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Assessment of the South Australian Marine Scalefish Fishery in 2019

MJ Drew, AJ Fowler, R McGarvey, J Feenstra, F Bailleul, D Matthews, JM Matthews, J Earl, TA Rogers, PJ Rogers, A Tsolos and JJ Smart

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Author(s): MJ Drew, AJ Fowler, R McGarvey, J Feenstra, F Bailleul, D Matthews, JM Matthews, J Earl, TA Rogers, PJ Rogers, A Tsolos and JJ Smart

Reviewer(s): A Linnane, K Heldt (SARDI), K Rowling and S Stone (PIRSA)

Approved by: S Mayfield
Science Leader – Fisheries

Signed:

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ALL ENQUIRIES
South Australian Research and Development Institute - SARDI Aquatic Sciences
2 Hamra Avenue West Beach SA 5024
PO Box 120 Henley Beach SA 5022
P: (08) 8207 5400 **F:** (08) 8207 5415 **E:** pirsa.sardiaquatics@sa.gov.au
W: http://www.pir.sa.gov.au/research

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EXECUTIVE SUMMARY

This report is the fourth in the annual reporting series for the South Australian Marine Scalefish Fishery (MSF). Data considered in this report extend for 36 years from 01 January 1984 to 31 December 2019. It provides a description of the dynamics of the multi-species, multi-gear fleet and assigns a stock status to 30 stocks of species or taxonomic groups that are harvested in the fishery. The report builds on the previous reports by Steer et al. (2020; 2018a, b), and includes a summary of the taxon-specific fishery information relating to: population biology; fishing access; management arrangements; recreational catches available from State-wide surveys; trends in commercial fishery statistics at the State-wide scale, biological stock or regional management units; and assessment of fishery performance.

<u>Fleet Dynamics</u>

Many of the changes in the operation of the MSF fleet in the past four decades occurred in response to changes made to the fisheries management arrangements. These included the reduction in fishing effort resulting from the rationalisation of the fishing fleet through the licence amalgamation scheme implemented in 1994, reductions in the number of B-class licences and two voluntary net buy-back initiatives during 2005 and 2014.

Declines in the productivity of the premium finfish species have contributed to the diversification of the MSF fleet over the last five years, with many commercial fishers switching their effort from Snapper, King George Whiting and Southern Garfish to targeting Southern Calamari. As a consequence, Southern Calamari has recently surpassed Snapper and King George Whiting as the most valuable MSF species. Increased fishing of Southern Calamari in some regions has caused concern, including in southern Spencer Gulf where targeted jig CPUE has declined over the last seven consecutive years.

A number of species considered in this report are taken in the hauling net sector, and some are caught when more valuable species are being targeted. Of these, Yellowfin Whiting, Australian Herring, Snook, Leatherjackets and Yelloweye Mullet are of medium value. These species share similar commercial catch and effort trends, whereby 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. There has also been an increase in catches of Ocean Jackets and Western Australian Salmon over the past four years, using fish traps and seine gear, respectively.

<u>Stock Status</u>

This report assessed the fishery performance of 20 species (or species groups) comprising 30 stocks. Of these, 23 (77%) stocks were classified as sustainable, three (10%) were classified as depleted and one (3%) was classified as recovering. The remaining three (10%) were classified as undefined as there was insufficient information to assign stock status (Table E-1). Since the previous MSF assessment (Steer et al. 2020), the status of the Snapper stock in Gulf St. Vincent (GSV) changed from depleting to depleted as a result of reduced biomass, declining catches and CPUE, and an absence of recruitment (Table E-1). The Leatherjackets stock has been changed from sustainable to undefined on the basis of limited data around the proportion of mixed species within the stock.

The focus of this report is the triennial King George Whiting stock assessment. State-wide levels of catch and effort were the lowest recorded in 2019 with 227 t and 12,971 fisher-days, respectively. However, the dominant targeted gear type of handlines has maintained high levels of CPUE since its peak in 2016. The West Coast region continued to provide the highest catches across all stocks in South Australia. Over this assessment period of 2016-2019, all three stocks (West Coast, Spencer Gulf and Gulf St. Vincent) displayed similar trends in fishery statistics, with some of the lowest levels of catch and effort and some of the highest levels of CPUE recorded. Similarly, for the three stocks, the model estimates of fishable biomass have continued to be high, reaching to its highest ever levels recorded in Spencer Gulf. As a result, all King George Whiting Stocks of the West Coast, Spencer Gulf and Gulf St. Vincent/ Kangaroo Island were classified as sustainable for 2019.

<u>Future Directions</u>

Considerable funding has been directed towards addressing research priorities to support the monitoring and recovery of the Spencer Gulf–West Coast (SG-WC) and GSV Snapper stocks. These include: undertaking a stock assessment for Snapper using the daily egg production method (DEPM) during 2019/20; developing a cost-effective method for monitoring the numbers of juvenile Snapper to provide an early indication of recruitment strength (FRDC 2019/046); quantifying post-release survival rates of Snapper in all sectors of the fishery (FRDC 2019/044); and undertaking stock enhancement of both gulfs through the release of Snapper fingerlings during 2020/21.

A significant knowledge gap in the assessment of the status of MSF fish stocks continues to be the contribution to the State-wide catch by the recreational fishing sector. Previously, recreational catches have been estimated using phone survey methods every five years. Imprecision in these estimates and the frequency of surveys has implications for the assessments of King George Whiting, Snapper and Southern Calamari, for which the recreational component was significant. A modernised recreational fishing survey is underway (FRDC 2020-056), which aims to improve the quality of information collected and streamline the frequency of estimates of recreational catch and effort.

The MSF is currently undergoing considerable transition through the structural reform process, development of new harvest strategies, and a review of the Fishery Management Plan. The reform of the MSF included a reduction off 99 licences through a voluntary licence surrender scheme, separation of the Sardine and Vongole fisheries from the MSF, formation of new management zones, the implementation of total allowable commercial catches (TACCs), and individual transferable quotas (ITQs) for species assessed as 'Tier 1'.

Keywords: Marine Scalefish Fishery, fleet dynamics, stock status.

Table E-1. Status of South Australia's Marine Scalefish Fishery stocks and fishery performanace indicators assessed between 2017–2019.

