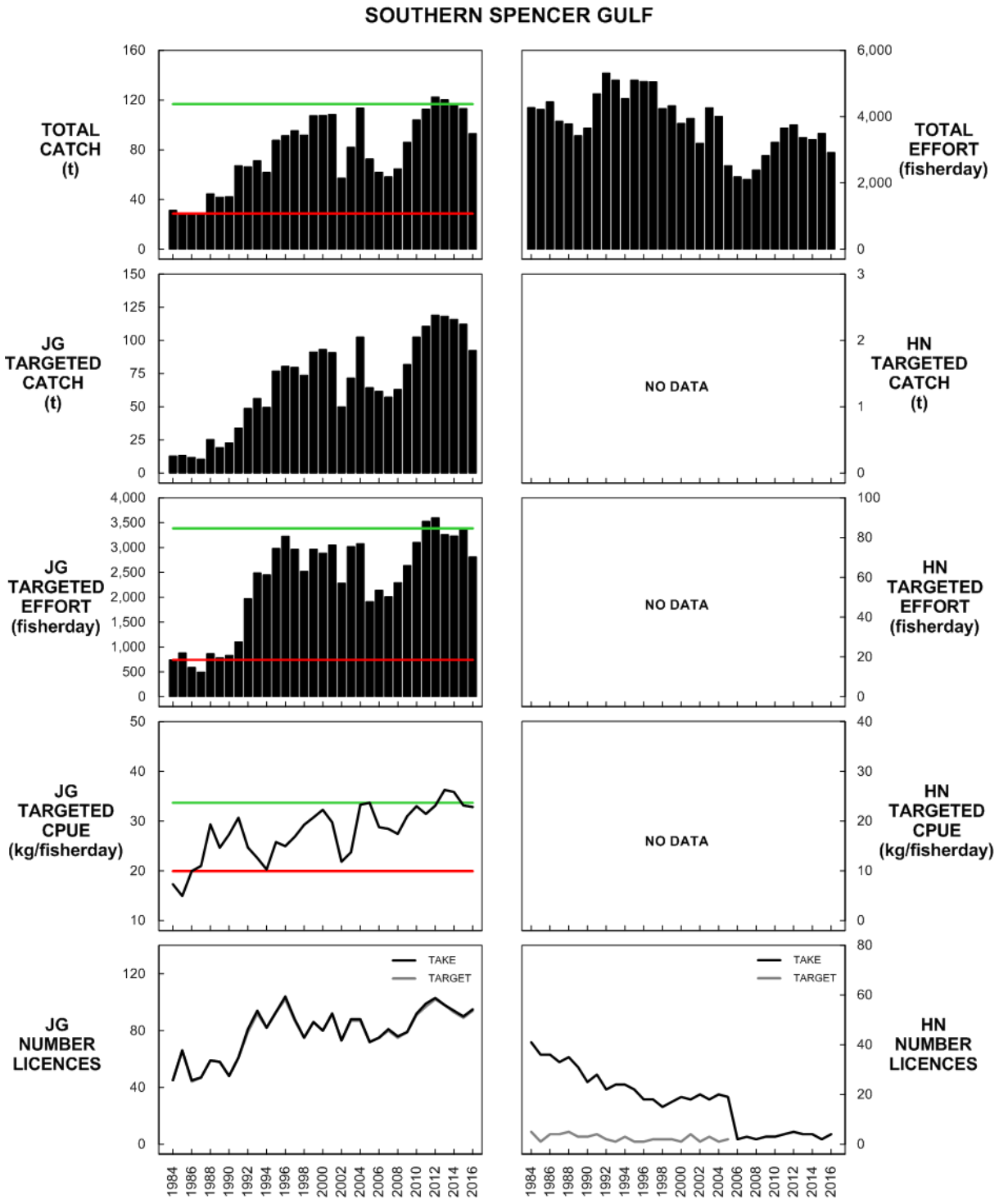

Figure 4-18. Key fishery statistics used to inform the status of Southern Calamari in the Southern Spencer Gulf. (Left) Trends in total catch, squid jig targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with jigs. (Right) Trends in total effort; hauling net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with hauling nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Northern Gulf St. Vincent

The relative contribution of the commercial Southern Calamari catch from this region to the annual State-wide total is approximately 25%. Annual catches have decreased from a peak of 148 t in 2004 to the most recent low of 68 t in 2009 (Figure 4-19). Since then, annual total catch has remained relatively stable at approximately 100 t per year. Total effort has declined from a peak of 5,907 fisher-days in 1996 to 4,050 fisher-days in 2016. Approximately 85% of the catch is targeted, of which 25% is by the hauling net sector and 60% by the jig sector. Targeted jig catches have steadily increased over the past six years from 24.6 t in 2010 t to 65.2 t in 2016. This increase coincided with record high levels of targeted effort, peaking at 1,989 fisher-days in 2016. The associated catch rates during this period, have ranged from 28.5 to 33.5 kg.fisherday.year^{-1}. Estimates of targeted catch, effort and catch rates in the hauling net sector have declined over the past five years, but remain relatively high in comparison to previous years.

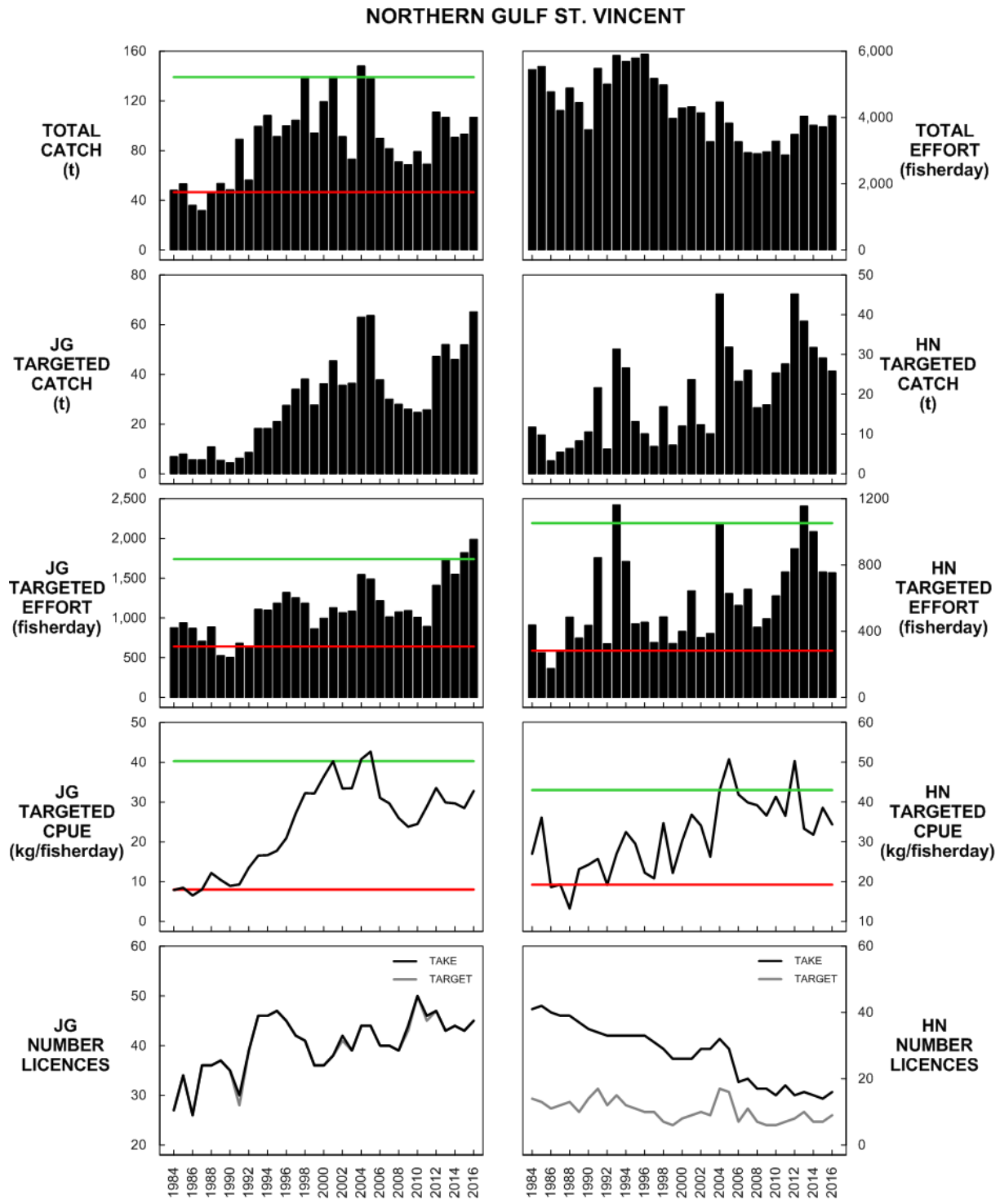

Figure 4-19. Key fishery statistics used to inform the status of Southern Calamari in Northern Gulf St. Vincent. (Left) Trends in total catch, squid jig targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with jigs. (Right) Trends in total effort; hauling net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with hauling nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Southern Gulf St. Vincent

Southern Gulf St. Vincent accounts for approximately 20% of the State-wide catch of Southern Calamari, with almost all (>98%) of it targeted by jig fishers. Total catch has declined from a peak of 122.7 t in 2011 to 52.4 t in 2016, representing a 57.3% decrease (Figure 4-20). This has been largely driven by a concomitant decrease in effort, declining from 3,870 fisher-days in 2011 to a record low of 1,935 fisher-days in 2016. Targeted jig CPUE has declined approximately 8 kg.fisherday.year^{-1} over the past three years, but remains relatively high in comparison to the long-term trend.

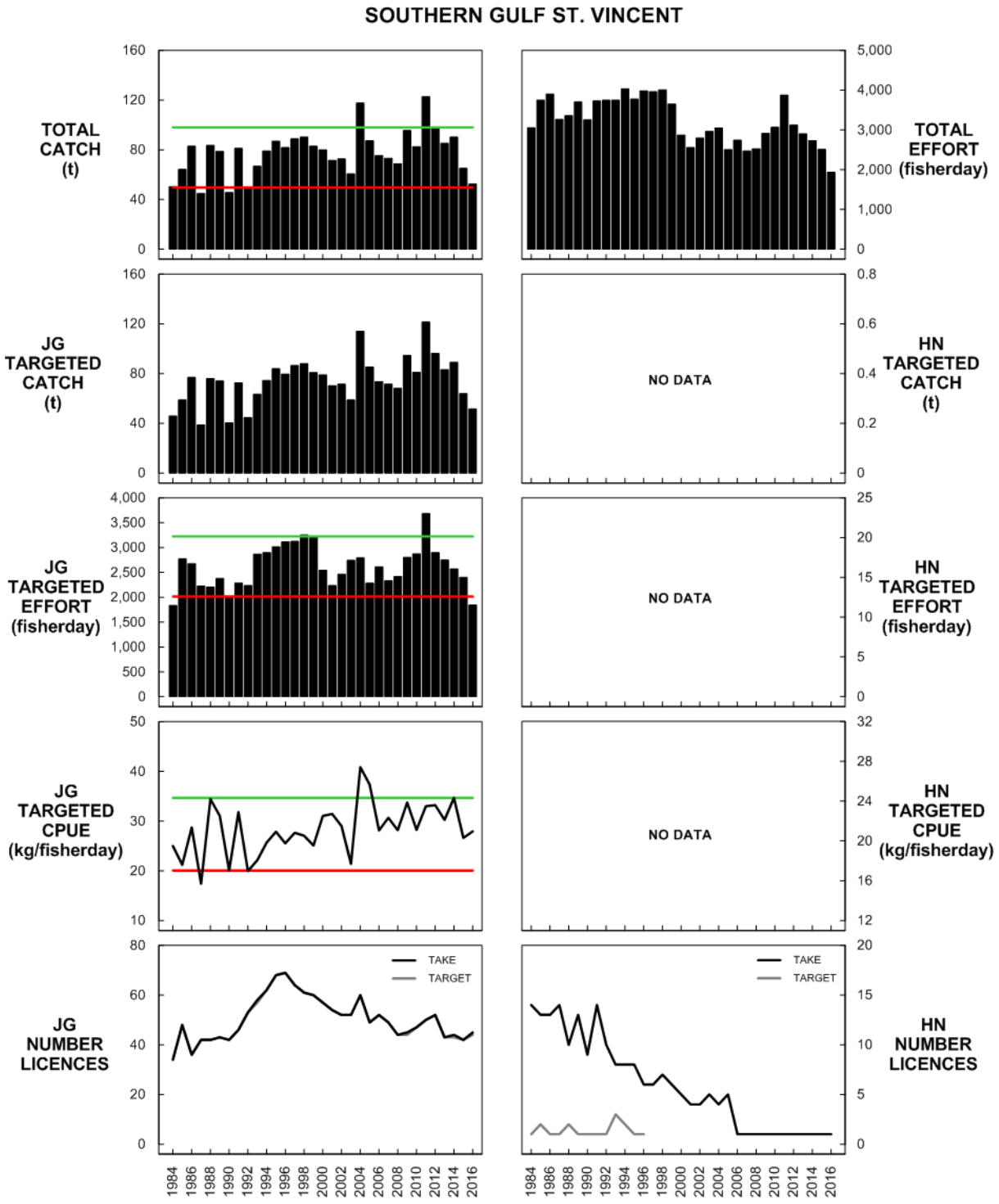

Figure 4-20. Key fishery statistics used to inform the status of Southern Calamari in Southern Gulf St. Vincent. (Left) Trends in total catch, squid jig targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with jigs. (Right) Trends in total effort; hauling net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting Calamari with hauling nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

South East

A negligible proportion of the State wide catch of Southern Calamari is landed in the South East (Figure 4-21).

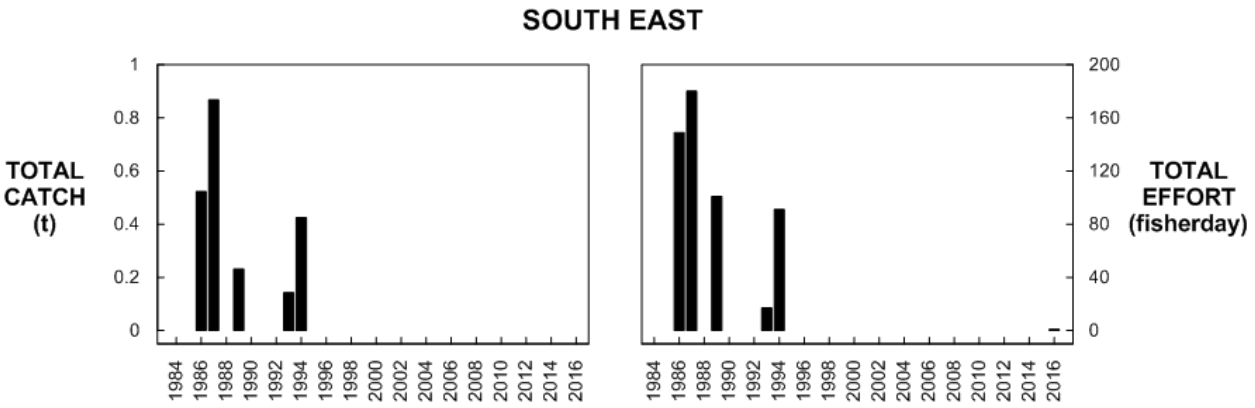

Figure 4-21. Key fishery statistics used to inform the status of Southern Calamari in the South East. (Left) Trends in total catch; (Right) Trends in total effort. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Fishery Performance

No trigger limits associated with the relative proportion of commercial catch shares were breached (Table 4-6). The general performance indicators were assessed at the regional scale. There were six breaches of trigger reference points across the six regions (Table 4-7). Four of these related to NSG, which yielded record catches in 2016, as well as the highest recorded catch rates within the targeted hauling net sector. Targeted jig effort for Southern Calamari was the highest in NGSV. Conversely, it was the second lowest on record in SGSV.

Table 4-6. Results from consideration of commercial catches of Southern Calamari by fishery against their allocation percentages and trigger reference points. MSF = Marine Scalefish, NZRL = Northern Zone Rock Lobster, GSVP = Gulf St. Vincent Prawn Fishery; SGP = Spencer Gulf Prawn Fishery; WCP = West Coast Prawn Fishery. Green colour – allocation not exceeded, red colour – allocation trigger activated.

COMMERCIAL ALLOCATION	MSF 90.91%	SZRL n/a	NZRLF 0.73%	GSVP 0.73%	SGP 7.47%	WCP 0.16%
TRIGGER 2	92.70%	-	1.46%	1.46%	8.20%	0.75%
TRIGGER 3	95.40%	-	2.19%	2.19%	11.20%	1.00%
2012	92.87%	-	0.36%	0.63%	6.04%	0.10%
2013	91.98%	-	0.66%	0.00%	7.23%	0.13%
2014	91.89%	-	0.34%	0.04%	7.60%	0.12%
2015	93.98%	-	0.21%	0.51%	5.22%	0.07%
2016	89.14%	-	0.34%	0.77%	9.69%	0.06%

Table 4-7. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the regional spatial scales for Southern Calamari.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	WC	NSG	SSG	NGSV	SGSV	SE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×	HIGHEST	×	×	×	conf.
	G	Greatest % interannual change (+/-)	×	HIGHEST	×	×	×	conf.
	G	Greatest 5 year trend	×	HIGHEST	×	×	×	conf.
	G	Decrease over 5 consecutive years	×	×	×	×	×	conf.
TARGET JIG EFFORT	G	3rd Lowest / 3rd Highest	×	×	×	HIGHEST	2nd LOWEST	conf.
	G	Greatest % interannual change (+/-)	×	×	×	×	×	conf.
	G	Greatest 5 year trend	×	×	×	×	×	conf.
	G	Decrease over 5 consecutive years	×	×	×	×	×	conf.
TARGET JIG CPUE	G	3rd Lowest / 3rd Highest	×	×	×	×	×	conf.
	G	Greatest % interannual change (+/-)	×	×	×	×	×	conf.
	G	Greatest 5 year trend	×	×	×	×	×	conf.
	G	Decrease over 5 consecutive years	×	×	×	×	×	conf.
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest		×		×		conf.
	G	Greatest % interannual change (+/-)		×		×		conf.
	G	Greatest 5 year trend		×		×		conf.
	G	Decrease over 5 consecutive years		×		×		conf.
TARGET HAULING NET CPUE	G	3rd Lowest / 3rd Highest		HIGHEST		×		conf.
	G	Greatest % interannual change (+/-)		conf.		×		conf.
	G	Greatest 5 year trend		conf.		×		conf.
	G	Decrease over 5 consecutive years		×		×		conf.

Stock Status

In the absence of conclusive evidence on the biological stock boundaries of Southern Calamari throughout its geographical range the assessment of its stock status is ascertained at the State-wide level. Trends in targeted catch and catch rates in northern and southern Spencer Gulf and northern GSV have remained relatively high over the past six years. Despite notable declines in targeted jig catch in SGSV and the WC, their respective catch rates have also remained relatively high. Although it is clear that many MSF licence holders have shifted their effort away from other primary species to target Southern Calamari, there appears to be little impact on the sustainability of the resource. This is most likely buffered by the high-paced life history of the species, which is capable of supplying a continual supply of recruits into the population. On this basis, South Australia's Southern Calamari Fishery is classified as **sustainable**.

4.3.4. YELLOWFIN WHITING (*Sillago schomburgkii*)

Biology

Yellowfin Whiting (*Sillago schomburgkii*) is the second valuable finfish species of the family Sillaginidae that occurs in South Australian waters (Kailola et al. 1993). It is a bottom-dwelling, elongate fish species with a long snout that facilitates feeding on demersal invertebrates (Gomon et al. 2009). The species is endemic to Australia, being found in the coastal waters from Dampier to Albany in Western Australia and in and near the gulf waters of South Australia (Kailola et al. 1993). There is some uncertainty about the continuity of distribution through the remote coastal waters of Western Australia and South Australia (Kailola et al. 1993).

Fishery catches indicate that in South Australia, Yellowfin Whiting occur in highest abundances in the two northern gulfs, with lower abundances in the southern gulfs and the west coast of Eyre Peninsula. Its life history appears particularly adapted to habitation of relatively protected, shallow, near-shore waters. Adults are generally associated with shallow, tidal creeks and coastal sand flats, and so are commonly found in waters of 1 – 10 m depth (Jones 1981). Spawning occurs during the summer months, and then between February and April, post-larvae are found along the shallow, protected, sandy beaches of the northern gulfs. Subsequently, juvenile fish occupy similar habitats as well as tidal creeks (Kailola et al. 1993, Ferguson 1999). Yellowfin Whiting demonstrate different growth patterns between the sexes that culminates in females reaching larger sizes-at-age than males (Ferguson 1999). Furthermore, market sampling of commercial catches has demonstrated considerable bias in sex ratios towards females. Ageing of fish from otoliths has indicated a longevity of approximately 12 years, although most fish taken in the commercial fishery were in the 2 to 4 year age classes (Ferguson 1999).

Based on the possible discontinuous distribution between South Australian and Western Australian populations, there is the possibility of separate stocks as well as genetic differentiation. However, even within South Australia, the oceanographic separation of the two gulfs during the spawning season in summer must considerably reduce the opportunity for mixing by egg and larval advection. As such, the populations in the two gulfs may constitute separate stocks. This remains to be resolved.

Fishery

Yellowfin Whiting is one of the more valuable ‘secondary’ species of South Australia’s Marine Scalefish Fishery (MSF) (PIRSA 2013). The ‘secondary’ classification might reflect that its catches have been variable, reflecting that in the past it was targeted when demand for, or

availability of, primary species was low (Jones 1981, Ferguson 1999). Because Yellowfin Whiting is a schooling species that occupies sandy, shallow habitats predominantly in the northern gulfs, it is particularly vulnerable to net fishers of the MSF. As such, historically the commercial catches have been dominated by the net sector, with hauling nets the predominant gear followed by bottom-set gillnets. Over many years, the Northern and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) have reported only incidental catches. Yellowfin Whiting is a popular target species of boat and shore-based recreational fishers who target them using hook and line. In 2013/14, this sector took an estimated 174,264 Yellowfin Whiting, equating to an estimated catch of 45.3 t (Giri and Hall 2015).

Management Regulations

For Yellowfin Whiting, there is a minimum size limit of 240 mm TL that applies to both sectors. Furthermore, for the commercial sector, the many regulations that are input controls for the different netting gears contribute to minimising the fishing effort directed at Yellowfin Whiting. These include restrictions to net lengths and mesh sizes as well as the extensive spatial closures and temporal restrictions that limit where and when net fishing can be legitimately undertaken. For the recreational sector, a bag limit of 20 fish and boat limit of 60 fish is well established for the species.

Commercial Fishery Statistics

State-wide

Estimates of annual, State-wide commercial catches of Yellowfin Whiting show considerable variation, ranging from 14.5 t in 1988 to 179 t in 2001 (Figure 4-22). The 114.6 t reported in 2016 was an intermediate level of catch. Hauling nets have always accounted for considerably higher proportions of annual catches than gillnets. The hauling net and gillnet effort that accounted for the annual total catches have declined considerably since 2002. State-wide estimates of CPUE for hauling nets and gillnets have been variable over the years, but nevertheless both show long-term increasing trends. From 1984 to 2016, the numbers of fishers who reported taking Yellowfin Whiting showed a long-term decreasing trend falling from the maximum of 129 to 49. The number who targeted Yellowfin Whiting has been variable but not shown a long-term trend.

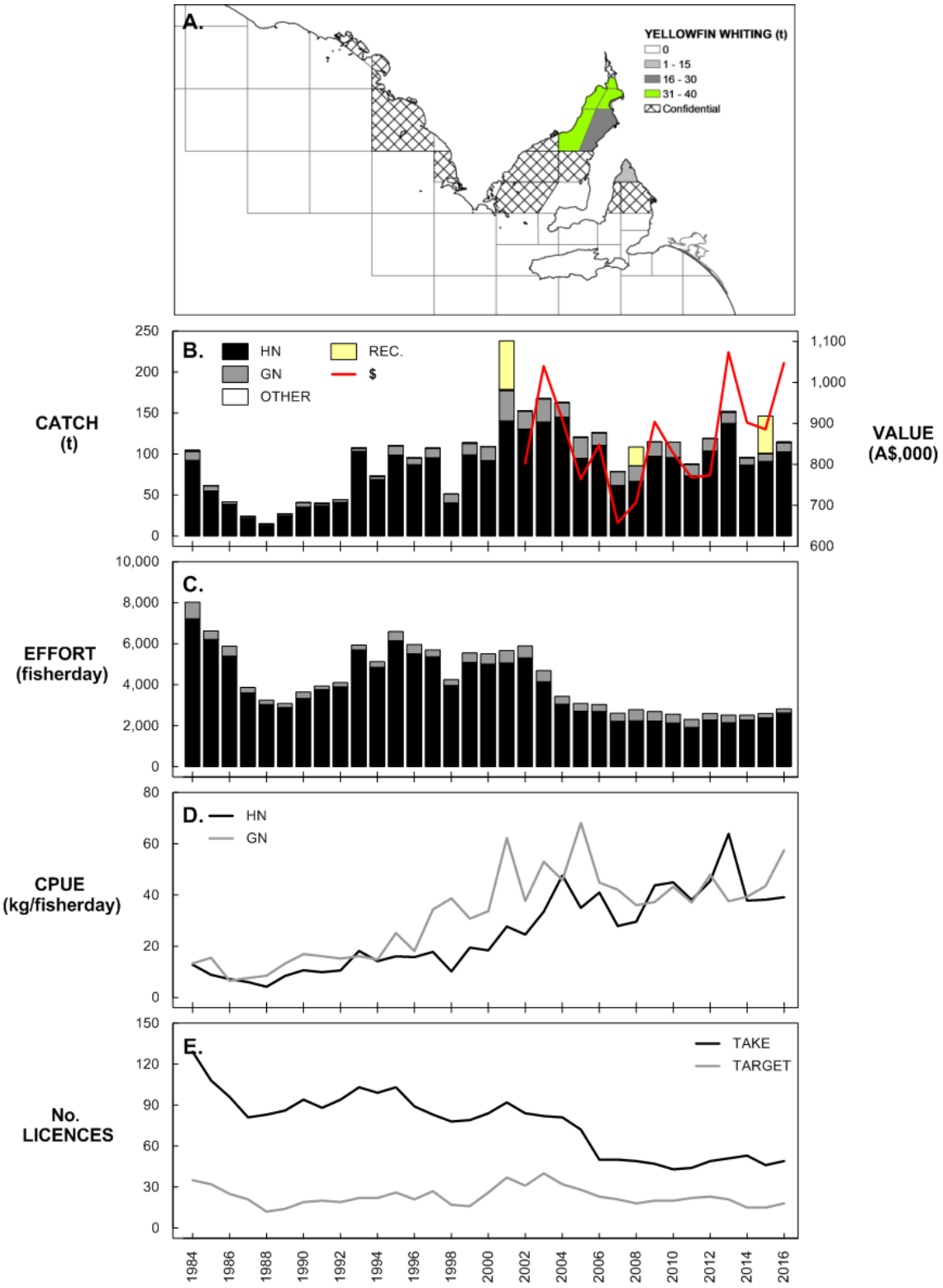

Figure 4-22. Yellowfin Whiting. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for the main gear types (hauling and gill nets) and gross production value; (C) Long-term total effort for hauling and gill nets; (D) total catch per unit effort for hauling and gill nets; and (E) the number of active licence holders taking or targeting the species.

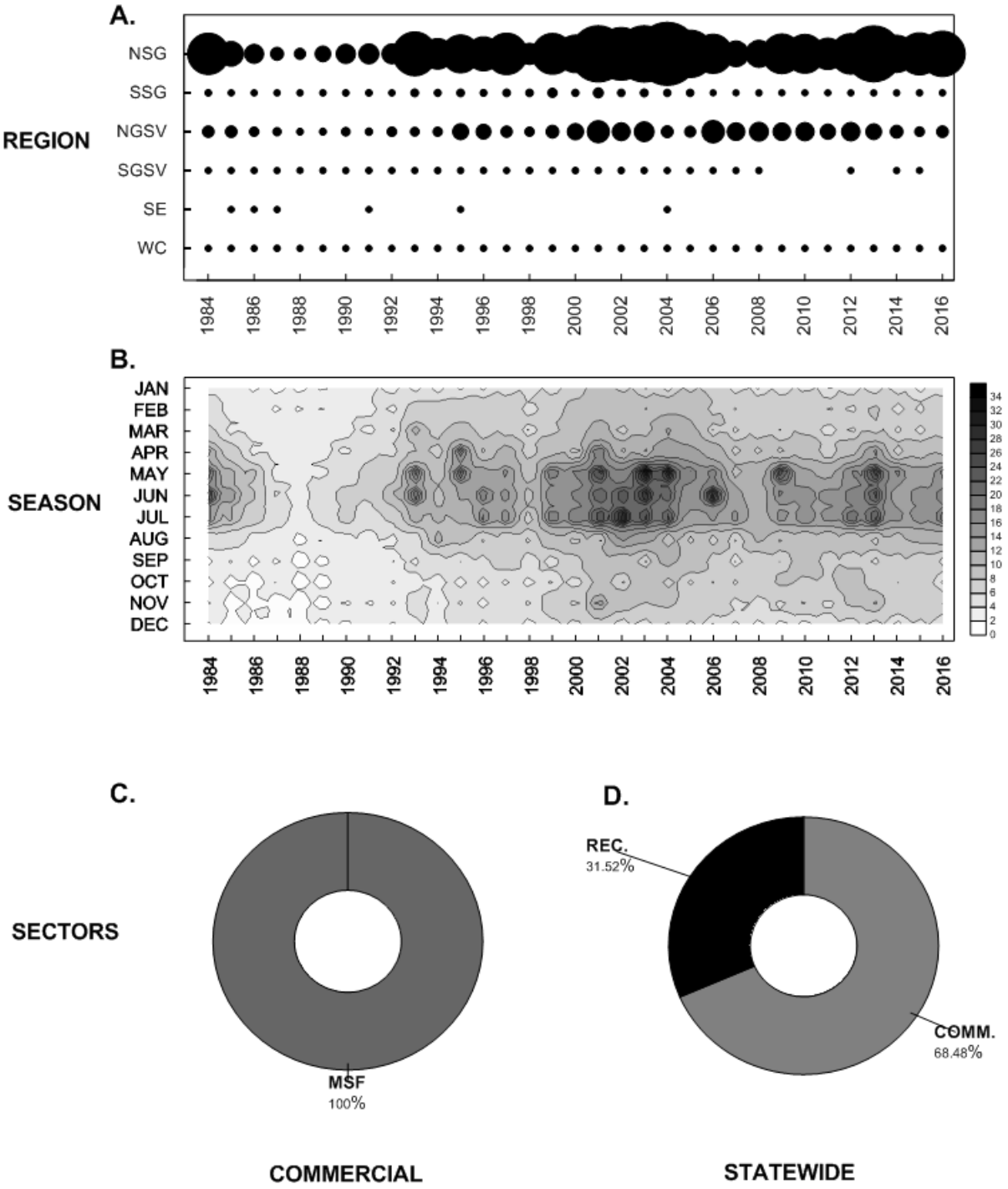

Figure 4-23. Yellowfin Whiting. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Regional

Although the annual catches of Yellowfin Whiting in NSG have been variable since 1984, they have always been higher than those from the other SA regions (Figure 4-23). Since the early 1990s, NGSV has been the second most productive region, whilst lower catches have come from the southern gulfs, and only incidental catches from the SE and WC.

Northern Spencer Gulf

Total catch of Yellowfin Whiting from NSG has varied considerably over the years. The lowest catch of 12.7 t was taken in 1988 and the highest of 145 t was taken in 2004. The total catch of 100 t in 2016 was moderate. Total effort used to take these annual catches has declined considerably since 2002, although there was some increase in 2015 and 2016.

Targeted hauling net (HN) catches have been highly variable, with the highest catches taken between 2001 and 2004 (Figure 4-24). Targeted HN effort also peaked through this period, but has subsequently dropped to a much lower level. Targeted HN CPUE has varied considerably, with no obvious long-term trend, peaking in 2013 and 2014, before subsequently dropping to intermediate levels in 2015 and 2016. The number of license holders who took Yellowfin Whiting with HN was highest at 59 in 1984, and has subsequently fallen to 24 in 2016. The number of fishers who targeted this species with HN has also declined, particularly since 2001, falling to only eight fishers in 2016.

Targeted gillnet (GN) catches and effort were much lower than those taken using HN (Figure 4-24). This reflects the low numbers of fishers who reported catches of this species with gillnets in NSG. As such, the catch and effort statistics for this gear type in this region were confidential.

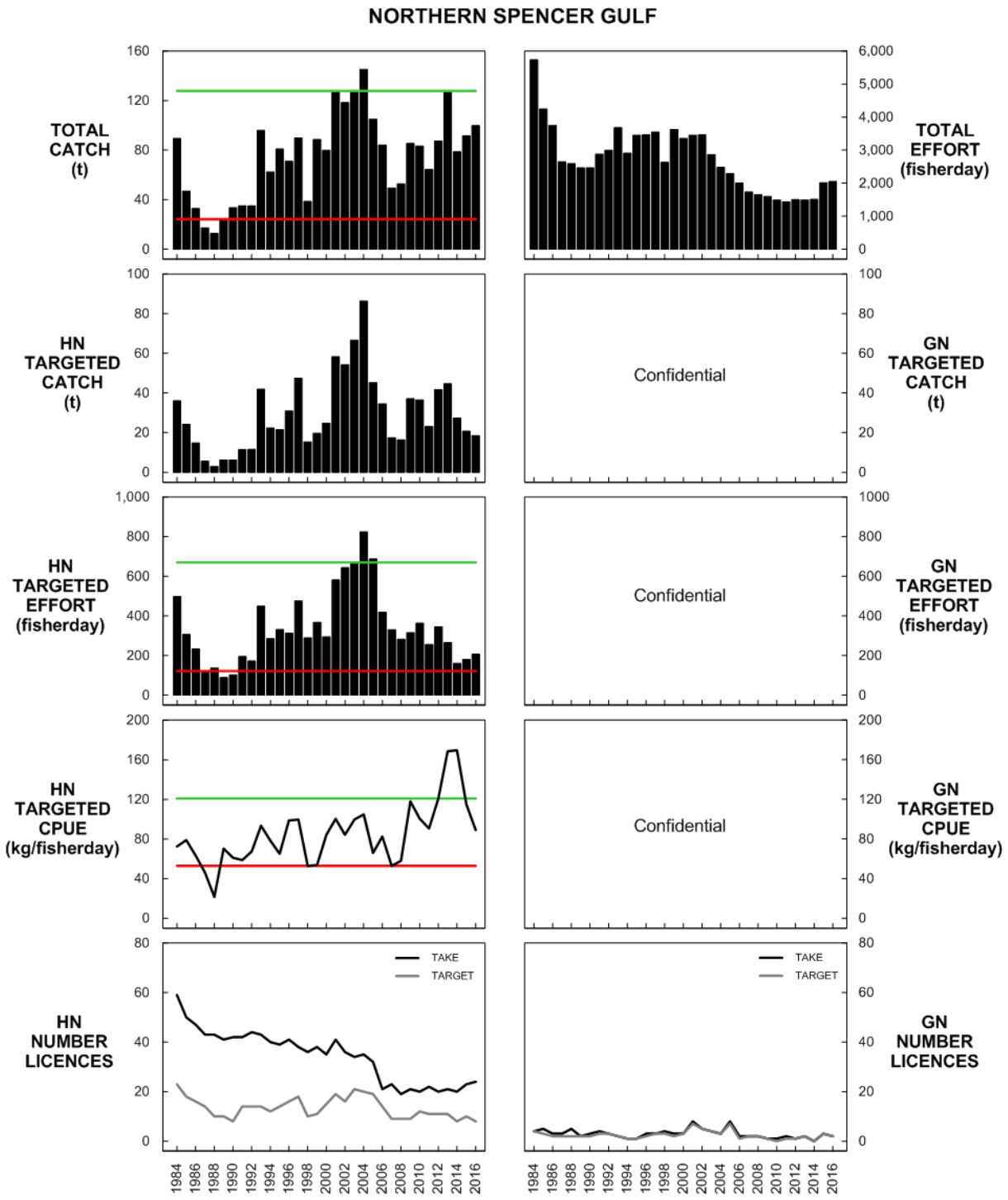

Figure 4-24. Key fishery statistics used to inform the status of Yellowfin Whiting in Northern Spencer Gulf. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting YFW with hauling nets. (Right) Trends in total effort; gill net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting YFW with gill nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Northern Gulf St Vincent

In NGSV, total annual catches of Yellowfin Whiting were highest between 2002 and 2012, ranging between 20 and 40 $t.yr^{-1}$ (Figure 4-25). They have subsequently declined to 14 t in 2016. The effort levels associated with these catches were higher during the 1980s and 1990s, and have declined considerably through the 2000s.

Targeted hauling net catches have generally been <5 $t.yr^{-1}$, associated with low levels of targeted effort (Figure 4-25). Such low levels of targeted catch and effort led to variable estimates of targeted CPUE for which there was no long-term trend. Relatively few fishers that took Yellowfin Whiting with HN in NGSV targeted this species, suggesting that it is largely a by-product species for hauling net fishers. The targeted gillnet catches were highest through the 2000s, reflecting relatively high levels of targeted effort. Nevertheless, targeted GN CPUE was relatively consistent through this period, as were the numbers of fishers who took and targeted Yellowfin Whiting.

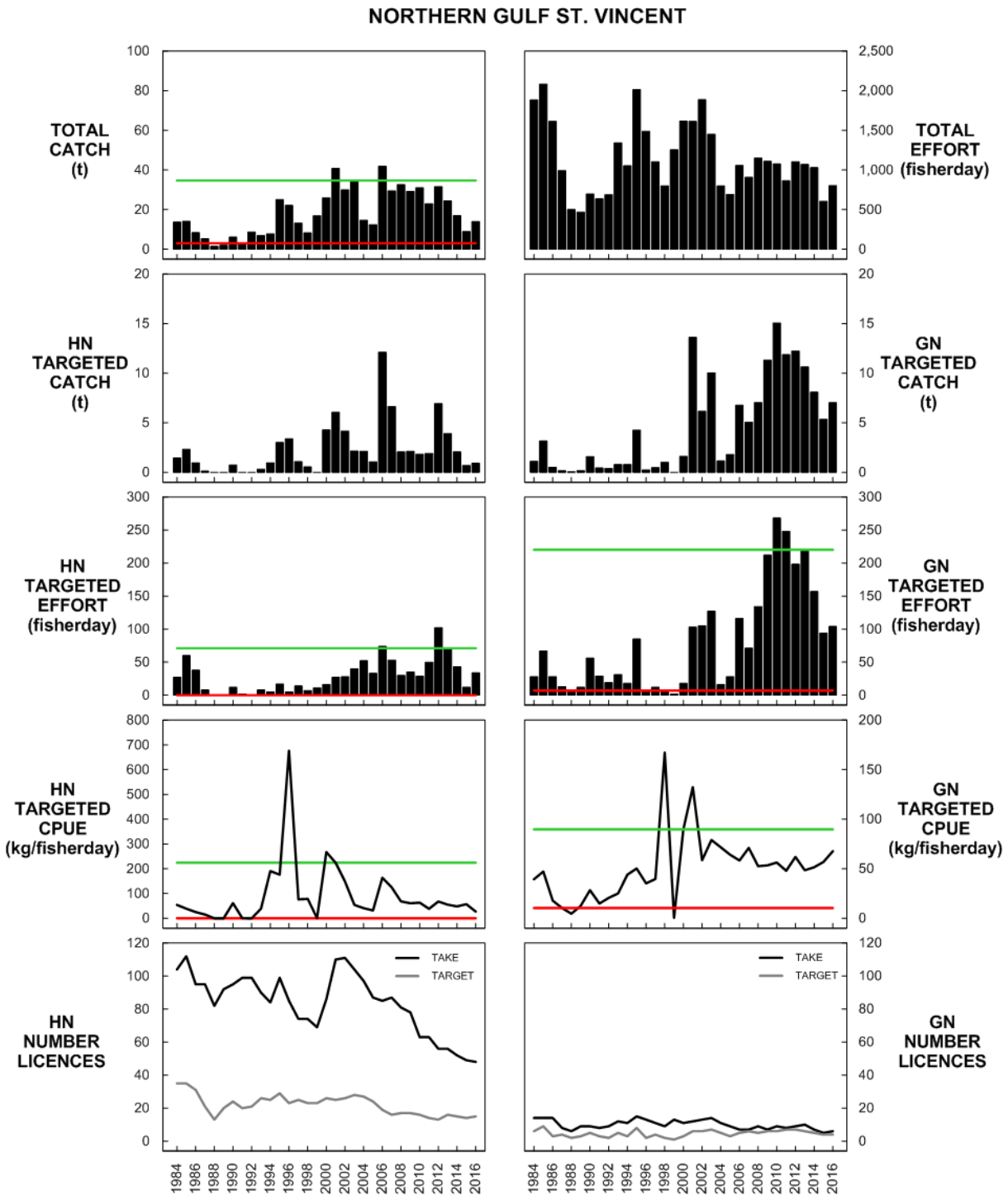

Figure 4-25. Key fishery statistics used to inform the status of Yellowfin Whiting in Northern Gulf St. Vincent. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licences holdes taking or targeting YFW with hauling nets. (Right) Trends in total effort; gill net targeted catch, effort and and catch rates (CPUE); The number of active licences holdes taking or targeting YFW with gill nets. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Fishery Performance

The general fishery performance indicators for Yellowfin Whiting were assessed for 2016 for both NSG and NGSV. Only a single breach of a trigger reference point was identified (Table 4-8). The declining trend in HN CPUE between 2014 and 2016 was the steepest recorded. However, this record decline was from exceptionally high levels in 2013 and 2014.

Table 4-8. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the regional spatial scales for Yellowfin Whiting.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	NSG	NGSV
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	×	×
	G	Decrease over 5 consecutive years	×	×
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	×	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	×	×
	G	Decrease over 5 consecutive years	×	×
TARGET HAULING NET CPUE	G	3rd Lowest / 3rd Highest	×	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	GREATEST DECREASE	×
	G	Decrease over 5 consecutive years	×	×
TARGET GILLNET EFFORT	G	3rd Lowest / 3rd Highest	×	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	×	×
	G	Decrease over 5 consecutive years	×	×
TARGET GILLNET CPUE	G	3rd Lowest / 3rd Highest	×	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	×	×
	G	Decrease over 5 consecutive years	×	×

Stock Status

Yellowfin Whiting is a secondary species for the commercial sector of the MSF (PIRSA 2013). This may reflect its history of variable catches that is thought to relate, at least partly, to the transient nature of it being targeted, as determined by the availability of the primary species (Ferguson 1999). The considerable discrepancy between the relatively large numbers of fishers that take this species compared to those who target it suggests that this species is retained as a by-product when other species are targeted.

The South Australian catches of Yellowfin Whiting were dominated by those from Northern Spencer Gulf, although the fishery performance indicators for this region are characterised by high levels of variability. This may reflect the transient nature of the targeted effort. The most obvious long-term trend in the fishery statistics is the decline in fishing effort used to take the

catches. Alternatively, time-series of total catch, targeted catch and targeted CPUE do not show long-term declines. Of the various performance indicators considered, the single breach of a trigger reference point was associated with declining HN CPUE. Nevertheless, in 2016, this only fell to a moderate level from high levels attained in 2013 and 2014. Overall, there is no indication in the time-series of fishery statistics that the biomass of Yellowfin Whiting in NSG is declining towards being recruitment overfished. On this basis, the NSG population is classified as a **sustainable** stock.

The Northern Gulf St. Vincent population has produced considerably lower annual catches than those from NSG. The targeted catches from both gear types in this region have declined in recent years, but these reflect lower effort levels rather than declining estimates of CPUE. No trigger reference points were breached in 2016. As such, there is no indication that the recent level of fishing effort is moving the stock towards being recruitment overfished. Consequently, the NGSV population is also classified as a **sustainable** stock.

4.3.5. WESTERN AUSTRALIAN SALMON (*Arripis truttaceus*)

Biology

The Western Australian Salmon (hereafter referred to as Salmon) biological stock extends from southern Western Australia to the east coast of Tasmania, with each State jurisdiction harvesting different life-history stages. The species intermixes with Eastern Australian Salmon (*Arripis trutta*) in eastern Victorian waters and around Tasmania. The Western Australian fishery typically targets mature spawning fish that aggregate around the south-western tip of the State, whereas the South Australian, Victorian and Tasmanian fisheries predominantly harvest juveniles and sub-adults in coastal waters as they migrate along the southern coast of Australia (Cappo, 1987; Jones and Westlake, 2003).

Spawning typically occurs in large schools in the offshore waters between Cape Leeuwin and Busselton, Western Australia, in late autumn and early winter when the eastward flow of the Leeuwin current is strongest. The developing larvae settle along the entire southern coastline of Australia, with the main nursery grounds located along the south-eastern coast. Juvenile fish remain in coastal nursery areas for approximately three years where they feed on epibenthic crustaceans and small fish associated with seagrass beds (Hoedt and Dimmlich 1995). As they mature and begin to migrate back to the spawning grounds their diet shifts to small pelagic fish, predominantly Australian Sardines. Salmon attain a maximum age of approximately 9 years and can reach a size and weight up to 800 mm (CFL) and 10.5 kg, respectively (Cappo 1987).

Fishery

The harvest of Salmon in South Australia has historically been confined to gulf and coastal waters and targeted by hauling net fishers and a few dedicated seine net fishers within the MSF. Some of the catch was sold for human consumption, but given the low value of the product much of it was used as bait in the Southern Rock Lobster Fishery. The Northern and Southern Zone Rock Lobster and Miscellaneous Fishery licence holders have reported negligible catches of Salmon over many years. The species is also a popular target of the State's recreational fishing sector. The latest estimate of catch from the recreational sector was 61 t, representing approximately 48% of the State's total catch in 2013/14 (Giri and Hall 2015).

Management Regulations

Since 1984 the commercial net harvest of Salmon in SA has been managed through the implementation of a 1,100 t catch limit with varying entitlements allocated to individual licence

holders on the basis of their net endorsements. Despite this capacity, the annual State-wide commercial catch has rarely exceeded 600 t (Fowler et al. 2016b).

There has been a minimum legal minimum length of 210 mm (TL) for both the commercial and recreational fishery for many years. In 1995, bag and boat limits were implemented for the recreational sector that were size related. For fish from 210 to 350 mm TL the bag and boat limits are 20 and 60 fish, respectively. For fish >350 mm TL, the limits are 10 and 30 fish.

Commercial Fishery Statistics

State-wide

The total State-wide commercial catch of Salmon in 2016 was 370.1 t, exceeding 350 t for the first time since 2003 (Figure 4-26). Historically annual catches fluctuated around 600 t per year and were dominated by modified purse seine (i.e. Salmon nets) fishers operating throughout the West Coast and Kangaroo Island/Investigator Strait of SGSV. Annual catches dropped to approximately 200 t in 2004 as a number of key Salmon net fishers exited the fishery. From 2007 until 2013, the hauling net fishers accounted for the bulk (up to 90%) of the annual catch, which also represented a period when the relative value of the fishery was at its lowest, averaging approximately AU$ 250,000 per annum. Since 2013, catches have increased in response to a developing market. In 2016, the overall value of this fishery was valued at AU$ 800,000, approaching the record high of AU$ 832,000 in 2003.

Targeted effort levels in the hauling net sector have remained relatively stable at approximately 55 fisher-days.year^{-1} since 2008 (Figure 4-26). This level of activity has steadily declined from a peak of 807 fisher-days in 1992. Associated catch rates peaked over 1,721 kg.fisherday.year^{-1} in 2009 (Figure 4-26). This peak was uncharacteristically high as catch rates in this sector have rarely exceeded 400 kg.fisherday.year^{-1}, and have typically ranged between 100 to 500 kg.fisherday.year^{-1}. Approximately 35% of fishers that take Salmon actively targeted the species, and this proportion has remained relatively consistent over the last 33 years.

Regional

Up to the early 2000s the highest catches were recorded from the West Coast or SGSV (Figure 4-27). Historically, SSG produced intermediate catches, but in recent years, this region has produced the largest catches. Most of this catch has been landed throughout spring and summer. In 2016, MSF fishers dominated the catches accounting for 94% of the commercial catch. The remainder was shared amongst the fishers of the NZRLF, SZRLF and MSF. In 2013/14, the recreational sector accounted for approximately 48% of the State-wide catch (Figure 4-27).

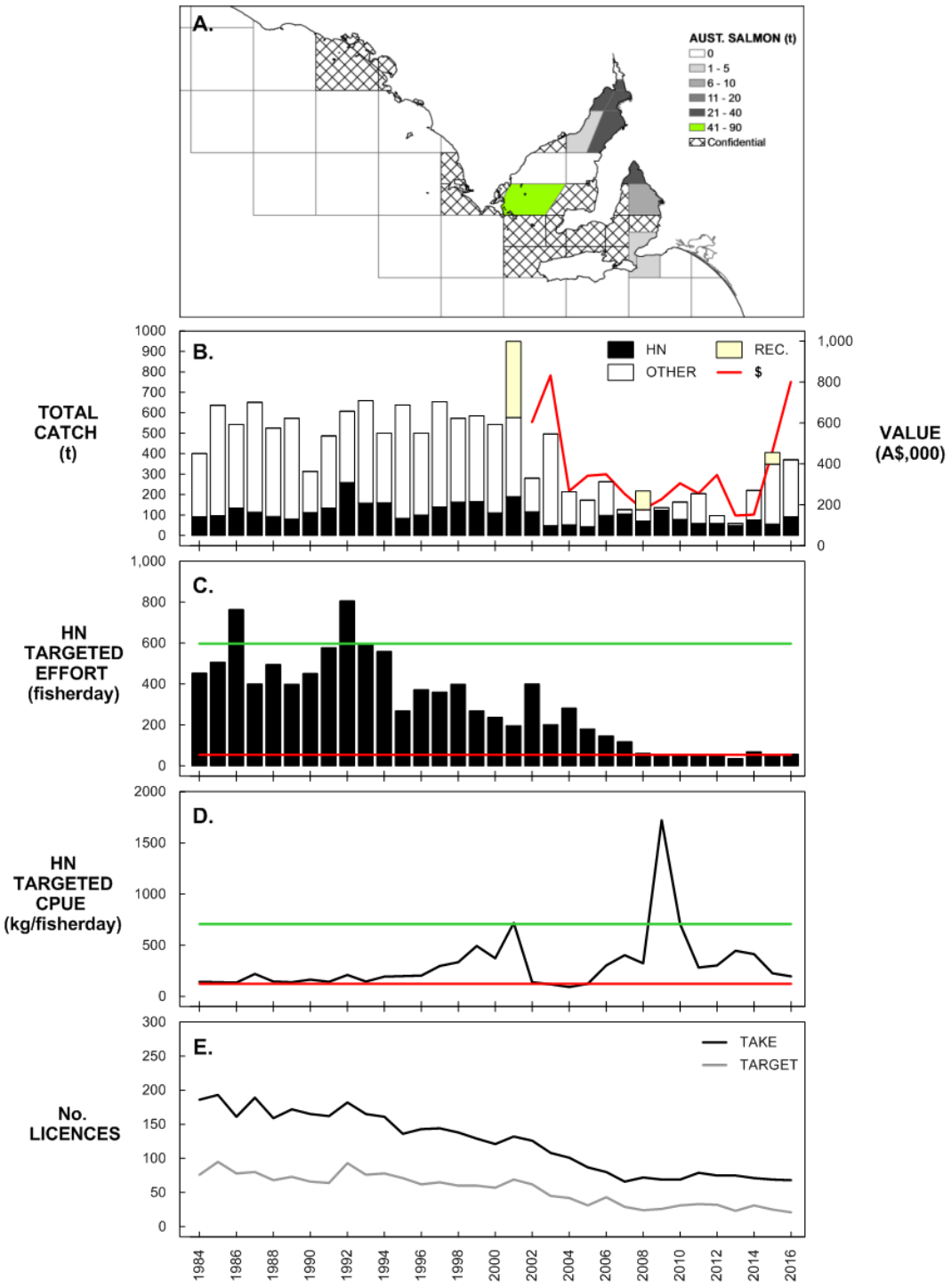

Figure 4-26. Western Australian Salmon. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for hauling nets and gross production value; (C) Long-term total effort for hauling; (D) total catch per unit effort for hauling nets; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5

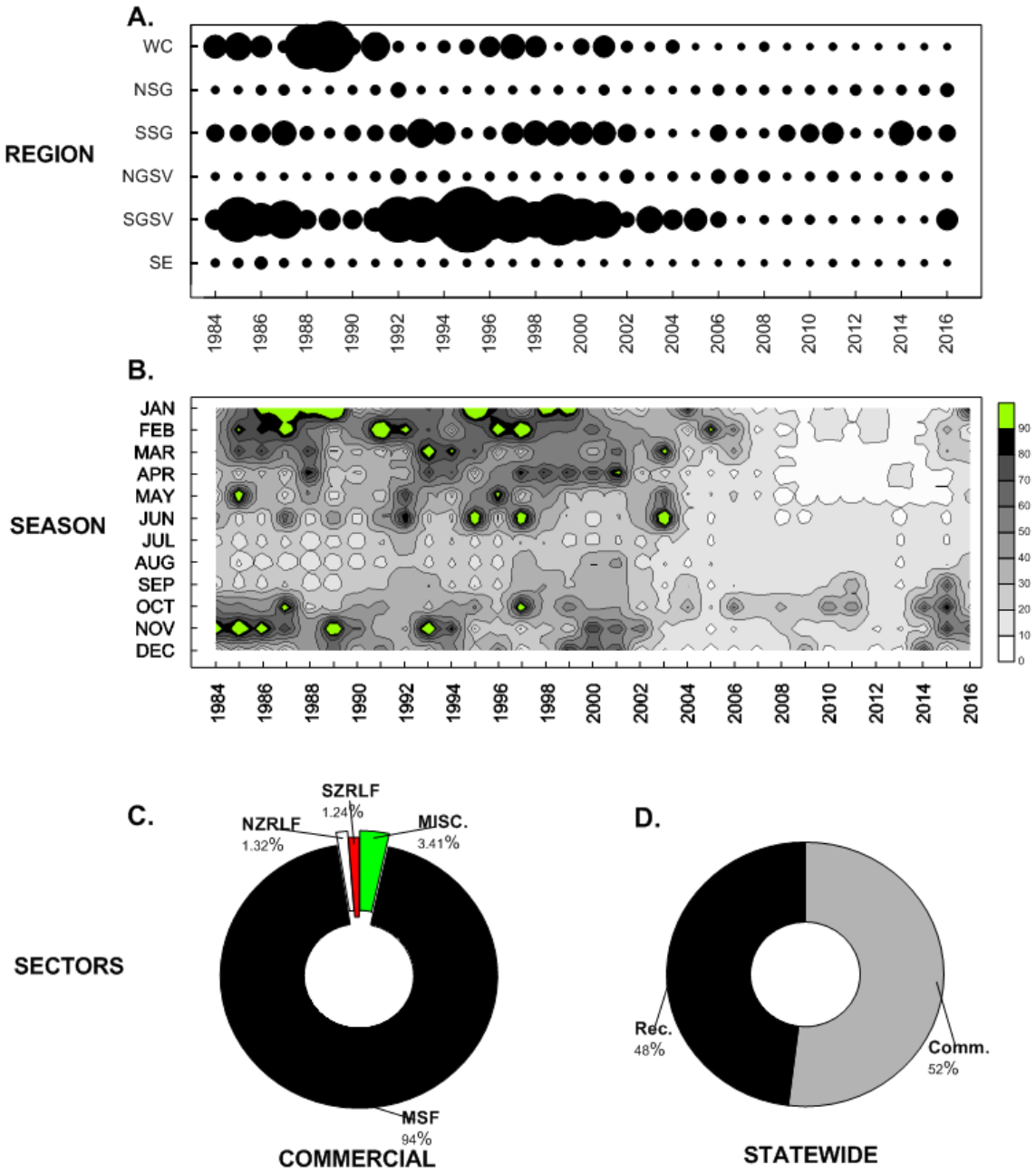

Figure 4-27. Western Australian Salmon. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general performance indicators for Salmon were assessed for 2016 at the State-wide scale, using the reference period of 1984 to 2016. No trigger reference points were activated (Table 4-9).

Table 4-9. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Western Australian Salmon.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET HAULING NET CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Given the shared nature of the stock across southern Australia it is important that each jurisdiction has adequate management in place to ensure that their respective fisheries do not compromise the overall sustainability of the resource. Currently this stock is considered to be 'sustainable' as the fishery has been relatively inactive due to weak market demand and low wholesale prices (Stewart et al. in press). Trends in catch and effort within South Australia's Salmon Fishery also reflect this inactivity and have been further restricted as a consequence of a series of netting closures that were implemented in 2005. Similarly, the relative inactivity of key 'Salmon' net fishers, is indicative of a weak market, however, the recent increase in annual catches over the past two years and escalating value suggest new, emerging markets for this species. There is an opportunity for this fishery to expand to satisfy emerging national and international seafood markets. The fishery has the capacity to alter its fishing practices to efficiently target large offshore schools and embrace new processing technologies to maximise the quality, value and marketability of the product for human consumption

There were no trigger references points breached in 2016, with current catches and associated catch rates remaining at relatively moderate levels. Consequently, there is no evidence indicating that the fishery is heading towards being recruitment overfished. On this basis, South Australia's Western Australian Salmon Fishery is classified as **sustainable**.

4.3.6. AUSTRALIAN HERRING (*Arripis georgiana*)

Biology

Australian Herring (hereafter referred to as 'Herring') is an abundant pelagic fish species that occurs along the west and south coasts of Australia. They are distributed in coastal marine and estuarine waters between Shark Bay, Western Australia, and Port Phillip Bay, Victoria, and are considered to constitute a single biological stock (Ayvazian et al. 2000). Herring share a similar life-history to Western Australian Salmon where they spawn around reefs off the lower west coast of Australia from late May to early June and the developing eggs and larvae are advected eastwards. The extent of their distribution depends on the relative strength of the Leeuwin Current which transports warm tropical water along Australia's southern coastline. Juveniles settle in inshore waters throughout this eastward distribution, some in close proximity to the spawning grounds, whereas others extend as far as Victoria. Juveniles prey upon small epibenthic crustaceans associated with shallow seagrass beds and as they mature switch their diet to include small fish (i.e. juvenile Australian Sardines), larger crustaceans and surface insects. Herring attain sexual maturity at two to three years of age and approximately 200 mm in length and typically return to southwestern Australia where they contribute to the spawning population (Smith et al. 2013).

Fishery

The schooling nature of Herring have made them a particularly important secondary species within the hauling net sector of the MSF, whereas they constitute a minor catch for the line sector. The majority of Herring caught in South Australia has been for human consumption, and given its relatively low value they are typically caught as a by-product when hauling net fishers target more valuable species, such as King George Whiting or Southern Garfish. Set and gill nets are also used to catch Herring for bait for either commercial longlining or Rock Lobster fishing operations. The Northern and Southern Zone Rock Lobster licence holders and Miscellaneous Fishery licence holders have reported negligible catches of Herring over many years. The species is a popular target within the State's recreational fishing sector. These fishers capture Herring using rod and line from boat and shore-based platforms. The latest estimate of catch from the recreational sector was 157.2 t (Giri and Hall 2015).

Management Regulations

Generic netting restrictions that have been implemented since the 1950s have affected many species within the MSF, including Herring. In 1983, the legal minimum length of 150 mm (TL)

that applied to the recreational fishing sector was abolished. A recreational bag limit of 60 fish per person and a boat limit of 180 fish per vessel was introduced in July 2001. This was reduced to 40 and 120 fish, respectively, in December 2016.

Commercial Fishery Statistics

State-wide

The total State-wide commercial catch of Herring in 2016 was 93.5 t, which was the third lowest on record (Figure 4-28). This represented an 81.1% decrease from the peak annual catch of 493.8 t in 1987. Annual catches have remained below 200 t since 2003. Rock lobster licence holders accounted for less than 0.1% of the 2016 commercial catch. The gross production value of this fishery has ranged from AU$292,000 to AU$453,000 during this time, and in 2016 was valued at AU$354,000. These netting closures also contributed to the erosion of fishing effort, where hauling net fishers have rarely exceeded 80 fisher-days.year^{-1} targeting Herring since 2005. Prior to this, total targeted effort for the hauling net sector declined from a peak of 738 fisher-days in 1992 to 182 fisher-days in 2005.

Target catch rates of Herring in the hauling net sector have been highly variable over the past 33 years ranging from 53.4 kg.fisherday in 2003 to 2016.5 kg.fisher-days in 2009 (Figure 4-28). Targeted hauling net catch rate of Herring in 2016 is confidential due to the <5 fisher rule. Despite such high variability, the long term trend has been relatively stable. Approximately 20% of fishers that take Herring actively target the species, and this proportion has remained relatively consistent over the last 33 years.

Regional

Prior to the implementation of the netting closures in 2005, the highest catches for Herring were shared amongst NSG, SSG, and NGSV (Figure 4-29). Since then, most of the catch from SSG has reduced. Similar reductions were evident in NGSV but only lasted approximately six years before returning back to moderate levels. The relative proportion of catch from NSG has remained relatively unchanged (Figure 4-29). Most of this catch has been historically landed throughout spring and summer. In 2016, MSF fishers dominated the catches accounting for >99.5% of the commercial catch. The remainder was shared amongst the fishers of the NZRLF, and SZRLF. In 2013/14, the recreational sector accounted for approximately 52% of the State-wide catch (Figure 4-29).

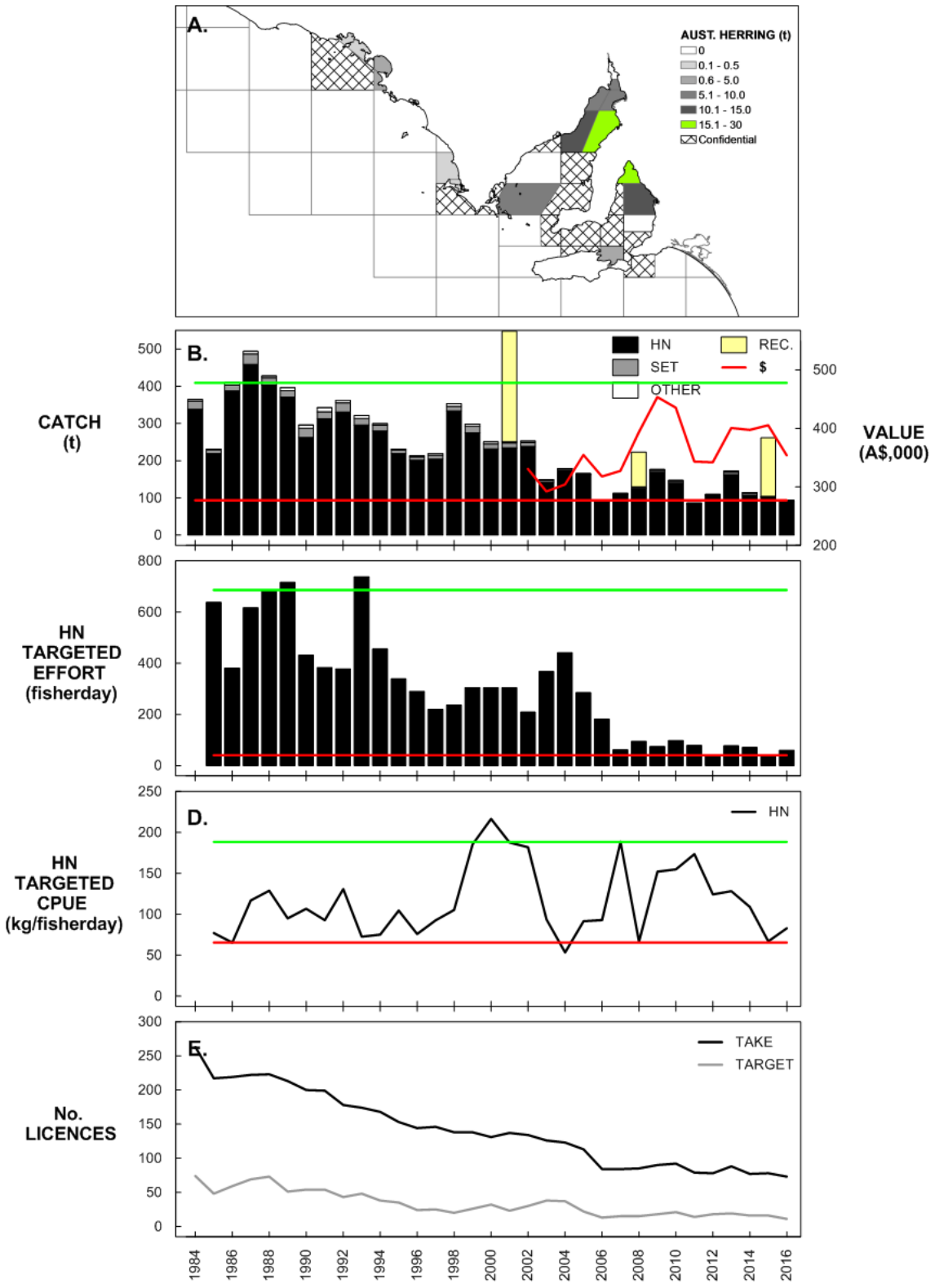

Figure 4-28. Australian Herring. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for hauling nets and gross produciton value; (C) Long-term total effort for hauling; (D) total catch per unit effort for hauling nets; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5

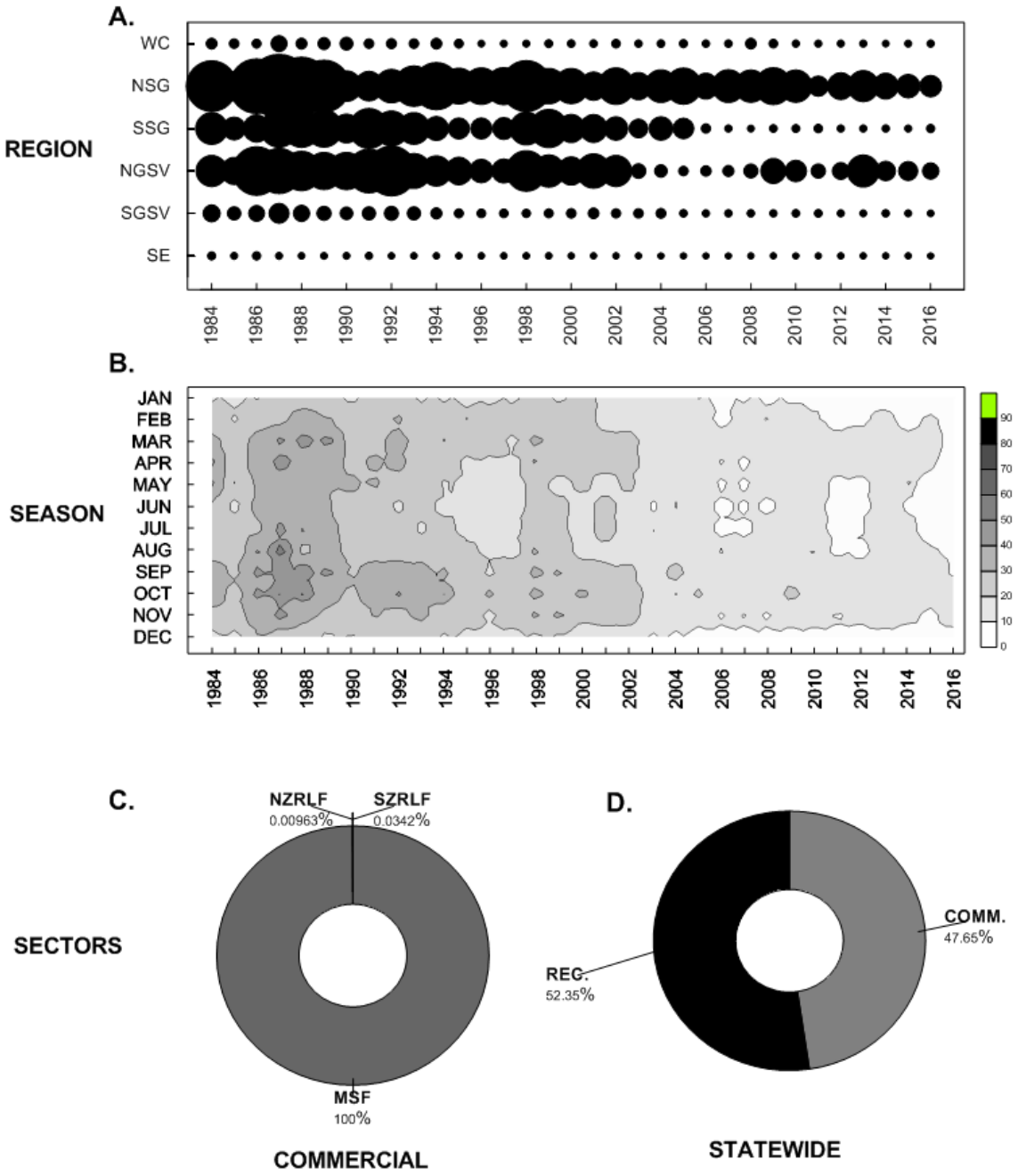

Figure 4-29. Australian Herring. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general performance indicators for Herring were assessed for 2016 at the State-wide scale, using the reference period 1984 to 2016. The resolution of the targeted effort and associated catch rates for hauling net fishers were confidential due to the <5 fisher rule. The 2016 catch of Herring in 2016 was the third lowest on record, breaching this single trigger reference point (Table 4-10).

Table 4-10. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State scale for Australian Herring. CONF. denotes confidential data, <5 fishers.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	3rd LOWEST
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖
TARGETED HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	CONF.
	G	Greatest % interannual change (+/-)	CONF.
	G	Greatest 3 year trend	CONF.
	G	Decrease over 5 consecutive years	CONF.
TARGETED HAULING NET CPUE	G	3rd Lowest / 3rd Highest	CONF.
	G	Greatest % interannual change (+/-)	CONF.
	G	Greatest 3 year trend	CONF.
	G	Decrease over 5 consecutive years	CONF.

Stock Status

Given the shared nature of the stock it is important that each jurisdiction has adequate management in place to ensure that their respective fisheries do not compromise the overall sustainability of the resource. A recent assessment of Australian Herring in southwestern Australia indicated that the sustainability of the resource was at a high risk (Smith et al. 2013). This was ascertained through a weight-of-evidence approach and justified the assessment on the basis of high fishing mortality rates; truncated age and size structures; a high proportion of immature fish in the commercial catch; and inferred low recruitment. The fishery-dependent indicators of the status predominantly related to the spawning stock, whereas other fishery-independent indicators (i.e. recruitment indices) of overall stock status were based on data collected at a broader regional scale (Smith et al. 2013). It was suggested that the fishery warranted a reduction in fishing effort and/or catch to promote its recovery. In 2015 management arrangements were introduced in Western Australia to curtail the capture of Herring which included the closure of the South Coast Trap Net Fishery that specifically targets Herring, and reduction in the recreational bag limit.

The levels of fishing effort and subsequent catch of Herring in South Australia have substantially declined over the past 33 years and were particularly eroded by the implementation of a series of netting closures in 2005. Total catch of Herring in 2016 was the third lowest on record. Despite this erosion, the long-term trend in catch rates within the hauling net sector have remained relatively stable over the past two decades. The contemporary trends in the fishery-dependent commercial catch and effort data for Herring in South Australia have not sufficiently reflected the concerning status of the Western Australian spawning stock. This is most likely due to it being infrequently targeted by the commercial sector as a result of its relatively low market value.

A dedicated research program that assessed the status of Herring at the biological stock level identified a strong relationship between a pre-recruit index in Gulf St. Vincent and sea level heights for Albany, Western Australia (Ayvazian et al. 2000; Jones and Westlake 2003). This indicated that the variation in annual recruitment within the South Australian nursery grounds and subsequently to the fishery is dependent on the Western Australian spawning stock. The high productivity of the species and the management arrangements introduced in WA in 2015, has contributed to the recovery of the resource (DPIRP 2017). Consequently the status of the South Australian Herring Fishery should reflect the Western Australian assessment that the resource is at a moderate risk of stock decline and be considered **sustainable**.

4.3.7. VONGOLE (*Katelysia* spp.)

Biology

South Australia has three Vongole species (commonly known as Mud Cockles) that are commercially harvested; 'Greys' (*Katelysia scalarina*), 'Yellows' (*K. rhytiphora*) and 'Whites' (*K. peronei*) (Dent et al. 2016a). All three species inhabit shallow estuarine and marine embayments and are broadly distributed along the temperate coastline from Augusta, Western Australia to Port Jackson, New South Wales (Roberts 1984). The stock structures of the three species are unknown, but given their species short larval periods (Gluis and Li 2014), it is expected that Vongole in individual bays would constitute separate stocks (Dent et al. 2015). In South Australia, three putative biological stocks have been identified as separate management zones: West Coast, Coffin Bay, and Port River Cockle Fishing Zones. Vongole reach a maximum age of 29 years and attain sizes of 55 mm shell length (SL). Size and age at maturity have been estimated at 23-31 mm SL and 4 years, respectively (Riley et al. 2005).

Fishery

Vongole have been commercially harvested in South Australia since the early 1960s with the majority of catch taken from the Port River and Kangaroo Island and sold as bait. Since the mid-1980s there has been an increasing demand for this species for human consumption, particularly driven by Melbourne-based markets. Despite this demand, South Australia's Vongole fishery remained lightly exploited (Dent et al. 2016a, b). Commercial MSF licence holders typically use hand-held cockle rakes to target Vongole in shallow, sand/mud substrates, although there are some records where they have been harvested by hand. These rakes can only be used if they are specifically endorsed on the commercial licence.

In 2013/14, an estimated 12,805 Vongoles, weighing approximately 0.14 t, were harvested by the recreational sector (Giri and Hall 2015).

Management Regulations

The Vongole fishery is managed separately from other MSF species. In October 2008 the fishery transitioned to an individual transferable quota (ITQ) management system. A total allowable commercial catch (TACC) was established as the principal output control for South Australia's commercial Vongole Fishery in 2008/09. This was initially set at 195 t for all zones on the basis of catch history, partitioned amongst the three zones: 100 t Port River, 70 t Coffin Bay, and 25 t West Coast. A fishery-independent program that estimated the harvestable biomass was developed in 2010 (Gorman et al. 2010). This research program provides survey-based

estimates of biomass and size-at-maturity in each of the three fishing zones. The subsequent estimates of harvestable biomass provide the key performance indicator for determining the TACC. The TACC is determined as a fraction of the biomass estimate (at 80% confidence), up to a maximum of 7.5%. All licence MSF fishers that do not own quota can harvest 10kg per day of Vongole for bait.

A size limit of 35 mm maximum shell width is current for Vongole (Whites and Yellows) within the Coffin Bay Cockle Fishing Zone, outside of this zone the size limit is lower at 30 mm for all three species. Recreational size limits for Vongole are 38 mm within Coffin Bay, and 30 mm outside of the bay. They are further restricted to a personal bag limit of 300 cockles. The Port River Cockle Fishing Zone was closed in 2011, and continues to be closed, due to sustainability concerns. SARDI is currently undertaking a research project to inform a potential re-stocking program.

Commercial Fishery Statistics

The total State-wide commercial catch of Vongole in 2016 was 66.1 t with an estimated gross production value of A$874,000 (Figure 4-30). Given the majority of this fishery has been managed under a TACC since 2008/09, annual catches have been relatively stable. The difference between the TACC for fishers with ITQ and the total annual catches was negligible, indicating that there is only a minor amount of Vongole harvested by other MSF fishers for bait. From 2005 until 2007, this fishery peaked above 300 t, and the gross value was approximately A$1 million per annum. Vongole are almost exclusively harvested using cockle rakes, with the majority of the catch taken from Coffin Bay on the West Coast. Given the highly selective nature of the gear, the long term trend in effort often reflects the catch. Cockle rake effort levels have declined below 700 fisher-days.year^{-1} in 2015 and 2016. These low levels of effort have not been observed since 1997. Catch rates of Vongole declined from a peak of 205.1 kg.fisherday^{-1} in 2002 to a low of 62.0 kg.fisherday^{-1} in 2011. They have since increased to 97.1 kg.fisherday^{-1} in 2016. Those fishers that have recorded catches of Vongole have generally actively targeted them. The number of licence holders has declined from 45 in 2007 to 14 in 2016, representing a 68.9% reduction over ten years.

The West Coast and NGSV regions have historically accounted for most of the State-wide catch, supporting the establishment of the three management zones (Figure 4-31). The closure of the Port River Cockle Fishing Zone in 2011 was responsible for removing the catch from NGSV. During the peak of the fishery in the late 1990s and 2000s most of the catch was harvested in late winter and spring. Marine Scalefish licence holders have accounted for almost 100% of the

commercial catch in 2016. The recreational sector accounted for <0.2% of the State-wide catch in 2013/14.

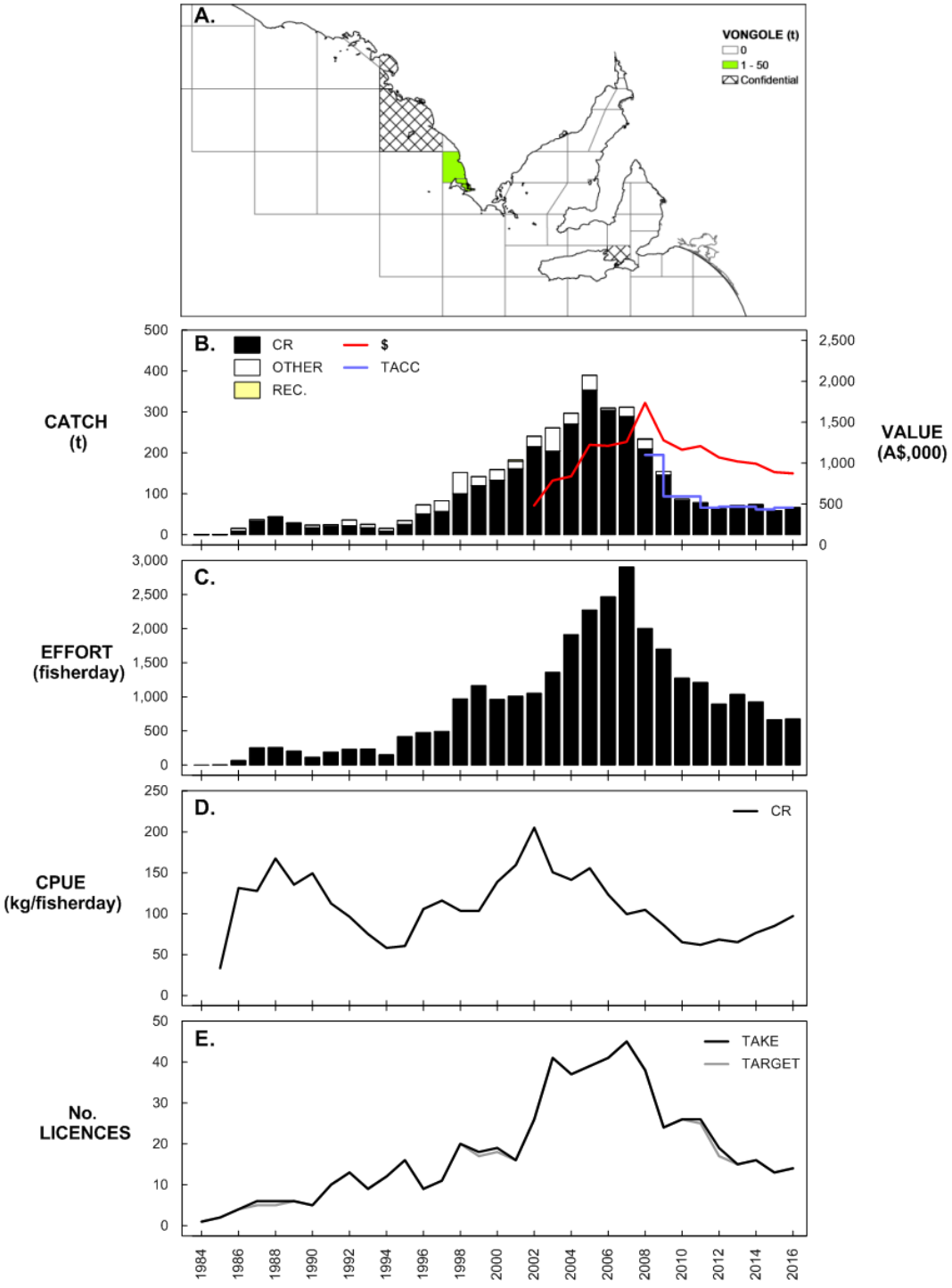

Figure 4-30. Vongole. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for cockle rakes and gross production value; (C) Long-term total effort for cockle rakes; (D) total catch per unit effort for cockle rakes; and (E) the number of active licence holders taking or targeting the species.

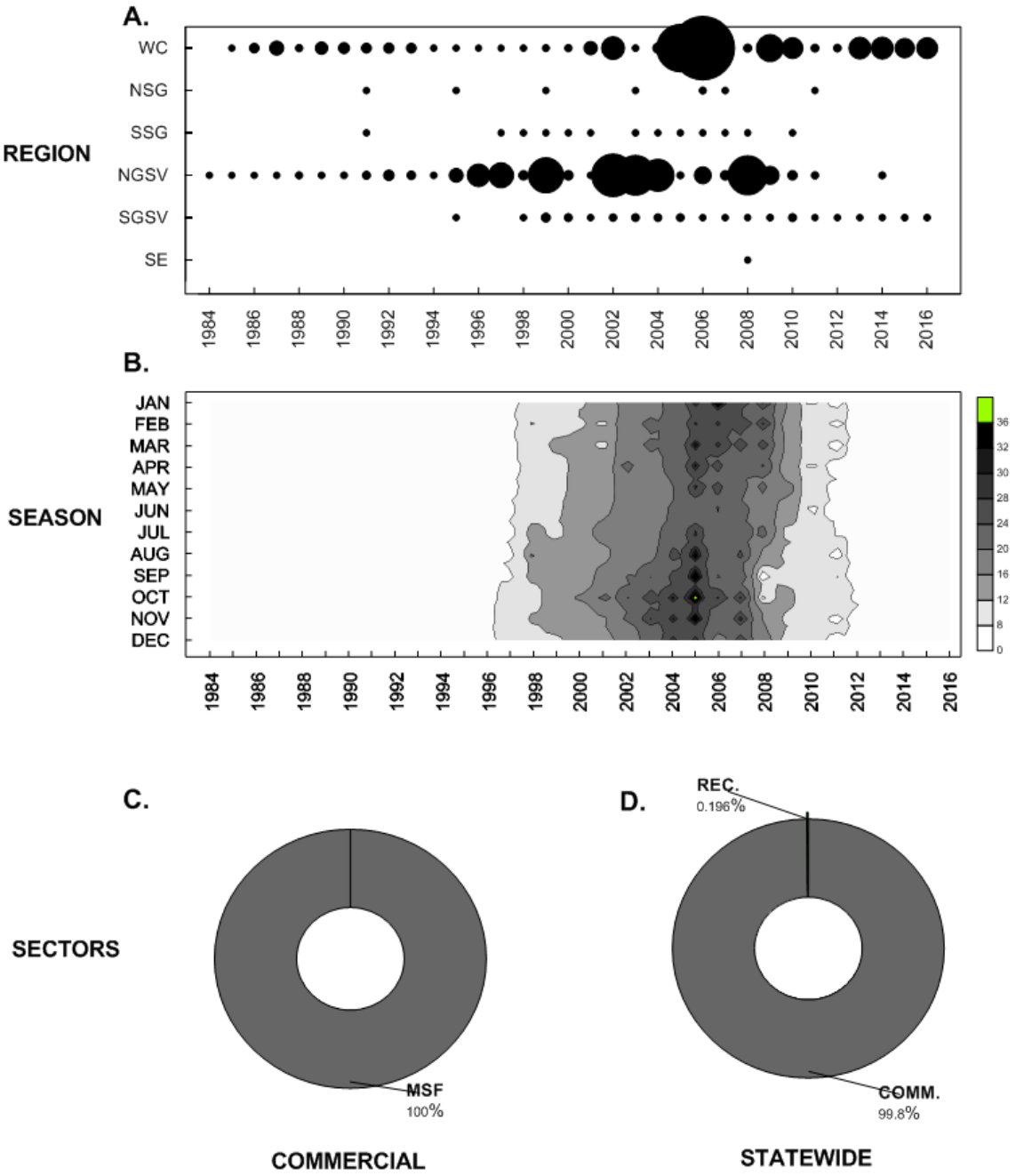

Figure 4-31. Vongole. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general MSF performance indicators and associated reference limits do not apply for Vongole fishery, as it is managed by a TACC (PIRSA 2013).

Stock Status

The status of South Australia's Vongole Fishery is determined from a routine fishery-independent research program that undertakes structured surveys to determine the relative density and size structure of Vongole populations within the three management zones; West Coast, Coffin Bay and Port River Cockle Fishing Zones (Gorman et al. 2010, Dent et al. 2016a). The overall objective of these surveys is to estimate the harvestable biomass to provide the key performance indicator to determine the TACC.

The latest assessment indicated that the based on collective evidence of high harvestable biomass, low exploitation rates and strong recruitment, the Coffin Bay and West Coast Cockle Fishing Zones were unlikely to be recruitment overfished and consequently classified as **sustainable** (Dent et al. 2016 a, b).

The first survey conducted for the Port River Cockle Fishing Zone in 2009 indicated that the biomass was low. Given this zone has historically produced significant catches, its low biomass raised sustainability concerns, and consequently it was closed to the taking of Vongole by all fishing sectors in 2011/12. A biomass survey conducted in 2016 showed that the stock had not yet recovered and remains in a depleted state. The status of this fishing zone is classified as **recruitment overfished**.

4.3.8. SNOOK (*Sphyraena novaehollandiae*)

Biology

Snook (*Sphyraena novaehollandiae*) is a member of the Sphyraenidae family, i.e. the Barracudas (Gomon et al. 2008). The species is broadly distributed across southern Australia from Perth to Sydney, including Tasmania as well as New Zealand (Gomon et al. 2008). There is little information available on stock structure throughout this broad Australasian distribution (Emery et al. 2016). Snook are usually found over seagrass beds and kelp reefs near the surface both in inshore and offshore waters of up to 20 m depth (Emery et al. 2016). They are elongate, slender fish with a pointed head and projecting jaw that facilitates their feeding mode. They are powerful swimmers and voracious predators that take a variety of prey including pelagic and demersal teleost fishes, crustaceans and cephalopods (Bertoni 1994).

Biological studies on this species have been limited, reflecting its status as a 'secondary' species for the Marine Scalefish Fishery. In 2002, a South Australian study considered several hundred specimens collected from northern Gulf St. Vincent and Spencer Gulf from which population structure and reproductive biology were considered (O'Sullivan and Jones 2003). The largest specimen was 820 mm TL, although most were from 300 to 500 mm TL. The modal age was 2+ years, with the oldest up to 12 years of age. The males and females demonstrated similar growth relationships, whilst in both gulfs there were strong biases in the sex ratio towards females. The fish are reproductively active during summer between late November and early February (Bertoni 1994). They are multiple batch spawners and have indeterminate fecundity. The L_{50} for females was 403 mm TL and that for males was 391 mm TL, with the associated ages for both sexes being 2 years of age.

Fishery

In South Australia, Snook are taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. In the former sector, they are generally taken with hauling nets and gill nets when commercial net fishers target higher value species such as King George Whiting, Southern Garfish, Southern Calamari and Yellowfin Whiting. Snook are also targeted by commercial troll line fishers.

Recreational fishers target Snook with rods and lines. The State-wide recreational survey in 2013/14 estimated that 187,165 Snook were captured, of which 12,941 were released, leaving

174,224 fish retained (Giri and Hall 2015). The latter provided a total estimated State-wide harvest of 126.3 t.

Management Regulations

For the commercial sector, the many regulations that constitute input controls for the different netting gears contribute to minimising fishing effort on Snook, as well as a minimum size limit. This was increased from 360 to 450 mm TL in July 2001. A reduction in size limit to 410 mm TL came into effect in 2017, to align with size at maturity information (Bertoni 1994). At the request of the recreational sector, the size limit remains at 450 mm TL, with a bag limit of 20 fish and a boat limit of 60 fish. These regulations were not changed in the recent review of the recreational fishery (PIRSA 2016).

Commercial Fishery Statistics

State-wide

Estimates of annual, State-wide commercial catches of Snook increased to the highest recorded level in 1995, before declining over the long-term to the lowest level of 40.3 t in 2014 (Figure 4-32). Since then there has been a marginal increase to 53.5 t in 2016. Hauling nets have generally accounted for at least half of the annual catches, with troll lines generally the second most significant gear type. Whilst Snook have been reported being taken with several other gears types, gillnets account for the majority of the 'other' catch. Annual estimates of total fishing effort used to take catches of Snook have always been dominated by hauling nets. Targeted hauling net fishing effort has declined since 1995 to the lowest recorded level in 2013, followed by marginal increases in 2014 and 2016. Targeted hauling net CPUE has been highly variable, often fluctuating by >30 kg.fisherday^{-1} in a single year. During the 1980s and 1990s annual targeted catch rates within the hauling net sector fluctuated around 25 kg.fisherday^{-1}, since the late 1990s onwards these catch rates have increased to approximately 50 kg.fisherday^{-1}. Targeted hauling net CPUE in 2016 was relatively high at 71.4 kg.fisherday^{-1} (Figure 4-32). The number of fishers that reported taking Snook has declined over the long-term at a faster rate than the lower number who targeted this species.

Regional

Catches of Snook have been reported from the six geographic regions of South Australia's marine waters (Figure 4-33). The highest regional catches were taken during the 1990s, mainly from NSG and NGSV, with intermediate catches from SSG and the WC. Catches from all regions were

lower during the 2000s. The fishery is seasonal with highest catches generally taken between July and November.

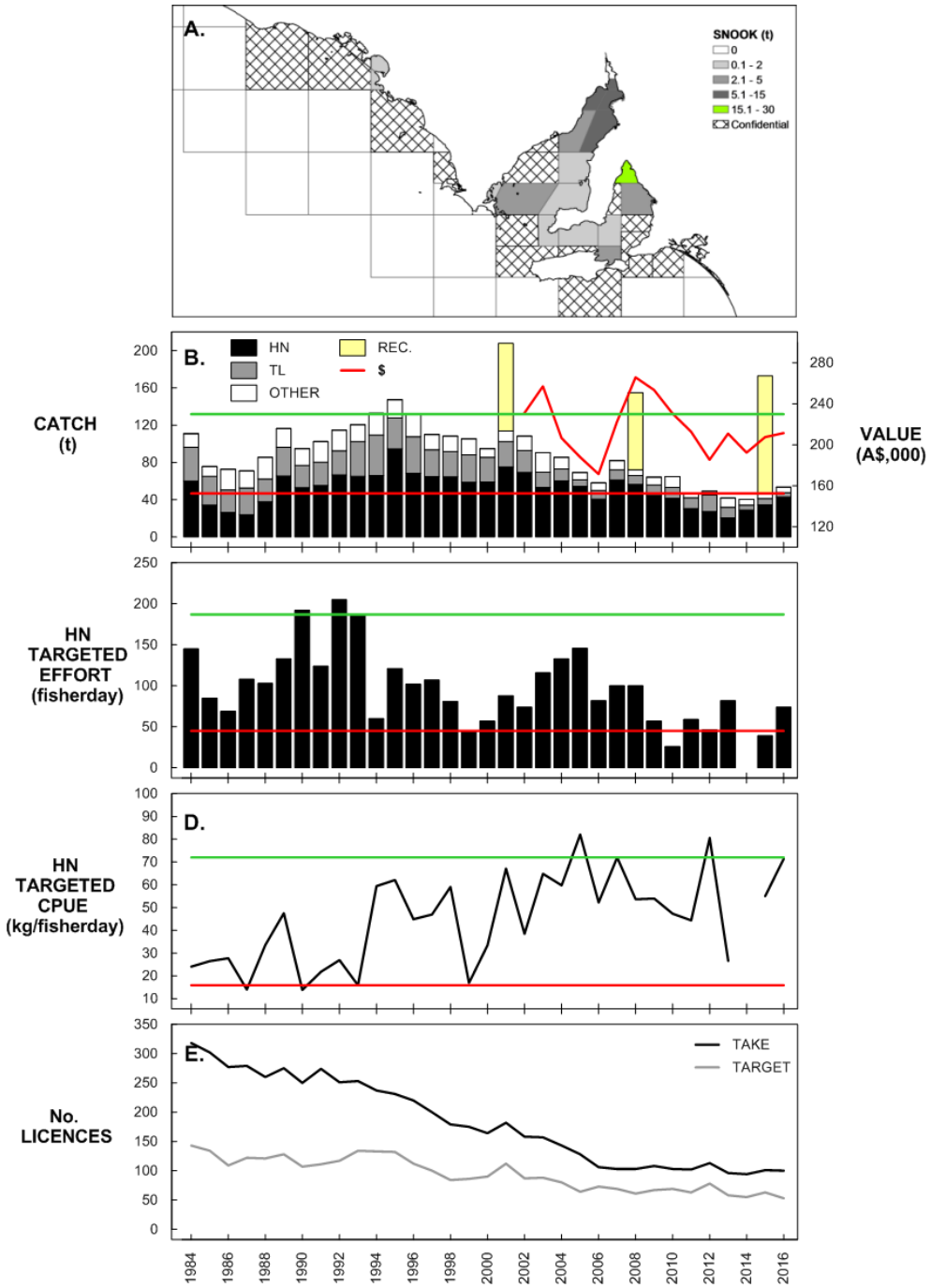

Figure 4-32. Snook (A) Catch distribution for 2016; Long-term trends in: (B) total catch for hauling net and troll line and gross produciton value; (C) Long-term total effort for hauling net and troll line; (D) total catch per unit effort for hauling net and troll line; and (E) the number of active licence holders taking or targeting the species.