SPECIES	STOCK	STATUS 2017	2018	2019	INDICATORS
SNAPPER	SG/WC	Depleted	Depleted	Depleted	Catch, CPUE, age structure, biomass
	GSV	Sustainable	Depleting	Depleted	Catch, CPUE, age structure, biomass
	WV	Sustainable	Sustainable	Sustainable	Catch, CPUE, age structure, biomass
KING GEORGE WHITING	WC	Sustainable	Sustainable	Sustainable	Catch, CPUE, age structure, biomass
	SG	Sustainable	Sustainable	Sustainable	Catch, CPUE, age structure, biomass
	GSV/KI	Sustainable	Sustainable	Sustainable	Catch, CPUE, age structure, biomass
GARFISH	WC	Sustainable	Sustainable	Sustainable	Catch & Effort
	NSG	Recovering	Recovering	Recovering	Catch, CPUE, age structure, biomass
	SSG	Sustainable	Sustainable	Sustainable	Catch & Effort
	NGSV	Depleted	Depleted	Depleted	Catch, CPUE, age structure, biomass
	SGSV	Sustainable	Sustainable	Sustainable	Catch & Effort
	SE	Sustainable	Sustainable	Sustainable	Catch & Effort
CALAMARI	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
YELLOWFIN WHITING	NSG	Sustainable	Sustainable	Sustainable	Catch & Effort
	NGSV	Sustainable	Sustainable	Sustainable	Catch & Effort
WA SALMON	WA/SA	Sustainable	Sustainable	Sustainable	Catch & Effort
AUST. HERRING	WA/SA	Sustainable	Sustainable	Sustainable	Catch & Effort
SNOOK	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
BLUE CRABS	MSF	Sustainable	Sustainable	Sustainable	Catch & Effort
SAND CRABS	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
YELLOW-EYE MULLET	MSF	Sustainable	Sustainable	Sustainable	Catch & Effort
MULLOWAY	MSF	Sustainable	Sustainable	Sustainable	Catch & Effort
WHALER SHARKS	STATE	Undefined	Undefined	Undefined	Limited data
OCEAN JACKETS	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
BLUE-THROAT WRASSSE	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
SILVER TREVALLY	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
LEATHERJACKETS	STATE	Sustainable	Sustainable	Undefined	Catch & Effort
RAYS & SKATES	STATE	Sustainable	Undefined	Undefined	Limited data
CUTTLEFISH	STATE	Sustainable	Sustainable	Sustainable	Catch & Effort
BLACK BREAM	MSF	Sustainable	Sustainable	Sustainable	Catch & Effort

1. INTRODUCTION

1.1. Overview

This is the fourth report in this series for the South Australian Marine Scalefish Fishery (MSF) that provides a taxon-specific summary of information on: 1) fisheries biology; 2) fishing access; 3) management arrangements; 4) trends in commercial fishery statistics at the scales of the biological stock or regional management units, and 5) assessment of fishery performance. Data included in this report were sourced from logbook returns provided to SARDI by MSF licence holders over 36 years between 01 January 1984 and 31 December 2019.

This report is partitioned into five sections. Section one provides an overall description of the MSF, its management arrangements, performance indicators, and details the indicators used to assess the status of the stocks within the fishery. Section two describes the dynamics of the commercial fleet, catch composition, and spatial and temporal trends in fishing effort, and section three contains the stock assessment for King George Whiting.

Section four consists of a series of species-based sub-sections arranged in order of their descending priority by catch. These are structured as 'stand-alone' updates for taxa taken in the fishery, for each of which a summary of the relevant biological information is presented, along with a description of the fishery, associated management regulations, the State-wide and/or regional fishery statistics, assessment of the fishery against the general performance indicators, and the classification of the stock status for 2019.

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 and management of South Australia's MSF.

1.2. Description of the Marine Scalefish Fishery

The MSF is a multi-species, multi-gear, multi-sector fishery with >300 active licence holders. Due to the number of licences, gear types used, the species taken, fishers ability to switch target species and the geographical range, it is considered to be the most complex fishery in South Australian waters.

Commercial fishers in the MSF are permitted to take in excess of 60 marine species, including bony fishes, molluscs, crustaceans, annelid worms, sharks, rays and skates. Fishery production by weight of catch is mainly comprised of Southern Calamari (*Sepioteuthis australis*), Snapper (*Chyrsophrys auratus*), King George Whiting (*Sillaginodes punctatus*), Southern Garfish (*Hyporhamphus melanochir*) and Yellowfin Whiting (*Sillago schomburgkii*). Other species such as Western Australian Salmon (*Arripis truttaceus*), Australian Herring

(*Arripis georgianus*), Sand Crabs (*Ovalipes australiensis*) and Vongole (*Katelysia* spp.) also contribute significantly to the overall catch.

Currently there are 30 types of fishing gear (or devices) endorsed in the MSF. Their uses differ depending on the location of fishing and the 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. For the commercial sector there are two types of licences, i.e. Marine Scalefish and Restricted Marine Scalefish (B-class). Marine Scalefish licence holders are more common. A proportion of the Marine Scalefish 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, licence holders from the Miscellaneous Fishery, the Northern (NZRLF) and Southern Zone Rock Lobster (SZRLF) fisheries, the Lakes and Coorong Fishery (LCF), three Western King Prawn fisheries and the Blue Crab Fishery (BCF) all have varying levels of access to the key MSF resources. For example, the three Western King Prawn fisheries can only take certain MSF species as by-product.

The broad mixture of participants, gear types, licence conditions and regulations associated with the MSF make the task of assessing the status of the stocks extremely challenging. This is further compounded by the highly dynamic nature of fisher behavioural responses to resource availability and seafood markets, as they can switch their target effort between species and regions throughout State waters. This complexity means there is considerable capacity for the fishery to expand through the activation of latent effort.

The recreational fishing sector also has access to many of the MSF species. Most recreational fishing effort occurs in marine waters, including estuaries, with fishers permitted to use several gear types to target a variety of MSF species.

1.3. Management Arrangements

The MSF is managed by the South Australian State Government's Department of Primary Industries and Regions (PIRSA) Fisheries and Aquaculture in accordance with the legislative framework provided within the *Fisheries Management Act 2017*, and subordinate *Fisheries Management (General) Regulations 2017*, *Fisheries Management (Marine Scalefish Fisheries) Regulations 2017* and licence conditions.

The commercial MSF has undergone considerable management changes over the past 40 years, including a settlement with the Commonwealth Government Australian Fisheries Management Authority (AFMA) for offshore waters resources management in 1992 (Offshore Constitutional Settlement), limitation through gear restrictions and configuration, licensing, spatial and temporal closures related to protection of spawning areas 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 MSF. The first occurred in 1977, when a freeze was imposed on the issue of new licences, which converted the commercial MSF into a limited-entry fishery. This also involved a 'show-cause provision' that prevented the re-issue of licences to fishers if a minimum level of commercial fishing had not been met. Non-transferable Restricted MSF 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 (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 was also implemented in 2014 in association with the establishment of the network of South Australian Marine Parks.

In July 2021 the commercial MSF was reformed which includes regionalisation, rationalisation, and unitisation. Four regional zones of management were established to include Spencer Gulf, Gulf St Vincent/Kangaroo Island, the West Coast and the South East. All fish stocks are now managed according to these zones through a tiered management framework that assigns each stock to a Tier based on its importance. Stocks in Tier 1 are now managed using a total allowable commercial catch (TACC) and individual transferable quotas (ITQS). Fleet rationalisation has also occurred with 99 licences being voluntarily surrendered. The purpose of the reform is to improve the economic performance of the commercial MSF and increase stock sustainability.

With the exception of recreational Southern Rock Lobster pot licenses, the recreational fishery is not licensed but 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 or partial protection (e.g. Western Blue Groper) of some species.

1.4. Fishery Performance Indicators

For each taxon, general performance indicators (PIs) are used to benchmark the performance of the fishery. These are derived from commercial catch, target effort and CPUE, and vary amongst the taxa. Annual time-series of these PIs were derived from commercial fishery statistics from 1984 to 2019 (reference period). Each performance indicator was benchmarked against the following trigger points:

1. the third highest and third lowest values of the reference period;
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 PI have decreased over the most recent five consecutive years.