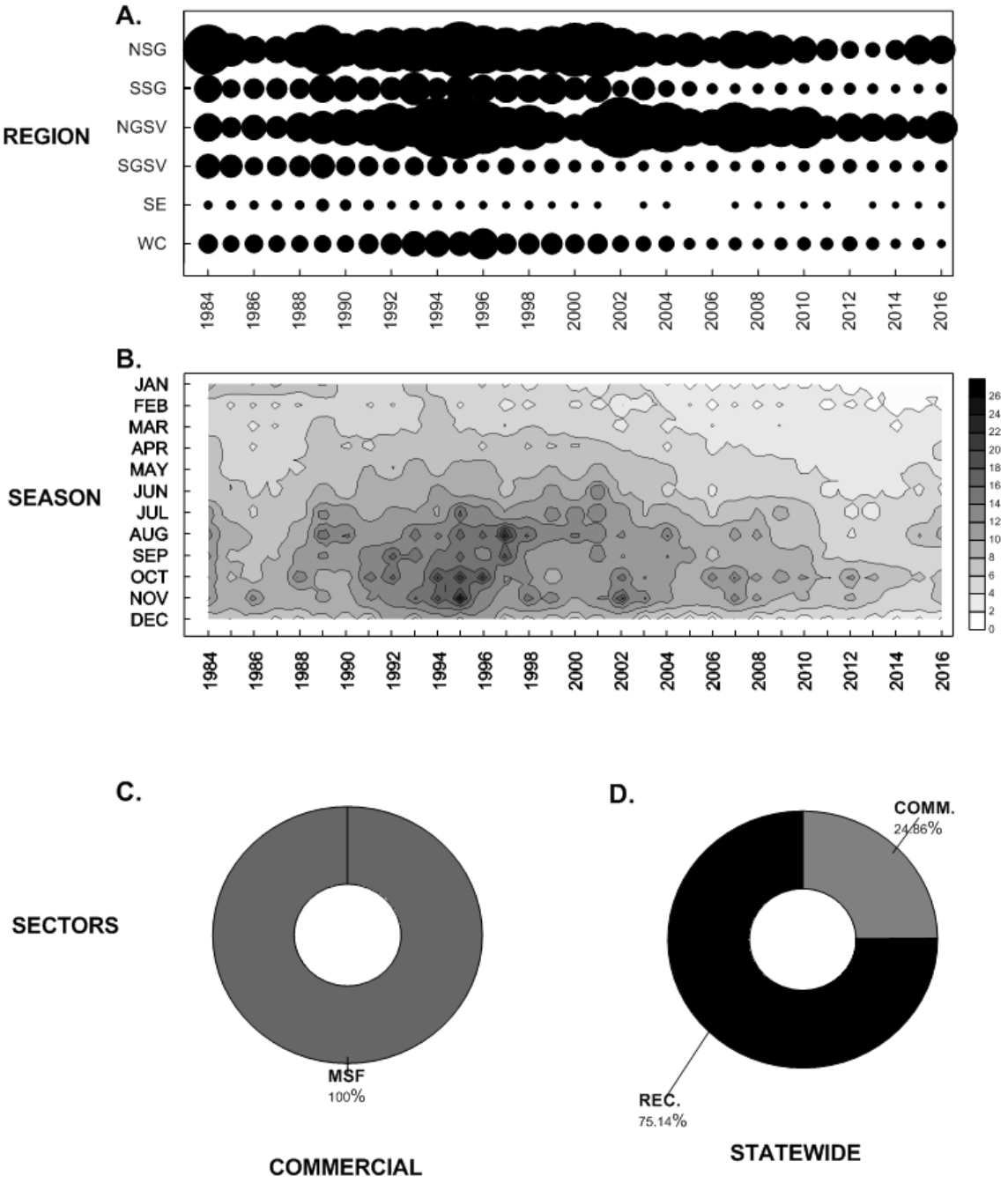

Figure 4-33. Snook. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Snook were assessed for 2016 at the State-wide scale. No trigger reference points were activated (Table 4-11).

Table 4-11. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide scale for Snook.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET HAULING NET CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Snook is a secondary species for the commercial sector of the MSF (PIRSA 2013). This reflects the relatively low catches taken compared to the primary species. The majority of the catch is taken either as by-product by the hauling net fishers or as targeted catch by trolling line fishers. This was reflected by the relatively high numbers of fishers who reported taking Snook, but considerably fewer who reported targeting it.

Total catch at the State-wide and regional scales have declined considerably since the mid-1990s. For the regional fisheries in the two northern gulfs, this largely reflects the declines in hauling net effort that have occurred over this time period. During this time, catch rates have been highly variable, but nevertheless have not shown any long-term decline. The relatively low recent catches and low targeted hauling net effort combined with high targeted catch rates are unlikely to cause the fisheries in either gulf to become recruitment limited. On this basis, South Australia's Snook fisheries are classified as **sustainable**.

4.3.9. SAND CRAB (*Ovalipes australiensis*)

Biology

The Sand Crab (*Ovalipes australiensis*) is a medium-sized crab species of the family Portunidae. It has a broad distribution across southern Australia from Wide Bay in Queensland, to Rottnest Island in Western Australia, including Tasmanian waters (Kailola et al. 1993). They occur on surf beaches and in sandy bays and inlets and in off-shore waters to approximately 100 m depth. In South Australia (SA), they occur in most inshore waters except the northern gulfs and west coast bays (Jones 1995), where blue swimmer crabs (*Portunus pelagicus*) are most abundant. The stock structure for Sand Crabs is unknown across the broad Australian distribution and also regionally within SA.

A study on the reproductive biology in Coffin Bay determined that they are winter spawners with reproductive activity peaking in July and berried females present until late August (Deakin 1996). The L_{50} values for both sexes are considerably lower than the legal minimum size of 100 mm carapace width. Most female crabs captured in a measuring program in Coffin Bay were below the minimum legal size, which meant that the fishery was essentially based on male crabs (Jones and Deakin 1997, Jones 2000).

Fishery

In SA, the commercial fishery for Sand Crabs developed from 1982/83 onwards, particularly in Coffin Bay, but later throughout southern coastal areas. It first developed as an experimental trap or pot fishery, but subsequently the hoop net and drop net gear types were employed and their use was extended outside Coffin Bay as more fishers entered the fishery (Jones 1995). Over the years, considerable efficiencies were introduced with gear modifications, the time of day of fishing and the use of net haulers (Jones and Deakin 1997).

Recreational fishers target Sand Crabs using hoop nets or drop nets from jetties along the southern metropolitan Adelaide coast, and from boats in some southern coastal waters. The estimated number of Sand Crabs captured by the recreational sector in 2013/14 was 52,557 animals of which 48.1% were released, resulting in a harvest of 27,277 animals, with an estimated total weight of 9.9 t (Giri and Hall 2015).

Management Regulations

A minimum legal size of 100 mm carapace width (measured across the widest point) was introduced in 1992 for market purposes (Jones 1995). For the commercial sector, there are gear restrictions, i.e. a license holder may only carry on-board the registered boat, the number of hoop and drop nets endorsed on the license. Within the MSF there a four dedicated Sand Crab licence holders with a combined access to 400 Sand Crab pots. The recreational bag and boat limits were reduced from 40 and 120 to 20 and 60 crabs (combined totals with blue swimmer crabs), respectively in 2016 (PIRSA 2016b).

Commercial Fishery Statistics

State-wide

Estimates of annual, State-wide commercial catches of Sand Crabs have been variable since the fishery commenced in 1984 (Figure 4-34). Annual catches were comparatively low until 1988. They then increased considerably between 1989 and 1991 reaching a peak of 152 t, before dropping to a minimum of 40.1 t in 1994. Since then, total catch increased again to the highest recorded level of 177 t in 2005, but has since declined over the long-term to 48.4 $t.yr^{-1}$ in 2016. During the early years the fishery was based on the use of crab pots. However, in 1989, the use of crab nets (hoop and drop nets) increased considerably. In the following years, the use of crab nets gradually increased, and since 1991 have accounted for the higher proportions of total catch and total effort. There were two peaks of targeted crab nets effort through the 1990s of approximately 800 – 1,000 fisher-days. Since 1998, there has been a gradual decline in targeted effort to 336 fisher-days in 201g, before increasing to 431 fisher-days in 2016.

Targeted crab net CPUE has demonstrated a long-term increase from around 50 $kg.fisherday^{-1}$ in 1988 to 143 $kg.fisherday^{-1}$ in 2015, before dropping back to 106 $kg.fisherday^{-1}$ in 2016 (Figure 4-34). The numbers of fishers taking and targeting Sand Crabs are closely linked, which indicates that this species is specifically targeted rather than being a by-product species. The numbers of fishers increased up to 45 in 1997, but have since declined to 16 in 2016.

Regional

The fishery has been heavily concentrated on the West Coast, primarily in Coffin Bay (Figure 4-35). Outside of this region, the highest catches have been taken from SSG. Lower annual catches have occurred in SGSV and NGSV, with only incidental catches ever recorded from NSG and the SE. The Sand Crab fishery has been seasonal with highest catches taken between October and March.

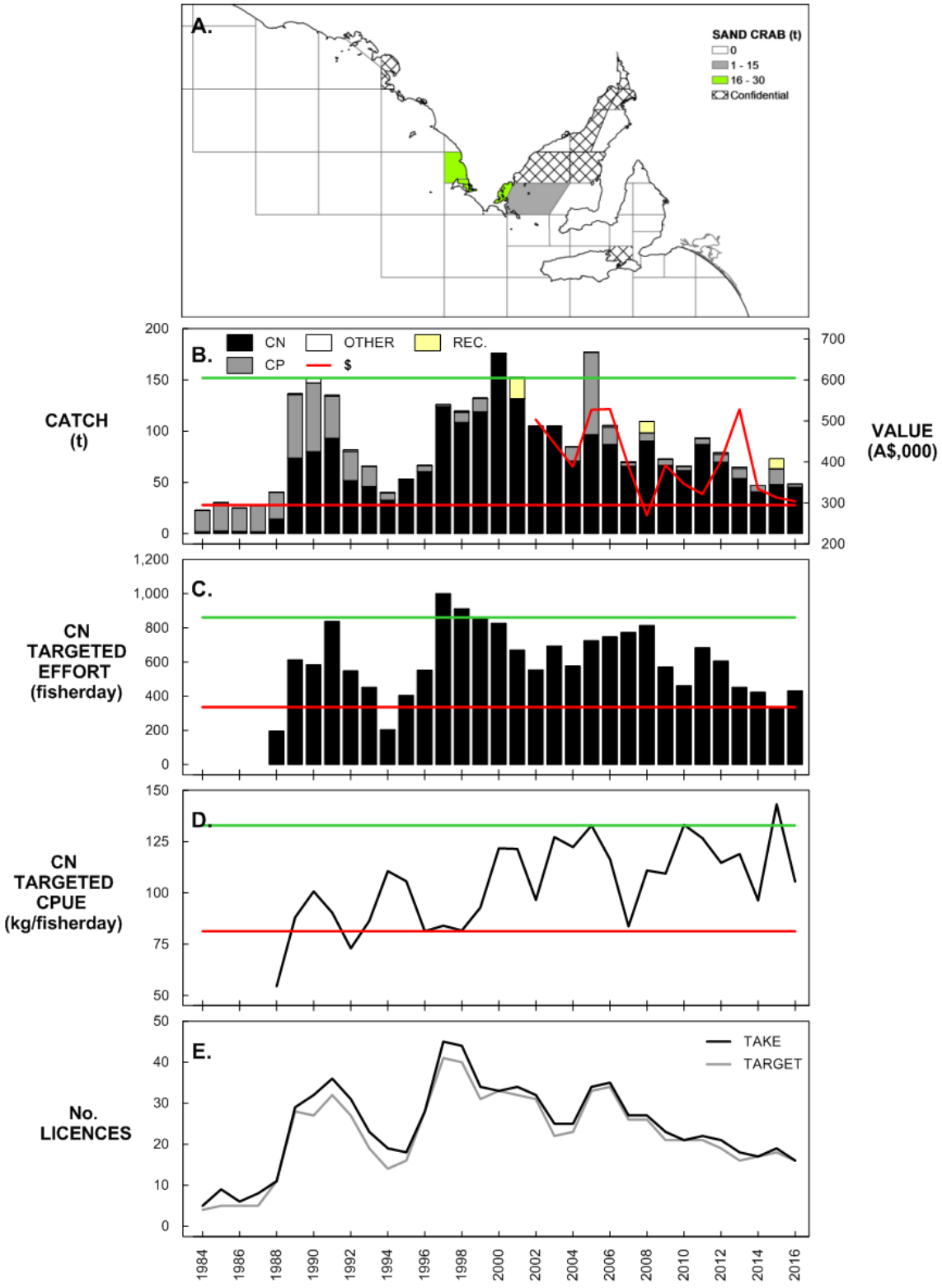

Figure 4-34. Sand Crab. (A) Catch distribution for 2016; Long-term trends in: (B) total catch crab net and crab pot and gross production value; (C) Long-term targeted effort for crab net; (D) targeted catch per unit effort for crab net; and (E) the number of active licence holders taking or targeting the species.

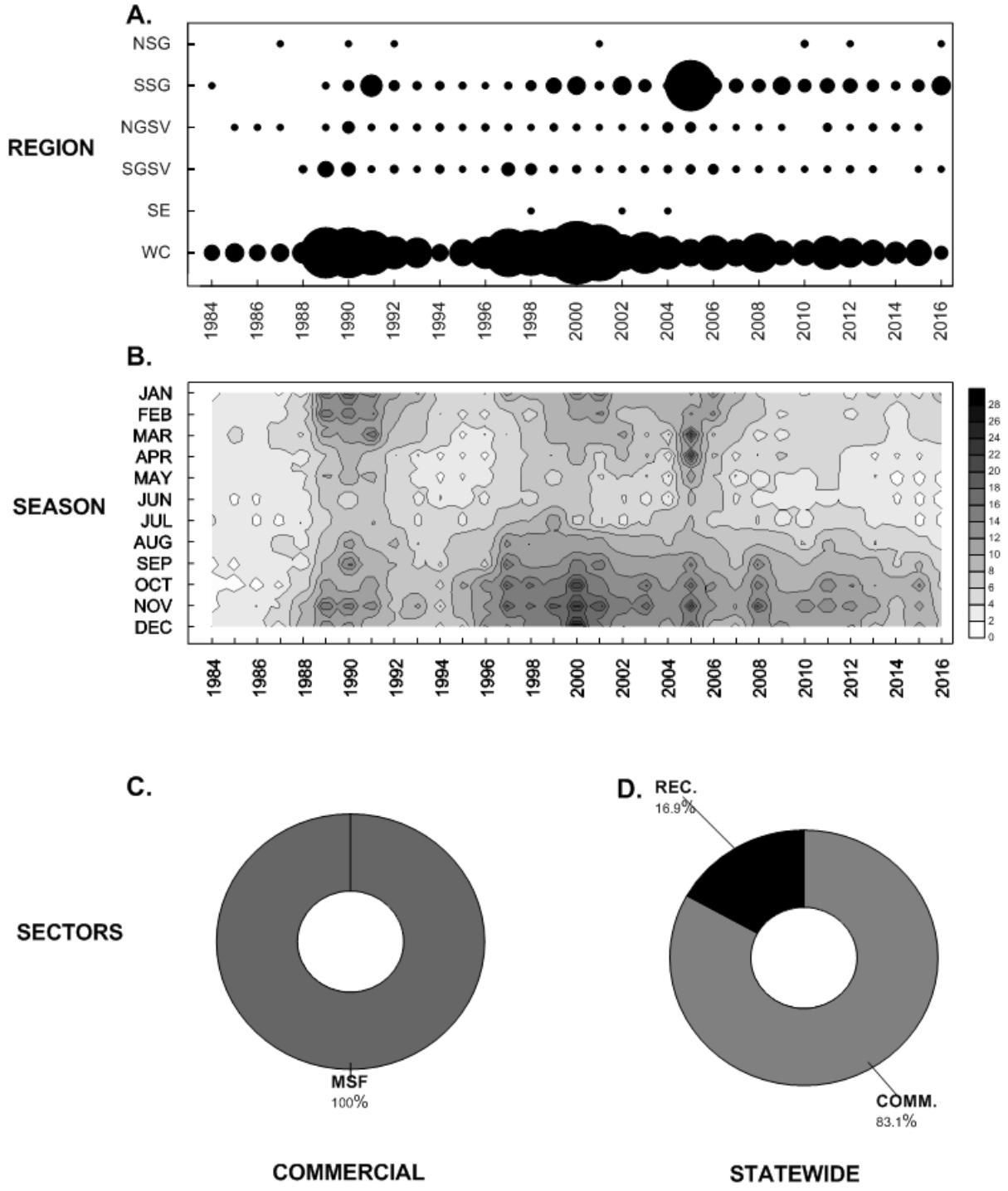

Figure 4-35. Sand Crab. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Sand Crabs were assessed for 2016 at the State-wide scale. No trigger reference points were activated (Table 4-12).

Table 4-12. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide scale for Sand Crab.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET CRAB NET EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET CRAB NET CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

The Sand Crabs fishery consists of specialist fishers that require endorsed net or pot types on their licences to target the species, consequently the fishery statistics considered here at State-wide scale related to targeted fishing effort. Nevertheless, the interpretation of such data is complicated by the development of the fishery since 1982/83 that resulted in improvements in fishing efficiencies (Jones 1995, Jones and Deakin 1997, Jones 2000). The early fishery involved a few fishers that primarily used crab pots. Then, as the number of operators increased they began using hoop nets, which were later replaced with more effective drop nets. Furthermore, fishers started to work at night when the crabs were more active, and to use portable, mechanical net haulers, which allowed further modifications to net design. The assessment of stock status must take these increases in efficiency into consideration.

The commercial fishery statistics for Sand Crabs are characterised by significant inter-annual variability, although with long-term trends apparent. The trends in State-wide catch statistics are largely driven by those from the West Coast, which was dominated by the Coffin Bay fishery. The recent catches and targeted crab net effort levels are relatively low compared to those in the past, whilst targeted catch rates have generally increased over time. As such, these data show evidence of the increases in efficiencies in the fishery but no indication that it is becoming recruitment limited. On the basis of these data, South Australia's Sand Crab fishery is classified as **sustainable**.

4.3.10. YELLOWEYE MULLET (*Aldrichetta forsteri*)

Biology

Yelloweye Mullet (*Aldrichetta forsteri*) is a member of the Mugilidae family, i.e. the Mullets (Gomon et al. 2008). It is found in bays, estuaries and inshore waters along the southern coast of Australia from the Murchison River in Western Australia to the Hunter River in New South Wales, including Tasmania and also in New Zealand (Earl et al. 2016a). Yelloweye Mullet typically school in brackish and nearshore marine waters over sandy and muddy substrates to 20 m depth and are often abundant in estuaries and the lower reaches of rivers (Kailola et al. 1993). Characterised by a silvery, slender, cigar-shaped form, this species is considered a marine estuarine-opportunist, i.e. spawns at sea; regularly enters estuaries, particularly as juveniles, but use, to varying degrees, coastal marine water as alternative nursery areas (Potter et al. 2015). Their tolerance of wide ranges of temperature and salinity make Yelloweye Mullet well adapted to the environmentally-dynamic nature of estuaries and nearshore coastal areas (Earl and Ferguson 2013).

The biological stock structure of Yelloweye Mullet throughout southern Australia is not well understood. It has been suggested that the populations of this geographic region form two discrete stocks, i.e. the Western and Eastern Stocks. The South Australian populations on the far West Coast contribute to the Western Stock (Smith et al. 2008), while populations in Spencer Gulf, Gulf St Vincent and Victoria are thought to be part of the Eastern Stock (Thomson 1954; Pellizzari 2001). In South Australia, Yelloweye Mullet are a fast growing, short-lived species that attains a maximum length of 440 mm and maximum age of 10 years (Earl and Ferguson 2013). Females reach maturity at around 240 mm TL, while males mature at 250 mm TL (Earl and Ferguson 2013). They have a protracted spawning season from winter to early autumn, with the highest frequency of spawning occurring between December and February.

Fishery

In South Australia, Yelloweye Mullet are taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. In the commercial sector, Yelloweye Mullet are targeted or taken as by-product with hauling nets and set nets. However, most (80–90%) of the annual State-wide commercial catches over the past decade have been taken by the Lakes and Coorong Fishery (Earl et al. 2016a).

Recreationally, Yelloweye Mullet is regarded as an important species and is taken with rod and line. In 2013/14, an estimated 100,876 Yelloweye Mullet were captured by the recreational sector, of which 29,598 fish were released, leaving 71,278 fish retained (Giri and Hall 2015). This provided a total estimated State-wide recreational harvest of 19.4 t, which was slightly higher than the total catch taken by the commercial Marine Scalefish Fishery of 18 t.

Management Regulations

Mullet of all species are permitted to be taken commercially by the Marine Scalefish Fishery (PIRSA 2013) and are classified as secondary taxa in the commercial Marine Scalefish Fishery Management Plan, due to their medium-high value and contribution to the total production value of the commercial fishery (PIRSA 2013). There is a minimum size limit of 210 mm TL for both the commercial and recreational sectors. The recreational daily bag limit of 60 fish and boat limit of 180 fish applies to all species of Mullet. There were no changes to these size, bag and boat limits in the recent review of the recreational fishery (PIRSA 2016b). Furthermore, for the commercial sector, extensive spatial and temporal netting closures and restrictions to net lengths and mesh sizes to limit fishing effort. No commercial harvest strategy has been developed for Yelloweye Mullet (PIRSA 2013).

Commercial Fishery Statistics

State-wide

Estimates of State-wide, annual commercial catch for Yelloweye Mullet increased to the highest recorded level of 175 t in 1990, before progressively declining to the lowest recorded catch of 12.5 t in 2016 (Figure 4-36). Most catch has been taken using hauling nets, with set nets making the second largest contribution. Annual estimates of total fishing effort that produced catches of Yelloweye Mullet were dominated by hauling nets. Total fishing effort declined from a peak of almost 8,000 fisher-days in 1984 to 600 fisher-days in 2009. Between 2009 and 2016, total effort has been relatively consistent.

Hauling net CPUE was relatively stable until increasing between 2003 and 2005 (Figure 4-36). It then remained high, increasing to a peak of 55 kg.fisherday^{-1} in 2011. Subsequently, it has decreased regularly to 22 kg.fisherday^{-1} in 2016. Set net CPUE showed greater fluctuation, initially increasing from the lowest recorded level in 1984 to a peak of 53 kg.fisherday^{-1} in 1994. Over the following decade, set net CPUE showed high interannual variability before generally declining between 2006 and 2016.

The number of fishers who reported taking Yelloweye Mullet declined over the long-term at a faster rate than the lower number that targeted this species until 2006. Over the last decade, the number of fishers who reported taking Yelloweye Mullet and the number who targeted the species have continued on a slow rate of decline.

Regional

Between 1984 and 1994, NGSV and SGSV provided the highest catches of Yelloweye Mullet. NSG was the third most significant region until 2003 when it became the most significant contributor. Since then, with only incidental catches have come from the other five regions (Figure 4-37). Catches in all regions were low during the 2000s. Historically, the fishery was seasonal, with catches generally concentrated between January and April. In 2016, the MSF fishers accounted for approximately 92% of the commercial catch, with the Southern Zone Rock Lobster fishers accounting for the remainder (Figure 4-37).

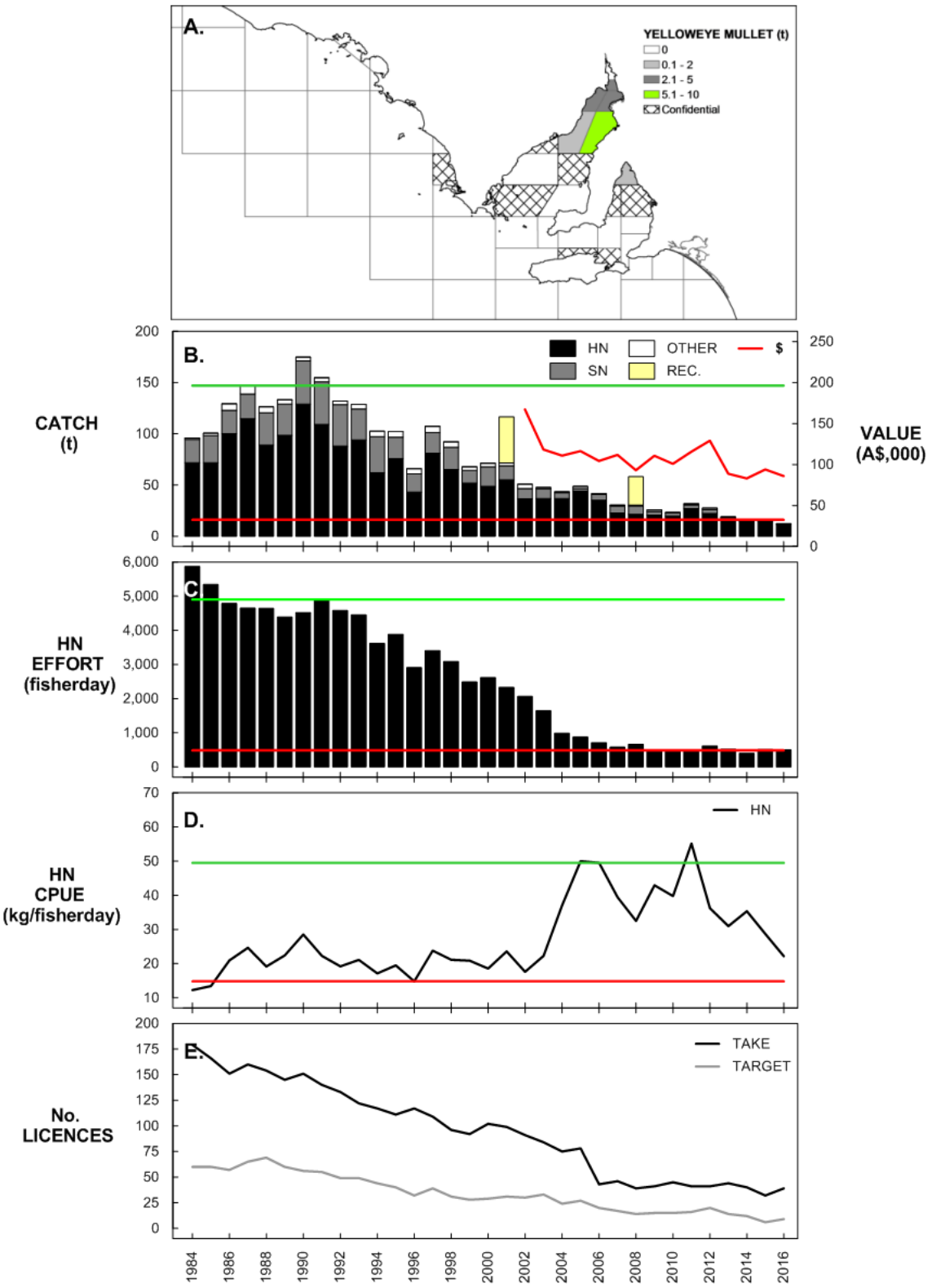

Figure 4-36. Yelloweye Mullet. (A) Catch distribution for 2016; Long-term trends in: (B) total catch for hauling and set nets and gross production value; (C) Long-term total effort for hauling and set nets; (D) total catch per unit effort for hauling and set nets; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5

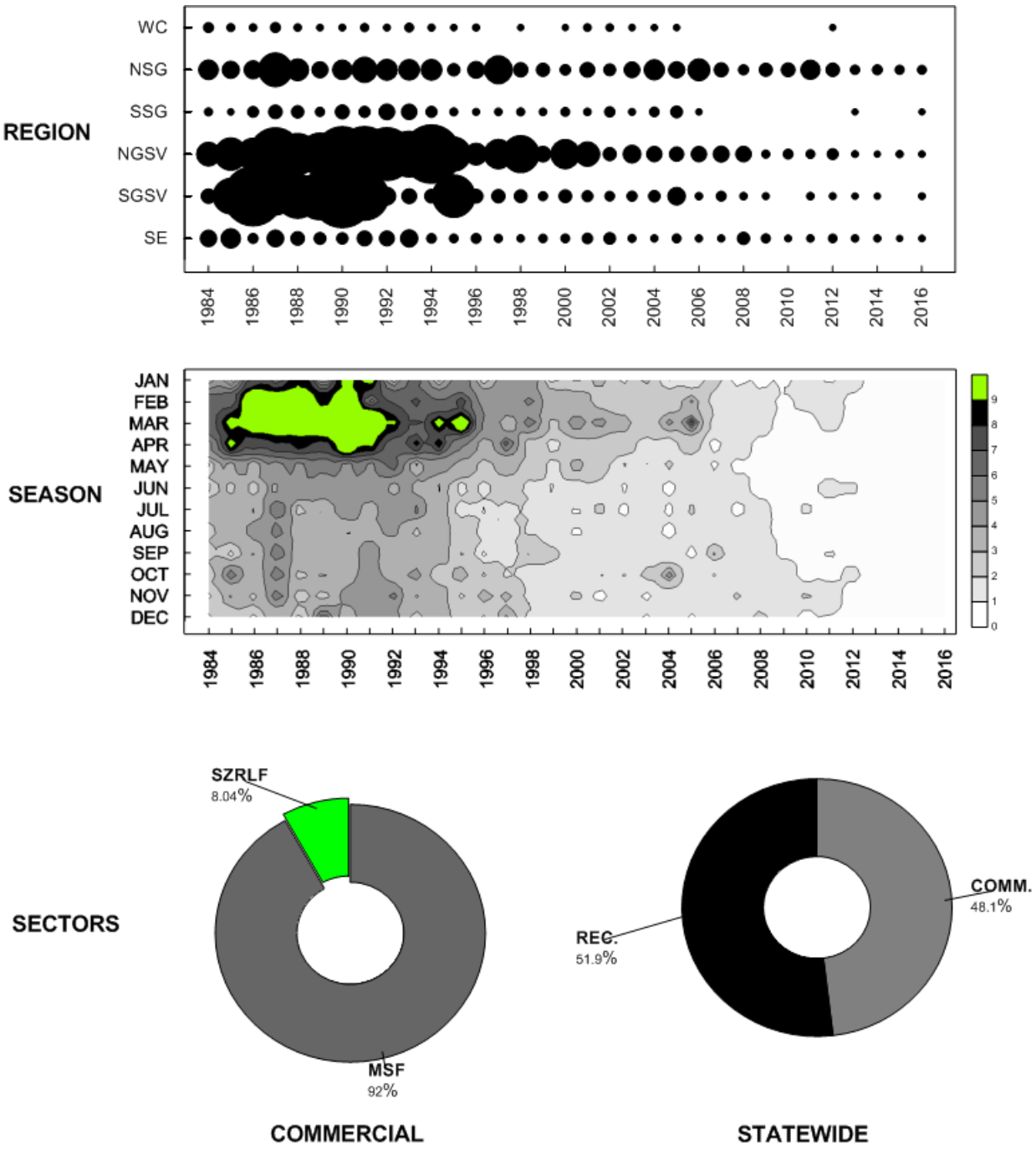

Figure 4-37. Yelloweye Mullet. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Yelloweye Mullet were assessed for 2016 at the State-wide scale. Two trigger reference points were activated (Table 4-13). Total catch in 2016 was the lowest recorded and declined over 5 consecutive years.

Table 4-13. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Yelloweye Mullet.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	LOWEST
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✓
TOTAL HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖
TOTALHAULING NET CPUE	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖

Stock Status

Yelloweye Mullet is predominantly taken as by-product within the hauling net sector when other species are targeted. As such, there have been consistently higher numbers of fishers who reported taking Yelloweye Mullet than those that targeted it. The overwhelming trend has been one of declining annual catches for Yelloweye Mullet. This largely reflects the significant declines in the effort in the hauling net sector of the Marine Scalefish Fishery. The long-term decline in fishing effort likely relates to the relatively low value of Yelloweye Mullet on the domestic market, rather than a declining biomass, as hauling net CPUE over recent years has been above the long-term average for the fishery. This information provides no evidence that the fishery is heading towards being recruitment overfished. On this basis, South Australia's Yelloweye Mullet fishery is currently classified as **sustainable**.

4.3.11. MULLOWAY (*Argyrosomus japonicus*)

Biology

Mulloway (*Argyrosomus japonicus*) is a member of the Sciaenidae family, i.e. Croakers and Drums (Gomon et al. 2008). It is found in subtropical to temperate regions of the Atlantic, Pacific and Indian Oceans including Australia, Africa, Pakistan, India, China, Korea and Japan (Silberschneider and Gray 2008). In Australia, Mulloway is an iconic species that is widely distributed from North West Cape, Western Australia, to the Burnett River, Queensland, excluding Tasmania (Kailola et al. 1993). It is a large, predatory, schooling species that inhabits estuaries and nearshore coastal waters to 200 m (Earl and Ward 2014). Mulloway demonstrates differential habitat preferences during different life stages. Early juveniles are found exclusively in estuaries, while older juveniles frequent both estuaries and nearshore coastal environments (including surf zones), and adults are predominantly found nearshore beyond the surf zone (Griffiths 1997).

Regional differences in otolith morphology and elemental chemistry suggest distinct populations along the eastern and western coasts of South Australia (Ferguson et al. 2014). Mulloway is a long-lived, late-maturing species that reaches a maximum age of 42 years and maximum length of 2000 mm TL. In South Australia, it reaches maturity at around 780 mm TL for males and 850 mm TL for females, or 5 years and 6 years of age, respectively (Ferguson et al. 2014). Mulloway is a group synchronous spawner, i.e. a cluster of eggs is developed and spawned simultaneously (Cabrita et al. 2008), and for which the spawning season extends from October to January each year (Ferguson et al. 2014).

Fishery

Mulloway is taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. In the commercial sector, this species is taken with multiple gear types. Set nets, fishing rods and handlines are the predominant gear types. In 2016, the Northern and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) reported only incidental catches.

Mulloway is considered an iconic recreational species and is targeted with rod and line. In 2013/14, the estimated number of Mulloway captured by the recreational sector was 47,238 of which 37,354 fish were released, leaving 9,833 fish harvested. The estimated total weight of these harvested fish was 59.5 t, significantly greater than the estimated commercial catch weight of 1.1 t (Giri and Hall 2015). As such, the recreational sector accounts for a high proportion of the total catch of this species (Giri and Hall 2015).

Management Regulations

Mulloway is permitted to be taken commercially by the MSF in all coastal waters except the Coorong estuary (PIRSA 2014). Multiple management regulations are used to ensure the long-term sustainable harvest of Mulloway. No specific commercial harvest strategy has been developed for Mulloway for the MSF (PIRSA 2013). For the commercial sector, temporal and spatial netting closures are used to manage fishing activity and effort. Restrictions to gear including net lengths and mesh sizes, and a minimum size limit of 820 mm TL was implemented in December 2016 for both sectors. For the recreational sector, a bag limit of 2 fish and boat limit of 6 fish applies in marine waters.

Commercial Fishery Statistics

State-wide

Total annual commercial catch of Mulloway by the Marine Scalefish Fishery was variable between 1984 and 2016 (Figure 4-38). Throughout the mid-1980s and early 1990s, total catch generally ranged from 10 – 15 t.yr^{-1}. Following this, annual catch increased to peak at 24.2 t in 1995 before declining to 6.5 t in 1998. Since then, it generally ranged from 6 – 8 t.yr^{-1} before dropping to a low level in 2008 and then to the lowest recorded level in 2016. This variation in total catch reflects fisher effort which showed two peaks during the mid-1980s and 1990s of approximately 1300 fisher-days.yr^{-1}, before generally declining from 1997 onwards. Since 1984, total catch and effort have been dominated by set net gear. Catch rates were relatively consistent for both gear types from 1984. While handline and pole CPUE remained consistent until 2016, set net catch rates have been highly variable since 2009. They increased significantly to 67 kg.fisherday^{-1} in 2012 before decreasing to 8.7 kg.fisherday^{-1} in 2014. In 2016, set net CPUE once again increased to 42.5 kg.fisherday.

The number of licence holders who reported taking Mulloway declined over the long-term at a faster rate than the lower number of fishers who reported targeting the species. While the former decreased from >50 fishers.yr^{-1} in the 1980s to 14 in 2016, the latter declined from 20 in 1985 to 4 licences in 2016 (Fig. 26.1). The higher numbers of fishers taking Mulloway compared to those targeting it suggests that for many fishers this species was taken as by-product when they fished for more valuable species.

Regional

Historically, catches of Mulloway have been reported from each of the six geographic regions of South Australia's marine waters (Figure 4-39). Between 1984 and 2003, SE provided the highest

catches of Mulloway, which peaked between 1994 and 1996. Since 2003, minor catches have been reported from all six regions.

Between 1984 and 1991, catches were primarily taken between November and March. However, during the mid-1990s when the SE produced the highest catches, they were taken throughout the year although concentrated in July, August and September. Following this, there has been no indication of seasonality.

In 2016, the commercial catch of Mulloway was dominated by the Marine Scalefish fishers, whilst the Southern Zone Rock Lobster fishers accounted for 4.81% and the Northern Zone Rock Lobster fishers 4.1% (Figure 4-39).

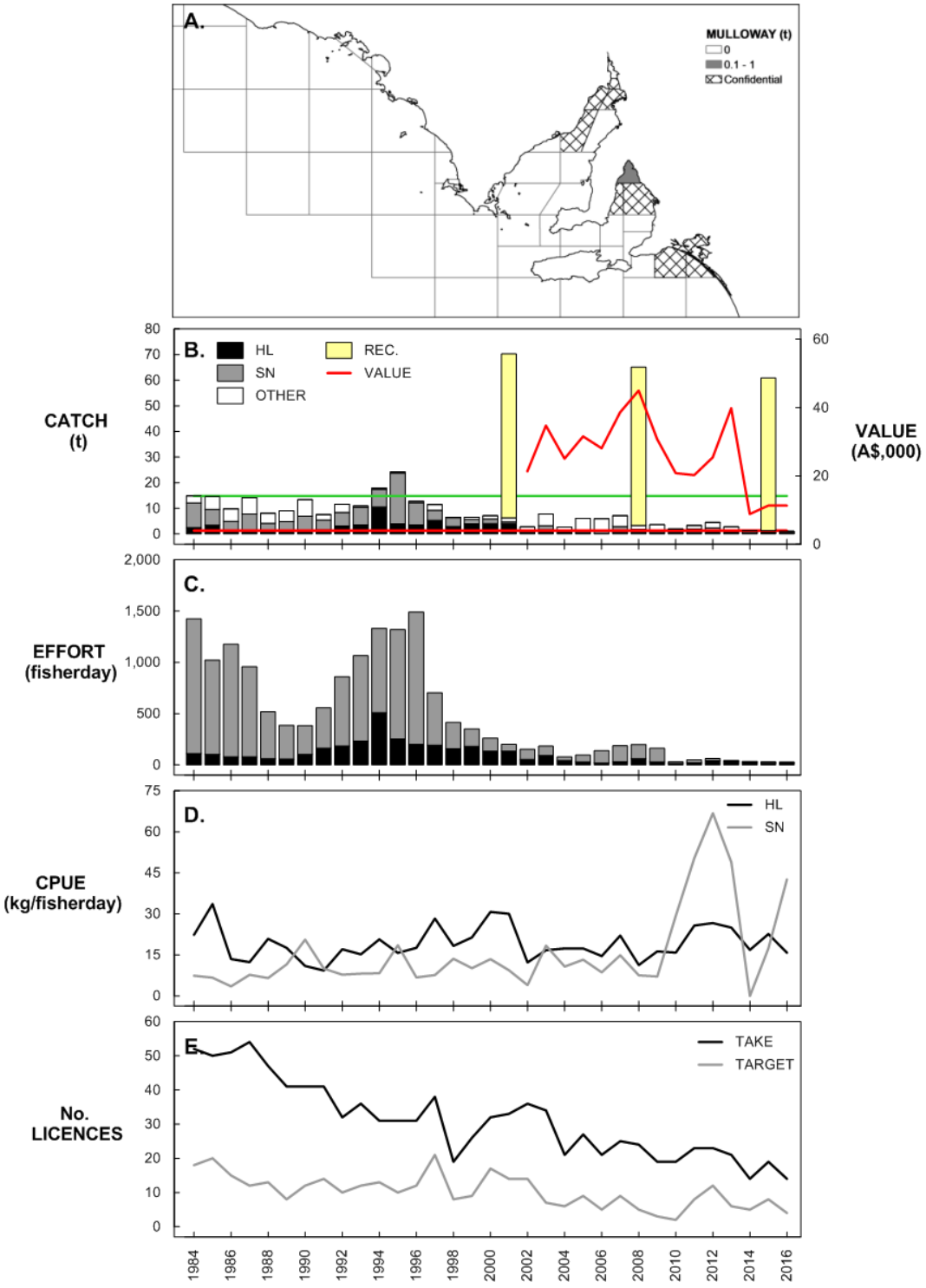

Figure 4-38. Mulloway (A) Catch distribution for 2016; Long-term trends in: (B) total catch for handline/pole and large/small set nets and gross production value; (C) Long-term total effort for handline/pole and large/small set nets; (D) total catch per unit effort for handline/pole and large/small set nets; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

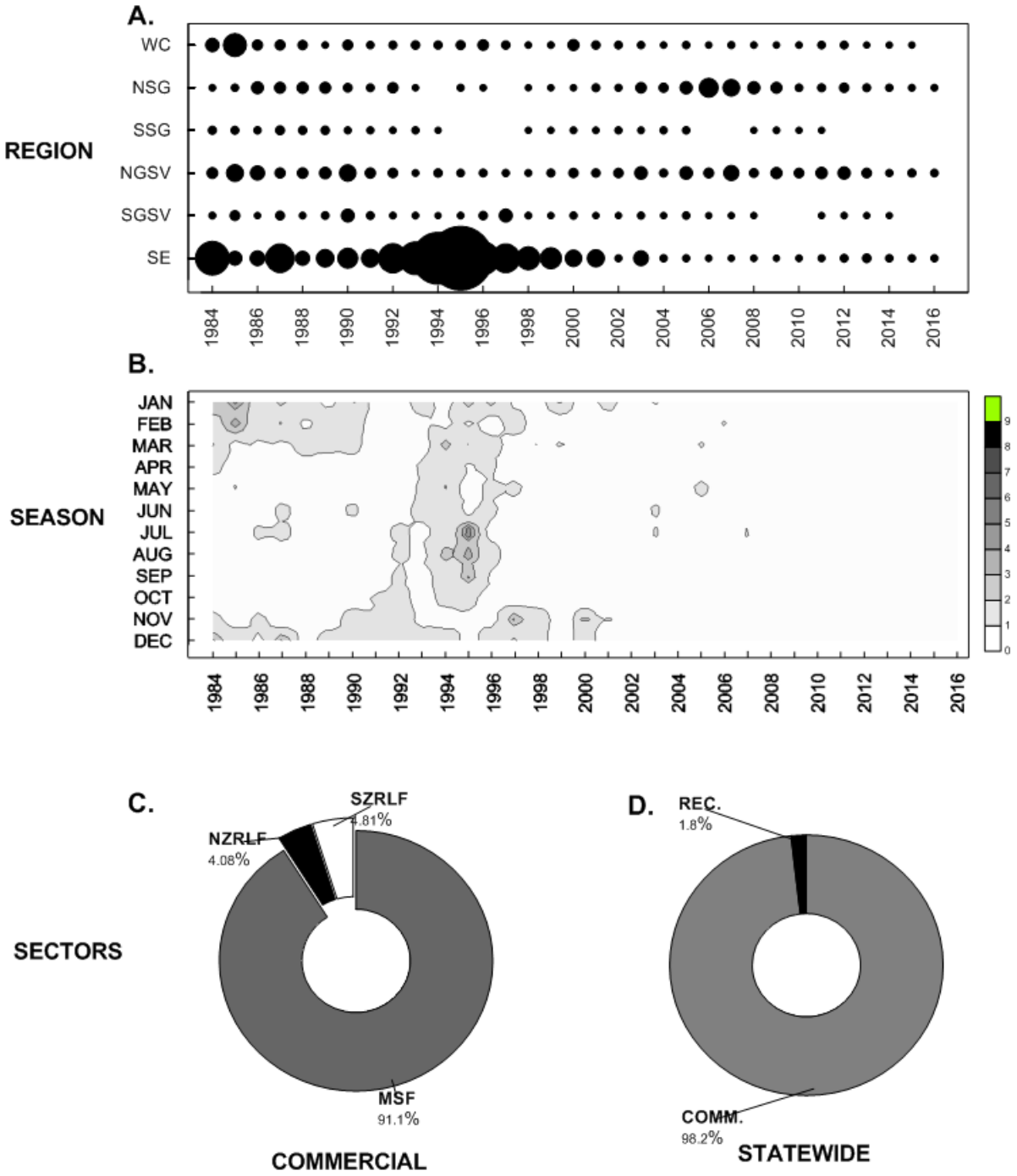

Figure 4-39. Mulloway. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Mulloway were assessed for 2016 at the State-wide scale. Two trigger reference points were breached (Table 4-14). Total catch in 2016 was the lowest recorded while total set net effort was the 2nd lowest recorded since 1984.

Table 4-14. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Mulloway.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	LOWEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL SET NET EFFORT	G	3rd Lowest / 3rd Highest	2nd LOWEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL SET NET CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Mulloway is of medium-high value but makes a relatively minor contribution to the commercial fishery's total production value. Whilst the species is taken as targeted catch, the higher numbers of fishers who reported taking Mulloway suggest it is taken predominantly as by-product. Total commercial catch of Mulloway has shown a long-term decline since the peak in the mid-1990s. This likely reflects the long-term reduction in fishing effort, rather than a decline in fishable biomass, as catch rates have generally remained consistent over the same period. These declines in catch and set net effort triggered two reference points. However, the very low recent catches, very low effort levels and generally stable CPUE provide no indication that the fishery is heading towards being recruitment overfished. On this basis, South Australia's Mulloway fishery is currently classified as **sustainable*.***

4.3.12. WHALER SHARKS

Biology

The term 'Whaler Shark' is a collective description of the Bronze Whaler (*Carcharhinus brachyurus*) and the Dusky Shark (*C. obscurus*) that both inhabit South Australian waters. The two species have sympatric distributions in southern Australia. They have similar morphologies and can be distinguished by subtle differences in dentition, body colour and morphology. Dusky Sharks have triangular serrated teeth, are dark brown-grey in colour and exhibit a defined ridge along the inter-dorsal section of their back, whereas Bronze Whalers have narrow non-serrated teeth, are copper coloured and lack a dorsal ridge (Jones 2008).

The Bronze Whaler has a patchy cosmopolitan distribution and is targeted by commercial and recreational fisheries throughout its Australasian range (Francis 1998; Rogers et al. 2013). Ageing studies indicate that females live longer than males, reaching 31 years compared with 25 years. Despite differences in longevity, both sexes mature at a similar age (16 years). Their growth rates differ with males attaining sexual maturity at 2240 mm TL, considerably smaller than for females (2700 mm TL) (Drew et al. 2016). Analysis of mitochondrial DNA indicated that Australian populations are genetically isolated from those inhabiting other southern hemisphere ocean-basins (Benavides et al. 2011).

Research on Dusky Shark in Western Australian (WA) State waters (Simpfendorfer and Donohue 1998), include studies of the population demographics (Simpfendorfer, 1999), and dietary dynamics (Simpfendorfer et al. 2001). Past studies also used tag-recapture data to determine the growth rates of neonates and juveniles (Simpfendorfer et al. 2000), and demographic data to assess the impacts of fishing mortality in WA waters (McAuley et al. 2007; Kinney and Simpfendorfer 2009). Satellite tagging of large juveniles (>2000 mm) showed there was migratory-mediated connectivity during autumn between the coastal and shelf waters of southern WA and the Indian Ocean and Spencer Gulf (Rogers et al 2012).

Fishery

In Australia, the largest proportion of the commercial catch of the Bronze Whaler is taken in the MSF in SA-managed waters. The fishery mainly targets these species during spring–autumn (October to May) (Rogers et al. 2013; Fowler et al. 2014). Contributions of the two species to the MSF are spatially and temporally variable, but are dominated by juvenile Bronze Whalers. Juvenile Dusky Sharks were estimated to represent <10% of the commercial catch in SA waters (SAFS, 2016). Given that the stock of Dusky Shark is mostly distributed off WA, and catches have

historically been several times higher than those in the other jurisdictions, its stock status is determined from stock assessments undertaken in the WA management jurisdiction.

The fishery for these species is reliant on access to two seasonally mobile and/or highly migratory stocks (Rogers et al. 2012; 2013). The commercial fishery predominantly targets Whaler Sharks from vessels in Spencer Gulf, Gulf St Vincent and the West Coast in spring–autumn. Recreational tag-recapture data collected by the NSW Game-Fish Tagging Program shows the recreational fishery is subject to the same pattern of availability of Whaler Sharks, i.e., during spring–autumn (Jones 2008, Rogers et al. 2013). Whaler Sharks are a desirable game fishing target species by recreational anglers. These species are targeted from vessels, metropolitan and regional jetties, rock shore-lines and beaches. A small number are captured in the SA Charter Fishery.

Management Regulations

The take of Whaler Sharks in the MSF is subject to management input controls on longlines, set nets, drop lines and handlines. Controls include limits on the daily number of hooks that can be set (n = 200), limits on leader diameter (2 mm) on longlines, and mesh size restrictions (150 mm) on bottom set gill nets. There are currently no individual quota, trip limit restrictions, or minimum legal length for Whaler Sharks in the MSF.

Recreational fishery regulations include a daily bag limit of one shark per person, which was introduced as part of the 2016 review. The daily boat limit is three sharks when three or more people may be on-board.

Commercial Fishery Statistics

State-wide

In 2016, the total State-wide commercial catch of Whaler Sharks was 49.6 t, which was the fourth consecutive year when catches were below 60 t (Figure 4-40). Prior to this, annual catches have frequently exceeded 90 t which peaked at 121.1 t in 2010. There has been a clear switch in fishing practices, whereby historically the majority of the catch was landed by set nets, which accounted for up to 85% of the catch in the mid-1980s. Since 2001, longlines have been the dominant gear type and by 2010 accounted for approximately 90% of the annual catch. Set nets were virtually eliminated by 2010, and the remaining 10% of catch was predominantly landed by drop and handlines.

Target longline fishing effort for Whaler Sharks had increased steadily from >100 fisher-days in 1993 to a peak of 535 days in 2010 (Figure 4-40). Since then there has been a marked decline

to 156 fisher-days in 2016. Lower catch rates were reflected in the declining gross production value, dropping from approximately A$473,400 in 2010 to A$187,500 in 2016. Despite, the recent declines in both total longline annual catch and targeted effort, targeted catch rates have remained relatively stable at approximately 140 kg.fisherday^{-1}. Overall these catch rates are relatively high and are approximately twice as high as those observed in the 1990s, but approximately 40 kg.fisherday^{-1} less than the peak catch rates observed in 2001. Approximately 40% of fishers that take Whaler Sharks have actively targeted them over the past 15 years.

Regional

Throughout the 1980s and 1990s, most of the commercial catch of Whaler Sharks was landed in the West Coast region, however since 2002 a greater proportion has been taken from Southern Spencer Gulf (Figure 4-41). Although Whaler Sharks are caught throughout the year, the fishery displays strong spring/summer seasonality. In 2016, MSF licence holders accounted for >95% of the catch with the remaining 5% predominantly landed by the NZRLF licence holders.

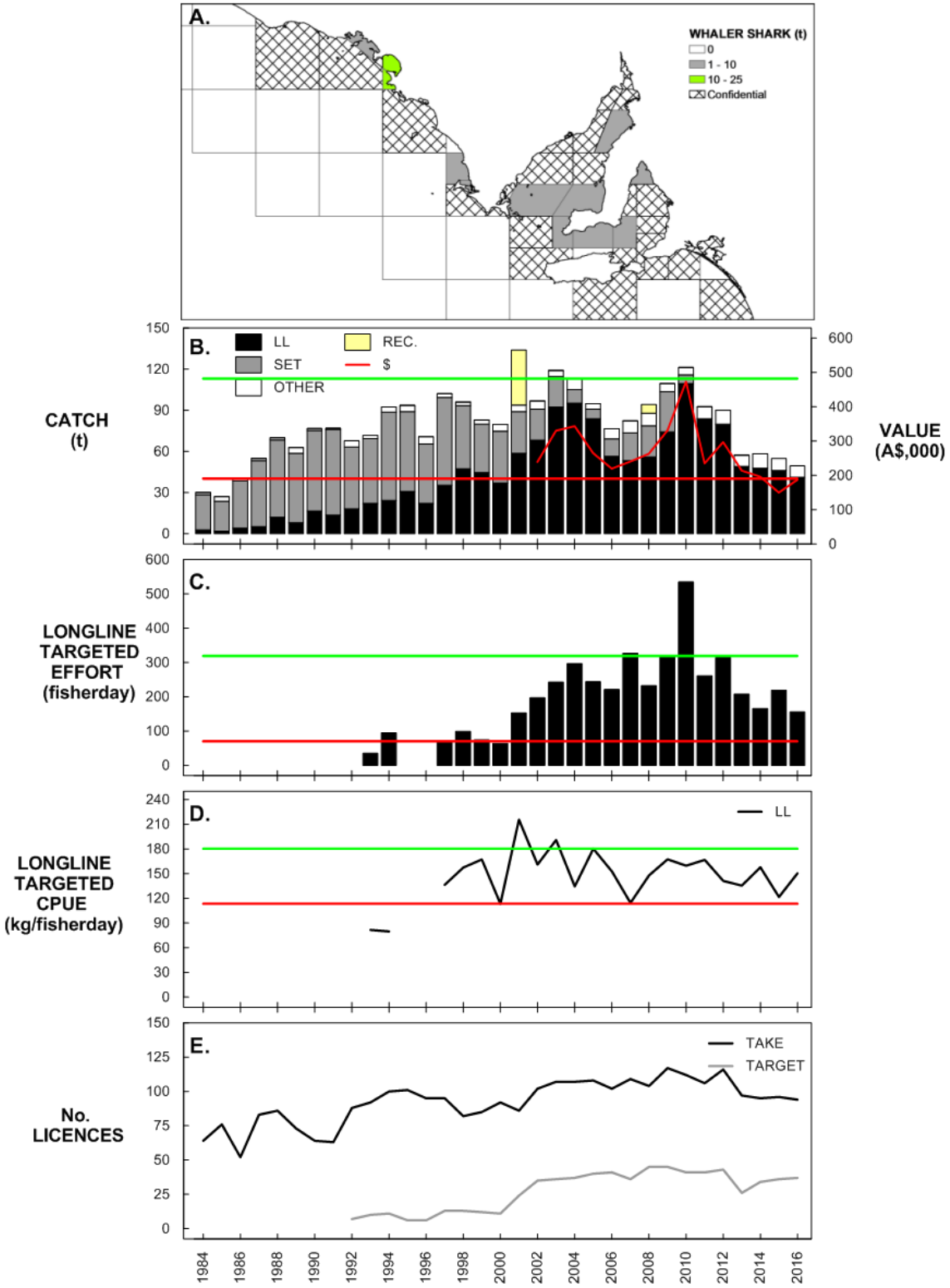

Figure 4-40. Whaler Shark (A) Catch distribution for 2016; Long-term trends in: (B) total catch for longline and set net and gross production value; (C) Long-term targeted effort for longline; (D) targeted catch per unit effort for longline; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

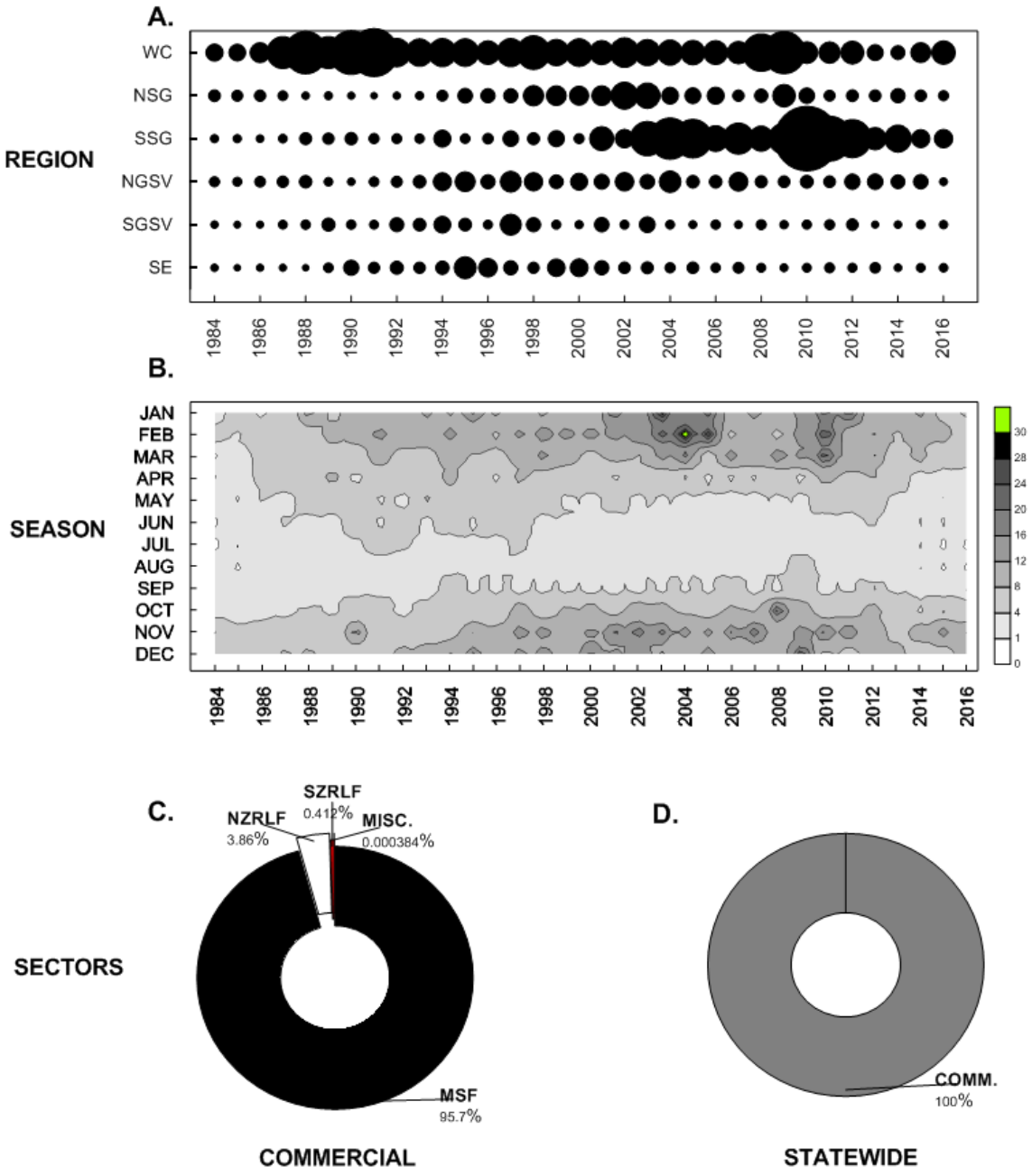

Figure 4-41. Whaler Shark. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Whaler Sharks were assessed for 2016 at the State-wide scale. No trigger reference points were breached (Table 4-15).

Table 4-15. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Whaler Shark.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGETED LONGLINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGETED LONGLINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

The mixed reporting of the two Whaler Shark species within the MSF catch returns complicates the assessment of the stocks, however the South Australian catch is assumed to be weighted towards Bronze Whalers (Jones 2008). Stock assessments have not been undertaken for Bronze Whalers due to insufficient biological and fishery data and has consequently been classified as 'undefined'. The cross-jurisdictional western Australian Dusky Shark biological stock, which is shared among the Western Australian, South Australian and Commonwealth managed fisheries has been classified as transitional-recovering (Braccini et al. 2015). This classification was based on demographic modelling, estimates of fishing mortality through tagging studies and catch and effort trends. The most recent assessment indicated that catches of juvenile Dusky sharks in the targeted fisheries have been stable since the mid-1990s (Simpfendorfer 1999, McAuley 2005).

Relatively stable trends in longline targeted catch rates for Whaler Sharks, in association with declining effort levels, provide no evidence that the fishery is heading towards being overfished. However, due to the fundamental need to differentiate the two species within the fishery and the requirement for improved biological data (i.e. age and size at maturity) to provide estimates of mortality and exploitation rates, the status of South Australian Whaler Shark fishery is classified as **undefined**.

4.3.13. OCEAN JACKETS (*Nelusetta ayraudi*)

Biology

The Ocean Jacket (*Nelusetta ayraudi*) is the largest species of leatherjacket of southern Australia that can reach 700 mm in length (Gomon et al. 2008). It is a demersal, schooling species that is distributed from central Queensland southwards, along the southern coastline and continental shelf and then up to the central coast of Western Australia (Kailola et al. 1993, Gomon et al. 2008). The species occurs across a broad depth range from very shallow to >350 m, due to off-shore movement associated with ontogenetic development. The juveniles occur in shallow, coastal bays whilst the adults are located over flat, sandy bottom in off-shore, continental shelf waters >60 m in depth (Grove-Jones and Burnell 1991). Stock structure throughout the broad distribution is unknown, but must be influenced by off-shore, ontogenetic migration, and capacity of adults for significant long-distance movement (Grove-Jones and Burnell 1991).

This is a dichromatic species of leatherjacket that is fast-growing and short-lived, as determined from ageing work based on rings in vertebrae (Grove-Jones and Burnell 1991). Most fish aged from the commercial fishery were 3 – 6 years of age, whilst the oldest male was seven years and oldest female was nine years old (Grove-Jones and Burnell 1991). Reproductive maturity was attained from 2 – 4 years of age, associated with size-at-first-maturity of 310 mm, and corresponded with the timing of off-shore migration. In South Australia, spawning occurs in April and early May in waters >85 m depth in off-shore waters.

Fishery

Because adult Ocean Jackets occur in deep, off-shore waters, the fishery is essentially a commercial one, although juveniles are likely to be taken incidentally by recreational fishers in shallow, near-shore coastal waters (Grove-Jones and Burnell 1991). The commercial fishery commenced in 1984/85 in continental shelf waters off Streaky and Venus Bays on Eyre Peninsula. It commenced as, and has remained a targeted, baited fish trap fishery. The catches rose very quickly until 1988/89, as new entrants came into the fishery and the geographic range of fishing activity spread throughout the Great Australian Bight (Grove-Jones and Burnell 1991). At that time, discussions commenced about regulating the fishery to control this expansion and to prevent catches from exceeding the long-term sustainable yield. As a result, regulations were introduced to: restrict access to Ocean Jackets to a limited number of MSF fishers; reduce the numbers of

fish traps per license; and regulate the dimensions of the fish traps (Grove-Jones and Burnell 1991). These regulations largely curtailed the expansion of the fishery.

Management Regulations

There are defined regulations for Ocean Jacket traps that differ from those for fish traps, as specified on the fishery licenses. Currently there are four MSF licenses with Ocean Jacket trap endorsements. Each license holder has access to 20 traps, equating to a total of 80 Ocean Jacket traps that can be used by the South Australia's MSF. Such traps can only be used in depths >60 m, and to target Ocean Jackets. Other fish traps can only be used in waters <60 m depth to target any species. As such, such traps can be used to take Ocean Jackets in these shallower waters catches.

Commercial Fishery Statistics

State-wide

The reported catch for Ocean Jackets in 1990 was 930 t (Figure 4-42). This related to a total fishing effort of 2,095 fisher-days by 11 license holders, and a relatively high fish trap CPUE of 444 kg.fisherday^{-1}. In the following few years, catch and effort increased to their maxima. Total catch was highest in 1991 at 977 t, whilst effort was highest in the following year at 3,103 fisher-days, of which most related to fish traps. Total catch and effort declined in 2000 before stabilising for several years. Catch and effort have subsequently declined to and remained at low levels. Nevertheless, there were noticeable increases in catch and effort in 2016. Also, since 2008, the numbers of fishers who took and targeted Ocean Jackets in each year have varied around five. CPUE for fish traps has been variable, shown a number of modes, ranged between 196 and 489 kg.fisherday^{-1}, but nevertheless showed no long-term trend. There was a considerable increase in fish trap CPUE between 2013 and 2016 from 199 to 424 kg.fisherday^{-1}.

Regional

Two regions have contributed the most to catches of Ocean Jackets in South Australia. High catches reported from the 'Other' region between 1989 and 1998 came from MFAs 37, 38, and 39, located off-shore from southern Eyre Peninsula (Figure 4-43). Subsequently, these declined to moderate to low levels. Very high catches were reported from the WC MFAs 24, 25, and 26 between 1989 and 1993. Catches declined before increasing to high levels again between 1998 and 2007. After this, they declined back to moderate levels before increasing again in 2015 and 2016. There have only ever been incidental catches of Ocean Jackets reported from the gulf regions and the SE.

Throughout the higher catch years between 1989 and 2006, commercial catches of Ocean Jackets were distributed throughout the year, although the highest catches were from September to March.

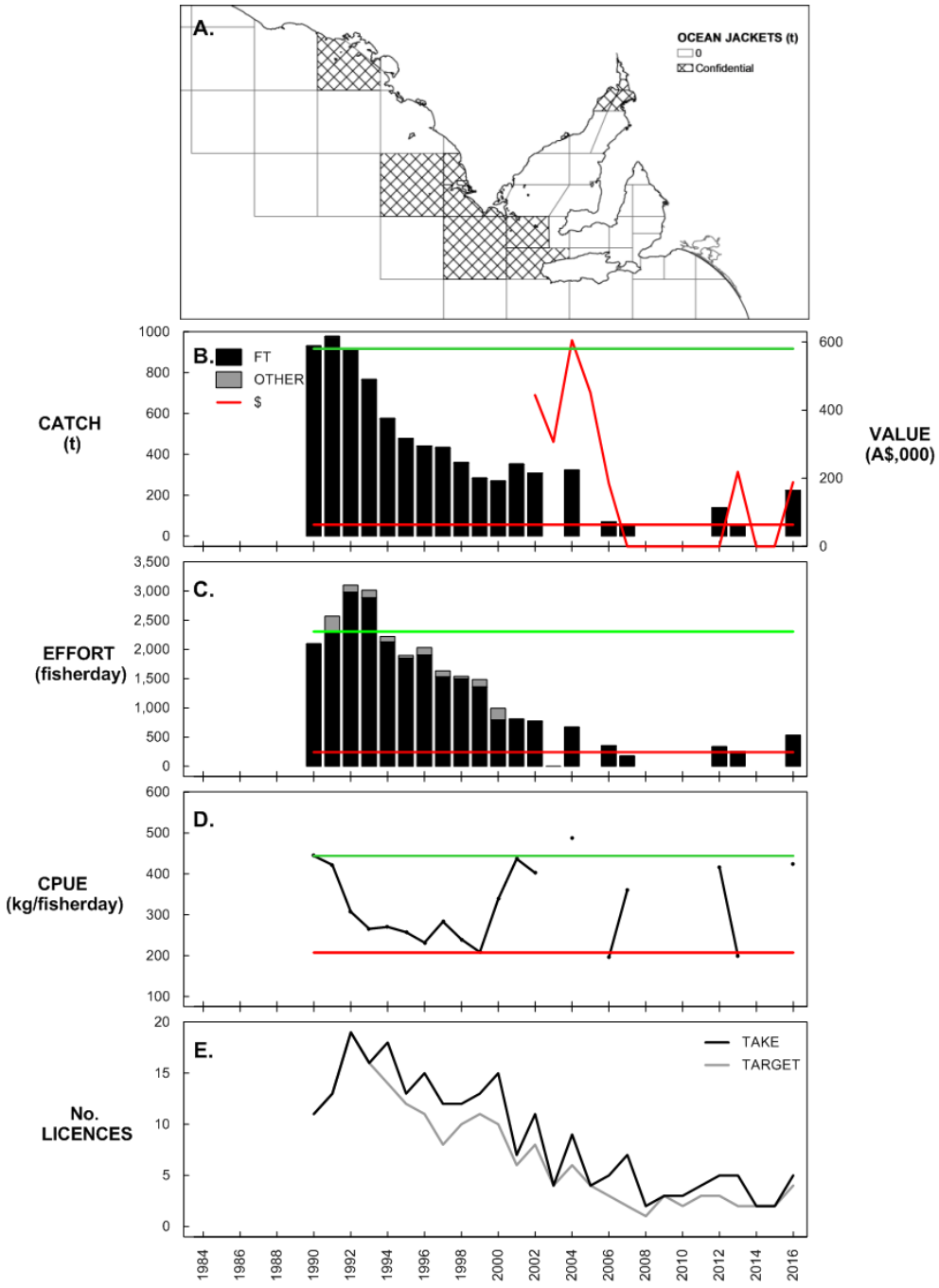

Figure 4-42. Ocean Jacket (A) Catch distribution for 2016; Long-term trends in: (B) total catch and gross production value; (C) Long-term targeted effort; (D) targeted catch per unit effort for fish trap; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

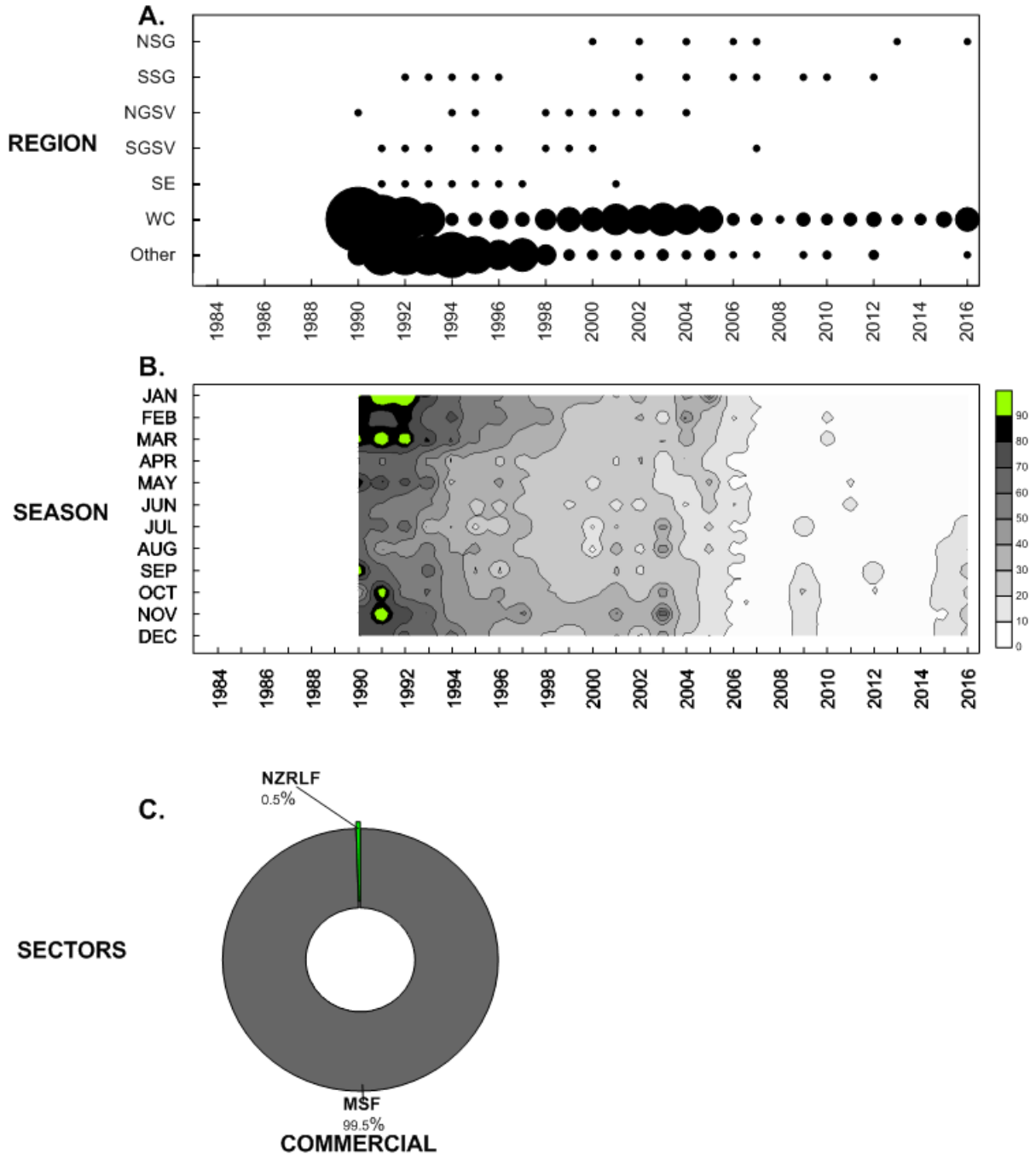

Figure 4-43. Ocean Jacket. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C).

Fishery Performance

The general fishery performance indicators for Ocean Jackets were assessed for 2016 at the State-wide scale. No trigger reference points were activated (Table 4-16).

Table 4-16. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Ocean Jacket.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET FISH TRAP EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TARGET FISH TRAP CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

The Ocean Jacket fishery developed very quickly between 1984 and 1988 with an exponential increase in total annual catch, reflecting increasing effort through new entrants into the fishery and geographic expansion (Grove-Jones and Burnell 1991). The fast rate of fishery development caused concerns about sustainability, which soon led to the introduction of regulations to limit the numbers of fishers and fishing effort. As a result, the fishery attained its highest productivity in the early 1990s. Since then, the fishery statistics have been dominated by declining levels of catch, effort, and numbers of specialist fishers. These declines are also likely to relate to the perception that developed early amongst some fishers that the Ocean Jacket fishery was not worthwhile due to the marginal economics associated with high fishing costs relative to low price in return (Grove-Jones and Burnell 1991).

In 2016, no limit reference points were activated that would raise concern for the fishery. The relatively low fishery catches, low level of targeted fishing effort and the long-term lack of decline in catch rates are not consistent with a stock that is becoming recruitment limited. As such, South Australia's Ocean Jacket fishery is classified as **sustainable**.

4.3.14. BLUETHROAT WRASSE (*Notolabrus tetricus*)

Biology

There are several species of temperate wrasse (family: Labridae) that occur in South Australian waters (Gomon et al. 2008, Shepherd and Baker 2008). They are generally colourful species that are associated with shallow, near-shore reef habitats, making them particularly vulnerable to fishing activity. Only one of these species, i.e. the Bluethroat Wrasse (*Notolabrus tetricus*) is recognised as a legitimate commercial species for the MSF (PIRSA 2013). Nevertheless, historically some or all of the other species have been taken by commercial fishers. Collectively they have been reported as Bluethroat Wrasse. Consequently, it is not possible to differentiate the fishery statistics amongst species, although it is likely that since the Bluethroat Wrasse is the most abundant species, it has historically dominated the fishery catches (Saunders et al. 2010).

Bluethroat Wrasse is the largest of the labrids, reaching a maximum size of 420 mm TL (Gomon et al. 2008). Its distribution includes the coastal waters of New South Wales, Victoria, Tasmania and extending as far west as central South Australia (Gomon et al. 2008, PIRSA 2016). It occupies algal beds and reefs through the depth range of 0 – 50 m, with fish size increasing with depth. It is a significant predatory species on benthic invertebrates that include crustaceans and molluscs (Shepherd and Baker 2008).

Bluethroat Wrasse are highly territorial and display long-term residency of their home-ranges (Barrett 1995, Shepherd and Baker 2008). Their strong site attachment is associated with their complex social structure and reproductive biology. The species is a monandric, sequential, protogynous hermaphrodite, i.e. the adult males only originate through sex change from a female fish (Smith et al. 2003). The social structure is based around the male that defends a territory which includes a harem of numerous females that have overlapping home ranges. This social structure is size-dependent, i.e. if the male is removed, its hierarchical position is quickly replaced by the largest female which then transitions into the territorial male over a period of a few weeks. This complex social and reproductive strategy complicates managing the fishery to ensure sustainability, because of concerns about localised depletion and the need to maintain sufficient males in the population to ensure reproductive output (Shepherd et al. 2010).

Fishery

Because Bluethroat Wrasse and the other temperate wrasse species inhabit nearshore, shallow waters, they are particularly vulnerable to line fishing by both the commercial and recreational sectors of the MSF. For the commercial sector there is a relatively small targeted fishery for which

the captured fish are sold either as fresh, ice-slurried product or as 'live fish' to the Sydney Fish Market. Alternatively, they are captured as by-product when other more valuable species are targeted. As such, there are considerable discrepancies between the numbers of fishers who report taking Bluethroat Wrasse, and those who actually target it.

For the recreational sector, Bluethroat Wrasse is not a prized target species. Rather, they are often taken as by-catch when more desirable species are targeted, which can result in a high discard rate. In 2013/14, there was an estimated 22,073 Bluethroat Wrasse captured by the recreational sector, of which 68.7% were released (Giri and Hall 2015). No estimated harvest weight was provided.

Management Regulations

Prior to December 1st 2016 there was no size limit nor were there recreational bag and boat limits for the Bluethroat Wrasse. In the review of the recreational sector undertaken in 2016, there was concern about size-selective harvesting that related to its hermaphroditic reproductive mode (PIRSA 2016). In response, a slot limit of 250 – 350 mm TL was introduced in order to maintain some males in the population to ensure the reproductive output. Given the complexity in identifying Bluethroat Wrasse, regulations apply to all wrasse species with the exception of Blue Groper. Also, a bag limit of 5 fish and boat limit of 15 fish was introduced for the recreational sector.

Commercial Fishery Statistics

State-wide

Between 1984 and 1996, the reported commercial catch of Bluethroat Wrasse was relatively low at <10 $t.yr^{-1}$ (Figure 4-44). In 1997 it increased considerably and remained at >20 $t.yr^{-1}$ until 2004. Since then it has generally been <20 $t.yr^{-1}$, with considerable decline between 2012 and 2016. The total catch of 13.6 t in 2016 was close to the lowest since 1996. Up to 2004, the catch was dominated by that taken on handlines. Subsequently, the proportion taken on longlines increased considerably. By 2016, handlines and longlines each accounted for approximately 50% of total catch.

Between 1984 and 1991, total line effort was low, before it increased considerably up to 1997. Since then it has been highly variable (Figure 4-44). From 2005, the proportion of total line effort taken by longlines has increased considerably. In 2010, the highest level of effort and the highest proportional contribution from longlines were recorded. Since 2012, effort has declined, as has the proportional contribution from longlines. Between 1984 and 1996, total line CPUE was low,

before it increased up to 2000. Over the following nine years there was a gradual decline in CPUE before it stabilised between 2009 and 2016.

Since 1984 there has been a considerable disparity between the high numbers of fishers who reported taking Bluethroat Wrasse and those who targeted it (Figure 4-44). The former increased up to 2013, after which there has been some decline. The numbers who targeted this species have been relatively constant since 1997.

Regional

Since 1997, the WC has provided the highest catches of Bluethroat Wrasse with SSG as the next most significant region, and only incidental catches from the other four regions (Figure 4-45). Furthermore, catches have not been concentrated in any season but have been distributed throughout the year. In 2016, the MSF fishers accounted for approximately 95% of the commercial catch, with Rock Lobster fishers accounting for the remainder (Figure 4-45). There was no estimate of the total weight of the recreational catch from 2013/14 to compare against that from the commercial sector (Giri and Hall 2013).

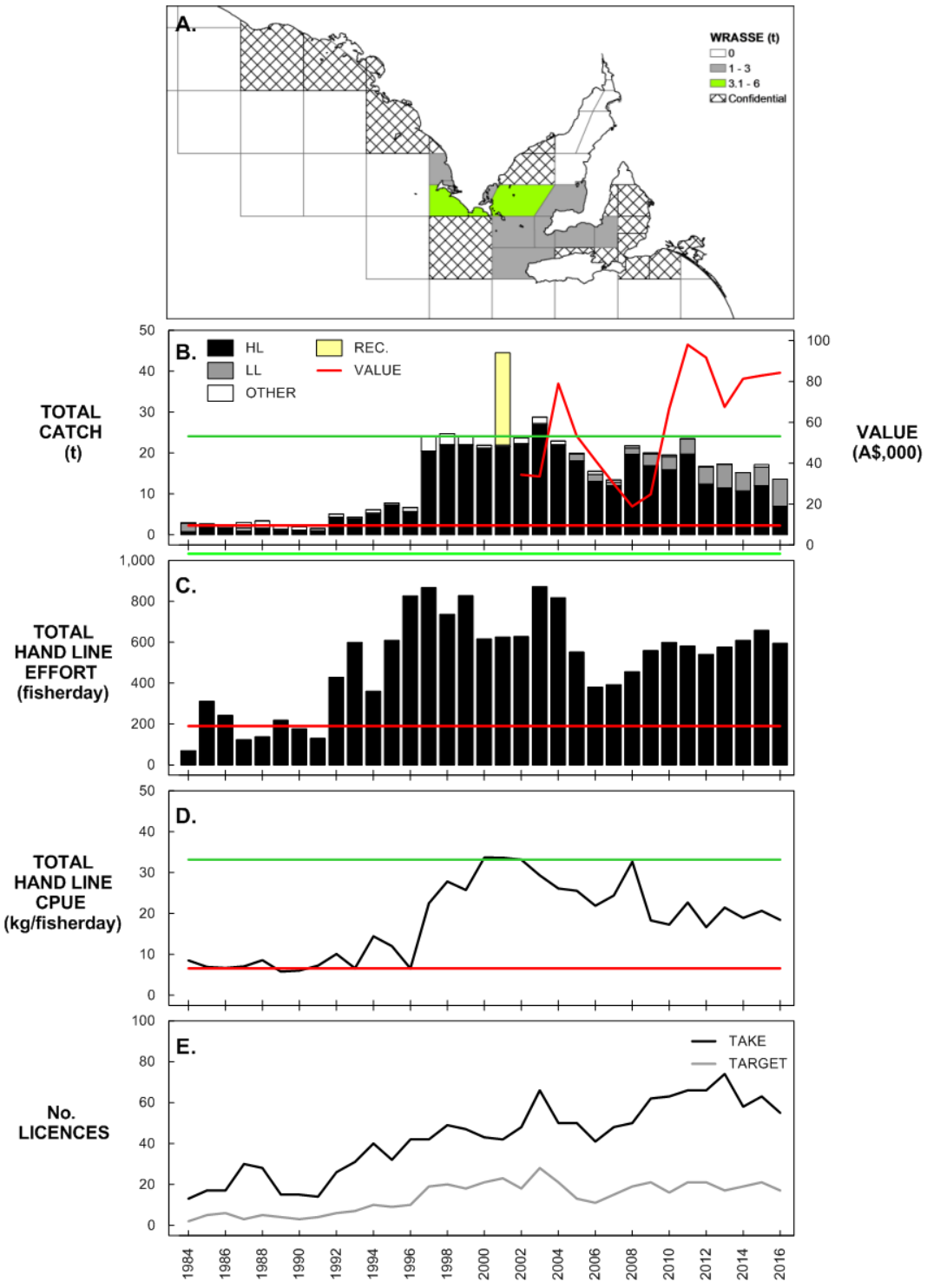

Figure 4-44. Bluethroat Wrasse (A) Catch distribution for 2016; Long-term trends in: (B) total catch for handline and longline and gross production value; (C) Long-term total effort for handline; (D) total catch per unit effort for handline; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

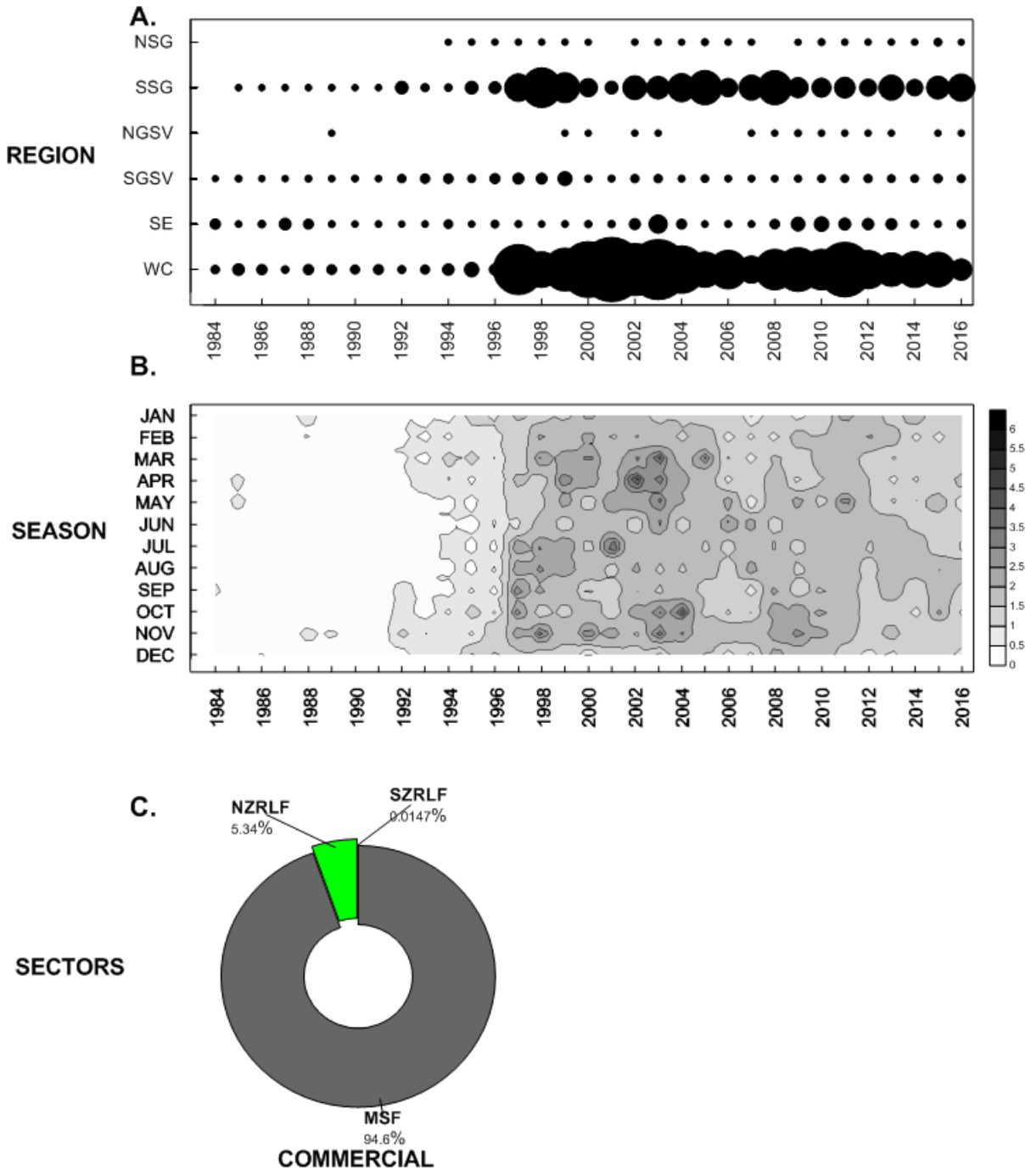

Figure 4-45. Bluethroat Wrasse. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Bluethroat Wrasse were assessed for 2016 at the State-wide scale. No trigger reference points were activated (Table 4-17).

Table 4-17. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Bluethroat Wrasse.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

There is a small targeted fishery for the Bluethroat Wrasse with the product directed towards the live fish trade, which accounts for considerable proportions of the annual total catches. The remaining catch is taken as by-product when other more valuable species are targeted. The tendency towards higher longline catches after 2004, might reflect the development of the longline fishery for Snapper in Southern Spencer Gulf. The later decline in longline effort that produced catches of Bluethroat Wrasse may well correspond with the decline in the Snapper fishery that occurred in that region.

Total catch of Bluethroat Wrasse has declined since 2009, corresponding with declining longline effort. During this time, annual catch rates have been relatively stable at medium levels. They are considerably lower than the high catch rates recorded through the peak period of the early 2000s, but nevertheless much higher than the low levels of the 1980s and 1990s. There were no trigger reference points breached for 2016. The medium-level recent catches and stable catch rates provide no evidence that the fishery is heading towards being recruitment overfished. On this basis, SA's Bluethroat Wrasse fishery is currently classified as **sustainable**.

4.3.15. SILVER TREVALLY (*Pseudocaranx georgianus*)

Biology

There has been confusion around the taxonomy of the species of the Carangidae family that inhabit southern Australia. Historically, *Pseudocaranx georgianus* was regarded as part of the widely distributed, anti-tropical species *Pseudocaranx dentex*, but it is now considered a separate species (Gomon et al. 2008). This species is thought to be distributed from around Coffs Harbour in northern New South Wales (NSW) to Perth in Western Australia (Stewart 2015). It is a schooling species that occupies estuarine and coastal waters, occurring over sandy substrata where it feeds on benthic and pelagic invertebrates.

Very little research has been undertaken on the population biology of Silver Trevally in South Australian waters. A preliminary investigation into otolith interpretation for ageing proved unsuccessful (Saunders et al. 2010). However in NSW, which provides most of the Australian catch, it has been shown to be a relatively long-lived, slow-growing species that can live up to 25 years (Stewart 2015), and even to 33 years in New Zealand waters (Langley 2004). They have an extensive reproductive season between spring and autumn, with the larvae occurring in coastal waters, which may enter estuaries before settling out as juveniles.

Fishery

Silver Trevally are taken by both the commercial and recreational sectors of the MSF. The commercial catches have been dominated by the MSF fishers, with only incidental catches reported by the Northern and Southern Zone Rock Lobster fishers. The commercial catches have been taken with a diversity of netting and line gear types, particularly handlines and longlines.

The recreational catch is taken by rods and lines and is substantial relative to the commercial catch. In 2013/14, the estimated number of Silver Trevally captured by the recreational sector was 73,924 of which 57,140 were harvested. The estimated total weight of these harvested fish was 14.6 t (Giri and Hall 2015).

Management Regulations

For Silver Trevally there is a minimum legal size limit of 240 mm TL that applies for both sectors (PIRSA 2014, PIRSA 2016). Furthermore, for the recreational sector there is a bag limit of 20 fish and a boat limit of 60 fish. These size, bag and boat limits were not changed during the recent review of the management regulations for the recreational sector (PIRSA 2016).

Commercial Fishery Statistics

State-wide

Total annual catch of Silver Trevally has been quite variable ranging from 2.1 t in 1985 to 21 t in 2000 (Figure 4-46). The period of lowest catches was from 1984 to 1991. Since then, they have generally ranged from 5 – 15 $t.yr^{-1}$, except for the exceptional catch taken in 2000. Recent catches have been at medium levels. Since 1992, the catches have been dominated by those taken with line gear types, as distinct from net catches.

Line fishing effort that produced catches of Silver Trevally has varied in phases (Figure 4-46). The 1980s was a period of low effort. It increased through the 1990s, attained a maximum in 1993, before declining to a minimum in 2001. Since then it has gradually risen to a high of 833 fisher-days in 2015, before declining considerably to 571 fisher-days in 2016. Line CPUE has shown no long-term trend. The exceptional catch in 2000 was associated with a catch rate that was considerably greater than taken in any other year. Catch rate has been relatively steady since 2004. In 2016 it was 11 $kg.fisherday^{-1}$.

Between 1984 and 2016, there has been a considerable difference between the numbers of license holders who take Silver Trevally compared with those who target this species. The former have often been >50 $fishers.yr^{-1}$, whilst the latter have generally been <10 $fishers.yr^{-1}$ (Figure 4-46). This suggests that for many fishers Silver Trevally was taken as by-product when they fished for more valuable species.

Regional

Some catch of trevally has been reported from each of the six regions in every year since 1984, except for a few years during the 1980s for NSG when there was no catch (Figure 4-47). Since 2000, the highest catches have been taken from SSG, with SGSV the second most significant region producing considerably lower catches. Through this period the catches were concentrated in May, June and July. However, during the 1990s, when SGSV was producing the highest catches, they were primarily taken during September, October and November.

In 2016, the commercial catch was dominated by the Marine Scalefish fishermen, with the Northern Zone Rock Lobster fishers accounting for <1% of the catch (Figure 4-47). In 2013/14, the recreational sector accounted for the higher proportion of the catch.

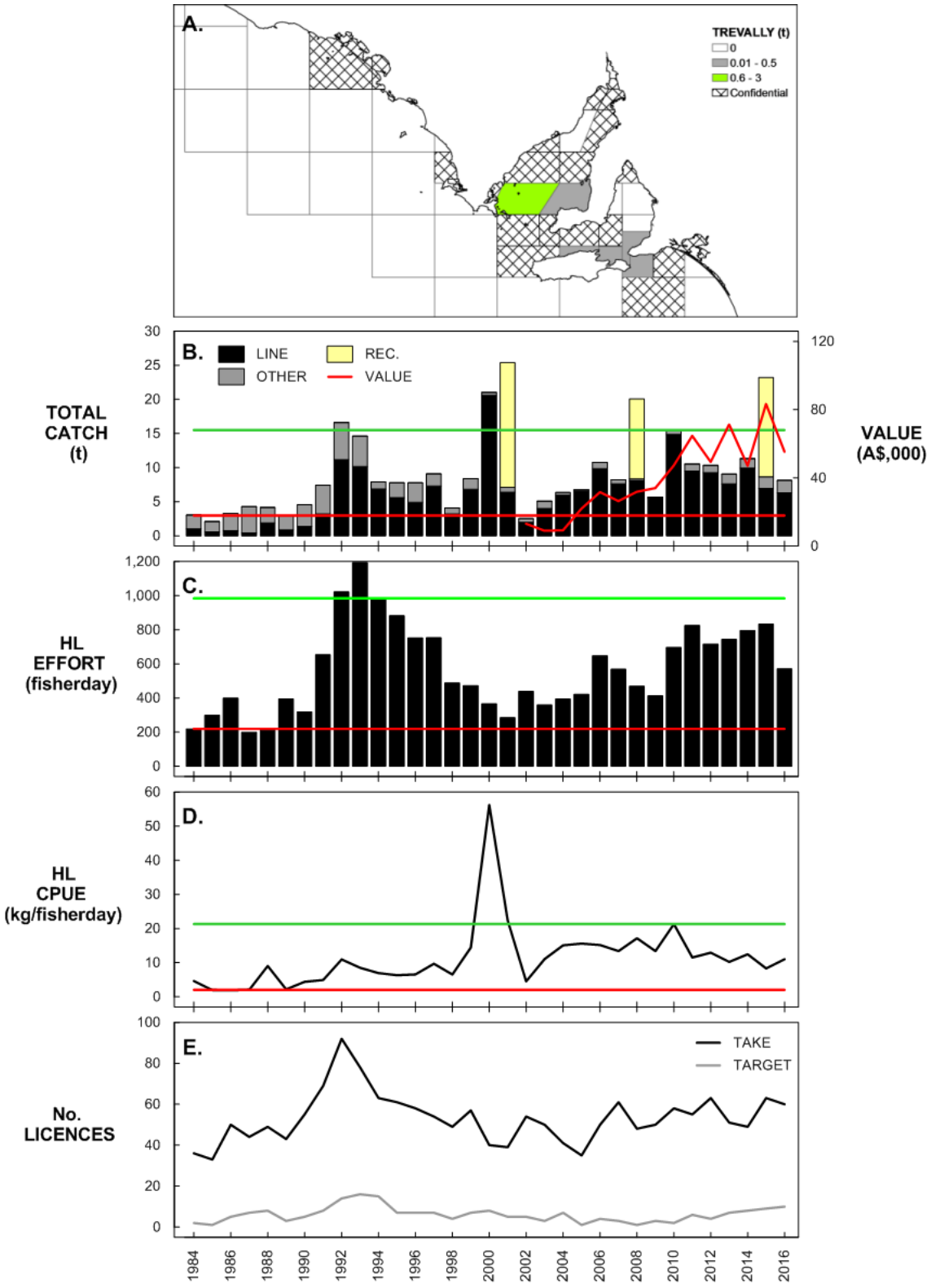

Figure 4-46. Silver Trevally (A) Catch distribution for 2016; Long-term trends in: (B) total catch for handline and gross production value; (C) Long-term targeted effort for handline; (D) targeted catch per unit effort for handline; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

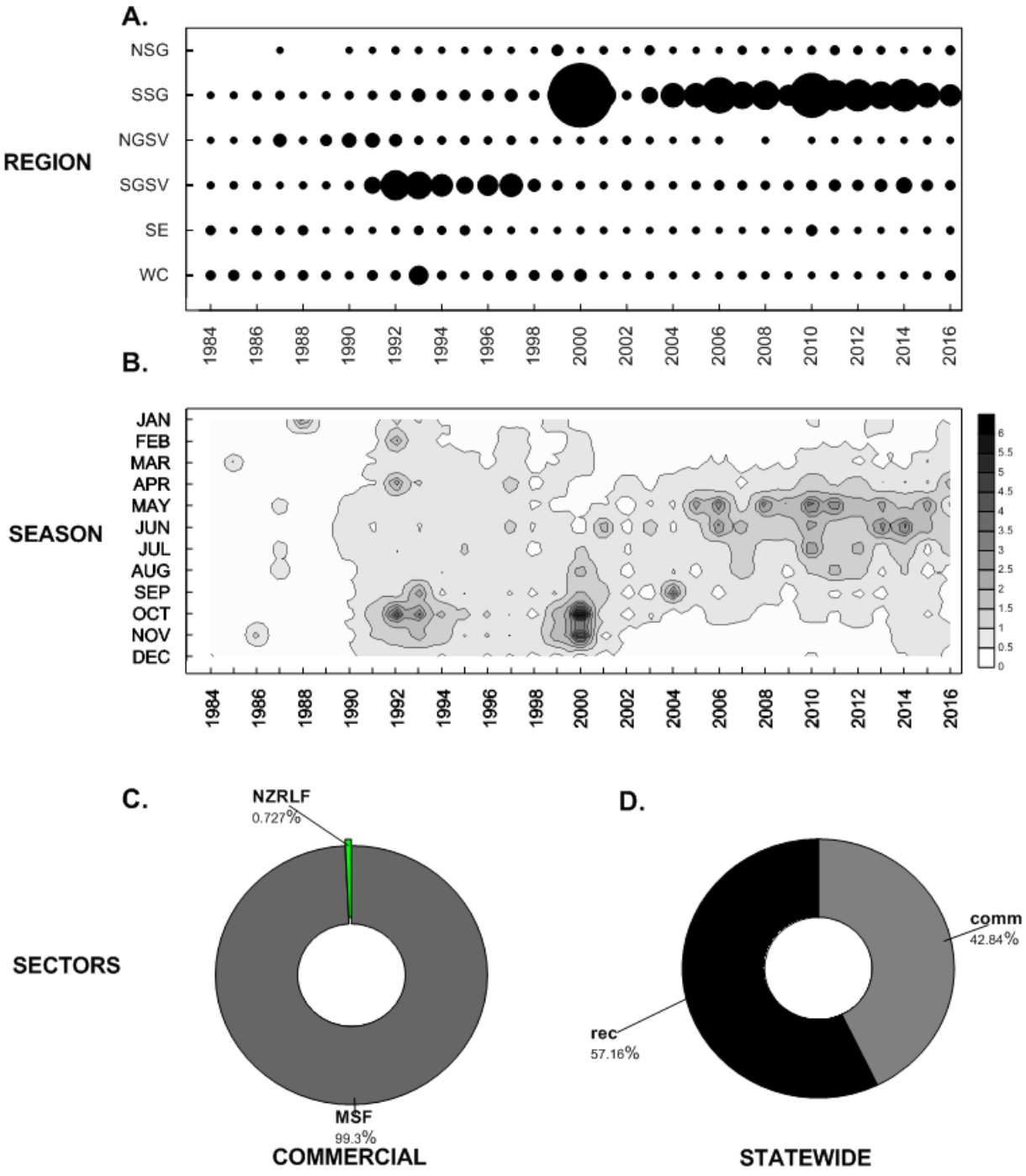

Figure 4-47. Silver Trevally. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Silver Trevally were assessed for 2016 at the State-wide scale. No trigger reference points were breached (Table 4-18).