1.5. Stock Status Classification

A national stock status classification system is available for the assessment of key Australian fish stocks (Flood et al. 2014; Stewardson et al. 2018). 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 level of exploitation into a single classification for each stock against defined biological reference points. Each stock is then classified as: sustainable, depleting, recovering, depleted, undefined, or negligible (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 (Stewardson et al. 2018).

	Stock status	**Description**	**Potential implications for management of the stock**
	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.* recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired	Appropriate management is in place
	Depleting	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired	Management is needed to reduce fishing pressure and ensure that the biomass does not become depleted
	Recovering	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and there is evidence that the biomass is recovering
	Depleted	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. 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
	Negligible	Catches are so low as to be considered negligible and inadequate information exists to determine stock status	Assessment will not be conducted unless catches and information increase

2. FISHING FLEET DYNAMICS

2.1. Introduction

Fishing fleet dynamics reflect the decisions made by fishers that relate to when and where to fish, the most appropriate gear to use for the target species, and the economics of seafood production. These decisions are influenced by a range of factors, such as the seasonal availability, movement and migration of target stocks, seasonal changes in weather conditions, management arrangements, running costs, market access and socio-economics.

A comprehensive evaluation of the spatial and temporal characteristics of fishing activities is required before stock assessment models can be reliably developed to inform management decisions (Hilborn and Walters 1992, Mahévas et al. 2008). In most cases, this includes a detailed break-down of fishery catch patterns, fishing effort, CPUE, the spatial distribution of catches, fishing gear, location and season for each species (Hilborn and Walters 1992).

Whilst most of this report is devoted to the assessment of fishery statistics for specific taxa taken in the MSF to determine stock status, this section provides a holistic view of the fishery by examining and comparing trends in catches, fishing effort, gear use, regions and seasonality. This summary illustrates the dynamic nature of this fishery at different spatial and temporal scales, the changes in licence participation rates, and the relationships and trends between target 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). Licensed fishers are required to log their fishing activities by reporting specific details such as MFA fished, number of fishers on board, gear used, species targeted, species caught, weight of catch, catch in numbers of specific species and method of capture. Prior to 2003, these details were recorded on a monthly basis, but since then the fishers have been required to provide a daily log of fishing activity. These records are submitted monthly to SARDI Aquatic Sciences where they are entered into the Marine Scalefish Fisheries Information System. This database is routinely reviewed and cross-checked as per quality assurance protocols (Vainickis 2010). 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 the assessments of stock status presented in this report. As such, they are based on a 36-year time-series.

The complexity of the MSF database was reduced to a smaller, more manageable dataset that allowed analysis of the major trends in 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 for this fishery (e.g., spatial and temporal closures). 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 (>15 cm mesh size) and set gill nets (5 cm mesh size) which were categorized as set nets. Similarly, handlines, troll lines and fishing rods/poles in the line sector were categorised as handlines. Longlines, drop lines and trot lines were grouped as longlines where appropriate.

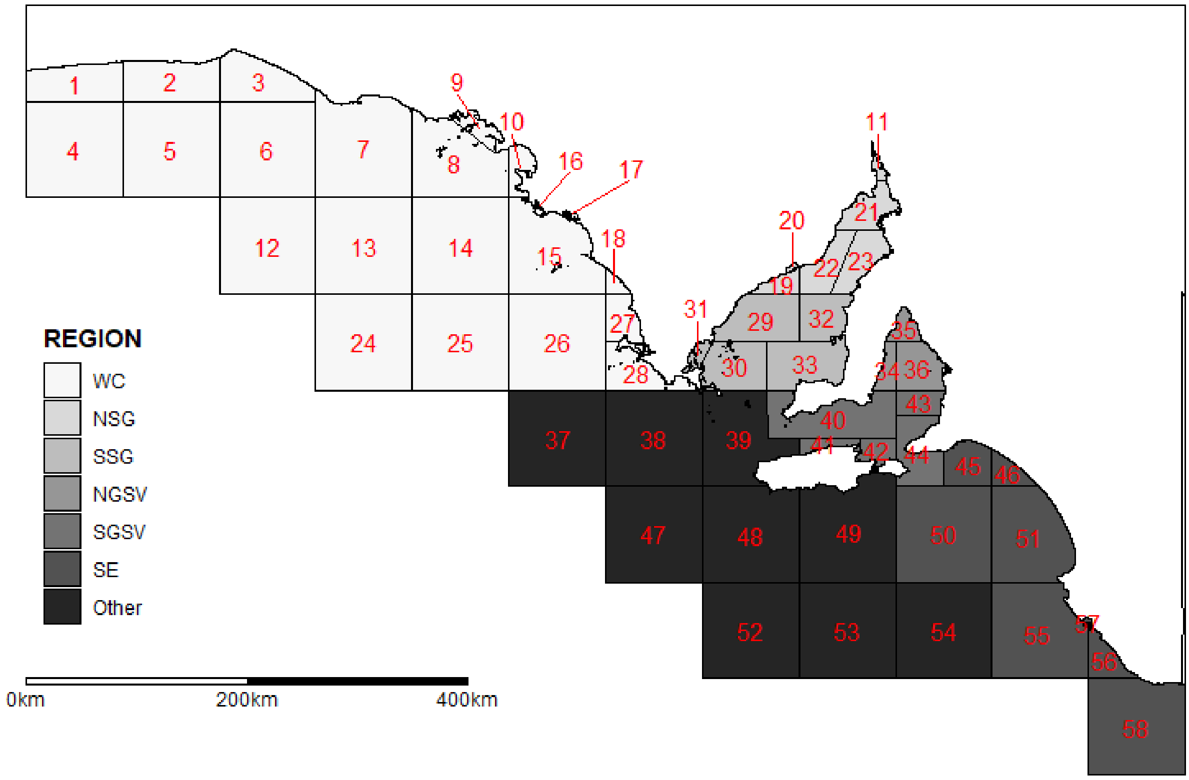

Figure 2-1. Marine Fishing Areas of South Australia's Marine Scalefish Fishery showing the seven regions: West Coast (WC), Northern Spencer Gulf (NSG), Southern Spencer Gulf (SSG), Northern Gulf St. Vincent (NGSV), Southern Gulf St. Vincent (SGSV), South East (SE), and Other.

2.3. Results

2.3.1. Trends in Number of Active Licences

There has been a 64% (from 865 to 307) reduction in the number of licence holders actively operating in the MSF between 1984 and 2019 (Figure 2-2). The largest proportional reduction occurred for the Rock Lobster fisheries, as the number of active licence holders that accessed MSF species declined from 175 to 31 over the same period, representing an 82% reduction. The active MSF and Miscellaneous Fishery licence holders declined by 59% and 77%, respectively. The rate of decline was accelerated from 1994 following the implementation of the licence amalgamation scheme. Two net buy-back schemes also contributed to removing active licences in 2005 and 2014 (Figure 2-2). Since implementation of the licence amalgamation scheme, the number of active licence holders has declined at a rate of approximately 15.5 licences.year^{-1}.