Table 4-18. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Silver Trevally.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAND LINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Silver Trevally make a minor contribution to the total production value of the commercial fishery. Relatively, few fishers target this species. Nevertheless, the targeted catch accounts for a considerable proportion of the total line catch. The remaining catch is taken as by-product by a considerably larger number of fishers when they target more valuable species such as King George Whiting and Snapper.

Total catch of Silver Trevally has shown no long-term trend since the increase that occurred in the early 1990s. Over the same period, fishing effort and catch rates have been variable but shown no trends. Furthermore, there were no trigger reference points breached for the data from 2016. The medium-level recent catches and stable catch rates provide no evidence that the fishery is heading towards being recruitment overfished. On this basis, the Silver Trevally fishery is currently classified as **sustainable**.

4.3.16. LEATHERJACKETS (family Monacanthidae)

Biology

There are 19 species of Leatherjackets (family: Monacanthidae) that occur in South Australian waters (Gomon et al. 2008). They are widely distributed across the southern Australian coast from WA to NSW (Gomon et al. 2008). They are characterised by a compressed, deep body, prominent dorsal spine above the eyes and leathery skin (Gomon et al. 2008). In South Australia, anecdotal evidence suggests two species, i.e. the Horseshoe Leatherjacket (*Meuschenia hippocrepis*) and the Sixspine Leatherjacket (*M. freycineti*) are the dominant commercial species for the MSF. Nevertheless, historically some or all of the other species may have been taken by commercial fishers. Collectively they have been reported as Leatherjackets and recorded in the Marine Scalefish Fishery Information System as such. Consequently, it is not possible to differentiate the fishery statistics amongst species.

The Horseshoe Leatherjacket and Sixspine Leatherjacket are two of only six species that are found on nearshore coastal reefs (Shepherd and Baker 2008) along the southern coast of Australia from Western Australia to Victoria (Horseshoe Leatherjack) and New South Wales (Sixspine Leatherjacket) including Tasmania (Gomon et al. 2008). Most species are sexually dimorphic in body shape and colouration (Gomon et al. 2008). They are omnivorous, feeding on small invertebrates, algal turf and seagrass (Shepherd and Baker 2008).

Fishery

In South Australia, Leatherjackets are taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. In the commercial sector, Leatherjackets are predominantly taken as by-product when more valuable species are targeted, however a small number of fishers target this species. Leatherjackets are caught in the commercial MSF using hauling nets or handlines.

Recreationally, Leatherjackets are taken with rod and line. In 2013/14, an estimated 121,962 Leatherjackets were captured by the recreational sector, of which 75,787 fish were released, leaving 46,175 fish retained (Giri and Hall 2015). No estimate of total State-wide harvest is available for either the recreational or commercial sectors.

Management Regulations

Leatherjackets of all species are permitted to be taken commercially by the MSF (PIRSA 2014) and are classified as tertiary taxa in the commercial MSF Management Plan as they are of low-medium value and make a minor contribution to the total production value of the commercial

fishery (PIRSA 2013). There is no size limit nor bag or boat limit for either the commercial or recreational fishing sectors.

Commercial Fishery Statistics

State-wide

The State-wide, annual commercial catch for Leatherjackets was highest during the early 1990s. It declined regularly over the long-term to the lowest recorded catch of 10.5 t in 2014 (Figure 4-48). It has subsequently increased considerably to 34 t in 2016. During this time, the catch was dominated by that taken with hauling nets. Catches taken by handlines were considerably lower and generally ranged from 1.7 – 3.6 $t.yr^{-1}$, peaking at 5.5 t in 1997. Annual estimates of total fishing effort that produced catches of Leatherjackets have also always been dominated by hauling nets. Total fishing effort has consistently declined from its peak of almost 5,000 fisher days in 1991 to 680 fisher days in 2014. Between 2014 and 2016, total effort has increased to 1,680 fisher $days.yr^{-1}$.

Between 1990 and 2001, hauling net CPUE was relatively consistent until it declined in 2002 to its lowest recorded level of 6 $kg.fisherday^{-1}$. Over the next 14 years, hauling net CPUE was variable before increasing to its peak of 19 $kg.fisherday^{-1}$ in 2016. The number of fishers who reported taking Leatherjackets declined over the long-term from 142 $fishers.yr^{-1}$ in 1990 to 75 $fishers.yr^{-1}$ in 2014. The number who targeted this taxon has remained consistent at a low level. The higher numbers of fishers who reported taking Leatherjackets compared to those who targeted the taxon suggests that for many fishers Leatherjackets were taken as by-product when they fished for more valuable species.

Regional

Between 1990 and 2016, NSG and NGSV provided the highest catches of Leatherjackets. Incidental catches were taken from the other four regions (Figure 4-49). Catches in all regions have been lower since 2006. Historically, catches have been highest between March and October. In 2016, the MSF fishers accounted for 99.1% of the commercial catch, with the Northern and Southern Zone Rock Lobster fishers accounting for the remaining 0.9% (Figure 4-49).

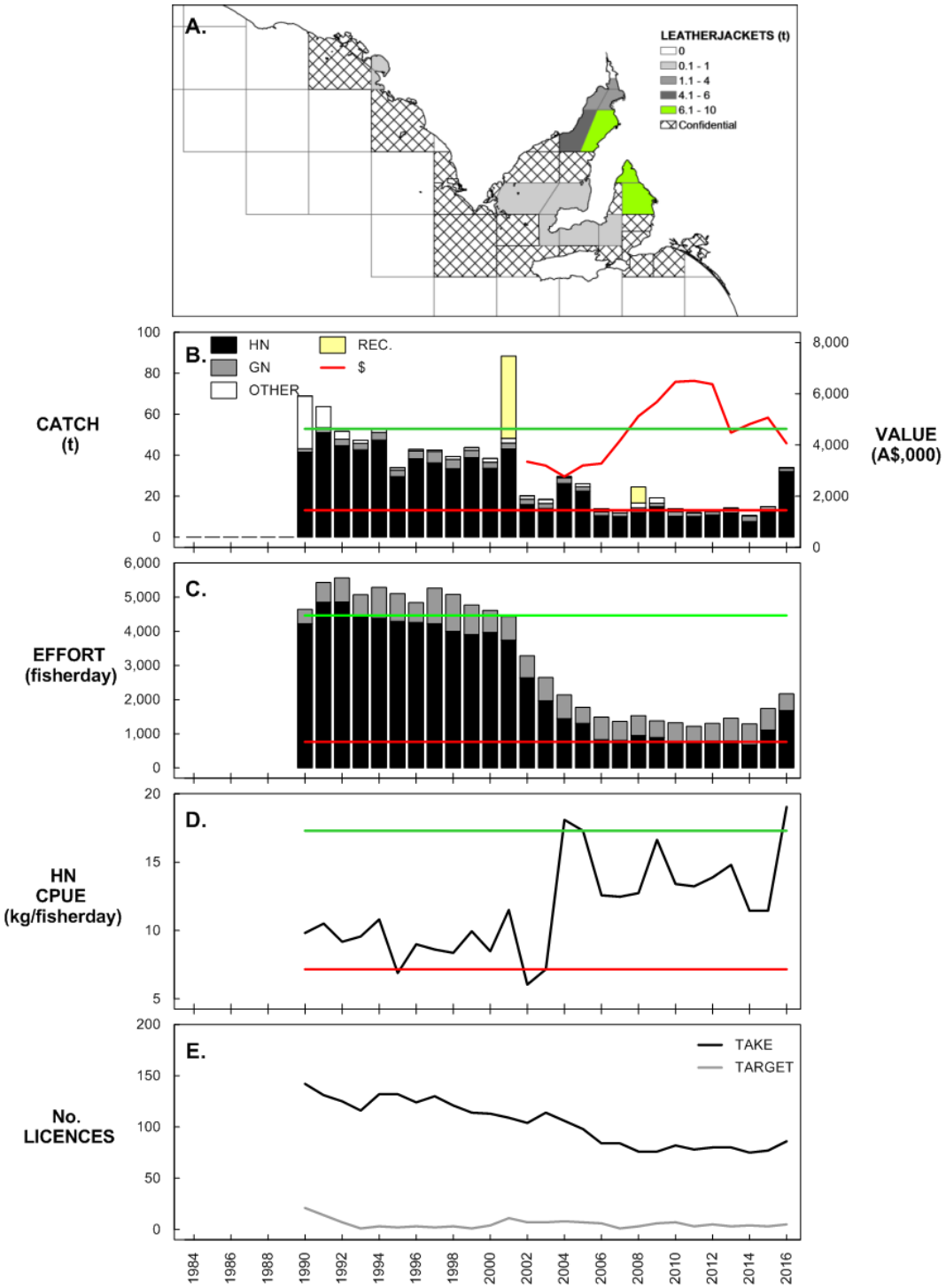

Figure 4-48. Leatherjackets (A) Catch distribution for 2016; Long-term trends in: (B) total catch for hauling and gill nets and gross production value; (C) Long-term total effort for hauling net and gill nets; (D) total catch per unit effort for hauling nets; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

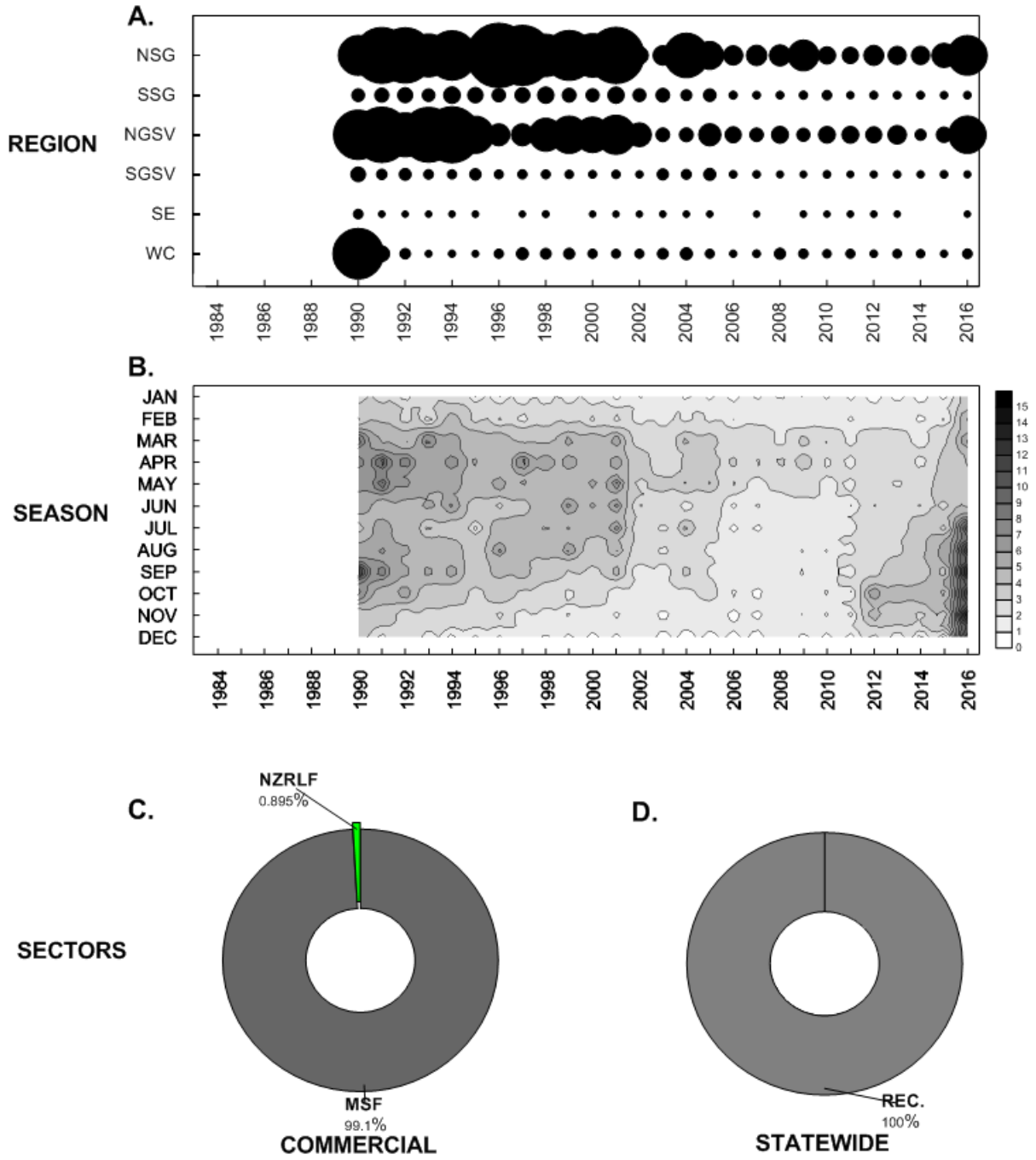

Figure 4-49. Leatherjacket. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Leatherjackets were assessed for 2016 at the State-wide scale, using the reference period of 1990 to 2016. One trigger reference point was activated (Table 4-19). Targeted hauling net CPUE in 2016 was the highest recorded.

Table 4-19. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Leatherjacket.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAULING NET CPUE	G	3rd Lowest / 3rd Highest	HIGHEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Although some catch is targeted, Leatherjackets are predominantly taken as by-product when more valuable species are targeted. As such, there have been consistently higher numbers of fishers who reported taking Leatherjackets than those that targeted it. Until 2016, the overwhelming trend has been one of declining annual catches for Leatherjackets. This largely reflects the significant declines in the effort in the net sector of the Marine Scalefish Fishery. However, targeted hauling net CPUE increased in 2016 resulting in a breach of this trigger reference point. This reflected increases in hauling net effort. However, the catch and effort levels remained lower than those up to the early 2000s. The low catches, low effort levels and medium levels of CPUE provide no indication that the fishery is heading towards being recruitment overfished. On this basis, South Australia's Leatherjacket fishery is currently classified as **sustainable**.

4.3.17. GUMMY SHARK (*Mustelus antarcticus*)

Biology

Gummy Shark (*Mustelus antarcticus*) is an endemic Australian demersal species, commonly found in the temperate nearshore and continental shelf waters to depths of 350 m (Last and Stevens 2009). Their southern Australian distribution extends from Port Stephens in New South Wales, to Geraldton in Western Australia (including Tasmania). Two biological stocks have been identified within this range: the Southern Australian stock which extends from the lower west coast of WA to Jervis Bay, NSW; and the Eastern Australian stock which extends along the remaining NSW coastline (Marton et al. 2016). The Southern Australian biological stock is considered to comprise four separate sub-populations for assessment purposes: the continental shelf of Bass Strait, Tasmania, South Australian, and Western Australia.

Gummy sharks are born ~300–350 mm total length (TL) and reach a maximum size of 1850 mm TL (Last and Stevens 2009). Males mature at a smaller size (950 mm TL) and younger age (4 years) than females (1110 mm TL and 5 years) (Walker 1992). In southern Australia, parturition occurs in November–December after a 12-month gestation period (Walker 2007). Parturition and ovarian cycles have been identified to vary spatially, with populations West of Kangaroo Island (KI) having annual cycles and populations East of KI possessing biennial and triennial cycles (Walker 2007). The sex ratio of embryos is 1:1 and litter sizes range from 1 to 57 pups.

Adult Gummy Sharks (>1100 mm TL) are capable of broad-scale and cross-jurisdictional movements, with a maximum displacement recorded of 2362 km after 6.8 years at liberty (Walker 2000). However, only 15% of adult sharks had movements of >250 km, with the mean distances travelled by adult sharks ~150 km (Walker 2000).

Fishery

Gummy sharks are the primary catch of the commonwealth managed Southern and Eastern Scalefish and Shark Fishery, which in 2015/2016 landed 1799 tonnes trunk weight (AFMA 2016). The South Australian Marine Scalefish Fishery (MSF) captures Gummy Shark as a by-catch species in most of the states coastal and gulf waters. This species is most frequently captured within the MSF by demersal longlines, gill nets and handlines. Gummy Sharks are also targeted by clients within the SA Charter Fishery and by recreational anglers. Recreational anglers access this species from vessels, metropolitan and regional jetties, rock shore-lines and beaches.

Management Regulations

The management responsibility for Gummy and School sharks was transferred from South Australia to the Australian Fisheries Management Authority (AFMA) in 2000 through a memorandum of understanding as a supplement to the Offshore Constitutional Settlement (OCS) (PIRSA 2013). The resource is managed under a quota-based system. There are a few State-based licence holders that have been issued quota through a South Australian Coastal Waters permit under the authority of AFMA. All other MSF licence holders are entitled to a by-catch limit of five sharks per day, and a possession limit of 10 sharks on a fishing trip of more than one day. The minimum size limit for Gummy Sharks is 450 mm, measured from the 5th gill slit to the base of the tail. This size limit also applies to the recreational sector and they are further restricted to a combined species bag and boat limit of 2 and 6, respectively.

Australian AFMA in 2010 implemented a range of management processes to reduce and monitor interactions between Australian Sea Lions and gill nets in the Commonwealth Southern and Eastern Scalefish and Shark Fishery. PIRSA worked with South Australian operators in the Marine Scalefish Fishery who use similar gill nets, as well as licence holders endorsed with the nets but not currently using them, to implement management strategies in 2016 to mitigate potential interactions with Australian Sea Lions (AFMA 2010, Goldsworthy et al. 2010).

Commercial Fishery Statistics

State-wide

The total State-wide commercial catch of Gummy Shark in 2016 was 75.5 t (Figure 4-50). From 1984 until 1997 the total annual catch exceeded 600 t, peaking at 1,074 t in 1989. The majority (>85%) of this catch was caught using gill nets, however this has subsequently been eroded as a function of a series of netting closures that have been implemented to reduce the risk of the gear interacting with Australian Sea Lions. These Commonwealth enforced management arrangements restricted commercial access to the resource to longline fishers. The long-term trends in catch for this sector peaked at 134.3 t in 2012 and has since declined to 55.5 t in 2016.

Despite an eight year consecutive decline in targeted longline effort for Gummy Sharks, dropping from 489 fisher-days in 2009 to 327 fisher-days in 2016, the level of activity remains comparatively high. Prior to 2009, targeted longline effort rarely exceeded 300 fisher-days.year^{-1}. With the exception of an anomalous spike in targeted longline catch rates of 347.8 kg.fisherday^{-1} in 1989, annual catch rates have remained relatively stable at approximately 45 kg.fisherday^{-1} (Figure

4-50). The enforced daily catch limit for Gummy and School Sharks introduced in 2000 has strongly contributed to this stabilisation.

Overall there has been a 43.4% reduction in the number of fishers taking Gummy Shark since 1984, reducing from 198 to 112 over a 33-year period. There was a slight increase in active licence holders in 2007 through to 2013 where it peaked at 189 fishers in 2010. During this time, approximately 30% of the fishers recorded Gummy Shark as a specific target species.

Regional

The West Coast and South East has historically accounted for most of the State-wide catch, however, since the introduction of the netting closures in 2000 their relative contribution has been diminished (Figure 4-51). Peak catches have historically occurred between late-summer and mid-autumn. Marine Scalefish Licence holders have accounted for 94.2% of the commercial catch in 2016, with the remaining almost equally shared among the SZRLF (3.5%) and NZRLF (2.3%) licence holders (Figure 4-51). The recreational sector accounted for approximately 26% of the State-wide catch in 2013/14.

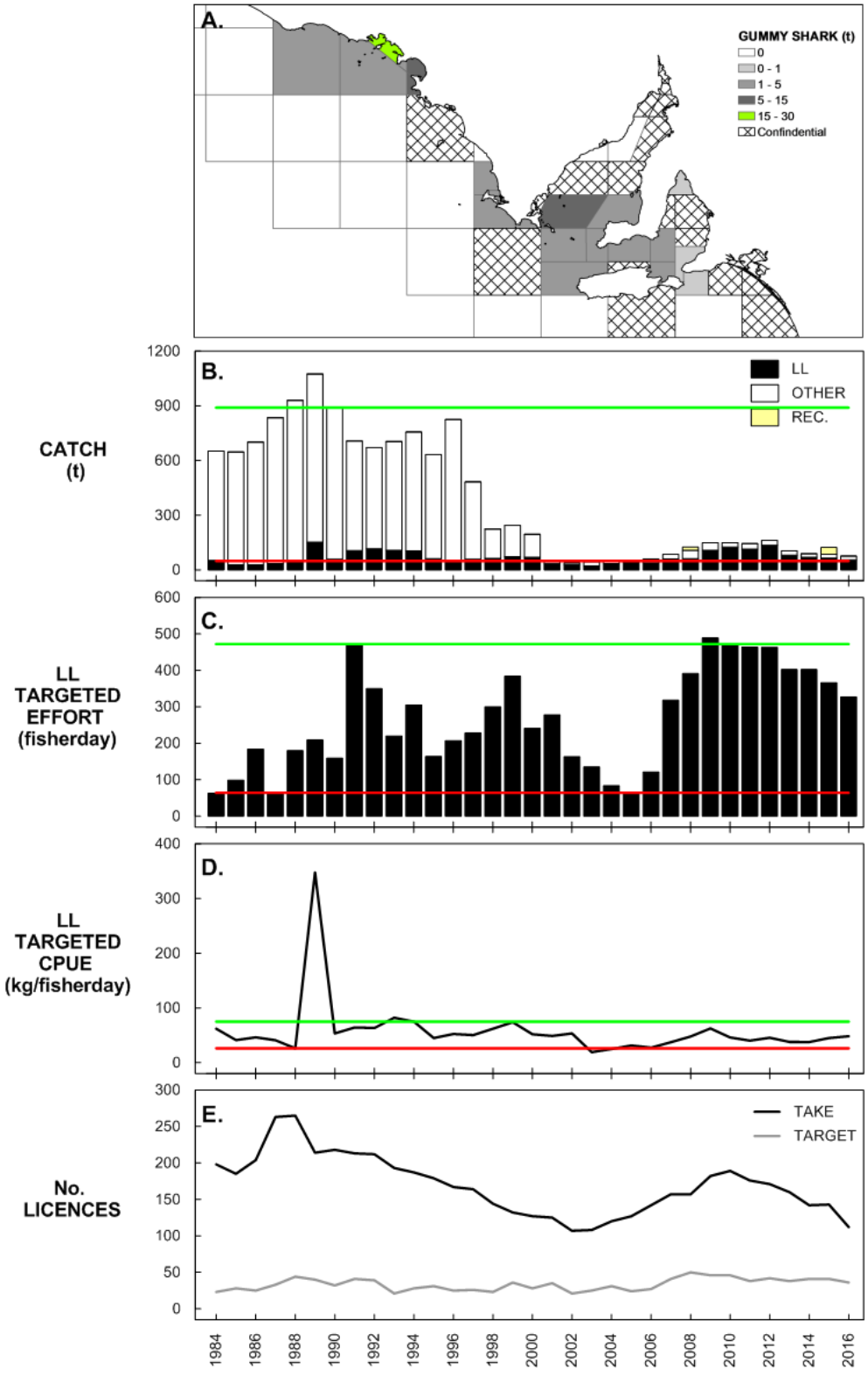

Figure 4-50. Gummy Shark (A) Catch distribution for 2016; Long-term trends in: (B) total catch for longline and gross production value; (C) targeted effort for longline; (D) targeted catch per unit effort for longline; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

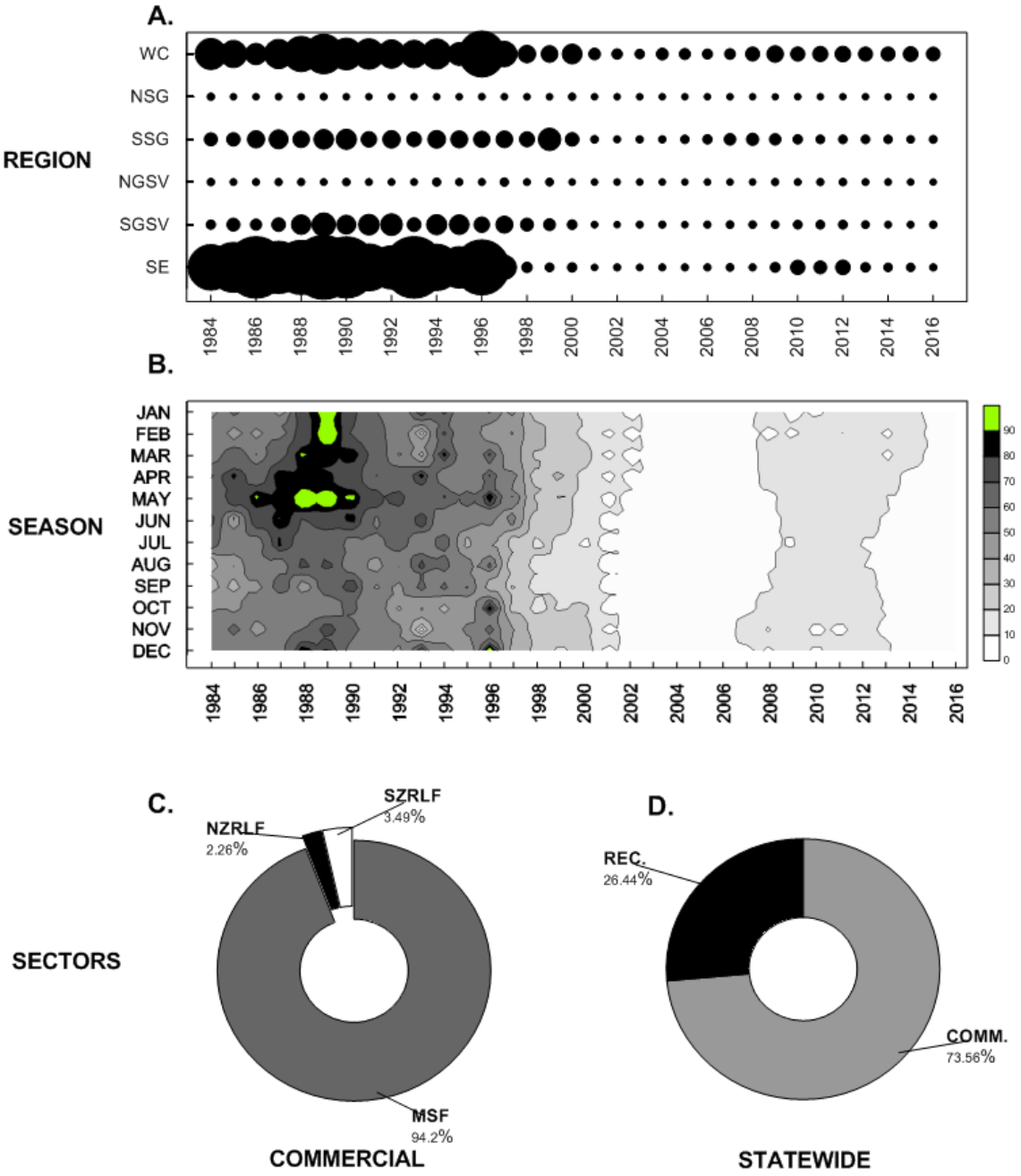

Figure 4-51. Gummy Shark. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Gummy Shark were assessed for 2016 at the State-wide scale. A single trigger reference point relating to a decrease in targeted longline effort 5 consecutive years was breached (Table 4-20).

Table 4-20. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Gummy Shark.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖
TARGETED LONGLINE EFFORT	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✓
TARGETED LONGLINE CPUE	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖

Stock Status

The South Australian MSF fishery for Gummy Shark is considered a component of a broader biological stock shared with the Western Australia, Victoria, Tasmania and the Commonwealth. A recent assessment of this stock, undertaken by the Commonwealth, indicated that the level of fishing pressure that is regulated through a total allowable catch (TAC) is unlikely to lead to overfishing (Marton et al. 2016). This was further supported by modelled biomass estimates, as derived from estimated pup production, which exceeded the prescribed limit reference point.

The considerable reduction of catch and effort as a result of the gill netting closures that extended from 2000 onwards, in association with declining targeted effort levels within the longline sector and highly stable catch rates that are largely regulated by commercial catch limits provide no evidence that South Australia's MSF in significantly impacting the broader biological stock. On this basis, SA's Gummy Shark Fishery is classified a **sustainable** aligning with the classification of the broader Southern Australian biological stock (Marton et al. 2016).

4.3.18. SCHOOL SHARK (*Galeorhinus galeus*)

Biology

The School Shark (*Galeorhinus galeus*) is a medium-sized (1750 mm maximum total length (TL)) and long-lived (60 years) species with a wide-spread, but disjunct, temperate distribution through the eastern North Atlantic, western South Atlantic, north-eastern and south-eastern Pacific, South African, New Zealand and southern Australian waters (Coutin et al. 1992; Moulton et al. 1992; Marton et al. 2016). This species mainly inhabits coastal, insular shelf and upper shelf slope waters to a maximum depth of 600 m (McAllister et al. 2015; Last and Stevens 2009).

The southern Australian population has been identified as a single mixed stock and tagging studies in Australia and New Zealand have identified a high degree of exchange across the Tasman Sea between New Zealand and southern Australia (Hurst et al. 1999). In Australian waters, maturity is reached at similar body size but younger age for males (1260–1310 mm TL, 8 years) than females (1240–1350 mm TL, 12 years). Females produce ~30 pups (range 15–54) per litter after a 12-month gestation period and reproduction occurs every three years (Last and Stevens, 2009).

Fishery

The targeting of School Sharks in Australia began during the 1920s by the Southern Shark Fishery, across much of south-eastern Australia (Walker 1998). In South Australia, School Sharks are captured as by-catch in the commonwealth managed, Southern Shark Fishery and in the State managed MSF. This species is mainly captured as by-catch by demersal set longlines and set gill nets.

In 2013/14, the State-wide recreational survey estimated that 7,749 School Sharks were caught of which 541 were released, retaining an estimated 7,208 Sharks with total weight of 53.5 t (Giri and Hall 2015). These fishers capture School Sharks using rod and line.

Management Regulations

The management responsibility for Gummy and School sharks was transferred from South Australia to the Australian Fisheries Management Authority (AFMA) in 2000 through a memorandum of understanding as a supplement to the Offshore Constitutional Settlement (OCS) (PIRSA 2013). The resource is managed under a quota-based system. There are a few State-based licence holders that have been issued quota through a South Australian Coastal Waters permit under the authority of AFMA. All other MSF licence holders are entitled to a by-catch limit

of five sharks per day, and a possession limit of 10 sharks on a fishing trip of more than one day. The minimum size limit for School Sharks is 450 mm, measured from the 5th gill slit to the base of the tail. This size limit also applies to the recreational sector and they are further restricted to a combined species bag and boat limit of 2 and 6, respectively.

Australian AFMA in 2010 implemented a range of management processes to reduce and monitor interactions between Australian Sea Lions and gill nets in the Commonwealth Southern and Eastern Scalefish and Shark Fishery. PIRSA worked with South Australian operators in the Marine Scalefish Fishery who use similar gill nets, as well as licence holders endorsed with the nets but not currently using them, to implement management strategies in 2016 to mitigate potential interactions with Australian Sea Lions (AFMA 2010, Goldsworthy et al. 2010).

Commercial Fishery Statistics

State-wide

The total State-wide commercial catch of School Shark in 2016 was 17.7 t (Figure 4-52). From 1984 until 1997 the total annual catch exceeded 570 t, peaking at 1,260 t in 1987. The majority (>85%) of this catch was caught using gill nets, however this has subsequently been eroded as a function of a series of netting closures that have been implemented to reduce the risk of the gear interacting with Australian Sea Lions. These Commonwealth enforced management arrangements restricted commercial access to the resource to longline dropline fishers. The long-term trends in catch for the longline sector peaked at 130.6 t in 1985, representing 12.3% of the annual commercial catch. Total annual longline catch of School Shark did not exceed 8 t from 2000 to 2011. Since then, catches have exceeded 10 t per year, peaking at 15.2 t in 2016. Trends in longline effort have followed catch, peaking at 1,729 fisher-days in 1987, enduring a decade of relatively low fishing activity (<200 fisher-days.year^{-1}) through the 2000s, and increasing to 308 fisher-days in 2016 (Figure 4-52). The associated catch rates have consistently increased from a record low of 17.5 kg.fisherday^{-1} in 2008 to 49.4 5 kg.fisherday^{-1} in 2016. Contemporary annual catch rates are moderate in comparison to those of the 1980s and 1990s where they frequently exceeded 60 5 kg.fisherday^{-1} (Figure 4-52).

Overall there has been a 65.6% reduction in the number of fishers taking School Shark since 1984, reducing from 151 to 52 over a 33-year period. There was a slight increase in active licence holders in 2007 through to 2012 where it increased from 37 to 55 fishers. A relatively small proportion of fishers (<10%) have actively targeted School Shark throughout the 33-year history of the fishery (Figure 4-52).

Regional

The West Coast and South East has historically accounted for most of the State-wide catch, however, since the introduction of the netting closures in 2000 their relative contribution has been diminished (Figure 4-53). Peak catches have historically occurred between late-summer and mid-autumn. Marine Scalefish Licence holders have accounted for 94.1% of the commercial catch in 2016, with the remaining shared among the NZRLF (4.0%) and SZRLF (1.9%) licence holders. The recreational sector accounted for approximately 77% of the State-wide catch in 2013/14 (Figure 4-53).

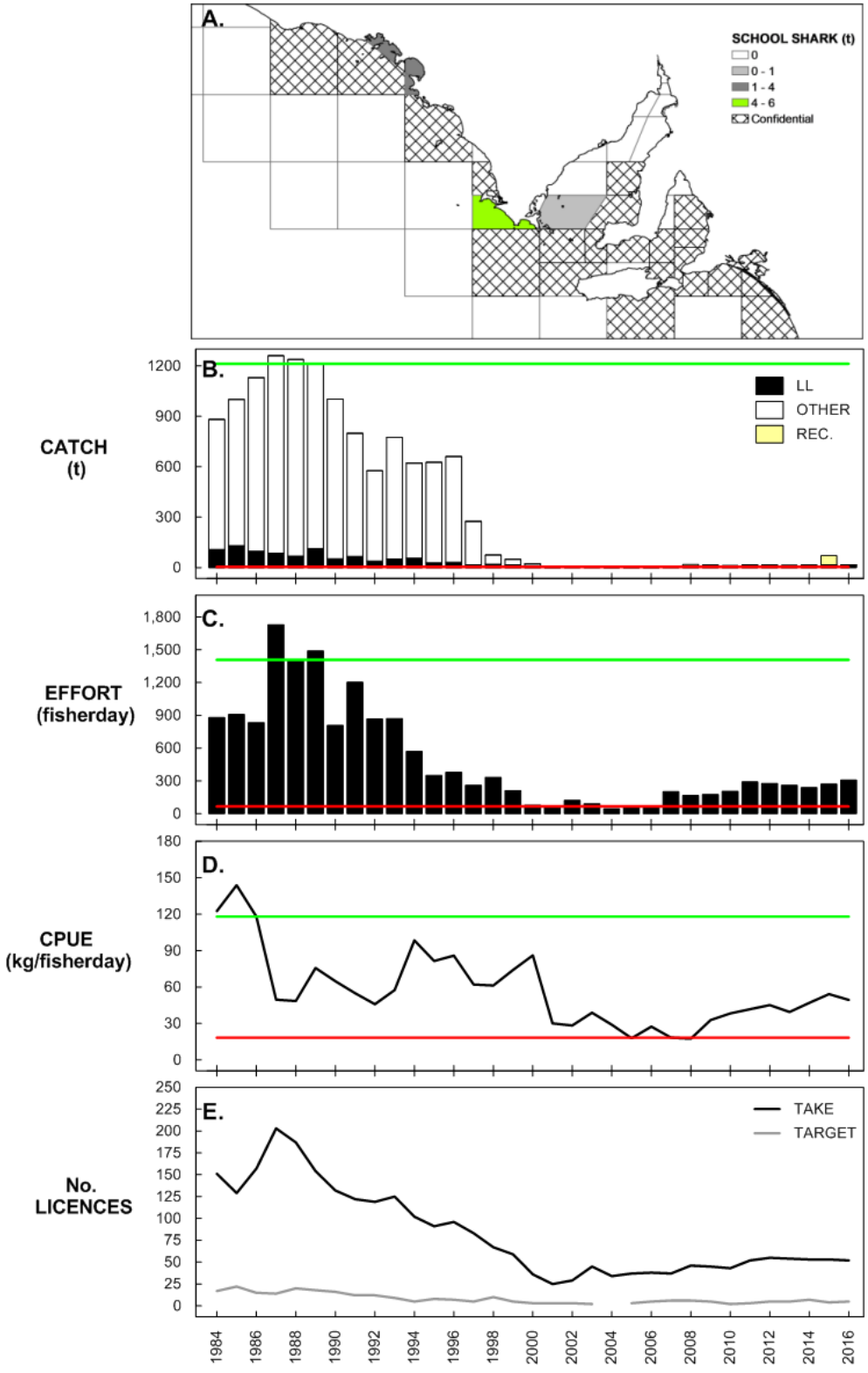

Figure 4-52. School Shark (A) Catch distribution for 2016; Long-term trends in: (B) total catch for longline; (C) total effort for longline; (D) total catch per unit effort for longline; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

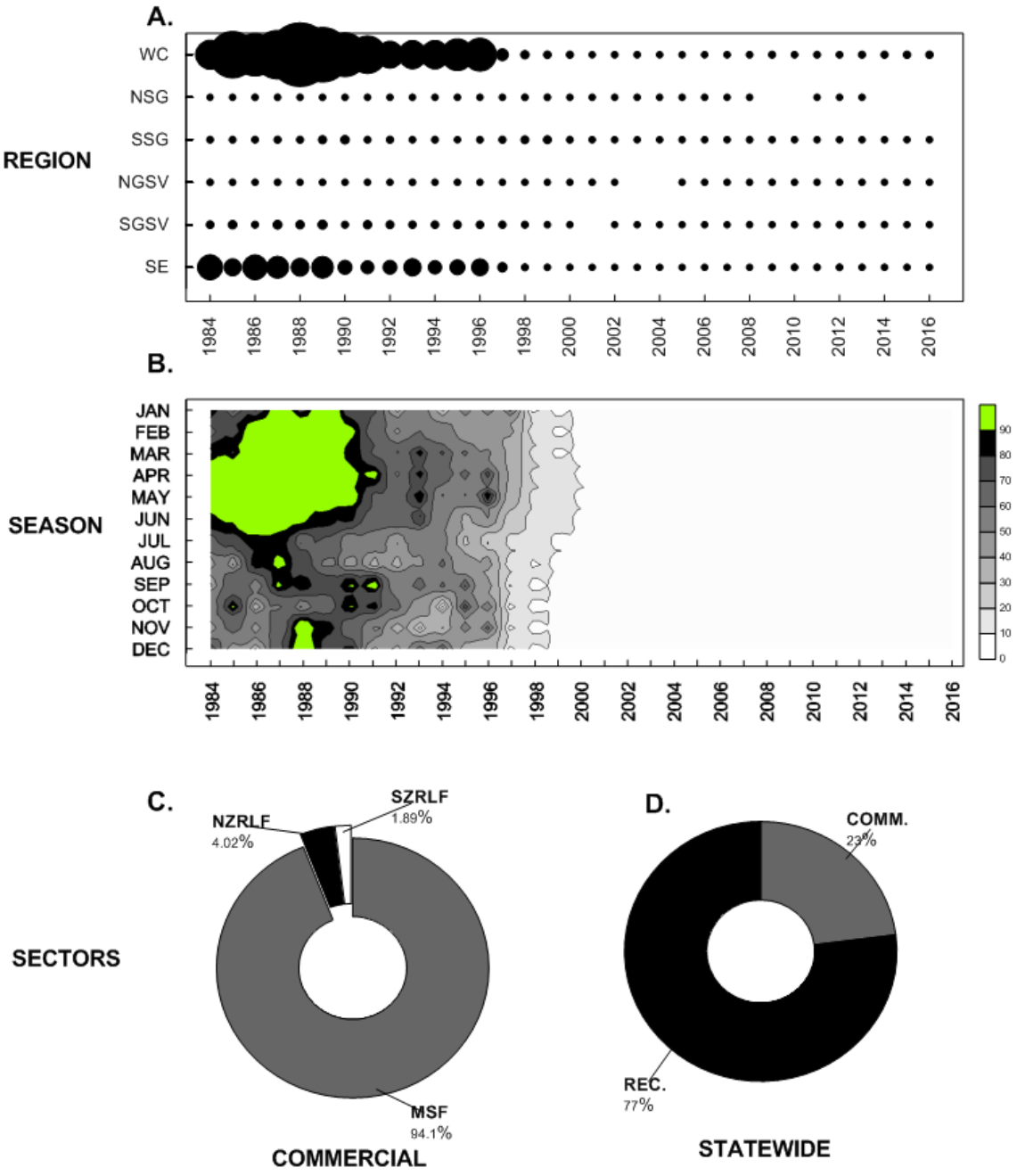

Figure 4-53. School Shark. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for School Shark were assessed for 2016 at the State-wide scale. No trigger reference points were breached (Table 4-21).

Table 4-21. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for School Shark.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL LONGLINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL LONGLINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Population demographic models have estimated the southern Australian population to be recruitment overfished and at <20% of the estimated virgin biomass (Thomson, 2012). There is some indication that adult biomass levels are recovering through anecdotal reports of increased availability of School Sharks in commonwealth waters, however measureable improvements in biomass are yet to be detected (Marton et al. 2016). It is possible that the slight increases in catch rates within South Australia's MSF longline fishing sector over the past decade reflects this increase in abundance, however, it is not known whether this was enough to allow the broader biological stock to recover from its recruitment overfished state.

Despite the relatively low catches of School Sharks within SA's MSF, in association with increasing catch rates within the longline sector and the management restrictions prohibiting gill netting and the enforcement of daily trip limits, the overall status of this fishery should align with that of the broader Southern Australian biological stock. Consequently, the status is considered to be **recruitment overfished**.

4.3.19. RAYS AND SKATES

Biology

There are 18 species of rays (family: Rhinobatidae, Narcinidae, Hypnidae, Torpedinidae) and 13 species of skates (family: Arhynchobatidae, Rajidae, Urolophidae, Dasyatidae, Myliobatidae) that occur in South Australian waters (Last and Stevens 2009). They are highly diverse species that vary in biology, morphology and distribution, however are generally characterised by long life spans, slow growth rates, low reproductive output and late maturation. These characteristics make them particularly vulnerable to fishing activity. In South Australia, only one of these species, i.e. the Southern Eagle Ray (*Myliobatis tenuicaudatus*) has been identified in commercial catches during market sampling and anecdotal evidence, suggesting that this is the dominant commercial species for the MSF. Nevertheless, historically some or all of the other species may have been taken by commercial fishers. Collectively they have been reported as Skates and Rays and recorded in the Marine Scalefish Fishery Information System as such. Consequently, it is not possible to differentiate the fishery statistics amongst species.

The Southern Eagle Ray is born at 200-300 mm disc width (DW), reaching a maximum size of up to 1600 mm DW (> 3000 mm TL) (Last and Stevens 2009) and age of >15 years for males and >26 years for females (Hartill 1989). Its distribution includes the inshore waters of southern Australia from Jurien Bay in Western Australia to Moreton Bay in Queensland, including Tasmania and New Zealand (Last and Stevens 2009). It is common in shallow water near beaches, shoals and over sandflats through the depth range of 0 – 130 m. It feeds on benthic invertebrates including crustaceans, molluscs, annelid worms, and teleost fishes (Last and Stevens 2009) and is considered a significant bioturbator and an important influence in structuring marine soft sediment communities (Hines et al. 1997).

Fishery

Because Southern Eagle Rays inhabit nearshore, shallow waters, they are particularly vulnerable to line fishing by both the commercial and recreational sectors of the MSF. For the commercial sector, rays are captured as by-catch when other more valuable species are targeted and are increasingly being retained and marketed as flaps or wings to the SAFCOL or Sydney Fish Markets.

For the recreational sector, Southern Eagle Rays are often taken as by-catch when more desirable species are targeted, which can result in a high discard rate, or during tag and release

activities. In 2013/14, an estimated 9,489 Southern Eagle Rays were captured by the recreational sector, of which 100% were released (Giri and Hall 2015).

Management Regulations

Rays and Skates of all species are permitted to be taken commercially by the MSF (PIRSA 2014) and are classified as “other species” in the commercial MSF Management Plan due to their low-medium value and minor contribution to the total production value of the commercial fishery (PIRSA 2013). There is no size limit nor bag or boat limits for either the commercial or recreational fishing sectors. No commercial harvest strategy has been developed (PIRSA 2013).

Commercial Fishery Statistics

State-wide

Between 1984 and 1992, the reported commercial catches of Rays and Skates rapidly increased from <10 $t.yr^{-1}$ to its peak at almost 70 $t.yr^{-1}$ (Figure 4-54). Catches fell until 1995 before stabilising for a number of years then steadily declining again to 24.5 t in 2006. Since then it has generally been <20 $t.yr^{-1}$, declining to <10 t in 2016. The total catch of 9.5 t in 2016 was close to the lowest since 1984. Between 1985 and 2016, the catch was dominated by that taken on longlines.

In 1984, total longline effort was low, before it rapidly increased until 1987 and peaked in 1992. Since then it has gradually declined to its second lowest level in 2016. Similarly, hauling net effort rapidly increased from 1984 until 1988 before declining to its lowest level in 2016 (Figure 4-54). In 1988, the highest level of effort and the highest proportional contribution from hauling nets were recorded. Since 1992, effort has declined, as has the proportional contribution from hauling nets.

Between 1986 and 2000, total longline CPUE steadily increased up to 2000. Over the following seven years it gradually declined before it stabilised between 2007 and 2016. Conversely, total hauling net CPUE stayed consistently low from 1984 until 2002 before increasing steadily until 2012 then declining marginally until 2016.

Regional

Since 1988, the WC has provided the highest catches of Rays and Skates. SGSV was the second most significant region until 2003, and only incidental catches have come from the other four regions (Figure 4-55). Furthermore, catches have generally been concentrated between October and April, until 2013 when catch became distributed throughout the year. In 2016, the MSF fishers accounted for approximately 92% of the commercial catch, with the Southern Zone Rock Lobster

fishers accounting for most of the remainder (Figure 4-55) and a marginal catch from the Northern Zone Rock Lobster fishers.

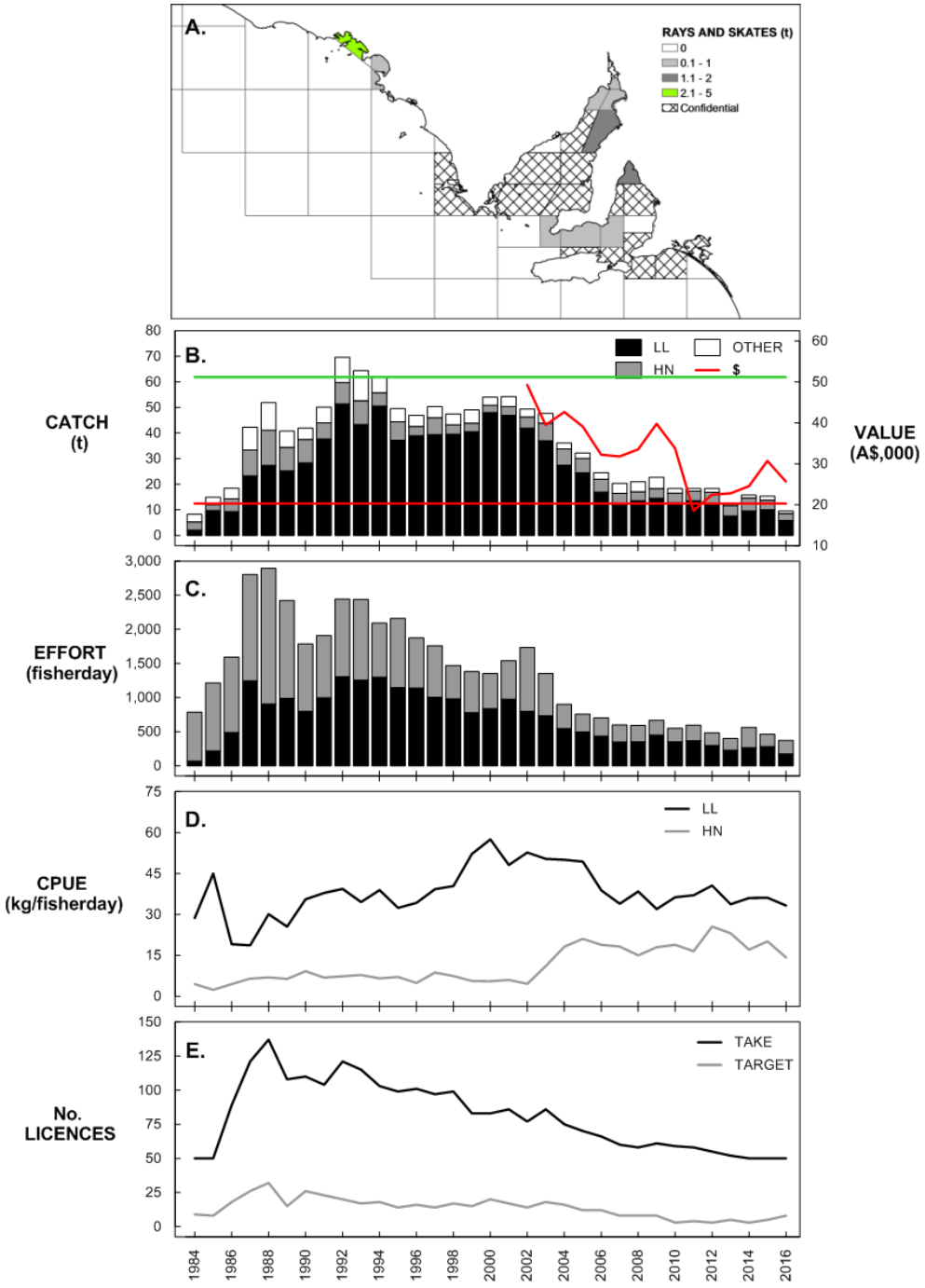

Figure 4-54. Rays and Skates (A) Catch distribution for 2016; Long-term trends in: (B) total catch for longline and hauling net and gross production value; (C) total effort for longline and hauling net; (D) total catch per unit effort for longline and hauling net; and (E) the number of active licence holders taking or targeting the taxa. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

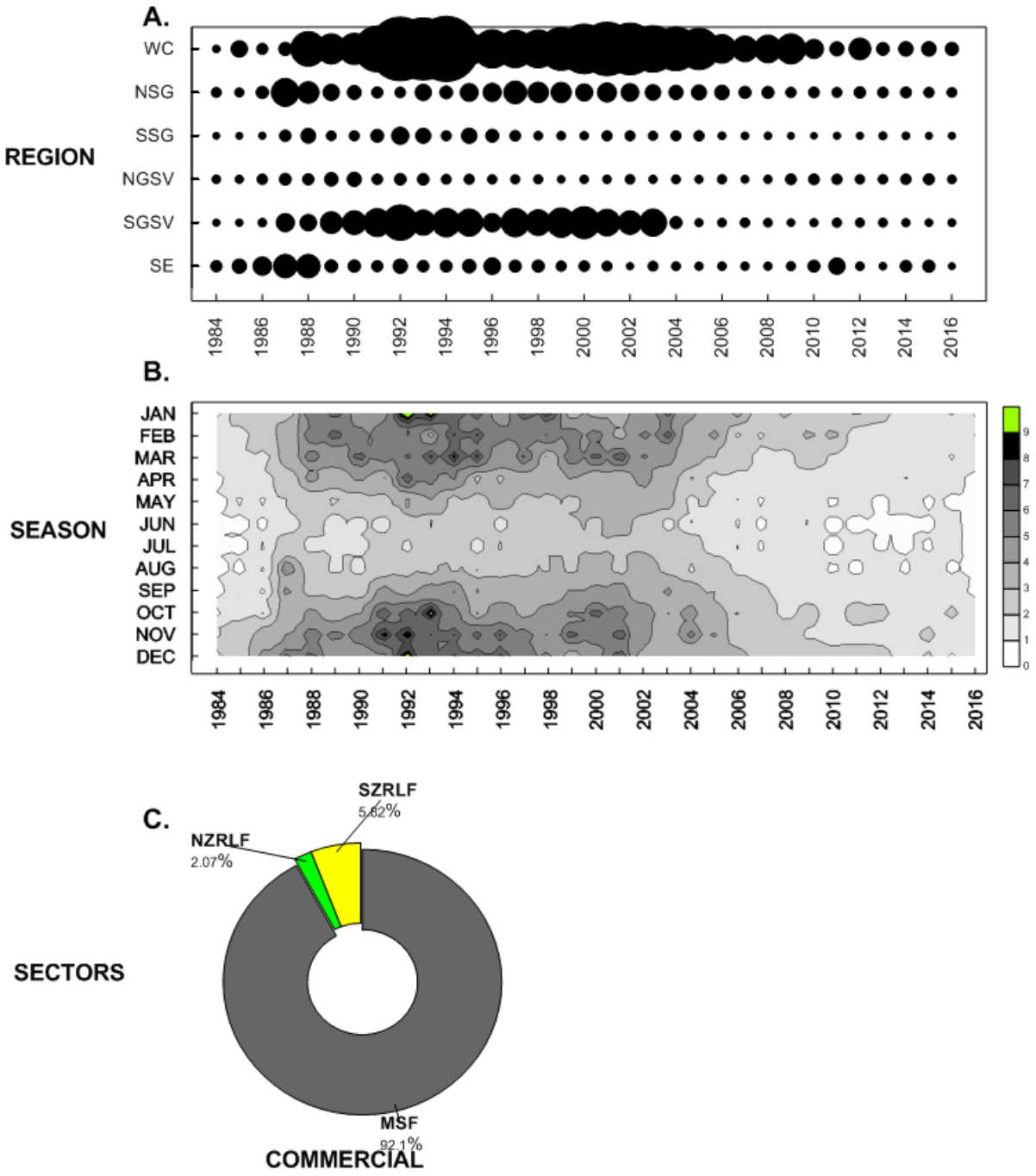

Figure 4-55. Rays and Skates. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C); and among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015) (D).

Fishery Performance

The general fishery performance indicators for Rays and Skates were assessed for 2016 at the State-wide scale. Two trigger reference points were activated (Table 4-22). Total catch and total longline effort in 2016 were both the 2nd lowest recorded.

Table 4-22. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Rays and Skates.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	2nd LOWEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAULING NET EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL HAULING NET CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL LONGLINE EFFORT	G	3rd Lowest / 3rd Highest	2nd LOWEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL LONGLINE CPUE	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

Total catch of Rays and Skates has declined since 2002, corresponding with declining longline and hauling net effort. Since 2006, annual catch rates have been relatively stable at low levels. Since 2006, longline catch rates have been relatively stable at a medium level, whilst those from hauling net have also been stable but at a historically high level. There were two trigger reference points breached for the data from 2016 reflecting low catch and low longline effort. The low-level recent catches and stable catch rates provide no evidence that the fishery is heading towards being recruitment overfished. On this basis, SA's Ray and Skate fishery is currently classified as **sustainable**.

4.3.20. CUTTLEFISH (*Sepia* spp.)

Biology

Two cuttlefish species, Giant Australian Cuttlefish (*Sepia apama*) and Nova's Cuttlefish (*S. novaehollandiae*), are commercially harvested in the MSF. Of these, Giant Australian Cuttlefish is the largest and most abundant local cuttlefish species (Edgar 2000) reaching a maximum size of 500 mm mantle length and weighing up to 10.5 kg (Jereb and Roper 2005). This species is endemic to Australia, broadly distributed around the southern coastline from Point Cloates, Western Australia to Moreton Bay, Queensland, including Tasmania (Edgar 2000). Giant Australian Cuttlefish are generally found over seagrass beds and rocky reef habitats in waters of up to 100 m depth (Jereb and Roper 2005).

Within South Australia, two genetically distinct populations of Giant Australian Cuttlefish have been identified (Gillanders et al. 2016). While the southern Spencer Gulf cluster extends into Gulf St. Vincent, the northern cluster is restricted to northern Spencer Gulf (NSG) and shows a clear pattern of philopatry, i.e. individuals return to the site of hatching to breed at either one or two years of age. This population forms a mass breeding aggregation at Point Lowly (Steer et al. 2013, Steer 2015, Gillanders et al. 2016) during late autumn and early winter each year. Water temperature conditions and suitable substrate are thought to drive the inshore migration (Hall and Fowler 2003). The species shows sexual dimorphism with males reaching larger mantle sizes with longer arms that are used in courtship. The species is semelparous, dying soon after spawning (Hall and Fowler 2003).

Fishery

In South Australia, Cuttlefish are taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. In the commercial sector, they are generally taken with handlines and jigs and are either targeted or taken as by-product when Southern Calamari are targeted. Historically, cuttlefish were retained by commercial fishers as bait for Snapper.

Cuttlefish are rarely targeted by recreational fishers and incidentally caught when fishers target Southern Calamari with squid jigs. In 2013/14, the State-wide recreational survey estimated that 2,648 Cuttlefish were captured, of which 1,217 were released, leaving 1,431 fish retained (Giri and Hall 2015). This provided a total estimated catch of 0.34 t, which was considerably lower than the estimated commercial catch of 2 t.

Management Regulations

Cuttlefish of all species are permitted to be taken commercially by the MSF (PIRSA 2014). There is no size limit for either the commercial or recreational fishing sectors. However, for the recreational sector there is a combined cuttlefish/squid bag limit of 15 fish and boat limit of 45 fish. A cephalopod fishing closure, that aimed to protect the iconic Giant Australian Cuttlefish spawning population in False Bay, Northern Spencer Gulf was implemented in 1998. This area was extended in 2012 to offer greater protection to the spawning population. An additional temporary closure was implemented in 2013 that prohibited the targeting and retention of Giant Australian Cuttlefish north of Wallaroo, Spencer Gulf, and remains current.

Commercial Fishery Statistics

State-wide

Between 1993 and 1997, the reported commercial catch of Cuttlefish increased from 12.3 $t.yr^{-1}$ to its peak at 262 $t.yr^{-1}$ (Figure 4-56) corresponding with a dramatic increase in both targeted and untargeted effort. In the following two years catches fell to >16 $t.yr^{-1}$ and have continued to decline until 2016. Since 1999 annual catches have generally been <20 $t.yr^{-1}$. The total catch of 1.3 t in 2016 was the lowest since 1988.

Until 1994, total jig effort was <350 $fisher\text{-}days.year^{-1}$, before peaking at 1,477 fisher-days in 1997 (Figure 4-56). Since then, it has fluctuated between 600 and 900 $fisher\text{-}days.yr^{-1}$ before dropping to 490 fisher-days in 2016. Jig CPUE followed a similar trend increasing from >50 $kg.fisherday^{-1}.year^{-1}$ to 173 $kg.fisherday^{-1}$ in 1997, and subsequently declining to <15 $kg.fisherday^{-1}.year^{-1}$ since 2007. The short-term expansion of the fishery between 1994 and 1997 reflects the fleet's concentrated of fishing effort on the spawning aggregation in northern Spencer Gulf. The fishery was effectively arrested by the False Bay spawning closure, which accounted for >90% of the State-wide catch.

Regional

Between 1994 and 2002, NSG has provided the highest catches of Cuttlefish with only incidental catches from the other regions. During these years, catch was concentrated at the time of the spawning aggregation between April and August. In 2016, the MSF fishers accounted for 100% of the commercial catch (Figure 4-57).

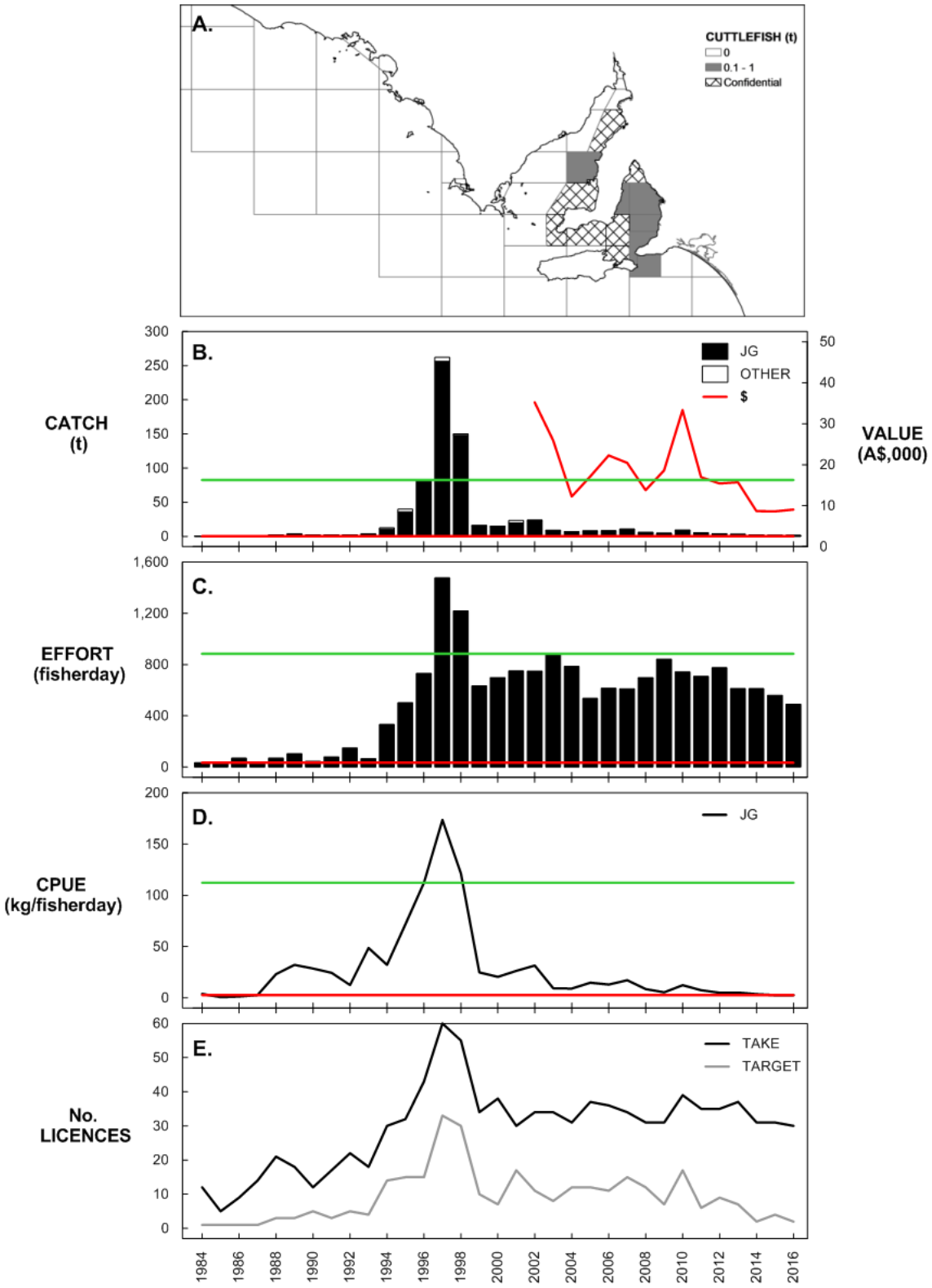

Figure 4-56. Cuttlefish (A) Catch distribution for 2016; Long-term trends in: (B) total catch for squid jig and gross production value; (C) total effort for squid jig; (D) targeted catch per unit effort for squid jig; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

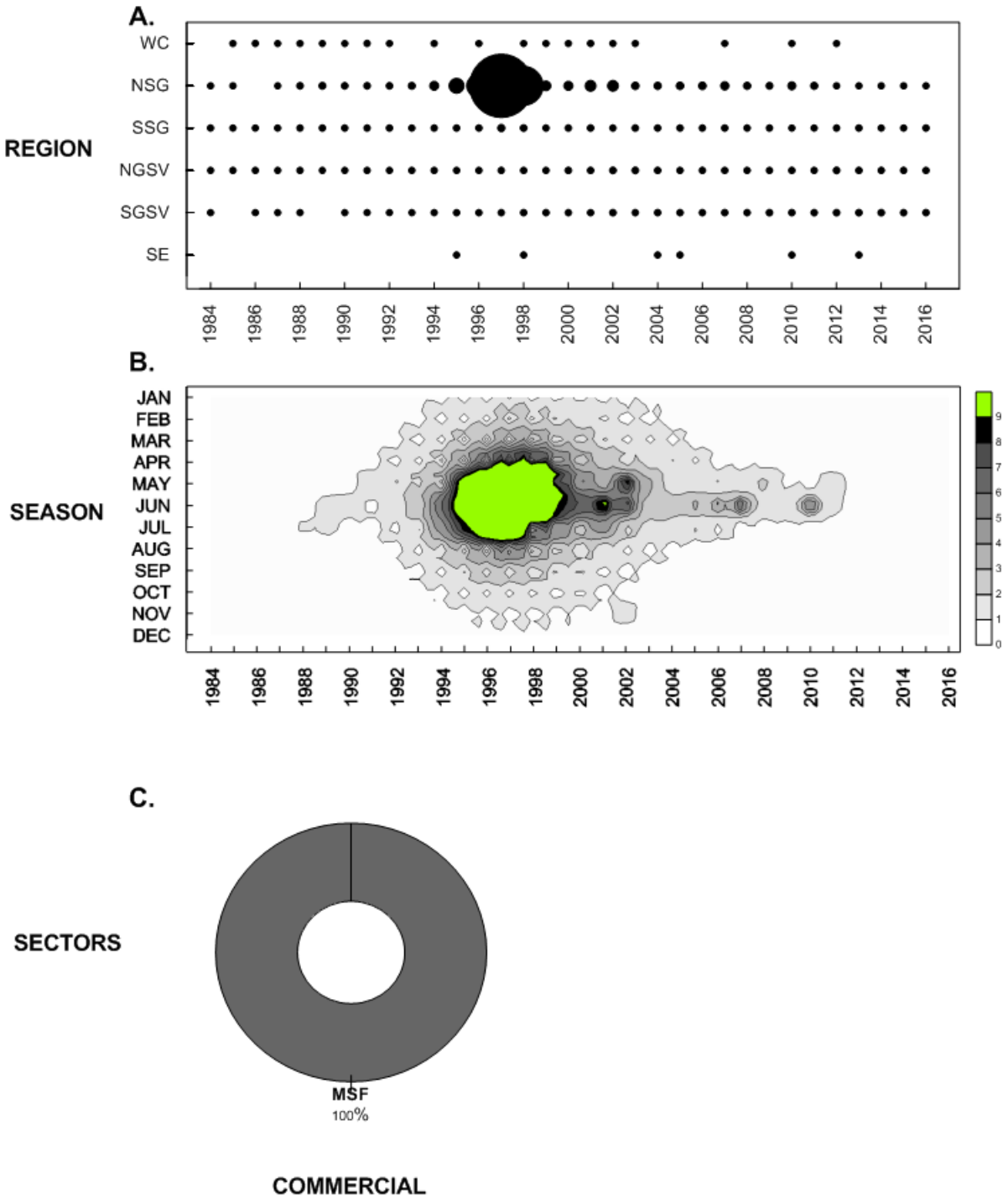

Figure 4-57. Cuttlefish. Long-term trends in the annual distribution of catch among regions (A) and months of the year (B). The proportion of catch distributed among the commercial sector in 2016 (C).

Fishery Performance

The general fishery performance indicators for Cuttlefish were assessed for 2016 at the State-wide scale. Two trigger reference points were activated in 2016 (Table 4-23). Total catch declined over 5 consecutive years, while total jig CPUE was the third lowest recorded since 1984.

Table 4-23. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Cuttlefish.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	✓
TOTAL JIG EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×
TOTAL JIG CPUE	G	3rd Lowest / 3rd Highest	3rd LOWEST
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

There is a minor targeted fishery for this species although it is primarily taken as by-product when other more valuable species, such as Southern Calamari, are targeted. As such, there is a large number of fishers who have reported taking Cuttlefish compared to those who reported targeting it. Total catch of Cuttlefish has generally declined since 1997, corresponding with the implementation of spatial and temporal closures. In 2016, the catch rate was the third lowest level recorded since 1984. This was considerably lower than the high catch rates recorded through the peak period of the mid to late 1990s, and only slightly higher than the lowest level recorded in 1985. There were two trigger reference points breached for the data from 2016 reflecting low targeted jig CPUE and a declining total catch over 5 consecutive years. However, fishery independent surveys of abundance in the Point Lowly closure area showed consecutive annual increases from 2014 and 2015, and relatively high abundance in 2016 (Steer, unpublished data). This, in addition to the low recent catches and decrease in effort, suggests that the fishery is unlikely to become recruitment overfished at the current level of fishing pressure. On this basis, SA's Cuttlefish fishery is currently classified as **sustainable**.

4.3.21. BLACK BREAM (*Acanthopagrus butcheri*)

Biology

Black Bream (*Acanthopagrus butcheri*) is a member of the Sparidae family, i.e. the Seabreams (Gomon et al. 2008). It is an endemic species widely distributed in estuaries and coastal areas across southern Australia from the Murchison River, Western Australia to Myall Lake, New South Wales, including Tasmania (Norriss et al. 2002). Black Bream is tolerant to a wide range of temperatures, salinities and dissolved oxygen concentrations (Ye et al. 2015), often entering rivers with low salinities (Gomon et al. 2008). Unlike most members of the Sparidae family, Black Bream complete their entire life cycle within their natal estuarine environment (Partridge and Jenkins 2002). This has led to genetically distinct populations between estuaries. Such separation makes it difficult for populations to be supplemented from surrounding waters, making them highly susceptible to overfishing (Chaplin et al. 1998).

Black Bream is considered a periodic strategist (Winemiller and Rose 1992), i.e. large-bodied fish with slow growth, late maturation, long life-span, high fecundity and low juvenile survivorship. The species is golden brown to bronze in colour with a blackish margin (Gomon et al. 2008). It reaches a maximum age of 29–32 years, maximum length of 550 mm TL and age of maturity at 1.9–4.3 years (Ye et al. 2015). It is an opportunistic carnivore that feeds on shellfish, worms, crustaceans, small fish and algae (Norriss et al. 2002).

Fishery

Black Bream is considered an important recreational and commercial fisheries species (Ye et al. 2015). In South Australia, Black Bream are taken by both the commercial and recreational sectors of the Marine Scalefish Fishery. For the former, Black Bream are targeted and taken as by-product using hauling nets and set nets.

Recreational fishers target Black Bream using rod and line in nearshore coastal waters, estuaries and lower reaches of rivers (Kailola et al. 1993). The State-wide recreational survey in 2013/14 estimated that 197,848 Black Bream were captured, of which 180,869 were released, leaving 16,979 fish retained (Giri and Hall 2015). The latter provided a total estimated State-wide harvest of 4.97 t, which, although low was still considerably higher than the estimated catch of the commercial sector of 1.4 t.

Management Regulations

Black Bream is considered a tertiary species of the commercial MSF, being of low-medium value and making a minor contribution to the total production value (PIRSA 2013). For the commercial sector, many regulations are in place that limit the take of Black Bream. Temporal and spatial netting closures and restrictions to net lengths and mesh sizes to manage fishing activity and effort. A minimum size limit of 300 mm TL, increased from 280 mm TL (PIRSA 2016), applies to all catches.

There are multiple management regulations in place for Black Bream in the recreational sector. Input and output controls ensure the total catch is maintained within sustainable limits and that access is distributed equitably among fishers (Earl et al. 2016b). These include a bag limit of 10 fish and boat limit of 30 fish, and gear restrictions. The minimum size limit of 300 mm TL was increased from 280 mm TL in the recent recreational review (PIRSA 2016). A temporal closure limits the take of Black Bream from 1 September to 30 November in the Onkaparinga River upstream of the Main South Road Bridge at Noarlunga.

Commercial Fishery Statistics

State-wide

Historically, State-wide estimates of annual commercial catches of Black Bream have been low, generally <1.5 t.yr^{-1}. From 2012, catch increased to a peak of 8.4 t in 2015 before declining to 5.8 t in 2016 (Figure 4-58). Annual estimates of total fishing effort used to take catches of Black Bream have been variable since 1984. The lowest estimate of fishing effort was recorded at 8 fisher-days.yr^{-1} in 1996 before increasing to 137 fisher-days.y^{-1} in 1997. The greatest interannual change was recorded between 2002 and 2003 when fishing effort increased from 29 fisher-days.yr^{-1} to peak at 253 fisher-days.yr^{-1}. In 2015 and 2016, total effort was relatively consistent at the second and third highest levels recorded. Total CPUE showed long-term interannual variability ranging between 3 kg.fisherday^{-1} and 21 kg.fisherday^{-1} until 2007 when it increased dramatically to 47 kg.fisherday^{-1}. Since then, total CPUE has generally stayed above 20 kg.fisherday^{-1}. The numbers of fishers who reported taking and targeting Black Bream have been quite different over time, suggesting the catch is largely by-product when other species are targeted.

Regional

Confidentiality constraints (<5 fisher rule) prevented an interrogation of the commercial catch and effort data at the regional scale.

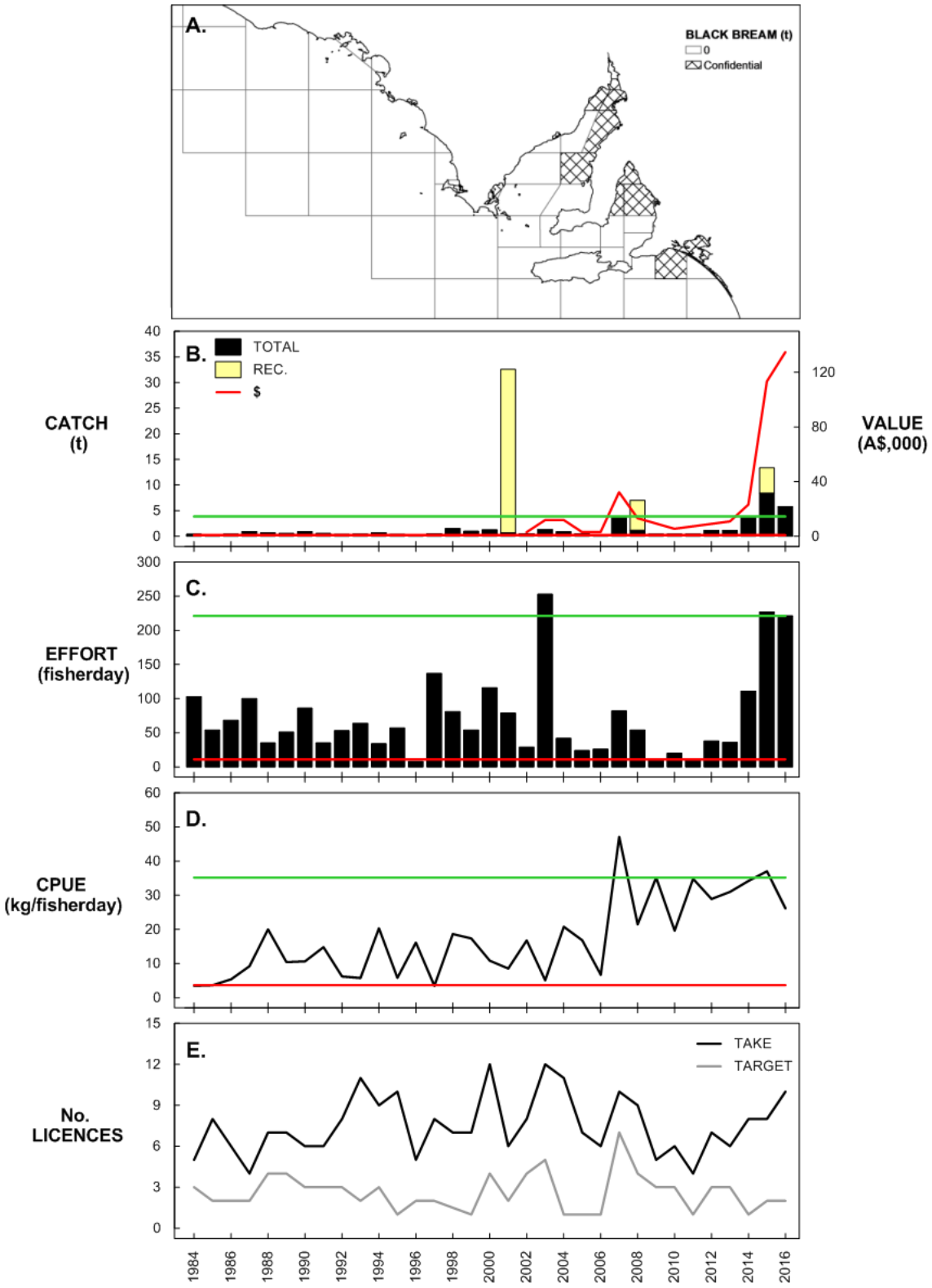

Figure 4-58. Black Bream (A) Catch distribution for 2016; Long-term trends in: (B) total catch and gross production value; (C) total effort; (D) total catch per unit effort; and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower trigger reference points outlined in Section 1.5.

Fishery Performance

The general fishery performance indicators for Black Bream were assessed for 2016 at the State-wide scale. Two trigger reference points were activated (Table 4-24). In 2016, total catch was the 2nd highest and total effort was the 3rd highest on record since 1984.

Table 4-24. Results from the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Black Bream.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE
TOTAL CATCH	G	3rd Lowest / 3rd Highest	2nd HIGHEST
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖
TOTAL EFFORT	G	3rd Lowest / 3rd Highest	3rd HIGHEST
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖
TOTAL CPUE	G	3rd Lowest / 3rd Highest	✖
	G	Greatest % interannual change (+/-)	✖
	G	Greatest 3 year trend	✖
	G	Decrease over 5 consecutive years	✖

Stock Status

Black Bream is a tertiary species for the commercial sector of the MSF (PIRSA 2013). This reflects low catches and its relatively minor contribution to the total production value of the commercial MSF. Catches were historically low from 1984 to 2010, as a result of relatively low fishing effort in most years. Since 2013, total catch at the State-wide scale has increased considerably, reflecting an increase in total effort. The recent increases in total catch and CPUE suggest a possible increase in Black Bream biomass, and are not consistent with a stock that is becoming recruitment limited. As such, SA's Black Bream fishery is classified as **sustainable**.

4.3.22. CATCH STATISTICS OF REMAINING PERMITTED SPECIES

Table 4-25. Summary table showing the total annual commercial catches in tonnes for the remaining permitted species available to the Marine Scalefish Fishery that were not considered separately in this report. Other sharks include Broadnose Shark, Dog Shark, Hammerhead Shark, Saw Shark, Thresher Shark, Whiskery Shark and Wobbegong. Crosses indicated confidential data (< 5 fishers).

YEAR	ANNELID	BLUE CRAB	VELVET CRAB	MUSSEL	OCTOPUS	OYSTER	SCALLOP	ARROW SQUID	ANCHOVY	BARRACOUTA	COD	DORY	FLATHEAD	FLOUNDER	BLUESPOT GOATFISH	YELLOWTAIL KINGFISH	PINK LING	BLUE MACKEREL	JACK MACKEREL	MORWONG	SCHOOL, SEA, JUMP MULLET	BIGHT REDFISH	SARDINE	SOLE	SWEEP	SWALLOWTAIL	BLUE-EYE TREVALLA	SCHOOL WHITING	OTHER SHARKS
1984	13.9	114.7	X	X	X	X	X	X	X	76.1	0.4	X	4.6	0.3	X	0.7	X	X	2.1	10.8	2.7	5.1	X	X	3.5	X	X	X	21.1
1985	14.6	126.1	X	X	0.2	X	X	X	X	24.0	X	X	3.2	1.0	X	X	X	X	X	13.4	2.6	8.9	X	X	3.1	X	X	X	25.3
1986	15.2	170.1	X	X	X	X	X	X	X	7.6	X	X	3.4	1.2	X	X	0.1	X	3.0	19.5	3.7	16.3	X	X	1.7	X	3.4	X	27.7
1987	11.1	165.2	X	X	1.4	X	X	X	X	5.8	X	X	3.3	0.5	X	X	1.1	3.7	X	24.4	3.3	13.8	X	X	1.8	X	3.6	X	80.3
1988	11.2	209.4	X	X	3.1	X	X	X	X	12.2	0.4	X	5.1	0.3	X	X	0.4	0.8	37.4	22.7	4.2	14.7	X	X	2.7	X	24.6	X	82.9
1989	13.5	323.6	X	X	2.6	X	X	X	X	9.1	0.2	X	4.0	0.3	X	X	0.2	1.3	X	28.7	4.7	22.0	X	X	9.6	0.2	153.9	X	72.4
1990	15.7	390.5	X	X	3.9	X	X	X	X	12.9	X	X	5.6	X	X	X	0.2	0.6	X	28.3	6.3	15.6	X	X	10.5	0.3	95.1	0.1	73.0
1991	15.6	434.6	X	X	6.2	X	X	X	X	5.2	X	X	6.9	0.2	X	0.4	0.1	1.4	0.3	20.5	3.9	9.4	8.8	X	7.0	0.4	54.9	X	102.4
1992	16.8	429.1	X	X	9.7	X	X	X	X	2.5	X	X	5.9	0.2	X	2.5	0.4	0.7	0.4	16.3	5.6	10.4	464.9	X	3.2	0.3	84.3	X	259.5
1993	13.7	566.3	X	X	6.5	X	X	X	X	2.0	X	X	4.5	0.1	X	1.7	2.1	0.5	0.4	13.6	4.6	13.5	1463.0	X	4.8	0.4	70.6	0.1	351.3
1994	13.7	484.3	X	X	5.3	X	X	X	X	0.5	X	X	3.9	0.1	X	0.7	0.7	6.7	0.0	20.1	4.9	13.7	3241.3	X	8.9	0.5	49.2	0.1	135.1
1995	13.7	692.9	X	X	6.8	X	X	X	X	X	X	X	2.8	0.5	X	0.5	0.6	5.0	0.3	25.8	4.1	18.2	2510.8	X	5.8	0.1	54.6	0.0	111.6
1996	14.0	559.6	X	X	11.4	X	X	X	X	0.9	X	X	2.3	0.2	X	X	1.3	5.7	X	29.8	4.9	11.9	3532.3	X	5.9	0.4	36.7	0.1	133.7
1997	11.5	320.9	X	X	5.9	X	X	X	X	X	X	X	2.2	0.1	X	X	1.6	4.0	X	14.1	3.5	9.3	3213.4	X	8.7	0.1	18.0	X	77.0
1998	11.2	74.3	X	X	X	X	X	X	X	0.3	X	X	2.5	X	X	X	X	4.6	X	8.6	4.7	4.6	5973.2	X	5.9	0.1	6.6	X	60.9
1999	11.5	123.9	X	X	7.4	X	X	X	X	X	X	X	2.8	0.2	X	X	X	2.4	X	3.7	6.1	5.5	2632.6	X	2.6	X	4.5	X	53.8
2000	14.3	78.5	X	X	7.5	X	X	X	X	X	X	X	2.1	0.0	X	X	X	3.6	X	1.6	3.8	3.0	1822.9	X	1.4	X	X	X	55.8
2001	10.8	92.9	X	X	X	X	X	X	X	X	X	X	2.1	X	X	X	X	0.4	X	0.5	4.9	1.6	X	X	1.8	X	X	X	75.6
2002	8.2	66.7	X	X	5.5	X	X	X	X	2.0	X	X	2.1	X	X	0.2	X	5.1	X	1.5	3.7	3.6	X	X	2.0	X	X	X	46.7
2003	7.0	66.2	X	X	5.1	X	X	X	X	2.4	0.0	X	2.2	X	X	0.4	X	1.5	X	2.6	3.6	3.4	X	X	2.0	X	X	0.1	36.2
2004	7.2	51.9	X	X	X	X	X	X	X	5.5	X	X	2.1	X	X	0.1	0.1	3.6	X	3.0	4.8	4.7	X	X	1.7	X	X	X	31.2
2005	7.5	47.8	X	X	X	X	X	X	X	4.3	X	X	2.2	X	X	0.4	X	0.8	X	3.8	3.9	7.5	X	X	1.4	X	X	X	24.8
2006	7.5	47.6	X	X	8.1	X	X	X	X	0.9	X	X	1.7	X	X	X	X	2.3	X	2.0	6.0	3.9	X	X	1.4	0.0	X	X	25.3
2007	6.6	41.8	X	X	18.9	X	X	X	X	X	X	X	2.1	X	X	X	X	3.6	X	2.3	14.2	4.6	X	X	0.8	0.1	X	X	19.5
2008	7.6	51.0	X	X	23.3	X	X	X	X	X	X	X	2.4	X	X	0.5	X	3.5	X	1.8	5.4	3.3	X	X	1.2	0.1	X	0.1	12.1
2009	6.1	60.4	X	X	X	X	X	X	X	2.2	0.4	X	3.3	X	X	0.1	X	2.1	X	2.6	7.3	6.8	X	X	2.5	0.4	X	X	16.3
2010	5.8	54.2	X	X	X	X	X	X	X	X	X	X	4.2	X	X	0.3	X	1.9	X	3.4	4.4	8.9	X	X	2.2	0.5	X	X	19.3
2011	5.9	53.6	X	X	14.6	X	X	X	X	X	X	X	5.7	X	X	X	X	X	X	2.9	4.3	14.2	X	X	3.1	0.2	X	X	22.9
2012	6.5	56.6	X	X	X	X	X	X	X	X	X	X	2.6	X	X	0.2	X	0.3	X	1.2	3.9	10.7	X	X	3.1	0.3	X	X	12.9
2013	5.4	62.5	X	X	7.6	X	X	X	X	X	X	X	1.6	X	X	X	X	X	X	1.0	5.7	10.0	X	X	2.4	0.2	X	0.0	8.4
2014	5.0	60.9	X	X	11.4	X	X	X	X	X	X	X	2.0	X	X	2.8	X	X	X	0.6	6.6	8.3	X	X	2.0	0.1	X	0.2	7.5
2015	5.2	45.0	X	X	10.6	X	X	X	X	X	X	X	2.0	X	X	1.3	X	X	X	0.9	3.8	12.6	X	X	1.1	0.1	X	X	7.1
2016	4.3	31.2	X	X	X	X	X	X	X	X	X	X	0.8	X	X	2.0	X	X	X	0.9	4.5	12.2	X	X	0.9	0.1	X	X	4.4

5. GENERAL DISCUSSION

5.1. Synthesis

This report assessed the fishery performance of 22 species/taxonomic groups within South Australia's Marine Scalefish Fishery (MSF). Collectively, these taxa were considered across 34 management units, at a resolution that aligned with either the biological stock, or the State-wide or regional level. Of these, 27 (79%) stocks were classified as 'sustainable', three (9%) were 'recruitment overfished', two (6%) 'transitional-depleting', one (3%) was 'transitional-recovering', and the remaining one (3%) was undefined as there was insufficient information to assign a stock status.

The four primary species (King George Whiting, Snapper, Southern Garfish, and Southern Calamari) have consistently accounted for more than half of the State-wide total commercial catch over the last decade, emphasising their importance to the MSF. Previous stock assessments for King George Whiting (Fowler et al. 2014), Southern Garfish (Steer et al. 2016) and Snapper (Fowler et al. 2016a) have identified different levels of concern regarding the sustainability of some stocks. The Spencer Gulf (SG) and Gulf St. Vincent/Kangaroo (GSV/KI) King George Whiting stocks were classified as 'transitional-depleting' on the basis of declining trends in commercial catch rates, estimates of biomass and high exploitation rates (Fowler et al. 2014). Similarly, the Spencer Gulf/West Coast (SG/WC) Snapper stock was assessed as 'transitional-depleting', as a result of below average recruitment and declining biomass (Fowler et al. 2016a). Persisting low rates of egg production, relatively high exploitation rates and declining catch rates lead to the Northern GSV Garfish stock being classified as 'recruitment-overfished' (Steer et al. 2016). In each case, these assessments supported the development and implementation of specific management arrangements to recover these stocks. With the exception of one King George Whiting stock (SG), whose status has improved from 'transitional-depleting' to 'sustainable' as a result of three consecutive years of positive recruitment, the status of the concerning Snapper and Southern Garfish stocks have remained unchanged in this assessment.

The improved status of the King George Whiting Spencer Gulf stock was unrelated to the management arrangements implemented in December 2016, which included a spatial closure to protect known spawning grounds and an increase in the legal minimum length, as it occurred prior to their implementation. Nevertheless, the new spatial spawning closure is likely to provide additional benefit, particularly as the advancement of fishing technologies, such as increased vessel power, affordable electronic fish-finding equipment, improved fishing gear, and rapid

communication through social media, has increased the fishing fleet's capacity to extend their effort into offshore areas that have been difficult to access in the past. A project is currently underway to determine key King George Whiting spawning areas throughout the southern gulfs and to understand their role in replenishing local stocks (FRDC 2016/003). It is anticipated that the results of that study will improve the assessment and management of this important resource.

The poor performance of the SG/WC Snapper stock has persisted, and although there have been considerable management arrangements implemented over the last five years to reduce exploitation and enhance reproductive output and recruitment, the manifestation of any benefit within the population is likely to extend over a longer timeframe. This is because Snapper are a long-lived species and this stock has historically been replenished by highly irregular recruitment events of varying strengths. The last notable recruitment events in SG/WC occurred in 1997 and 1999 (Fowler et al. 2016a). Conversely, the short lifespan and rapid generation turnover of Southern Garfish increases the populations' capacity to respond rapidly to effective management arrangements. This was indeed the case for the NSG Garfish stock which has displayed promising signs of improvement in biomass, recruitment and egg production. Consequently, this stock was classified as 'transitional-recovering' in the last full stock assessment (Steer et al. 2016). The NGSV Garfish stock is yet to display any evidence of improvement and remains classified as 'recruitment-overfished', indicating that it has not responded as favourably to the current management arrangements. However, it should be noted that only the interim trends in the commercial catch and effort statistics have been interrogated in this report, and a full stock assessment, which will evaluate the performance of the fishery against modelled biological indicators, is scheduled for 2018.

Declines in the productivity of the premium finfish species have contributed to the diversification of the MSF fishing fleet, with many fishers switching their effort from Snapper, King George Whiting and Southern Garfish towards Southern Calamari. This change has most likely been economically driven, where it has become more cost-effective to target Southern Calamari based on their relative abundance, catchability, low set-up costs and high market value. The increase in targeted jig effort has been particularly evident over the past five years, exceeding the associated trigger limits in NSG, SSG, NGSV and SGSV. This recent trend indicates that Southern Calamari has been established as an opportunistic target species for commercial fishers, and has surpassed Snapper and King George Whiting as the most valuable MSF species for the first time in history. Although the resource is considered 'sustainable' at the biological stock level there are concerns within industry about local productivity, with anecdotal reports

suggesting some areas are displaying signs of localised depletion. These inferences have been based on Southern Calamari becoming increasingly difficult to catch in areas that were previously highly productive, a lack of eggs in known spawning areas, and a notable absence of large animals. Although localised depletion can occur through intense fishing pressure on spawning aggregations, their high-paced life history, dynamic spawning behaviour, and movement potential, favours population replenishment at the broader biological stock level (Pecl et al. 2006).

The long-term erosion of fishing effort through licence reduction is a distinct feature of the MSF. Since 1994, 399 MSF licences have been removed, representing an overall reduction of 55.8%, and translating to a 55.6% reduction in total fishing effort. With the exception of NGSV, where the number of active licences has remained relatively stable and annual effort levels have slightly increased over the last decade, the long-term erosion of licence numbers is clearly evident in all other regions considered in this report. Despite a halving of the commercial MSF over 23 years, industry and government have recently committed to a structural reform of the Fishery, to ensure its long-term sustainability and economic viability. This reform aims to address the inherent complexities of the fishery through firstly developing a mechanism to further rationalise the fleet, then reform its overall structure, to ultimately refine its future management. Aspects of this reform will be informed by a dedicated research project that aims to firstly disentangle and understand the fleet dynamics of this complex multi-species, multi-gear fishery, then explore the implications of strategic management options (e.g. regionalisation, unitisation) on the future structure and viability of the MSF, from resource sustainability, economic and social perspectives (FRDC 2017/014).