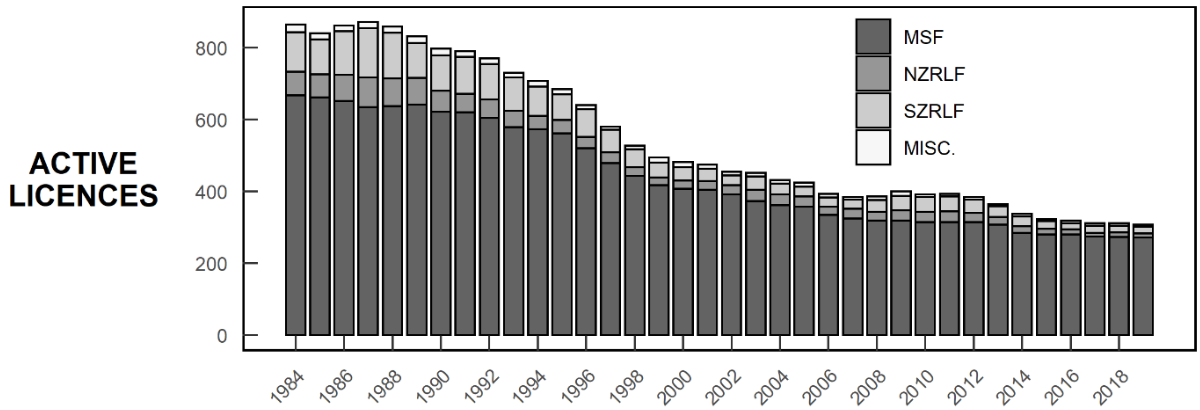

Figure 2-2. Long-term trend in the number of active licence holders that have access to the Marine Scalefish Fishery (MSF), including those from the Southern and Northern Zone Rock Lobster (SZRLF, NZRLF) and Miscellaneous (MISC.) Fisheries.

2.3.2. Trends in Commercial Catch

Since 1984, there has been a major shift in the composition of the commercial MSF catches. This related to the substantial removal of 'other' species catch in 2001 and was a result of the establishment of an exclusive South Australian Sardine Fishery (Figure 2-3). In the six years prior to this separation, Sardines accounted for up to 58% of the total MSF catch. Annual catches in the contemporary MSF fishery are dominated by the four primary species (~45%), followed by the secondary (~30%), tertiary (~12%), and the remaining permitted species (~10%) (Figure 2-3). Appendices 1 and 2 provide summaries of annual commercial catches of permitted species taken in the Marine Scalefish Fishery between 1984 and 2019.

Total catch of primary species peaked at 2,089 t in 2001 and has since declined to a record low of 995.7 t in 2019, representing a 52% decline over 21 years (Figure 2-3). Prior to 1999, the composition of the primary species catch was relatively stable, where annual King George Whiting catch accounted for approximately 36%, followed by Southern Garfish (26%) Snapper (22%) and Southern Calamari (16%). Since then, the relative proportions of the KGW and Garfish catches have declined to 23% and 19%, respectively, whereas annual catches of Southern Calamari (33%) have increased, particularly from 2007 onwards (Figure 2-3). The proportion of Snapper in catches has decreased significantly from 53% to 25% of the catch composition of the primary target species between 2010 and 2019.

The total annual catch of secondary species was above 1,000 t from 1984 to 2006, peaked at 2,127 t in 1995 and was 765 t in 2019 (Figure 2-3). Western Australian Salmon and Australian Herring collectively accounted for most (up to 68%) of the catch of secondary species up to 2002. From 2002 until 2009, the annual catch of Vongole increased substantially, accounting for up to 34% of the catch of secondary species at its peak in 2007. Before separating into a dedicated fishery in 1996, Blue Crabs accounted for approximately 30% of the catch of secondary species. Since 1996, Blue Crab annual catch has declined to a low of 31 t in 2016, but increasing to 53 t in 2019 (Figure 2-3). The relative proportion of secondary species catches has remained the same since 2009, with the exception of Western Australian Salmon which had three years of increased catches between 2015 and 2017. Total catches then fell by 39% from 374 t in 2017 to 229 t in 2019.

Annual catches of tertiary species peaked in 1991 at 1102 t and were dominated by Ocean Jackets (88.6%). Leatherjackets and Ocean Jackets have accounted for most tertiary species catch up to 2005, before rarely exceeding 100 t annually up to 2015 (Figure 2-3). Cuttlefish catches peaked for three years from 1996 to 1998, reaching 262 t in 1997. Ocean jacket catches in 2019 were 226 t, which was the highest recorded since 2005.