The multi-species nature of the MSF can be considered a strength of the fishery, as it provides considerable flexibility in the fishing dynamics of the fleet. As seen with the recent increase in effort targeted towards Southern Calamari, there is also evidence of other, relatively low value, secondary and tertiary species becoming more prominent within the fishery. Snook and Leatherjackets have been increasingly targeted by hauling net fishers, more fishers are taking Wrasse using handlines and longlines; and there has been a resurgence in catches of Ocean Jackets and Western Australian Salmon over the past four years. For some of these species, increased effort has presumably been in response to developing markets, whereas others have arisen out of the need for fishers to counteract diminishing access to more valuable species as a consequence of management arrangements, sustainability concerns or competitive interactions. Reducing the MSF's reliance on the four primary species through the development of under-utilised species has been identified by industry and government as a means of redirecting effort

away from compromised stocks to facilitate their recovery, and to increase the overall productivity and profitability of the fishery. A study has recently been funded to explore the MSF's potential to diversify by increasing production of these lower value, under-utilised species, whilst conforming to the principles of ecologically sustainable development (FRDC 2017/023).

A number of species considered in this report constitute by-product for the hauling net sector, where they are incidentally caught when fishers target more valuable species. Of these, Yellowfin Whiting, Australian Herring, Snook, Leatherjackets and Yelloweye Mullet are of medium value, with moderate market appeal. Each of these species, share similar commercial catch and effort trends, where fishing effort within the hauling net sector has been sequentially reduced as a function of the licence amalgamation scheme implemented in 1994, and two net buy-backs associated with increased netting closures introduced in 2005 and 2014. These management arrangements, have effectively constrained the fishing capacity of the hauling net sector to predominantly target premium MSF species (i.e. Southern Garfish, King George Whiting, Southern Calamari). Nominal catch rates for the by-product species have trended upwards, suggesting that they are relatively abundant and being harvested at sustainable levels.

5.2. Research Priorities

Currently, the most significant gap in our knowledge in the assessment of the status of MSF fish stocks is in determining the relative contribution of the State-wide catch by the recreational fishing sector. This sector's total harvest has recently been determined through telephone/diary surveys that are undertaken on a five-year cycle (Henry and Lyle 2003, Jones 2009, Giri and Hall 2015). Although these surveys adopt a standard methodology that allows the results to be compared through time, their estimates of catch and effort are typically imprecise. This imprecision has flow-on ramifications in the assessment of primary MSF species, for which the recreational contribution is considered significant (i.e. King George Whiting and Snapper). It also has implications for determining resource shares against prescribed allocations, which can ultimately lead to changes in the management of the resources amongst the fishing sectors. Improving the precision of the recreational catch estimates, either through more frequent surveys or increased participation rates, will broadly benefit the assessment and subsequent management of the MSF.

Determining stock status through the weight-of-evidence approach for all the MSF stocks considered in this report has relied heavily of fishery-dependent statistics. Given the diverse structure and function of the fishery, these data sources will continue to form the basis of both quantitative and qualitative assessments. This is particularly relevant for the secondary and

tertiary species that have fewer data available and limited resources to develop more sophisticated fishery-independent assessment programs. In recent years, it has become increasingly evident that the fishing dynamics of the MSF fleet has changed, and, in some cases, these changes have compromised the reliance on fishery-dependent information to determine stock status. For example, changes in fishing efficiency combined with new management arrangements for Snapper had compromised the use of CPUE as a suitable index of stock biomass, and lead the development of an alternate fishery-independent estimate (Steer et al. 2017). Similarly, the issue of advancing fishing technologies and improved efficiency was identified as a key concern for King George Whiting. The WhitEst model does not assume long-term changes in 'effective' effort, and estimating this rate is challenging without reliable fisher-dependent measures. This evolution of the fishery was acknowledged in the previous King George Whiting stock assessment (Fowler et al. 2014) which also lead to a project to explore fishery-independent alternatives (FRDC 2016/003). For the primary species, that have dedicated quantitative stock assessment models, there is a need to explore the relative effects of nominal increases in effective effort, and to determining whether greater influence be placed on biological metrics, or if fishery-independent data streams can be used to 'ground-truth' model-derived estimates of biomass. For the other lower-value species, there may be a need to revisit whether nominal estimates of targeted CPUE are the most informative metric of relative abundance, as opposed to standardized catch rates. The MSF is currently undergoing considerable transition through the structural review, development of new harvest strategies and pending review of the Management Plan. An FRDC project that will provide statistical support to this structural reform will review current fishery assessment methods and consider the implementation of data-limited approaches to optimise its sustainable utilisation of the resource.

The re-activation of a number of key fishers that have targeted Western Australian Salmon in recent years may be indicative of a resurging fishery. Industry have indicated the potential for this fishery to expand by altering fishing practices to efficiently target large, offshore schools and to embrace new processing technologies to maximise the product quality for human consumption. The current level of biological information that exists for Western Australian Salmon in South Australia is dated (Malcolm 1960, Cappo 1987) and largely focused on the coastal component of the shared stock. The potential expansion of the fishery into offshore waters represents access to an unknown component of the resource. There is a fundamental need to update our understanding of the population structure of Western Australian Salmon throughout State and southern Australian waters including both the inshore and offshore components of the stock. There is also a need to update key biological metrics for this species (e.g. size/age structure, size

at maturity, reproductive condition, growth rates) to underpin the development of a species-specific harvest strategy to ensure the sustainability of the resource.

The inability to differentiate between the two species of Whaler Sharks caught within the MSF precludes an accurate assessment of their respective statuses. Although it is understood, that Bronze Whalers tend to dominate the catch, this needs to be accurately reconciled by discriminating the species at the time of capture and subsequent documentation. Fishers will need to become familiar with the slight, yet distinguishable characteristics that separate Bronze Whaler and Dusky Sharks, which may be achieved through the development of an identification guide. Although, a lessor priority, similar guides may also be of value in the discrimination of Bight Redfish, Wrasse, Leatherjacket, and other Shark species that are retained within the MSF.

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APPENDICES

5.3. Appendix 1. Recreational Catch Data in 'WhitEst'

Recreational data constitute the majority of the catch of King George Whiting in South Australian waters. But the data available to inform the catch from that sector is relatively limited and imprecise, provided predominantly from three telephone and diary survey surveys conducted in 2000/01, 2007/08, and 2013/14. Since 2007, charter boats have reported their catch totals in logbooks. In this Appendix we summarise the pre-processing of these recreational harvest survey data for use as input to the WhitEst stock assessment model. We have modified the method for pre-processing the survey data in this most recent assessment, notably for how recreational catches are allocated among months of the year.

The most recent recreational fishing survey (Giri and Hall, 2014), covering 2013/14 and used here for the first time in WhitEst modelling, did not provide the estimated King George whiting catch number broken down by month, as the two previous surveys had done, and included no effort data specific to King George whiting. Because WhitEst uses a monthly time step, we introduced several additional steps of data pre-processing to obtain the required data inputs for recreational catch by region and month. We give details of this pre-processing in first subsection below. In the second subsection, we outline modifications to the WhitEst model fitting procedure undertaken in the absence of recreational effort data for 2013/14. Surveys report all catches in numbers rather than weight landed, and the model fits to catches in number. In the third subsection we plot model-computed recreational catches of King George Whiting in weight landed for comparison with commercial catches which is always reported in tonnes.

Giri and Hall (2015, Table 8) reported a single total number of King George whiting harvested (1,467,601) by recreational fishers (including charter boats and onshore) for the 12 month period covered by the telephone and diary survey in the 12-month period from December 2013 to November 2014. They also reported percentages by region (Giri and Hall 2015, p. 34, Figure 11B) that we applied to the total yearly harvest number, giving estimates of total yearly King George whiting recreation harvest by region for the year. We further separated the catches of northern GSV from southern GSV and KI, which are separate regions in the WhitEst spatial model, using the average regional northern and southern GSV catch proportions from the two previous recreational surveys (2000/01 and 2007/08). We denote the resulting 2013/14 yearly recreational King George whiting regional catches in number harvested as $\left\{N_r;\ r=1,n_{Region}\right\}$, where the subscript *r* is an index over the n_{Region} = 5 regions. This number harvested (1,467,601) excludes King George whiting (534,335, Giri and Hall 2015, Table 8) that were caught and subsequently released.

Pre-processing to obtain catches by month for the 2013/14 recreational survey

To obtain monthly numbers harvested, from the yearly totals $\left\{N_r;\ r=1,n_{Region}\right\}$ by region, we inferred monthly proportions harvested by fitting to the monthly recreational catch total estimates available from the two previous recreational surveys of 2000/01 and 2007/08.

Specifically we fitted the following statistical model in R

RecHarvestNos ~ -1 + factor(*Survey_no*) + factor(*Region*) + factor(*Region*):factor(*Month*),

using a gaussian GLM with an identity link, to the data of King George whiting catches by *Month* and WhitEst model *Region* for the two previous surveys, *Survey_no* = 1 or 2.

This GLM model fit generated parameter estimates yielding unscaled relative proportions harvested, which we denote $\left\{x_{m,r}; r=1,n_{Region}\right\}$, for each combination of *Region* and *Month* (red line in Figure A1.1) computed as GLM[factor(*Region*)] + GLM[factor(*Region*):factor(*Month*)].

To convert the GLM unscaled $\left\{x_{m,r}; r=1,n_{Region}\right\}$ inferred from the two previous surveys, into monthly catch estimates for 2013/14, we scaled the estimated catch parameters by month for each region independently. Denoting the rescaling factor to be derived for each region as F_r, we require that the sum of the 12 monthly catches equals the yearly 2013/14 survey harvest number $\left\{N_r;\ r=1,n_{Region}\right\}$ for each region:

$$\sum_{m=1}^{12}\left(x_{m,r}\cdot F_r\right)=N_r\,.$$

Solving for F_r we obtain

$$F_r=\frac{N_r}{\sum_{m=1}^{12}x_{m,r}}\,.$$

The final constructed King George whiting harvest number totals by region and month for 2013/14 become

$$C_{m,r}^{rec,1314}=x_{m,r}\cdot F_r=x_{m,r}\cdot\frac{N_r}{\sum_{m=1}^{12}x_{m,r}}\,.$$

The $C_{m,r}^{rec,1314}$ estimates are plotted as the “Rescaled GLM” line in Figure A1.1.

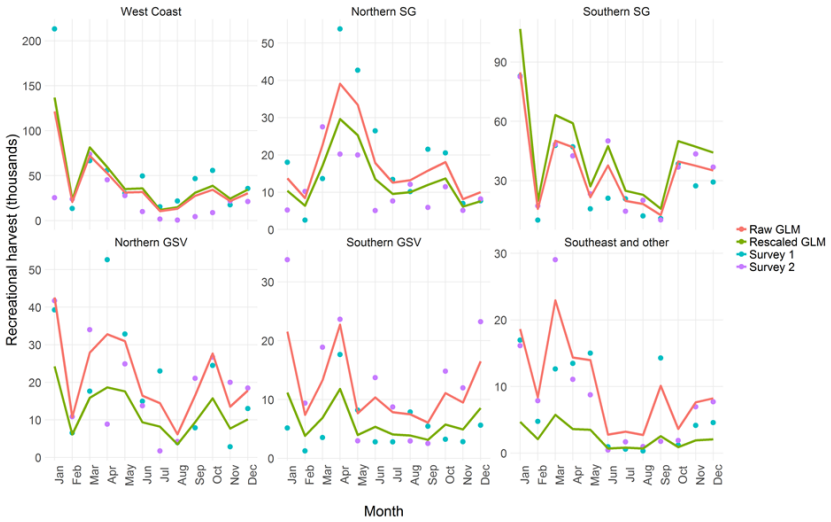


Figure A1.1. Rescaled monthly estimates of King George whiting catch in numbers of fish harvested ("Rescaled GLM") excluding fish released. Raw input data to the GLM analysis of monthly estimates of King George whiting from two previous surveys are plotted as dot marker points, 2000/01 as "Survey 1", 2007/08 as "Survey 2". The monthly GLM parameter estimates are shown as "Raw GLM".

The final recreational WhitEst input data set of monthly catches (after rescaling for 2013/14 and extrapolating between the three surveys) are shown in Figure A1.2. The summer holiday month of January is the highest recreational catch month, in all regions. Other peaks (around March or April, and October) also appear to coincide with yearly times of school holiday.

The yearly catches, showing the breakdown between charter and non-charter recreational catches are shown in Figure A1.3.

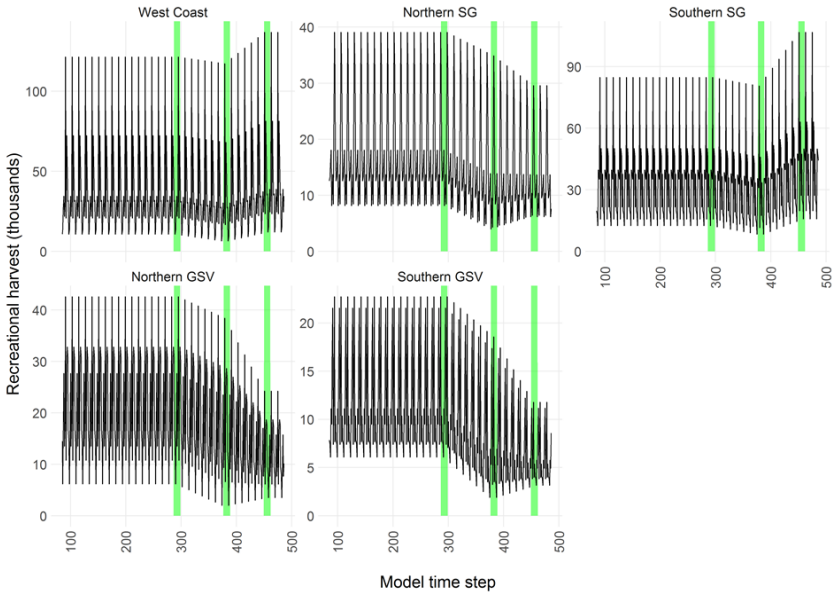


Figure A1.2. Monthly catches of King George whiting by the recreational sector used as data input by the WhitEst model. From November 2007 onward, charter boat catches have been reported in logbooks by that sub-sector, and these were subtracted from the survey estimates which included all recreational catch. The charter boat logbook catches are fitted separately in WhitEst from November 2007 onward. Green bands indicated years of recreational survey.

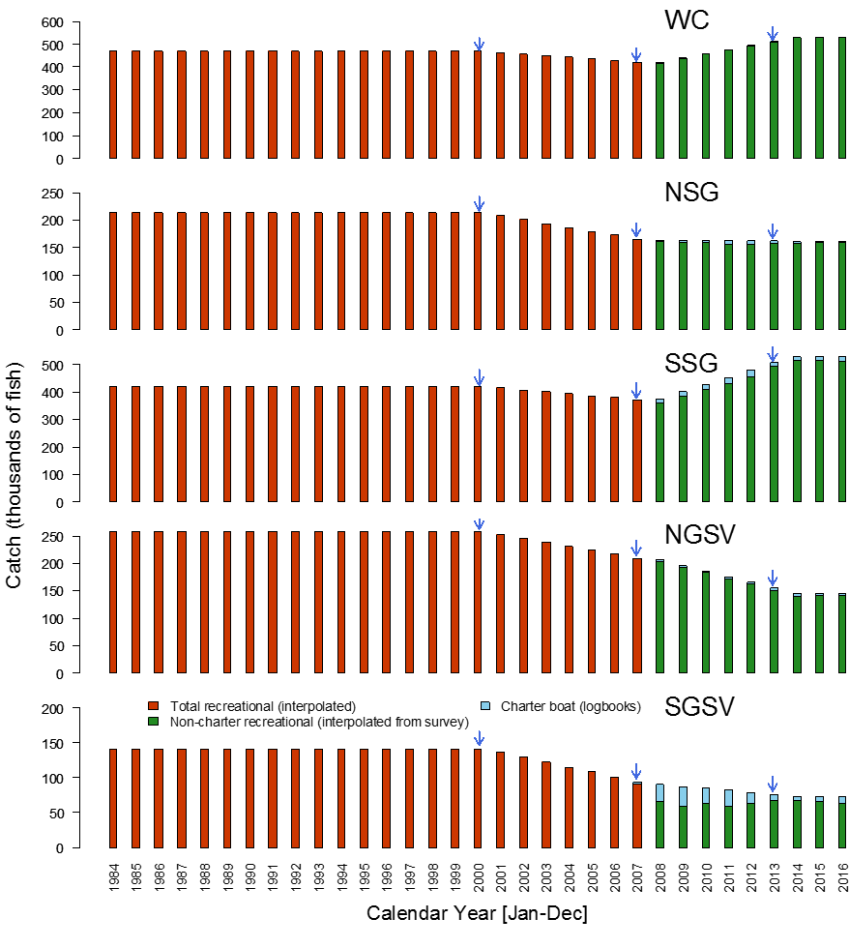


Figure A1.3. Yearly catches of King George whiting by the recreational sector. The blue arrows indicate the three years when telephone and diary recreational harvest surveys were undertaken. Between those survey years (see also Figure A1.2), catches were obtained by interpolation. Recreational catches for all years preceding the first 2000/01 survey assumed those values verbatim. Charter boat logbook reported catches are shown in light blue. Uncertainty in the survey estimates is wide, implying that the time trends indicated for non-charter recreational catches (green bars) and charter-recreational combined catches (red bars) are relatively uncertain.

Fitting WhitEst to recreational catches in the absence of effort data from the 2013/14 survey

To address the absence of effort estimates from the most recent recreational survey (Giri and Hall 2015), we altered the fitting procedure in WhitEst. For all other effort types, the model assumes a linear relationship between fishing mortality (*F*) and fishing effort (broken down by monthly model time step, region, and effort type). This is then incorporated into the corresponding Baranov relationships used to model catches and population survival in each time step (Equations A2.1-A2.4). The principal modifications undertaken in this 2017 WhitEst assessment run to account for the absence of recreational effort data in the most recent Giri and Hall survey was to (1) set recreational effort equal to 1 for all time steps, and (2) freely estimate the remaining cell- and month-specific catchability parameters (see Appendix 2, Equation A2.2b). With effort set to 1, these catchabilities effectively equal fishing mortality, *F*, for the recreational effort type, thereby obviating the need for recreational effort data. The final step was to substantially reduce the

weighting assigned to fitting recreational catches by region and model time step so that they have little effect on model-estimated trends in stock biomass.

Model computed catches of King George Whiting in weight

As a natural outcome of WhitEst modelling, the reported recreational catches are also converted to catches in weight harvested (Figure A1.4). This uses the tracking of catches by length bin (by slice) of each cohort as it passes through the fishery. Bear in mind, also that these tonnages landed do not include any release mortality. For comparison, we plotted both commercial and total recreational King George Whiting harvest, by year. The trend of increasing proportions taken by the recreational sector are evident, driven mainly by greatly reduced commercial fishing effort in the two gulfs since the late 1990's (Figure 3-4 and Figure 3-5).

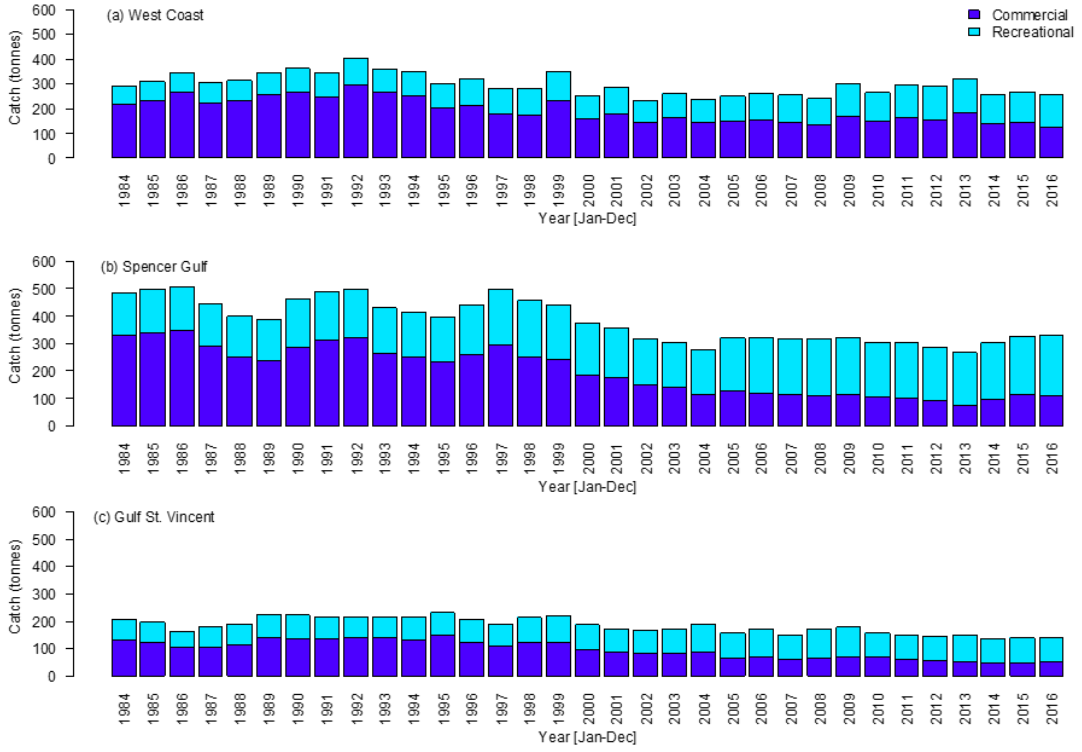


Figure A1.4. Yearly recreational (light blue) and commercial harvests of King George Whiting in the three main South Australian regions, given in tonnes landed.

5.4. Appendix 2: Specifications of the 'WhitEst' Stock Assessment Model

Introduction

The biological performance indicators of fishable (legal-size) biomass, harvest fraction, and recruitment for South Australian King George Whiting are estimated using the WhitEst stock assessment model. In this Appendix we present the full details of WhitEst, with equations. The model is coded in the ADMB language for statistical (likelihood) modelling and parameter estimation.

WhitEst uses a method developed in South Australia to represent both the length and age of modeled fish stocks by partitioning the continuous length-at-age distribution of each age cohort into length bins called slices (McGarvey et al. 2004; McGarvey et al. 2007). Rather than pre-chosen length bins of say 1 cm in width, we allow the slices, and so also the partition lengths separating neighboring slices, to grow with the cohort. The slice partition points (i.e. fish lengths separating neighboring bins) specify this growing length partition. These were chosen to achieve two objectives: (1) to permit the creation of one new length bin for each model time step, and (2) in each model time step, to cleanly separate fish above and below legal minimum length (LML). In each model time step, as each cohort crosses into legally harvestable size, a calculated proportion of the sublegal fish are assigned to the newly created length slice, namely the proportion reaching or exceeding LML in that time step. This length-and age-based fishery model formalism is also used for South Australian Snapper and Garfish. Here we outline the WhitEst model equations used to assess King George Whiting.

South Australian King George whiting (*Sillaginodes punctata*) are heavily exploited in the year or two immediately following recruitment to legal size. The larvae settle out in the near-shore, and reach legal size around ages 2-3 years in seagrass and shallow-water habitats, notably in the northern reaches of the two gulfs in South Australian waters (Figure A2.1). In early summer of ages 2 and 3, they migrate from inshore habitats to spawning grounds in deeper water, moving southward in the two gulfs (Fowler et al. 2002). For this reason, modelling both movement and on-going monthly recruitment of each cohort into legal size enhances model assessment accuracy.

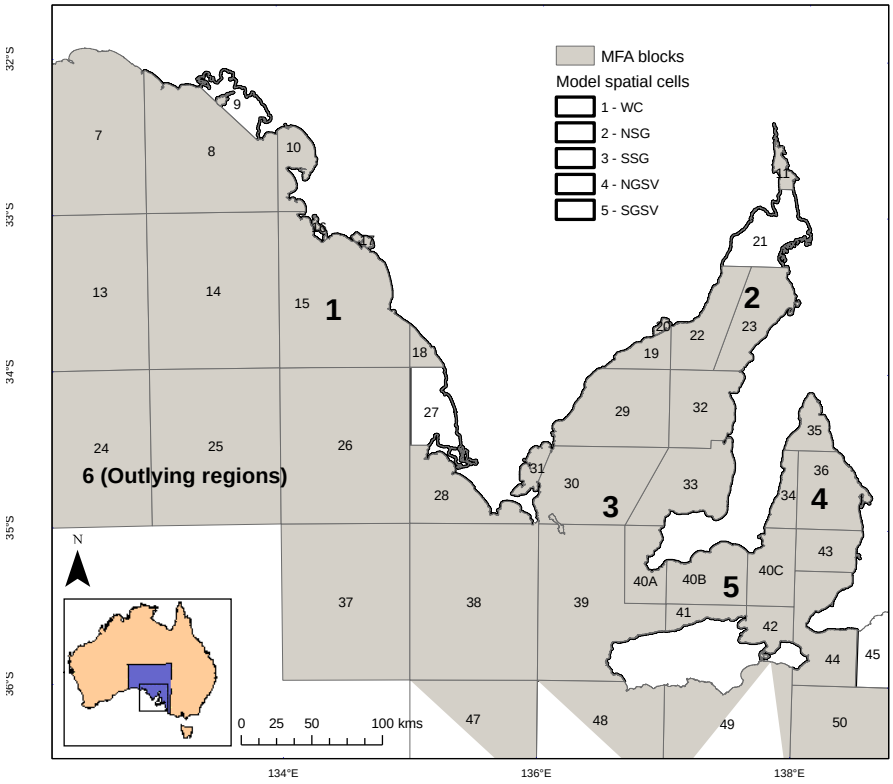


Figure A2.1. Map of South Australia showing the Marine Fishing Areas in which commercial catch and effort are reported, and the 6 spatial cells used in WhitEst. Three regions are defined as West Coast (cell 1 and its offshore areas), Spencer Gulf (cells 2 and 3), and Gulf St. Vincent (cells 4 and 5).

Tag-recovery data gathered over three decades were previously used to estimate a yearly movement matrix for King George whiting among 12 South Australian spatial cells (McGarvey and Feenstra 2002). Since then we have aggregated and thereby reduced the number of spatial cells to 6. These estimated movement rates, refined by integration into the WhitEst stock assessment model described below, were consistent with qualitative analysis of this migration (Fowler et al. 2002). A principal advantage of the recapture-conditioned movement estimation method (McGarvey and Feenstra 2002) employed with these standard fishery single tag-recovery data was that, unlike previous movement estimators (e.g. Hilborn 1990; Anganuzzi et al. 1994), a number of prior assumed inputs, such as tag-reporting rate, tag-release mortality, survival in the release cell, and, to a good approximation, tag shedding and natural mortality rates, cancel from the recapture-conditioned movement proportions, and are thus not required to estimate movement rates.

A growth submodel, using prior-estimated parameters, was also incorporated into the slice-based stock assessment model. WhitEst uses a monthly time step. For each cohort of for South Australian King George whiting, there is strong seasonality in growth, which is linked to seasonal changes in the predicted catch numbers-at-age and the catch totals by weight. (Fast growth in late summer autumn bring the next cohort into legal size, resulting in high catch rates and effort in later autumn and winter.) Thus, model-predicted catches vary markedly over relatively short time scales in the approximately 6-20 months of intensive exploitation. The stock assessment model sought to capture on-going growth of fish into the legal size range above LML, especially in the high-growth months of late summer and autumn and the simultaneous rapid harvest of legal-size fish from the population, with monthly catches peaking in winter following recruitment

of two- and three-year-olds and prior to subsequent summer migration. Estimates of mortality, and thereby most important fishery management indicators, must therefore be inferred from monthly rather than yearly change in catch data. These estimates benefited from a spatial age- and length-specific population model, running on a monthly time scale.

Data

There were four principal King George whiting data sets: (1) commercial logbook totals of catch in weight (kg) and effort (fisher-days) since July 1983, (2) catch proportions by age and sex from otoliths sampled in selected months and spatial cells during 1994-2016, (3) three separate years of recreational catch (numbers) and effort obtained from three national telephone and diary surveys (Appendix 1), and (4) tag-recoveries used to estimate movement rates.

The catch and effort data sets, and the fitted model quantities, were partitioned by 'effort type', that is, by recreational and commercial sector, and for the commercial sector, by gear and species targeted. Commercial harvest reported on catch logbooks was broken down by 4 categories of gear type, namely (1) handline, (2) haul net, (3) gill net, (4) all other gear types, and by 3 categories of target type: (1) specifically targeting King George whiting, (2) specifically targeting any other single species, (3) not specifically targeting any particular species. Catch and effort totals were thus partitioned into 13 'effort types', corresponding to 4 commercial fishing gears, and 3 categories of species targeted, plus recreationals. In November 2007, charter boats began reporting catches in number landed (Appendix 1), requiring the creation of a 14th effort type.

Data variable names are denoted by a tilde (~). For example, $\tilde{C}^{w}[t, cell, Etype]$ and $\tilde{E}[t, cell, Etype]$, give catch and effort totals by month, spatial cell, and effort type. A catch sample of 10,800 King George whiting were aged by otoliths, measured for length, and sexed during dissection (Fowler and Short 1998; Fowler et al. 2000) over 1994-1998, and a further 15,315 were sampled over 2004-2016. Counts of fish by age and by sex are written $\tilde{n}[a, sex \mid i_{AX}]$ for each sampled month and spatial cell, where i_{AX} is an index over all months and sexes for which age-sex samples were taken.

In (SAFCOL) market sampling, the sampling by length was controlled and representative, while the sub-sampling of ages from each length sample varied in non-representative fashion. For some combinations of month and spatial cell, more or fewer fish were aged relative to the (representative) sample size by length. The 2004-2016 age-sex sample counts by length bin, for each month and spatial cell, were corrected for non-representative age sampling by using the sample size ratios of the (presumed representative) fraction sampled in each length bin to the subsample fraction in each length bin that were aged and sexed. Similar correction for length representation in aged-sex sampled animals was applied for garfish and snapper (McGarvey and Feenstra 2004).

Cohort Length Partition by Slices and Recruitment

The algorithm by which length bin slices are created uses the length-at-age growth submodel. To partition cohorts by length, the underlying growth submodel must describe the full distribution of fish lengths for every cohort age, notably those crossing into legal size. This is derived from the estimated probability density function (pdf) for every monthly age, specified by length-at-age parameters estimated using a normalized likelihood of the growth model fitted to catch samples of King George whiting of measured length and (otolith-inferred) age (McGarvey and Fowler 2002). A normal likelihood pdf was used, though the slice partition method can assume any pdf for the lengths-at-age, specifically any growth curve giving mean length and the spread of lengths for each model age. Separate length-at-age growth parameters were estimated for each of three

regions in South Australian waters (Figure A2.1), and both sexes (McGarvey and Fowler 2002). Growth as increasing mean length (and modestly increasing spread of lengths-at-age) is modelled as increases in the slice partition points with successive ages.

From the growth (length-at-age pdf) submodel, an algorithm was constructed to effectively 'slice off' that portion of the length-at-age distribution which has recruited to legal size in each time step (Appendix 3). Once a (by definition legal-size) slice is created and fish transferred into it from the sublegal component, fish within each slice can only die or move between spatial cells.

The 'birth' (i.e. creation) of new King George Whiting cohorts to the model population happens at the age of 1 year after spawning, which is about a year prior to first reaching legal size. The number of fish born into each cohort at age 1 serves as the model estimate of yearly recruitment and was a freely estimated parameter for each year class. Yearly recruit numbers were estimated for each of the three South Australian regions (Figure A2.1), each assumed to constitute largely separate unit stocks of King George whiting. Only 2 of about 2000 tagged and recovered fish were observed to move between regions. Regional recruit numbers by sex assumed a 50:50 sex ratio, while the apportionment of recruits among spatial cells within each region was estimated as a set of yearly movement proportions for each region that were assumed constant across years. Subsequent to its creation at age 1 year, each cohort is reduced by natural mortality until reaching legal size. Faster growing fish (the upper tail of the pdf) reach and grow beyond legal minimum length sooner, and from those, in each model time step, legal slices are created and become subject to harvesting.

The slice-creation algorithm assumes the existence of a fixed legal minimum length (LML). The entire cohort is classified as 'sublegal' until at least 2% of the fish have reached legal size. When this criterion is reached, the first legal slice is created comprising that component of the length pdf having length $\geq$ LML. In subsequent model time steps, the number of fish (a real number) to be transferred from the surviving sublegal component of each cohort and assigned to each newly created slice is calculated. When 98% or more of the original cohort (the pdf) is above legal size, all remaining sublegal fish are summed into the last slice.

The numerical inputs needed to implement the slice growth form of length-based modelling inside a stock assessment model are threefold: (1) the proportions transferred from sublegal to each newly created slice, in the age when each slice reaches legal size, (2) the slice partition points (or the slice midpoints), and (3) the mean weight of each slice. The derivation of these quantities is given in Appendix 3. These three slice-growth quantities were needed and calculated (for WhitEst, prior not integrated) for each combination of sex and region (fish in each region and sex having different growth parameters), and for all three regulated levels of legal minimum length in this fish stock (28 cm, 30 cm, and 31 cm). The recent LML increase (from 31 to 32 cm in the gulfs in December 2016) was not modelled given that month was the last model time step in this assessment. Each fishery change in LML regulation required the model to re-map the old population numbers by slice into the new partition of slice bins for each cohort. This is accomplished by transferring fish in each old slice into each new slice in linear proportion to the amount of slice width overlap.

The slice partition points (or slice midpoints) were not used explicitly with the King George whiting stock assessment since it contained no selectivity by length. Using a length-weight relationship (McGarvey and Fowler 2002), and numerically integrating under the length-at-age pdf inside each slice, we calculated the mean weight of fish in each slice, $w[slice \mid sex, region, a]$, one slice partition for each possible monthly age in the model population. This triangular matrix of mean weights by age and slice (detailed in section *Slice Length Partition* below and Appendix 3) was used in model fits to catch totals from logbooks, which is reported as weight landed. Summing

over all legal slices, cohorts, and sexes, the model-predicted catch total by weight was calculated by summing the predicted number of fish captured times the derived mean weight in each slice.

While the recruit number of each cohort varied yearly, these slice-growth inputs, based on the growth submodel, varied only with age. To reduce computation time, for King George whiting in particular, we re-aggregated the slices into a single number of fish by age (creating 'post-legal cohorts') once each cohort had fully recruited to legal size. The majority of the catch in this fishery occurs while the cohort is crossing into legal size, that is, while the full slice-formulated length partition is retained.

King George Whiting stock assessment model

In this section, we describe the basic dynamic model components (submodels), and how they fit together to describe the change in the exploited King George whiting population over time. In the next subsection we explain how this population model is fitted to fishery data.

The stock assessment model has four principal submodels: (1) recruitment, (2) growth, via the slice formalism, (3) harvest and natural mortality, and (4) yearly migration. The recruitment and slice-growth submodels were described above. In this section, we detail submodels of harvest and movement and mortality equations of the model population array.

Model Population Array

The model population array, *N*[*t, cell, sex, cohort, slice*], is 5-dimensional, fish numbers broken down by (1) monthly model time step, (2) spatial cell, (3) sex, (4) cohort year, and (5) slice (i.e. length bin).

Ages ran from 13 months (1 year) to 157+ months. The highest age is a 'plus' group, comprising fish of the oldest monthly age (12 years 12 months) and older. Higher level independent variables of $month$, $gear$, a, and $region$ specify seasonal month of the year, gear, cohort age, and region. In model coding practice, these were calculated as functions of the five primary independent variables given in section *Symbols of index quantities*.

Effort and Catch

The catch equations assumed are effort conditioned. That is, fishing mortality is written as a linear function of reported monthly effort totals, which are assumed to be reported without error. The equation for each component of fishing mortality has the following form:

(A2.1) $F[t,\ cell,\ sex,\ cohort,\ slice,\ Etype] = q[cell,\ month,\ sex,\ Etype] \cdot \tilde{E}[t, cell, Etype]$.

The catchability, *q*, can vary with spatial cell, calendar month, sex of the fish, and the effort type, multiplicatively separable. For commercial catch and effort, the catchability is written:

(A2.2a) $q[cell,\ month,\ sex,\ Etype] = q_{CE}[region,\ Etype] \cdot s_m[cell, month] \cdot s_X[sex] \cdot s_3[a]$

with $q_{CE}[region,\ Etype]$ being an absolute catchability that varies among the three regions and by effort type, $s_m[cell, month]$ accounting for differing relative vulnerability among the 12 calendar months and for each spatial cell (January = 1), $s_X[sex]$ accounting for differing relative vulnerability by sex (females = 1), and a scalar $s_3[a]$ permitting a higher selectivity for fish of age 3 years (= 1 for $a < 37$ or $a > 48$), the age at which King George whiting are primarily targeted.

For the recreational effort type, the code includes the same structure as for commercial catch. But for this 2017 assessment, due to the absence of effort data in the 2013/14 (Giri and Hall,

2014) recreational survey, we set all effort data values equal to 1 for all time steps and spatial cells. This effectively removes effort as a meaningful input. See Appendix 1 for details.

(A2.2b) $$q_{rec}[cell,\ month,\ sex] = q_{rec}[cell,\ month] \cdot s_X[sex] \cdot s_3[a]$$

The absolute recreational catchability parameter $q_{rec}[cell,\ month]$ was then freely estimated for each spatial cell and calendar month but shared among years. With recreational effort input values all set equal to 1, the recreational catchability $q_{rec}[cell,\ month,\ sex]$ effectively equals fishing mortality, *F*.

The instantaneous fishing mortality rate for each element of the population array is given by a sum of fishing mortalities over all fishing effort types:

(A2.3) $$F[t,cell,sex,cohort,slice] = \sum_{Etype=1}^{nEtype} F[t,\ cell,\ sex,\ cohort,\ slice,\ Etype].$$

For King George whiting, changes in selectivity are primarily mediated by offshore movement to cells of lower exploitation, and no explicit length selectivity is postulated. *F* is thus constant among legal slices in any cohort and spatial cell.

Mortality

The depletion equation for each element of the population array was written:

(A2.4) $$N[t+1,cell,sex,cohort,slice] = N[t,cell,sex,cohort,slice] \cdot \exp\left[-\left(M + F[t,cell,sex,cohort,slice]\right) \cdot p_{yr}[t]\right]$$

where $p_{yr}[t]$ quantifies the proportion of a year spanned by the days in each monthly time step. The yearly rate of instantaneous natural mortality, M = 0.45, was taken from a prior-estimated constant.

Movement

Yearly summer migration was modeled by applying movement rates among model cells, as movement transition matrices in the three months of November, December and January. A yearly movement rate matrix was estimated previously from tag-recoveries (McGarvey and Feenstra 2002). Each movement rate probability, P_{ij}, gives the proportion of fish moving from cell *i* to cell *j* in early summer of each year. Likelihood ratios implied that a single matrix was optimal, applicable to both ages of migrating King George whiting, ages 2 and 3 (McGarvey and Feenstra 2002). Essentially all King George whiting aged 4 years or older are caught offshore on spawning grounds. All but 2 of 2000 tagged fish remained within their region, and within regions most movement was from upper gulf to lower gulf cells or, in the West Coast, from inshore cells to offshore. Therefore, P_{ij} = 0 for cells *i* and *j* lying in different regions and for movement from the southerly spawning gulf cells (cell 3 in Spencer Gulf, and cell 5 in Gulf St. Vincent, Figure A2.1) to upper gulf cells. P_{ii} = 1 for spawning cells (*i* = 1, 2, 4), where fish are assumed to remain. For age 4 whiting (55-57 months of age in November to January), all remaining fish are moved to the spawning cells of each gulf.

In West Coast cells, the destination of migratory fish remains uncertain. No West Coast harvest samples have shown evidence of spawning and nearly all were aged 3 years or less. Thus, the King George whiting fishery on the West Coast does not overlap with spawning aggregations and tag recaptures supplied no information about rates of movement to the (presumed offshore)

spawning locations. Consequently, a 7th spatial cell was defined as the hypothetical destination of West Coast spawning migration. An attempt to estimate these rates of offshore migration from the absence of older fish in commercial catch samples was not successful. Instead we assumed that all fish migrate from the West Coast fishery cell (1) to cell 7 (effectively out of the modeled population) at age 3 (43-45 months).

In the gulfs, we integrated the tag-recovery movement rate estimation, refining, by freely re-estimating, the specific movement rate parameters which were not 0 or 1 in the two gulf regions. Movement rate estimates are sensitive to mortality rates, notably fishing mortality in each cell. The converse is also true; mortality estimates can be strongly affected by movement. Integrating the estimation of movement with mortality can improve both.

Movement of fish occurring over three migration months (November-January) rather than just once yearly in January provided a more realistic migration time frame of several months and smoothed the impact of movement on the model population and thus on model-predicted catches in early summer. For age-3 movement to hypothetical spawning cell 7 from the West Coast, we moved 1/3 of the fish in November, 1/2 of the remaining fish in December and the rest in January. In this way, an equal number of fish (namely 1/3 of those originally present prior to November movement) are moved in each of those three months.

Parameters

Estimated parameters for the model fall into five general categories: (1) yearly recruit numbers for each region, and proportions allocated among cells within each region, (2) catchabilities, (3) relative selectivities, (4) likelihood standard deviations (sigmas) for fits to catch totals, (5) movement rate parameters (not 0 or 1) in the two gulf regions.

Initialization: State Array and Parameters

The initial population state variable array and the initial parameters were obtained using a two-stage method. First, the initial population state array was derived assuming a steady-state age structure. In the second stage, initial parameter estimates were inferred from the population array, in combination with catch and effort data. For initialization, no movement was considered. In recent runs, the values of initial population array values, and parameters were taken from earlier runs.

Model likelihood

The fitting procedure generally followed that of Fournier and Archibald (1982), with catch proportions by age and sex fitted using a multinomial likelihood and catch totals fitted with a normal likelihood.

The likelihood function has four components for fitting to the four data sets: (1) commercial catch totals by weight (kg) in each cell and monthly time step; (2) recreational catch totals by number in each cell and monthly time step; (3) catch number proportions partitioned into a matrix by both age and sex, from catch samples taken in selected months and cells during 1994 to 2016; (4) movement tag-recovery data from the two gulfs.

The movement likelihood component was the same form used in prior fitting to tag-recoveries (McGarvey and Feenstra 2002) but a much more limited set of parameters (those not 0 or 1 in the two gulfs) were re-estimated. This integration of the movement likelihood into the WhitEst model involved provision of a) predicted average yearly total mortality (*M*+*F*) by *cell* and calendar month, and b) a predicted yearly movement matrix as the cube of the monthly movement matrix (the one used to move animals among *cells* in three months of the year as part of the population dynamics model).

The remaining likelihood components are described below.

Catches-by-weight

Model commercial catch totals by weight (kg) were fitted to data using a normal likelihood, though a lognormal was also tested. The catch by weight was calculated using the standard Baranov formula as:

(A2.5)

$$\hat{C}^w\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right] = N\left[t,\ cell,\ sex,\ cohort,\ slice\right] \cdot w[slice \mid sex, region, a] \cdot \frac{F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]}{M + F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]} \cdot \left\{1 - \exp\left[-\left(M + F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]\right) \cdot p_{yr}[t]\right]\right\}$$

where derivation of weights by age and slice $w[slice \mid sex, region, a]$ are given in Appendix 3.

The likelihood for each choice of spatial *cell*, and effort type, *Etype,* was written:

(A2.6) $$L_{Cw} = \prod_{t=1}^{nt} \prod_{Etype=1}^{nEtype-2} \prod_{cell=1}^{ncell} \frac{\exp\left[-\frac{1}{2}\left(\frac{\hat{C}^w[t, cell, Etype] \ - \ \tilde{C}^w[t, cell, Etype]}{\sigma^C[region, gear]}\right)^2\right]}{\sqrt{2\pi} \cdot \sigma^C[region, gear]}$$

where

nt and *ncell* are the numbers of model time steps and spatial cells respectively, and where, for each *cell*, and each commercial *Etype*, of which there are *nEtype*–2,

$\sigma^C[region, gear]$ = estimated standard deviation parameter, which varies only by region and gear type;

$\tilde{C}[t,\ cell,\ Etype]$ = reported catch by weight total for each time step, *t*, *cell*, and *Etype*;

$\hat{C}[t,\ cell,\ Etype]$ = predicted catch by weight total for each time step, *t*, *cell*, and *Etype*.

The region and gear are specified by their *cell* and *Etype* respectively.

The normal likelihood for fitting to the remaining effort types of charter and recreational catch in numbers was similar, with a separate set of σ-parameters.

A reduced log-likelihood weighting (of 0.1) was applied for the catch total fits for model time steps prior to May 1994 when catch sampling by age and sex commenced. The recreational catch log-likelihood for the entire period was further down-weighted (by 0.01).

The $\sigma^C[region, gear]$ parameters were not directly estimated, and a concentrated likelihood form of L_{Cw} was computed as described in Appendix 4.

Catch samples by age and sex

A two-dimensional multinomial likelihood was used to fit to both observed sex ratios in the catch and to the relative proportions by age, since both were contained in the same set of catch samples. The fitted data, in each month and spatial cell where catch was monitored, consisted

of the counts of sampled fish falling into each possible combination of sex and age, $\tilde{n}[a, sex \mid i_{AX}]$. The multinomial likelihood was written:

(A2.7) $$L_{AX} = \prod_{i_{AX}=1}^{n_{AX}} \prod_{a=1}^{12+} \prod_{sex=0}^{1} \hat{p}[a, sex \mid i_{AX}]^{\tilde{n}[a, sex \mid i_{AX}]}$$

where

i_{AX} = index over the full set of n_{AX} catch samples by age and sex;

$\hat{p}[a, sex \mid i_{AX}]$ = two-dimensional array of model-predicted fish proportions captured by age and sex, for each sampled month and cell indexed by i_{AX};

$\tilde{n}[a, sex \mid i_{AX}]$ = observed fish numbers sampled, corrected to be representative by length for each age and sex, obtained from catch-at-age sample i_{AX}.

Objective Function Minimization

The negative logarithm of likelihood components were summed to form the model objective function. Penalty functions were also added to the objective function to ensure that proportions sum to 1. One penalty constrains proportions migrating from any given cell to all other possible cells. Another penalty constrains the apportionment of recruits among spatial cells within each region.

The objective function was minimized using the AD Model Builder parameter estimation software. This package uses a powerful algorithm for calculating derivatives, reverse auto-differentiation, which allows model solution convergence in computation times one or several orders of magnitude faster than conventional minimization methods. With 255 free parameters, convergence takes about an hour.

Slice Length Partition

The slice length partition of each cohort of fish as it crosses into legal size, based on calculations carried out prior to model stock assessment fitting (Appendix 3), produces three principal model inputs. Each slice partition is specified by the sequence of slice left-hand-side length-partition points, one partition of legal lengths derived for each age of growth (e.g. Table A2.1). One of these triangular matrices of slice left-hand-sides was generated for each set of growth parameters, of which there were 6, with separate growth curves derived for each of the three regions and two sexes. The legal minimum length was raised in August 1995 from 28 cm to 30 cm, and in the two gulfs from 30 to 31 cm in September 2004, each requiring additional sets of slice-partitions.

Mean weights (kg) of each slice (e.g. Table A2.2) were used to calculate model-predicted catch by weight. The quantity $P_{sublegslice}(a)$ (derived in Appendix 3, Equation A3.3) needed to create a new slice in each model time step, by transferring a designated proportion of fish from the sublegal component to each newly created slice, is a vector over age (e.g. Table A2.3). This was derived from the probability, for each slice, and thus each monthly age *a*, under the normal length-at-age pdf curve of each newly-created slice subinterval (Appendix 3), denoted $P_{slice}(a)$ (Table A2.3).

The explicit representation of population numbers by length in each cohort altered the (1) shape of the length distribution (Figure A2.2), and thus the (2) mean length and (3) mean weight of harvested fish. For example, for the 1992 cohort of Gulf St. Vincent females, after 13 months in

legal size (thus 13 slices, age 34 months, Figure A2.2), the mean legal-size length of modeled King George whiting was 321 mm, while when the more rapid removal of larger fish is accounted for using a slice partition by length, the legal-size mean length was 316 mm, and mean weight of legal fish was similarly reduced from 199 to 190 g. The first-recruiting (right-hand tail) slice population number was reduced to 30% of its recruiting size after 13 months; the newest (left-hand) slice was reduced to 94% after one month.

Symbols of index quantities

These symbols are used to index data and model quantities in this appendix. Further symbols are defined near each of the equations further above.

- *t* = monthly time step. Model time runs from July 1983 to December 2016.
- *a* = month of age of a *cohort* at time *t*, ranging from 13 to 157.
- i_{AX} = index over the months and spatial cells in which age-sex samples were taken.
- *cohort* = year class designated by the year each cohort was spawned. New cohorts are created in the model population array as one-year olds the year following spawning in May, at age 13 months. Over the period modelled this ranges from 1983 to 2014.
- *month* = calendar month, January to December, of any given year.
- *cell* = spatial model cell. There are 6 spatial cells (Figure A2.1), plus a hypothetical 7th cell to which West Coast fish migrate. The “outlying regions” (cell 6, Figure A2.1), from which King George Whiting catches are very small, was excluded from this model assessment.
- *sex* = female (*sex* = 0) and male (*sex* = 1).
- *region* = amalgamated *cell*s, consisting of the West Coast, Spencer Gulf, and Gulf St. Vincent.
- LML = legal minimum length.
- *slice* = dynamic length bin, which partitions the fish in each cohort age by length.
- *gear* = including four commercial gear types (handline, haul net, gill net, other) and a recreational gear.
- *Etype* = fundamental classification into which catch and effort data are partitioned, as combinations of four gear types and three target types, namely targeting King George Whiting, targeting some other species, or not declaring any target type, plus charter boats and recreational; ranges from 1 to nEtype=14.

Tables

Table A2.1. Left-hand length boundaries for each slice length subinterval: Gulf St. Vincent females, LML = 280 mm.

		Slice number															
Age (month)	Month legal	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
22	1	280.0															
23	2	294.1	280.0														
24	3	306.7	292.5	280.0													
25	4	317.0	302.7	290.1	280.0												
26	5	324.6	310.2	297.6	287.4	280.0											
27	6	329.8	315.4	302.7	292.5	285.1	280.0										
28	7	333.4	318.9	306.2	296.0	288.5	283.5	280.0									
29	8	336.4	321.9	309.2	298.9	291.5	286.4	282.9	280.0								
30	9	340.0	325.5	312.7	302.4	294.9	289.8	286.4	283.4	280.0							
31	10	345.0	330.5	317.6	307.3	299.8	294.7	291.2	288.3	284.8	280.0						
32	11	351.9	337.2	324.4	314.0	306.5	301.3	297.8	294.9	291.4	286.6	280.0					
33	12	360.3	345.6	332.6	322.3	314.7	309.5	306.0	303.0	299.6	294.7	288.1	280.0				
34	13	369.6	354.8	341.8	331.4	323.7	318.5	315.0	312.0	308.5	303.6	297.0	288.8	280.0			
35	14	378.8	363.9	350.8	340.3	332.7	327.4	323.9	320.9	317.4	312.4	305.8	297.6	288.7	280.0		
36	15	387.0	372.1	358.9	348.4	340.7	335.4	331.8	328.8	325.3	320.3	313.6	305.4	296.5	287.8	280.0	
37	16	393.7	378.7	365.5	354.9	347.1	341.9	338.3	335.3	331.7	326.8	320.0	311.8	302.8	294.0	286.3	280.0

Table A2.2. Weight in kilograms of an average fish in each age and slice. Gulf St. Vincent females, LML = 280 mm.

		Slice number															
Age (month)	Month legal	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
22	1	0.140															
23	2	0.164	0.135														
24	3	0.187	0.155	0.134													
25	4	0.207	0.172	0.150	0.133												
26	5	0.223	0.186	0.163	0.144	0.131											
27	6	0.234	0.196	0.172	0.153	0.139	0.130										
28	7	0.242	0.203	0.178	0.158	0.144	0.135	0.128									
29	8	0.249	0.209	0.183	0.163	0.149	0.139	0.133	0.128								
30	9	0.257	0.216	0.190	0.170	0.155	0.145	0.138	0.133	0.128							
31	10	0.269	0.227	0.200	0.178	0.163	0.152	0.145	0.140	0.136	0.129						
32	11	0.286	0.242	0.213	0.191	0.175	0.164	0.156	0.151	0.146	0.139	0.131					
33	12	0.309	0.262	0.231	0.207	0.190	0.178	0.170	0.165	0.159	0.152	0.143	0.132				
34	13	0.334	0.284	0.252	0.226	0.208	0.195	0.187	0.181	0.175	0.167	0.158	0.146	0.133			
35	14	0.361	0.308	0.273	0.246	0.227	0.213	0.204	0.198	0.191	0.183	0.173	0.160	0.146	0.133		
36	15	0.386	0.330	0.294	0.265	0.244	0.230	0.221	0.214	0.207	0.199	0.187	0.174	0.159	0.145	0.132	
37	16	0.407	0.349	0.311	0.281	0.259	0.244	0.234	0.227	0.220	0.211	0.200	0.186	0.170	0.155	0.142	0.131

Table A2.3. Portion of fish in slice as a proportion of total normal length-at-age cohort (P_{slice}) and as a proportion of the sublegal component ($P_{sublegslice}$). Gulf St. Vincent females, LML = 280 mm.

Age (month)	Month legal	Pslice	Psublegslice
22	1	0.023	0.023
23	2	0.052	0.053
24	3	0.095	0.103
25	4	0.116	0.140
26	5	0.104	0.145
27	6	0.076	0.124
28	7	0.053	0.099
29	8	0.044	0.091
30	9	0.051	0.116
31	10	0.068	0.176
32	11	0.083	0.259
33	12	0.083	0.350
34	13	0.065	0.425
35	14	0.041	0.468
36	15	0.022	0.470
37	16	0.025	1.000

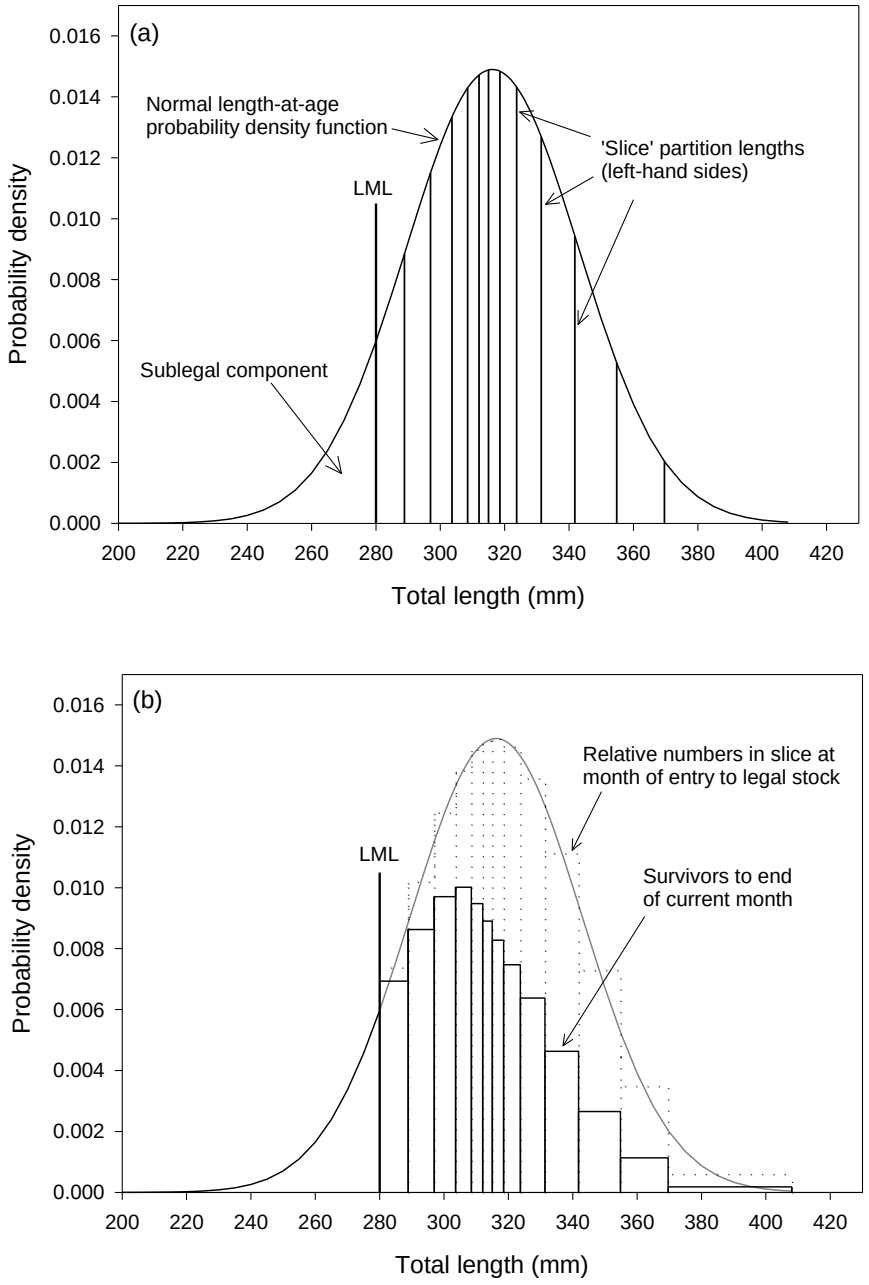


Figure A2.2. Length partition of a Gulf St. Vincent female model cohort, here having been of legal size for 13 monthly time steps. Fish are transferred from the sublegal component to each newly created slice (dotted bars). Thinner slices are created during slow-growth months. The normal length-at-age distribution for these age-34 fish (in the absence of harvesting) is shown in both graphs. The greater reduction in numbers of faster growing fish, which were subject to harvesting for longer time, is shown in (b), where dotted bars are the slice-created proportions and the solid bars are proportional to the model population numbers by slice after mortality has occurred in that (January 1993) time step.

5.5. Appendix 3: Algorithm for generation of slice length partition

In this Appendix, an underlying algorithm of the WhitEst model is presented. The objective of this slice-partition algorithm was to derive three sets of quantities needed to implement the slice-growth length- and age-based population array inside the stock assessment model. These are (1) the proportions of the sublegal component assigned to each newly created slice, (2) the slice left-hand-side partition points, and (3) the mean weights in each slice.

Unlike for Garfish and Snapper, where the slice partition algorithm is integrated into the stock assessment likelihood and a more efficient algorithm assuming a normal distribution was applied (see Appendix C in the 2005 Garfish assessment report), all slice partition quantities for King George Whiting were computed in advance. This more general slice partition algorithm requires the numerical ability to (1) represent and integrate normal distribution functions, and the more sophisticated computational task, to (2) solve for the unknown lower limit of integration in a probability integral equation. Numerical integrals and integral equations under the length-at-age pdf were solved using Mathematica software (Wolfram 2003).

The principal inputs to the creation of the slice partition are the 8 growth submodel parameters (θ) describing the normal distribution of the lengths of fish in a cohort, the length-at-age distributions, for each monthly age. These parameters for South Australian King George whiting were estimated previously (McGarvey and Fowler 2002). The fully normalized probability density is denoted $P(l \mid \theta; a)$, where the parameters θ specify the mean and standard deviation of the normal distribution over length, l, of King George whiting in each monthly age, a. The curve of mean length-at-age was given by an exponent-generalized seasonal von Bertalanffy formula with six parameters (McGarvey and Fowler 2002, Eq. 2). The standard deviations of the normal length-at-age distributions, one for each age of growth, increased allometrically with mean length, using two parameters (McGarvey and Fowler 2002, Eq. 3). Overestimation bias in fitted mean length-at-age due to the absence in catch samples of fish below legal size was avoided by explicitly accounting for this knife-edge cutoff in the fitted length-at-age likelihood (McGarvey and Fowler 2002, Eq. 4).

The cohort ages of model King George whiting were divided into three categories: 'sublegals', for ages before the stock reaches LML, 'crossing legals', the ages when part of the cohort length-at-age distribution lies in sublegal and part in the legal range of lengths, and 'postlegals' ages when the cohort is designated to be of fully legal size.

In order to partition by length only 'crossing' cohorts, i.e. only ages in which meaningful proportions of the cohort lie on both sides of LML, slice probabilities of 2% and 98% were chosen as cut-offs. The first step, therefore, was to identify and integrate over the normal density tails for the youngest and oldest ages, i.e. right- and left-hand tails respectively, that first satisfied the 2% and 98% thresholds. Dividing lengths-at-age in two, the portion of the length-at-age distribution that is of legal size ($\geq$ LML) in monthly age a is $P_{leg}(a)$:

$$P_{leg}(a) = \begin{cases} 0, & \text{at age } a \text{ if } \int_{LML}^{\infty} P(l \mid \theta; a)\, dl < 0.02 \\ 1, & \text{at age } a \text{ if } \int_{LML}^{\infty} P(l \mid \theta; a)\, dl > 0.98 \\ \int_{LML}^{\infty} P(l \mid \theta; a)\, dl & \text{otherwise.} \end{cases} \quad \text{(A3.1)}$$

A 'slice' is the portion of legal King George whiting entering the fishable stock, by growing across the LML, in any given month. It was obtained as the proportion of the length-at-age cohort that is legal in the current month of age (*a*) minus the proportion that was legal the month of age preceding (*a* – 1). These were calculated for all ages, assuming the cohort is created at an age *a* = 1 prior to reaching legal size, i.e. $P_{leg}(1) = 0$:

$$P_{slice}(a) = P_{leg}(a) - P_{leg}(a-1), \qquad a = 2, \ldots, \max(a). \quad \text{(A3.2)}$$

The sum of $P_{slice}(a)$ over all ages equals 1. The critical ages that specify when the cohort was 'crossing', call them a_{1c} and a_{fc}, for youngest and oldest ages of crossing legal, are given by the youngest and oldest ages of non-zero $P_{slice}(a)$, in other words, the ages when more than 2% and less than 98% of the cohort straddled LML.

The proportion of sublegals entering legal size in each time step, $P_{sublegslice}(a)$, was calculated for every age *a* in which new slices are created, that is, for each crossing-cohort age. These new-slice proportions, needed to transfer fish from the sublegal component to each newly created slice, are defined by a ratio over the proportion that are sublegal at the start of each time step:

$$P_{sublegslice}(a) = \frac{P_{slice}(a)}{1 - P_{leg}(a-1)}, \qquad a = a_{1c}, \ldots, a_{fc}. \quad \text{(A3.3)}$$

Note that the intuitively expected outcomes for the two critical ages, a_{1c} and a_{fc}, were obtained (Table A2.3), namely, $P_{sublegslice}(a_{1c}) = P_{slice}(a_{1c})$ and $P_{sublegslice}(a_{fc}) = 1$. The first is expected because all of the cohort was sublegal in the month of age preceding a_{1c}, so the proportion of sublegals assigned to the first legal slice must simply equal the probability under the first, upper-tail, length slice in the cohort length-at-age distribution. Similarly, in the oldest 'crossing' age a_{fc}, all remaining sublegal fish become legal, and thus 100% are assigned to the last crossing slice.

To derive the mean weight of each slice, we need the first derive the length subinterval defining each slice, to find its midpoint, at which we apply the mean-weight-versus-length relationship. With each increasing crossing-legal month of age (*a*), the number of (necessarily) legal slices increases by 1 and is equal to the number of months of age the cohort has had a legal component greater than 2%. Define the function specifying the number of crossing-legal slices $n_s(a)$ for any crossing age *a* as:

$$n_s(a) = a - a_{1c} + 1, \qquad a = a_{1c}, \ldots, a_{fc}. \tag{A3.4}$$

In the model population array, slices are enumerated starting with *slice* = 1 to designate the first crossing slice to be created, at age a_{1c}, the upper tail of the length-at-age distribution. At higher ages, *slice* = 1 continues to refer to this same fastest-growing (and first-created) slice, fish of longest length in that cohort. Similarly, *slice* = 2 identifies the second slice created, the next length bin to the left of second-longest fish, and so on.

The left-hand-side partition point of fish length for all newly created slice subintervals is the legal minimum length (LML). For the first (i.e. youngest) crossing age, we can notate this as $L_{lhs}[a=a_{1c}, slice=1]$ = LML. Indeed, for all crossing ages except the last, i.e. for $a = a_{1c}, \ldots, a_{fc} - 1$, $L_{lhs}[a, slice=n_s(a)]$ = LML.

All other slice left-hand sides were derived to be consistent with the $P_{slice}(a)$ probabilities defined in Equation A3.2. Unlike the numbers of fish in any given slice, these probabilities under the curve $P_{slice}(a)$ for each slice subinterval are fixed. Each $P_{slice}(a)$ is associated with one newly created slice. For example consider the right-hand-tail, *slice* = 1, at the second legal monthly age (which as noted, will have 2 legal slices, the other newly created slice, *slice* = 2, having LML as its left hand side). The left-hand side $L_{lhs}[a=a_{1c}+1, slice=1]$ was obtained by numerically solving for it, being the left-hand integration limit in the integral equation, $P_{slice}(a_{1c}) = \int_{Llhs[a_{1c}+1,\ 1]}^{\infty} P(l \mid \theta;\ a_{1c}+1)\ dl$.

For all higher crossing cohort ages, and for all slices in each age except the newly created ones, a similar integral equation was numerically solved using Mathematica software to derive $L_{lhs}[a, slice]$. The crossing month when each slice was created is given by ($a_{1c} - 1 + slice$), thus

$$P_{slice}(a_{1c} - 1 + slice) = \int_{Llhs[a,\ slice]}^{Llhs[a,\ slice-1]} P(l \mid \theta;\ a)\ dl \tag{A3.5}$$

for ages, $a = a_{1c+1}, \ldots, a_{fc}$ and *slice* = 1, . . ., $n_s(a)$-1. Because the upper integration bound, $L_{lhs}[a, slice-1]$ is given by each previous successive solution, derived as the left-hand side of the slice immediately to its right, *slice*-1, these integral equations for successive slices were solved iteratively starting with the right-hand tail slice (*slice* = 1) and progressing to the left.

These slice right- and left-hand-side partition lengths were employed as integration limits on fish length for calculating mean weight in each slice subinterval:

$$w[a,\ islice] = \int_{Lhs[a,\ islice]}^{Lhs[a,\ islice-1]} \alpha\, l^{\beta}\ \ P(l \mid \theta;\ a)\ \ dl \tag{A3.6}$$

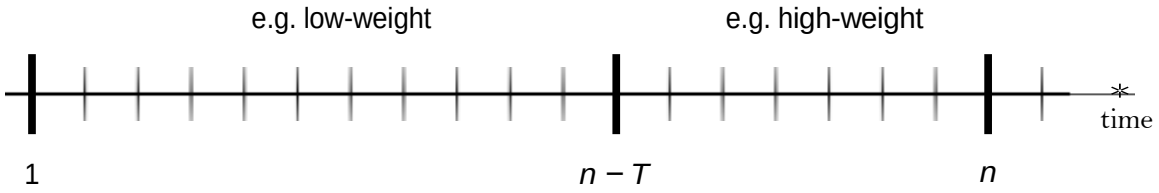
where $\alpha\, l^{\beta}$ or other function gives mean fish weight as a function of length using prior-estimated parameters.

Integrations were also carried out to calculate mean weights for the 'postlegal' whole normal cohort length-at-age distributions, which are not subdivided by slice.

5.6. Appendix 4. Derivation of the time-specific weighted concentrated log likelihood for catch fits

In this Appendix, we provide the mathematical details for how the likelihood is constructed, and how the estimates are obtained for the σ parameters, in the fits to the King George Whiting catch time series in WhitEst. Specifically, we applied a reduced weighting on the years prior to when sampling for ages and lengths commenced in 1994. Here, the reduced weighting is applied to all time steps up to 1994, denoted here as those falling into the range (1 to *n-T*). The level of reduced weighting for those earlier years was *Y* = 0.1. The total number of model time steps is, for WhitEst in the 2017 assessment, n = 402, covering all months from July 1983 to December 2016. Below we present a derivation for the more general case of any values of *Y*, *T*, and *n*. This concentrated likelihood case applies where we assume a normal likelihood with constant σ across all time steps. In WhitEst, separate σ parameters are assumed for each region and gear type.

Consider a sample of *n* independently and identically distributed data points distributed in time from time *i* = 1 to *n,* and that we wish to have an early period (1 to *n-T*) of the sample carry either more or less influence on estimation than the later period (*n-T+1* to *n*). This appendix provides a derivation of how to obtain an expression for the concentrated negative log likelihood (*NLL*) given the distribution of a sample point is Normal and points are "weighted" differently for each of the two periods.



For each point *i*, the Normal probability density function is given by

$$p_i = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x_i-\mu_i)^2}{2\sigma^2}} \qquad (0)$$

where σ and μ_i are the standard deviation and mean, with the latter varying per datum x_i (e.g. estimated and data catch in model Whitest for a given effort type, spatial cell, and month). The likelihood is the product of the RHS expression in Eq (1) across the *n* individual points (*i)*, and if there was no internal weighting, this would simply be, for x and μ representing the set of n terms of x_i and μ_i respectively,

$$L(x;\mu,\sigma) = \prod_{i=1}^{n} p_i . \qquad (2)$$

However, with a weighting power being applied for the earlier period, *Y* say, while not applying a specific weighting for the later period (i.e. 1), we require

$$L(x;\mu,\sigma)=\left(\prod_{i=1}^{n-T}p_i\right)^{Y}\left(\prod_{i=n-T+1}^{n}p_i\right). \tag{3}$$

And hence

$$\begin{aligned} NLL &= -Y\sum_{i=1}^{n-T}\ln(p_i)-\sum_{i=n-T+1}^{n}\ln(p_i) \\ &= -Y\sum_{i=1}^{n-T}\left(-\ln(\sqrt{2\pi})-\ln(\sigma)-\frac{(x_i-\mu_i)^2}{2\sigma^2}\right)-\sum_{i=n-T+1}^{n}\left(-\ln(\sqrt{2\pi})-\ln(\sigma)-\frac{(x_i-\mu_i)^2}{2\sigma^2}\right). \end{aligned} \tag{4}$$

In order to obtain the concentrated form of *NLL* the derivative of *NLL* will be minimized for σ.

$$\partial NLL/\partial\sigma=(Y(n-T)+T)\sigma^{-1}-\sigma^{-3}\left(\sum_{i=1}^{n-T}Y(x_i-\mu_i)^2+\sum_{i=n-T+1}^{n}(x_i-\mu_i)^2\right). \tag{5}$$

Denoting the weighted sum of squares as $S=\sum_{i=1}^{n-T}Y(x_i-\mu_i)^2+\sum_{i=n-T+1}^{n}(x_i-\mu_i)^2$, and setting this derivative to zero one obtains an expression for σ^2,

$$\sigma^2=\frac{S}{Y(n-T)+T}=\frac{S}{F}. \tag{6}$$

Inserting the square root of Eq (6) into the NLL — Eq (4) — provides the expression to be minimized (ignoring some additive constants) for parameter estimation

$$\begin{aligned} NLL &= Y\sum_{i=1}^{n-T}\ln(\sigma)+\sum_{i=n-T+1}^{n}\ln(\sigma)+\frac{1}{2\sigma^2}S \\ &= F\ln(\sigma)+\frac{1}{2}F\cdot \end{aligned} \tag{7}$$

5.7. Appendix 5: Model fits to data

Parameters, and thus biological performance indicators, are estimated in the WhitEst model by fitting to data for commercial catch totals by weight, recreational catch total numbers, and to commercial catch proportions by age and sex, in each month when sampling occurs. In this Appendix, we present graphs of model fits for these three data inputs: to the reported monthly commercial King George Whiting catch totals for the 5 principal subregions (Figure A5.1), to catch age composition samples for the 24 most recent fitted combinations of region, month and sex (Figure A5.2), and to sex ratios for the 24 most recent fitted combinations of region and month (Figure A5.3). Age and sex composition data were obtained predominantly as weekly samples prior to the Wednesday auction at SAFCOL market. Market samples were obtained from September 1994 to June 1997, July 2004 to June 2007, July 2008 to December 2010, April 2011 to December 2013, and August 2014 to October 2016.

It is visually evident that the fits to the catch totals by the effort-conditioned WhitEst model (Figure A5.1) are quite close for most months and regions.

The fits to the catch-at-age proportions (Figure A5.2) and the sex ratios (Figure A5.3) are evidently closer for combinations of region, sex and month with higher sample sizes of aged King George Whiting.

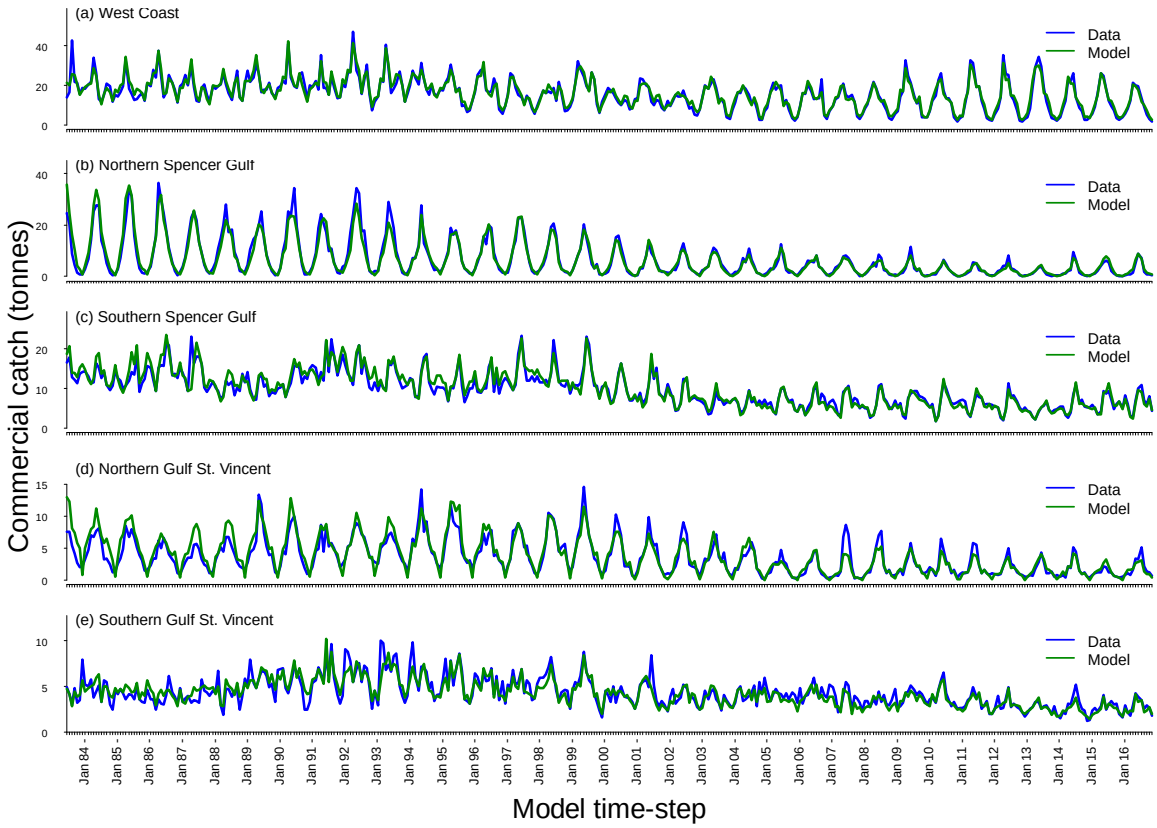


Figure A5.1. Fits of model to data monthly commercial catch totals (all gears and target types combined), for the 5 principal King George Whiting regions of South Australia.

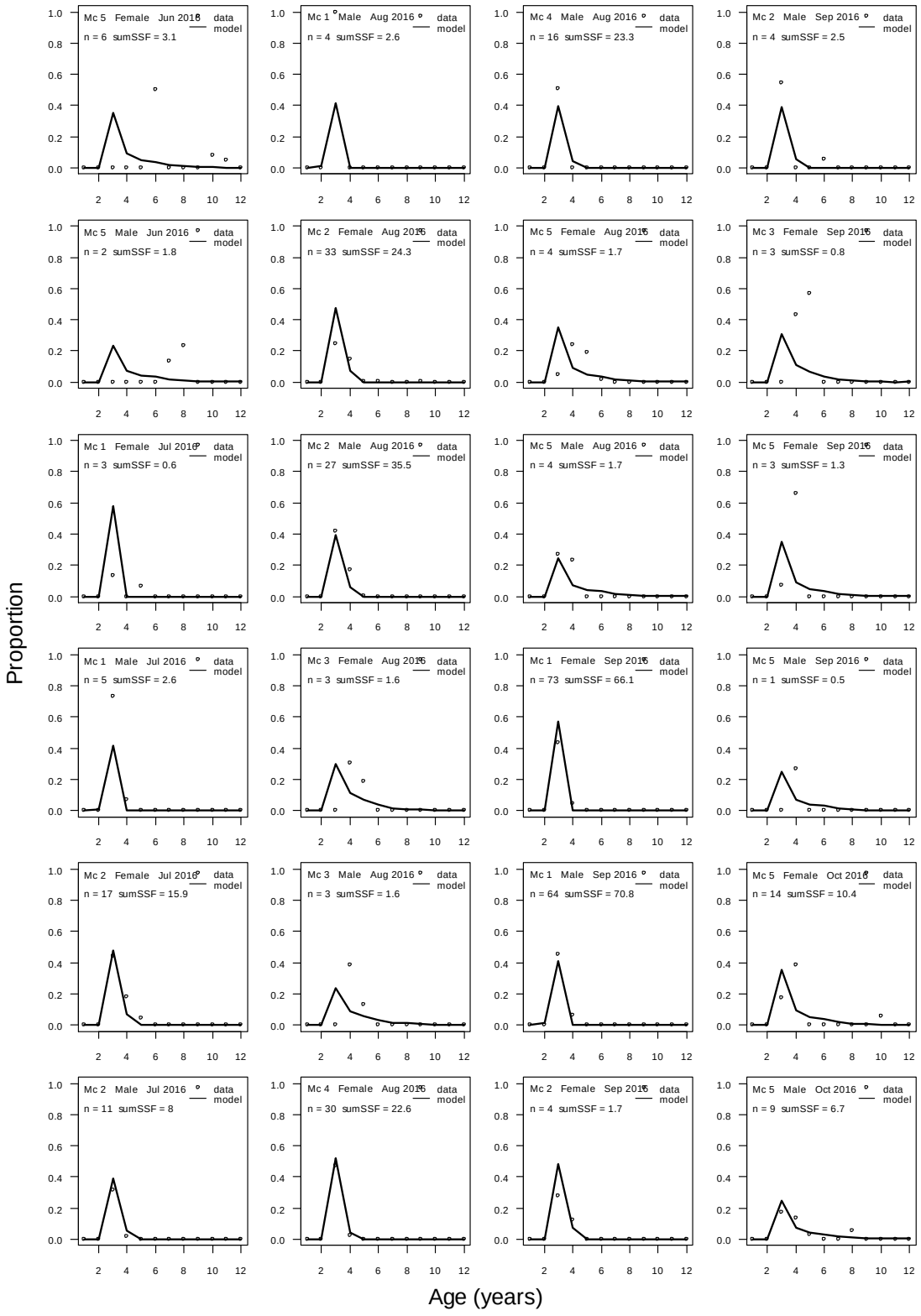


Figure A5.2. Fits of model to SAFCOL market sample data catch-at-age proportions (all gears and target types combined), in the regions (denoted Mc1-Mc5), sex, and months shown.

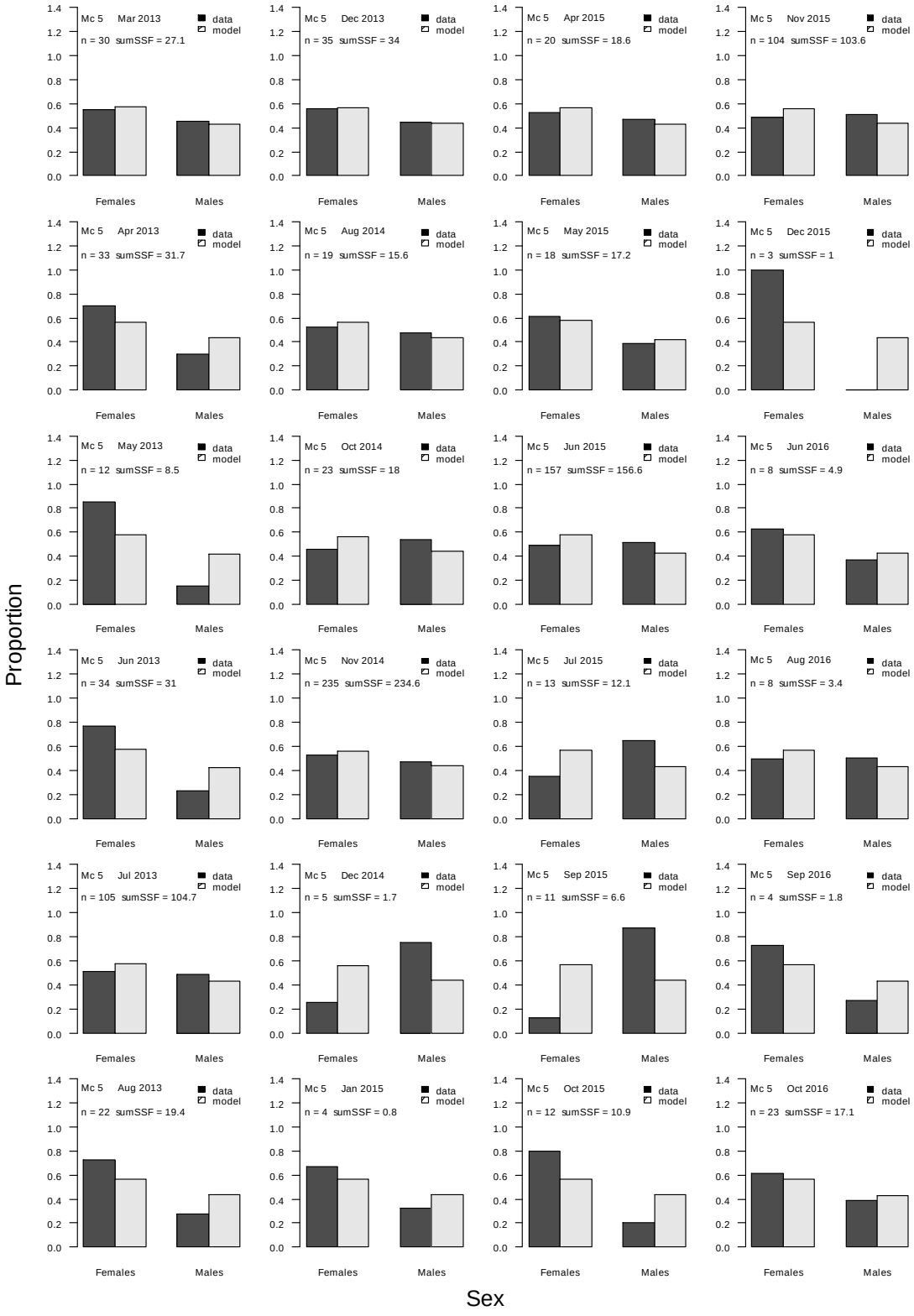


Figure A5.3. Fits of model to SAFCOL market sample catch-by-sex proportions (all gears and target types combined), in the regions (denoted Mc1-Mc5) and months shown.

5.8. Appendix 6. WhitEst Model Sensitivity Analysis: Weighting age-sex data relative to commercial catch log data

Introduction

In this Appendix, we test WhitEst model sensitivity testing under alternative weightings for the two principal data sources in the model likelihood: (1) age-sex proportions sampled from the commercial catch, and (2) commercial catch log totals. Age and sex data are fitted together, using a multinomial likelihood, the model predicting a catch proportion by age and sex in each month and model spatial cell where (usually SAFCOL) sampling was undertaken. Regarding catch-log data, the WhitEst model is effort-conditioned, so the model fits to the monthly catch totals for each of 12 effort types, in each of the five spatial cells, conditioned on the corresponding reported effort for each effort type.

Method

In this sensitivity analysis we adjust only the weighting on the age-sex data component, leaving the likelihood weightings for the other data sources, catch-log and recreational survey catch data, and movement tag-recoveries, unaltered. The baseline (i.e. the current WhitEst model, as reported in this assessment) value for this age-sex weighting is 1. The two alternatives we examine for this weighting are 4 and 8. This sensitivity test will examine the effect of increasing by 4- and 8-fold the relative influence of age-sex data relative to other data sources, notably relative to commercial catch totals.

Results

The biomass estimates for the West Coast were quite insensitive to increasing the relative weighting of age-sex data (Figure 6.1a). This is consistent with a region where the two principal data sources are in close agreement as interpreted by the model. When two data sources are inconsistent, increasing the weighting on one forces model outputs to change in order to most optimally reconcile those differences with the other.

In Spencer Gulf, increasing the weighting on age-sex data produced a decrease in the absolute levels of biomass by about 15% for age-sex weighting = 4 and 18% for age-sex weighting = 8 (Figure 6.1b). But while the absolute biomass levels were reduced, the time trend was not much altered. This outcome does not point to strong disagreement among the two data sources. Considering NSG and SSG separately (Figure 6.2, a and b), we find that they are about equally sensitive, each showing similar biomass reduction.

The biomass results for Gulf St. Vincent are much more sensitive to the weighting of the age-sex data source and are less consistent in their response to higher age-sex weighting over yearly time (Figure 6.1). Most notably, after about 2011, biomass estimates rise substantially for age-sex weighting = 4, and more so for age-sex weighting = 8. Such high sensitivity implies inconsistency between the two data sets in those later years, from 2011 onward. Considering NGSV and SGSV separately (Figure 6.2, c and d), we find that most of this sensitivity to age-sex weighting is associated with SGSV, which comprises most of the region's King George Whiting biomass.

In summary, the sensitivity analysis showed no effect for the West Coast and a relatively modest effect for Spencer Gulf. However for Southern Gulf St. Vincent, the effect was strong, especially from 2011 onward, implying inconsistency of the two data sources, and greater uncertainty for model outputs in that sub-region.

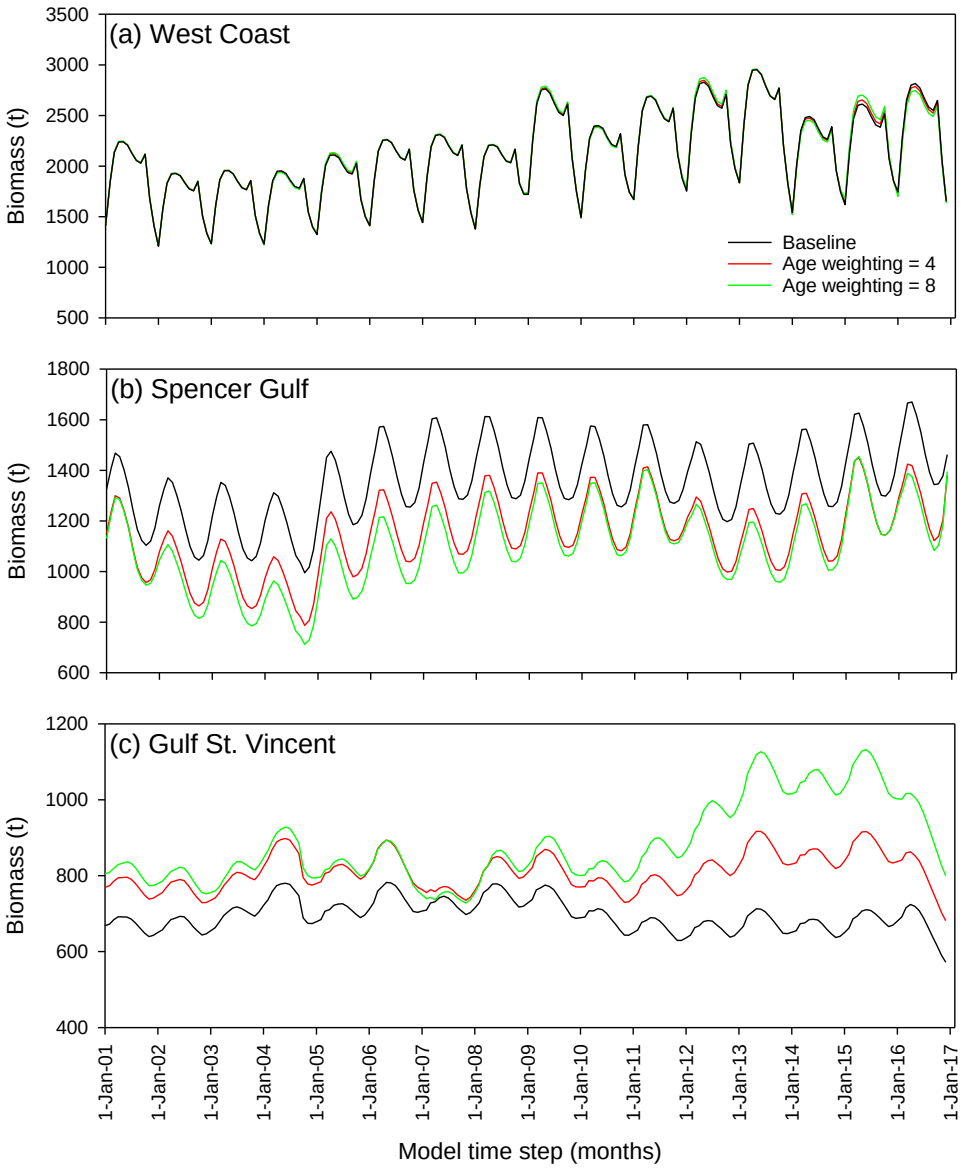


Figure 6.1. Plot of biomass by region from three runs of WhitEst: the baseline (with age-sex weighting = 1), and two alternatives: age-sex weighting = 4 and age-sex weighting = 8.

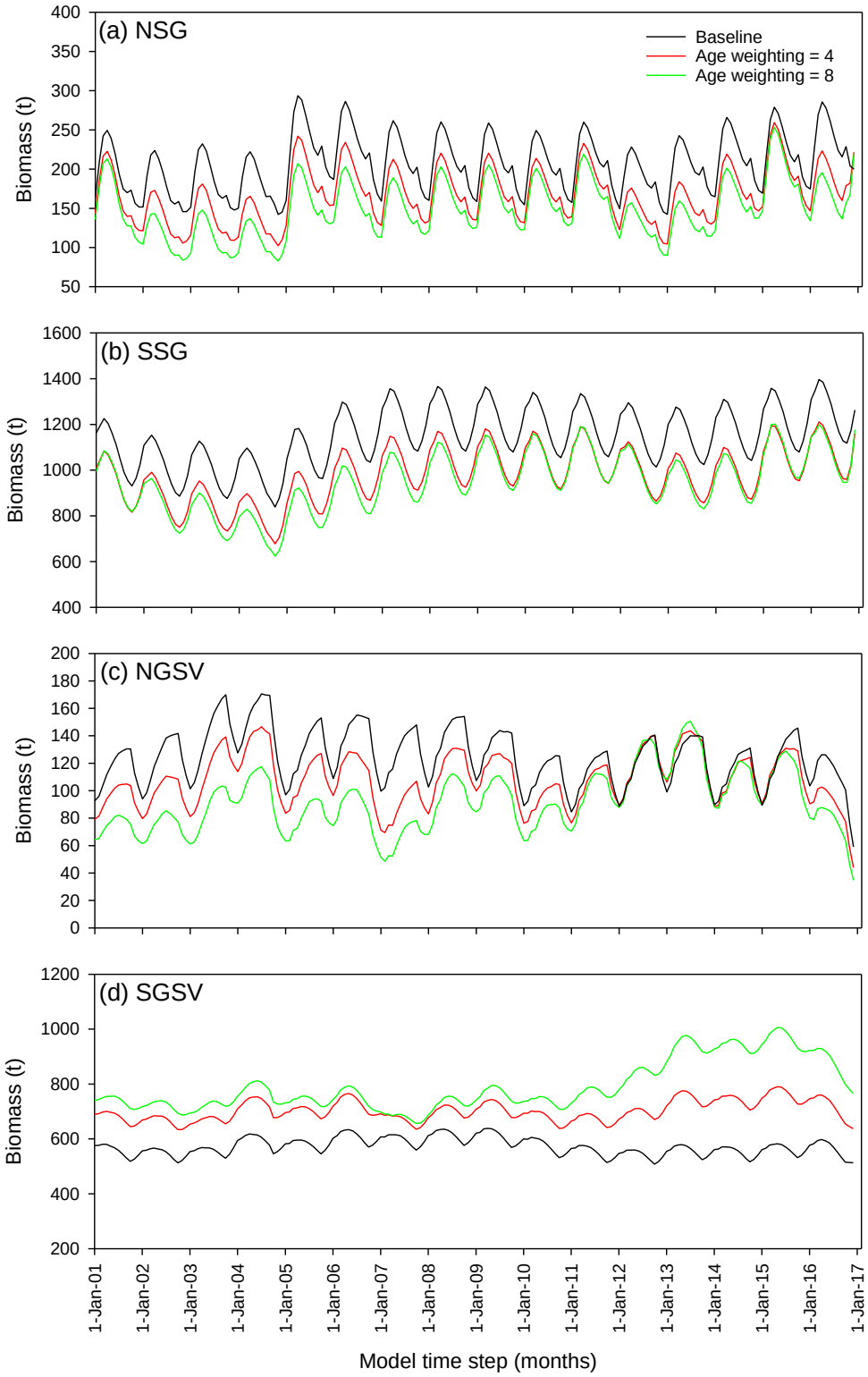


Figure 6.2. Plot of biomass by gulf subregion from three runs of WhitEst: the baseline (with age-sex weighting = 1), and two alternatives: age-sex weighting = 4 and age-sex weighting = 8.

Discussion

Two features of the model inputs for SGSV are likely candidates for explaining its high sensitivity. First, and most importantly, the age composition samples from the spawning areas of GSV (bottom right of Figure 3-5) show a greatly extended tail of older fish in the later years. Unlike SG and WC, where nearly all fish in age samples are 2 or 3 years old, King George Whiting in southern GSV contain many fish of ages 4-6. Second, there is a small difference in the trends of biomass compared with target HL CPUE in the last few years (Figure 3-5), where biomass shows a flat trend over the last 6 years, while catch rate has risen since 2012.

The principal source of uncertainty in the SGSV model outputs, and very probably the cause of the differing trends for CPUE and model biomass, is inconsistency between age composition and catch log (including catch rate) data. This is likely to be associated with the qualitatively important presence of older King George Whiting in the SGSV market samples.

There are three hypotheses that could explain catches-at-age of older and larger whiting in the catch samples for SGSV. First, this may represent sampling error or bias. The sample sizes are quite small, in particular, for the last year shown. However, there are many 4-year old fish sampled in all years, which are not observed in SSG or WC, and substantial proportions of 5- and 6-year-old King George Whiting in some or most years, inconsistent with a sampling error effect in the last season. The second hypothesis is that levels of exploitation are so low, along with migration of older fish to these southern spawning grounds that many older fish have survived in this spawning subpopulation. The third hypothesis is that there has been a shift of (here commercial) fishing effort towards these larger and older spawners, which appear in the market samples as more older King George Whiting, reflecting enhanced targeting of larger older fish rather than a greater abundance of them in the population.

In reality, all three hypotheses can potentially be acting. The sample size in the last year was small as noted. Bigger older King George whiting in the SGSV region have been observed consistently over several decades (Fowler et al. 2014) suggesting this population is characterized by larger older fish. And the risk of increased targeting of the spawning subpopulation is one all previous assessments have highlighted, and this was the principal basis for enhanced management arrangements, notably May closure, implemented in 2017 to protect spawning in these southern gulf waters. The plausible hypothesis of greater targeting of these older larger spawning King George Whiting in the last two sample years (2014/15 and 2015/16) imply that the new management arrangements are helpful in addressing this higher risk to population sustainability, notably in SGSV.