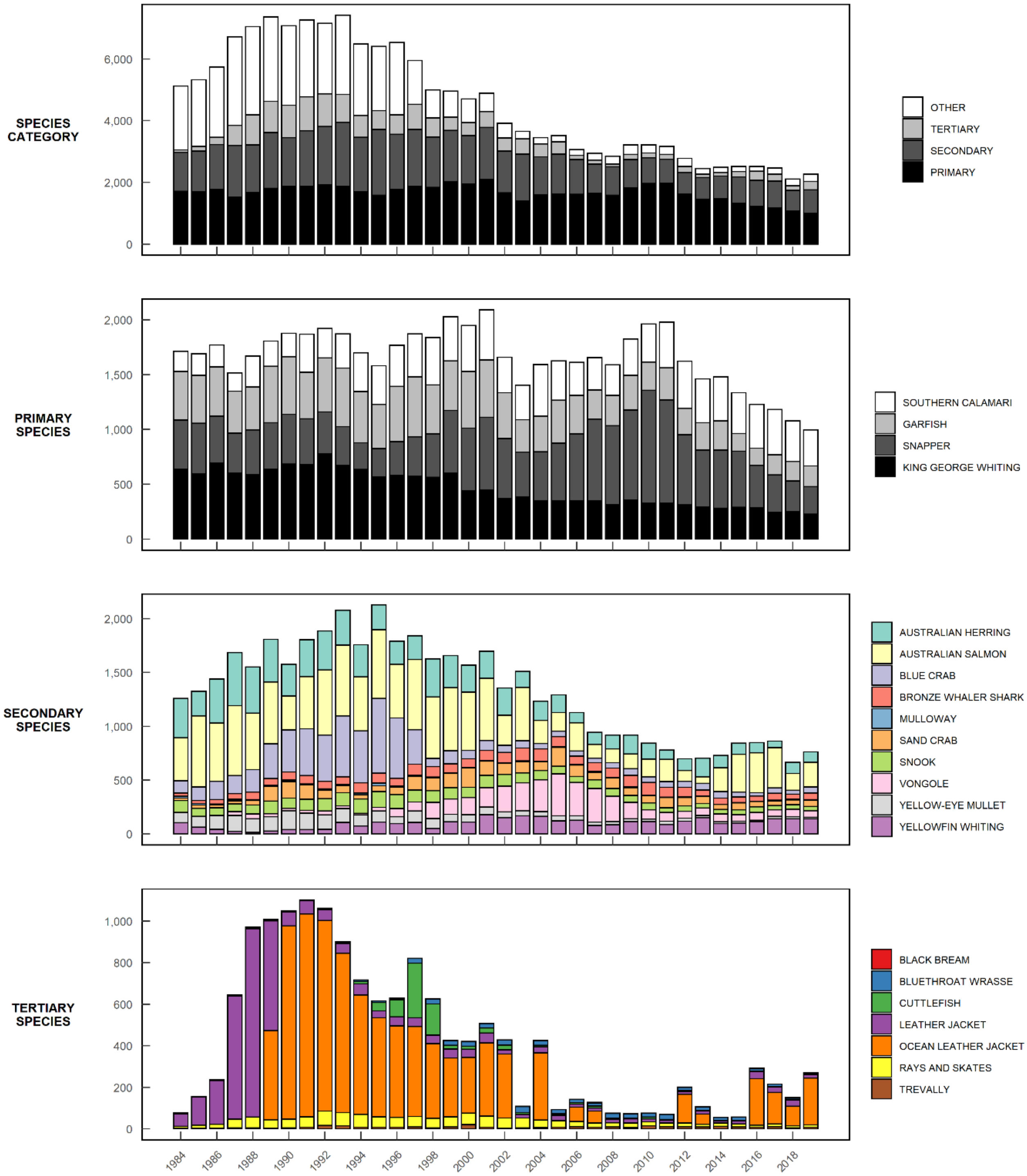

Figure 2-3. Long-term trends in total catch (t) in the commercial Marine Scalefish Fishery for primary, secondary and tertiary species between 1984–2019.

2.3.3. Trends in Fishing Effort

Species

Annual estimates of total fishing effort in the MSF peaked at 136,623 fisher-days in 1992 (Figure 2-4). This represented an 18% increase in annual effort since 1984, after which there was a 52% reduction to 65,500 fisher-days in 2019.

Up until 2015, most (>75%) fishing effort was targeted at particular species. In 2019, 25% of the effort was non-specific, with fishers identifying 'any target' in their catch returns. This level of 'non-specific' reporting was the second highest on record and was marginally lower than in 2016 when 29% of fishers were non-specific in their fishing target. Of the reported targeted effort, the four primary species have consistently accounted for the greatest proportion of which King George Whiting has historically dominated. Since 2011, there has been a distinct shift in fishing activity, as fishers have directed targeted effort away from Snapper and King George Whiting towards Southern Calamari. The relative proportion of effort targeted towards Southern Calamari has increased to a historical peak of 35% in 2017, and was a similar level of 33% in 2019 (Figure 2-4).

The secondary species accounted for approximately 8% of the total targeted fishing effort in 2019. The distribution of targeted effort amongst these species has changed over the past 36 years. Historically, Blue Crabs, Western Australian Salmon, Snook and Yelloweye Mullet attracted the most effort during the mid-1980s accounting for up to 98% of targeted effort directed at secondary species. Fishers increasingly targeted Sand Crabs from the late 1980s, and Vongole became a prominent target from 2002 to 2008, accounting for up to 15% and 40% of secondary species effort, respectively (Figure 2-4). In each instance, these increases were associated with management initiatives that supported the development of the fisheries.

During 2019, approximately 2% of the State-wide fishing effort was targeted towards the six tertiary species considered in this report (Figure 2-4). There were a few periods of notable expansion for some 'niche' tertiary species across the time period, such as Leatherjackets, Ocean Jackets and Cuttlefish. Targeted effort for each of these species doubled over short (<5 years) periods but did not persist.

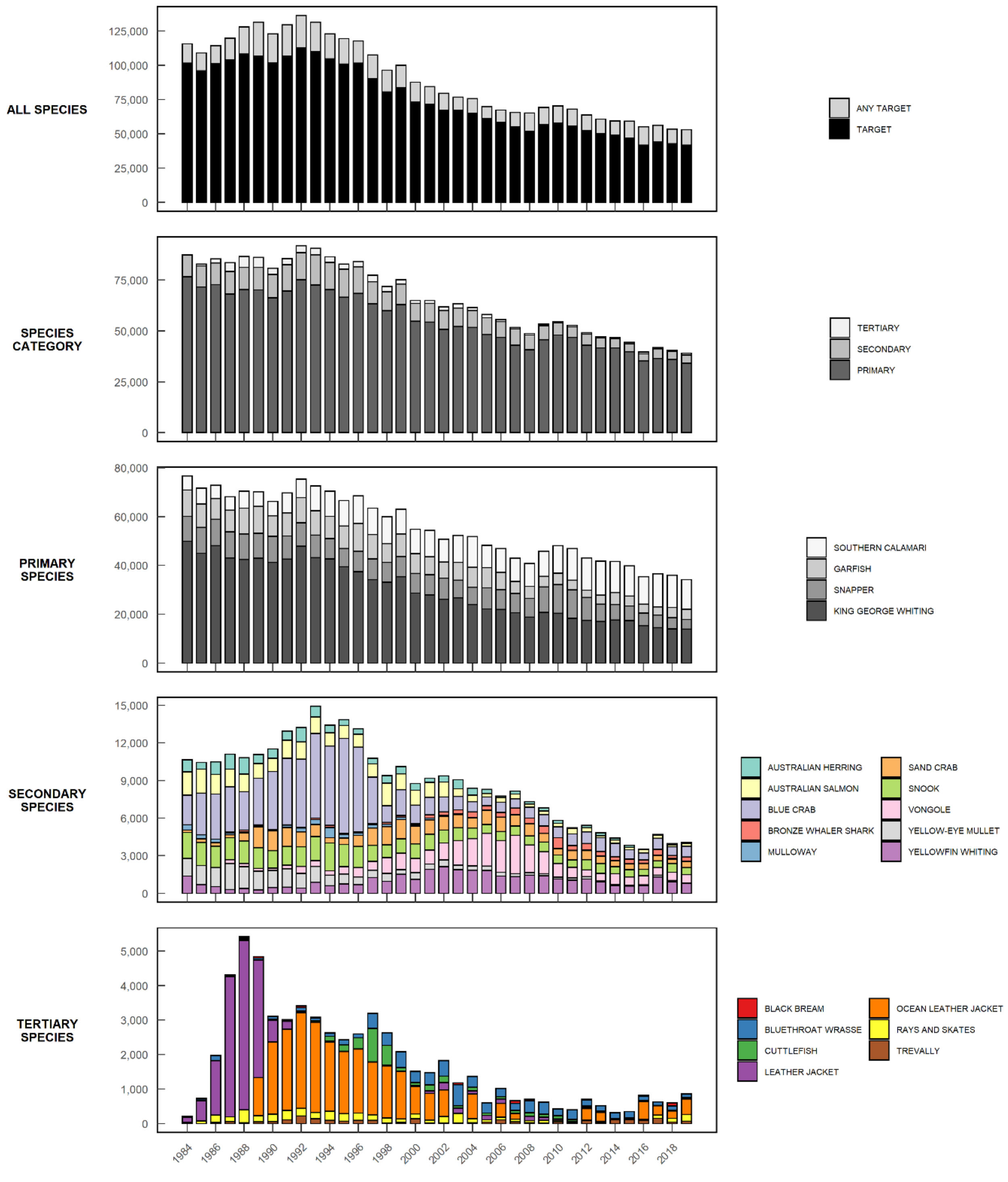

Figure 2-4. Total effort (fisher-days) in the commercial Marine Scalefish Fishery partitioned into targeted and non-targeted ('any target') effort (top graph) and into species-specific targeted effort for the period of 1984–2019.

Gear

Hauling nets and handlines have consistently been the dominant gear types used in the fishery, collectively accounting for >60% of the total fishing effort (Figure 2-5). The proportional use of set nets has declined from 16% in 1987 to 2% in 2019, with the greatest reduction occurring throughout the late 1990s and early 2000s in response to the State-wide netting review and associated restrictions. The use of squid jigs has steadily increased from 1994 as the Southern Calamari fishery evolved from a bait resource to a priority target species, and has further increased from 2011 onwards, accounting for 15% of the State-wide total fishing effort in 2019. The proportional use of longlines doubled from 2009 through to 2016, and accounted for 11% of the total fishing effort in 2019 (Figure 2-5).

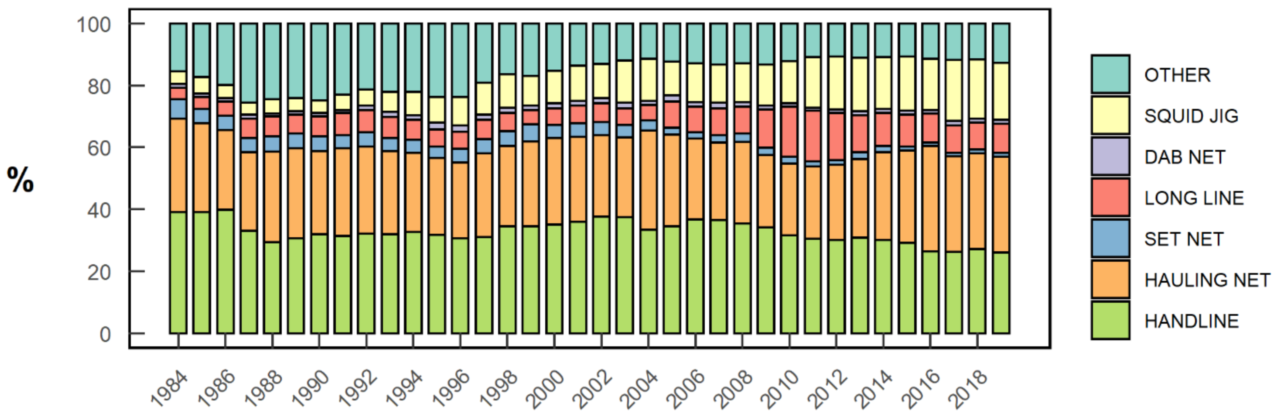

Figure 2-5. Gear usage (% of total fishing effort) within the commercial Marine Scalefish Fishery (MSF).

Location

Historically, the spatial distribution of fishing effort was widespread with most of the State's MFAs registering some level of fishing activity (Figure 2-6). Fishing effort was most intense in the northern gulfs and near the major regional ports of Ceduna (MFAs 8, 9, 10), Coffin Bay (MFAs 27, 28), Port Lincoln (MFAs 30, 31) and Beachport (MFAs 55, 56, 57). Since 2000, 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 fishing effort, but this has also declined over the past 35 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 four years (2015 to 2019), which is the lowest level recorded for this area (Figure 2-6).

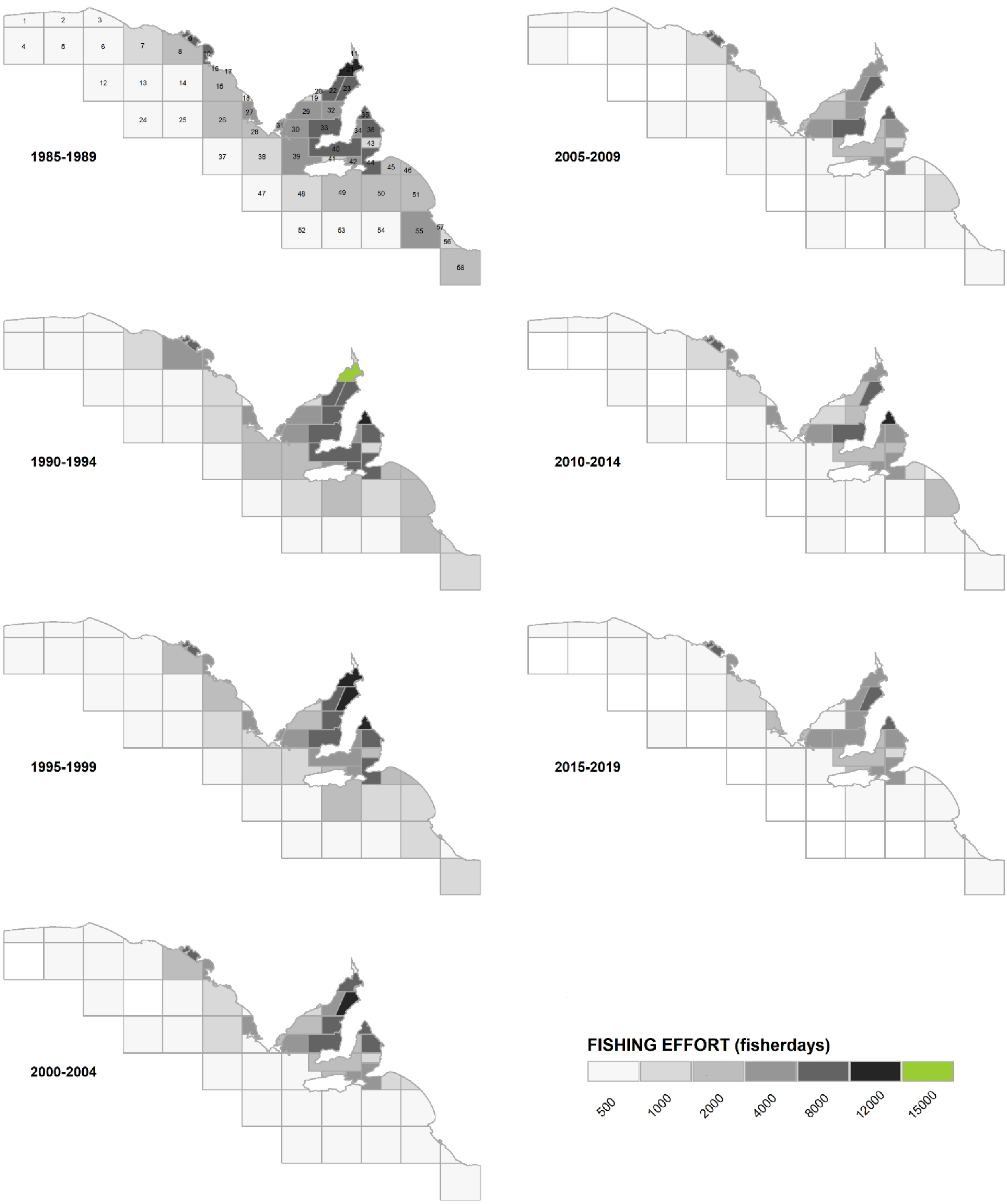

Figure 2-6. Spatial and temporal distribution of fishing effort (fisher-days) in the Marine Scalefish Fishery. Effort data by MFA were averaged over five-year periods from 1985 to 2019.

Season

The high diversity of target species within the MSF provides fishers with considerable flexibility across seasons (Figure 2-7). Among the four primary species, monthly targeted fishing effort for KGW peaked at just under 1,500 fisher-days in June, 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 just over 300 fisher-days in February. Fishing effort for Southern Garfish was affected by the seasonal closures of the fishery in late winter and early spring. The seasonal pattern of fishing activity for Southern Calamari and Snapper was similar, with both maintaining relatively high levels of fishing effort throughout the year, peaking in autumn and again in late spring (Figure 2-7). Low effort in November reflects the Snapper closure during this month since 2000.

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

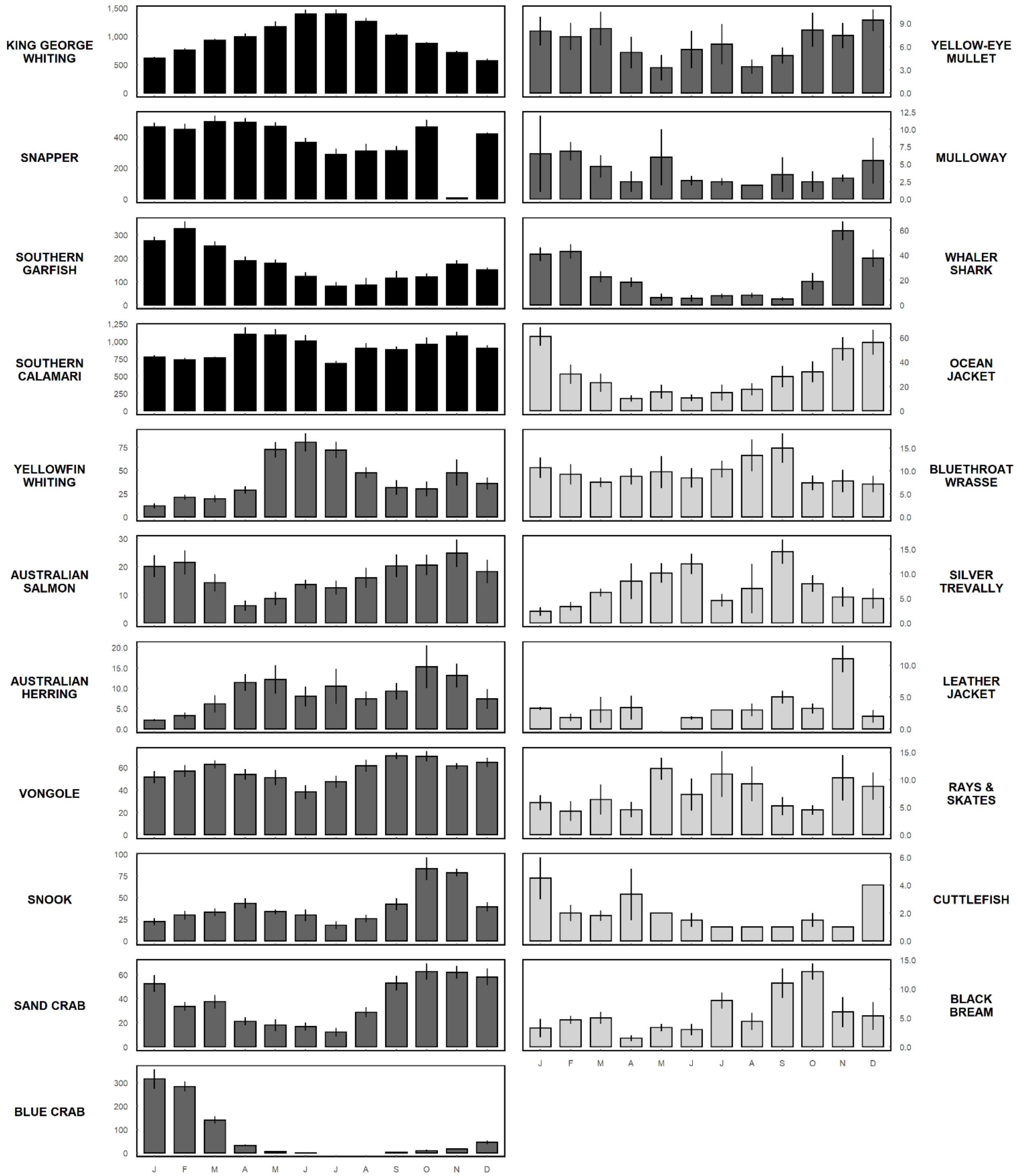

Figure 2-7. Monthly pattern of targeted fishing effort (fisher-days averaged (± se)) from 2012 to 2019 for each species/taxon assessed. The different shades denote species category; primary (black), secondary (dark grey), tertiary (light grey).

2.4. Summary

The dynamics of the MSF fleet have shifted in recent years primarily due to management arrangements. The most obvious changes have been the: a) decline in fishing effort driven by the licence amalgamation scheme, two voluntary net buy-back initiatives and reduction in the number of B-class and Rock Lobster licences active in the fishery, and b) expansion and reduction in Snapper catches, a steady reduction in King George Whiting and Southern Garfish catches, and the shift in effort towards targeting Southern Calamari.

Since their implementation, the major management arrangements have successfully reduced the number of active licence holders by 64.5%, which has led to a 58.2% reduction in fishing effort. This has resulted in a gradual spatial contraction of effort across the State, with the fishery becoming almost exclusively confined to gulf waters and a few protected bays on the west coast of the Eyre Peninsula. Most fishing effort within the MSF was targeted, although a greater proportion of fishers in 2016–2019 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 (59.2%) of targeted effort, of which King George Whiting has historically dominated. Since 2011, there have been substantial 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 and 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 in the fishing fleet.

The ephemeral periods of increased fishing activity for other secondary and tertiary species, such as Western Australian Salmon, Snook and Ocean Jackets 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 to 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 overtime.

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). This 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 offshore 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, Rogers et al. 2019). 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, Drew et al. 2020). 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 kilometres (Drew et al. 2020, Rogers et al. 2019). 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 Tasmania (Jenkins et al. 2016). The similarity in genotypes between SA and Victoria were 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 indicates that there must be at least some 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 (Steer et al. 2018a). 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. Therefore, 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 (NZRLF) and Southern Zone Rock Lobster Fisheries (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 the species 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 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 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, boat, possession 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 31 to 32 cm TL for all waters east of longitude 136°E, whilst the LML of 30 cm TL was retained in the waters of the west coast of Eyre Peninsula; (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; (3) a possession limit of either 72 fish or 10 kg of fillets or 36 fish and up to 5 kg of fillets; and (4) an introduction of a spatial spawning closure in Investigator Strait and southern Spencer Gulf from 1st to 31st May that was first implemented in 2017. This spatial closure was removed in 2020 as all three stocks were classified as sustainable (Steer et al. 2020).

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 36-year period of 1984 to 2019. These data were aggregated to provide annual catch statistics 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). However, additional CPUE series that correspond to different gear types are included in the WhitEst stock assessment model. 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

The SA King George Whiting fishery stock assessment model, WhitEst, was developed under an FRDC project (Fowler and McGarvey 2000) as a dynamic, spatial, age- and length-structured model. WhitEst integrates multiple data sources, biological and fishery-derived, to estimate three model-based fishery biological indicators specified for King George Whiting in the MSF management plan (PIRSA 2013; Table 3-1). The model runs over the calendar years of available State catch logbook data, from 1984 to 2019.

The WhitEst model accounts for natural and fishing mortality, yearly recruitment, growth, yearly migration to spawning grounds, differences in selectivity by month and age, and the gradual recruitment of each yearly cohort to legal size as the fish of varying lengths in each year class grow above the LML (McGarvey et al. 2007). Legal minimum length, which has been the principal method of management regulation for controlling exploitation rate in SA King George Whiting, was increased in the two gulfs several times over the model time frame. One important model improvement was to make explicit the increase in gulfs LML from 31 to 32 cm from December 2016 onward, which includes the extended model years of 2017–2019 for this assessment. As the biomass performance indicator specifically includes only legal size fish, the increase in LML inadvertently reduces total biomass measured by this indicator, leaving out King George Whiting in the 31–32 cm size range that are included in fishable biomass for years prior to 2017.

WhitEst analyses the South Australian King George Whiting population broken down into six spatial cells (Figure A4.1), two cells for each stock. These include the northern and southern regions of the two gulfs and the fished areas of the West Coast. A sixth model cell is located offshore from the West Coast where spawning occurs but from where catches are negligible. This spatial breakdown permits model accounting for the annual summer migrations from inshore nursery areas in the northern gulfs to the spawning areas in the southern gulfs and from inshore to offshore on the West Coast.

The data sources that were used as input to the WhitEst model, by month and spatial cell, were (1) monthly totals for commercial catch (kg) and effort (fisherdays), (2) market samples of the commercial catch giving proportions by length, age and sex 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, August 2014 to October 2016, and April 2017 to November 2019, (3) monthly estimates of recreational catch (fish numbers), and (4) estimates of movement by King George Whiting in the two gulfs (McGarvey and Feenstra 2002), 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 to account for migration over three months of summer and seasonal variation in exploitation levels and growth. The model employs the slice-partition method used also for South Australian Snapper and Garfish, to quantify population numbers by age as well as by length slices within each age group (McGarvey et al. 2007). Commercial catch and effort data are broken down by 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 a specific species), as reported in monthly commercial catch returns. WhitEst is fitted assuming Baranov dynamics to these monthly catches in proportion to a fishing mortality rate assumed to vary directly with monthly effort in fisherdays.

Estimates of recreational catch 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). Because of relatively high sample variability and because monthly break-downs were not obtained in the most recent recreational survey of 2013/14, seasonal (monthly) variation in recreational catches was modelled based on the first two recreational surveys, and applied to all years. Details of the generalised linear model developed to estimate this seasonal variation in recreational catch is presented in Appendix 3. The yearly recreational catch totals in number landed for non-survey years were obtained by interpolation or extension.

WhitEst integrates these input data sets and, by maximum likelihood, estimates the three biological performance indicators for each of the three stocks: yearly recruitment, fishable biomass, and exploitation rate. Yearly fishable biomass (the population in tonnes of legal-size King George Whiting) is computed as the mean of the monthly model estimates in each calendar year. Exploitation rate, the fraction of biomass harvested annually, is calculated as the sum of model monthly catches across all commercial gear and target types and both recreational sub-sectors in each calendar year divided by (year-average) legal biomass. WhitEst estimates each yearly recruitment as the initial number of fish in a cohort at age 13 months in May when these are all sublegal in size. A cohort first becomes partially subject to fishing around 2.5 years old depending on growth which varies by region, sex and LML. In the recruitment time series graphs below, the recruitment year shown on the x-axis is the year each cohort reached 2.5 years. The January 1 year of birth conventionally used to designate year classes is obtained by subtracting two years from the plotted recruitment year.

Detailed model specifications and equations for WhitEst fishery and population dynamics and for the data-fitting likelihood functions are given in Appendices 4-6. Fits of the model to data are plotted and discussed in Appendix 7.

One important aspect of integrated fishery modelling is how much weighting to place on each data source. The two principal SA King George Whiting data sources that vary from assessment to assessment are age composition samples and catch and effort data. To quantify the impact of different choices for the relative data weighting of age samples relative to catch logbook returns and tag-recoveries, sensitivity analyses, i.e. multiple alternative runs of the model under different assumptions for these weightings, were undertaken. The results of these sensitivity tests are presented in Appendix 8.

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 2019 for the three indicators were calculated. Then, the value for 2019 was compared against the trigger reference point (Table 3-1), calculated for the 'reference period' designated in the management-plan, from the historical data time series for years prior to 2019 back to 1984 (PIRSA 2013).

There are four yearly biological performance indicators: fishable biomass; harvest fraction; recruitment; and age structure (Table 3-1; PIRSA 2013). The first three are estimated by WhitEst, whilst the age structures are catch proportions by age computed directly from market sampling.

Performance indicators were produced for each of the three King George Whiting stocks. The assessment status of each stock was classified based on the national reporting system, considering all general and biological performance indicators, using a weight-of-evidence approach (Flood et al. 2014).

For assessment of catch shares amongst the commercial fisheries, the total catches reported in 2019 were compared against their allocations and associated trigger reference points (Table 3-2).

Table 3-1. Fishery performance indicators and associated 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. This involved a 71% reduction from the highest catch of 776 t recorded in 1992 to the lowest of 227 t recorded in 2019 (Figure 3-1a). 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 have been relatively consistent (Fowler et al. 2014, Giri and Hall 2015). The economic value of the annual commercial catch of King George Whiting has varied considerably over time (Figure 3-1a). It fell from $5.5 M in 2003 to $3.6 M in 2005, and was $4.1 M in 2019 (*c.f.* $4.5 M in 2018) (Figure 3-1a).

Handlines have always been the dominant gear used by the commercial sector to target King George Whiting. Between 1984 and 1999, handline catches were around 400 $t.yr^{-1}$ (Figure 3-1a). Subsequently, handline catch fell by 53% from 431 t in 1999 to 202 t in 2019. The catch by hauling nets has fallen by 93% from the record of 266 t in 1992 to only 19 t in 2019. The total State-wide gillnet catch has always been less than 50 $t.year^{-1}$, and since 2012 has been <10 $t.yr^{-1}$.

The annual estimates of total fishing effort across gear types used to take the total catches of King George Whiting declined from 54,254 fisher-days in 1984 to 12,971 fisher-days in 2019, i.e. a reduction of 76% over 36 years (Figure 3-1b). This declining trend relates, at least partly, to the reduction in number of licence holders in the commercial fishery. Between 1984 and 2019, the number of fishers who reported taking King George Whiting fell from 646 to 242, and those targeting King George Whiting from 592 to 201 (Figure 3-1d). 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 3-1c). 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 gradually increased to the highest recorded level in 2016, and has maintained this high level of CPUE between 2017–2019 (Figure 3-1c).

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

Seasonality in the King George Whiting fishery has been a consistent feature (Figure 3-2c). Catches have generally been higher through the cooler months and lower during summer. In 2019, the commercial catch was dominated by that from the MSF Fishery, with a relatively small contribution of 0.79% from the NZRLF.

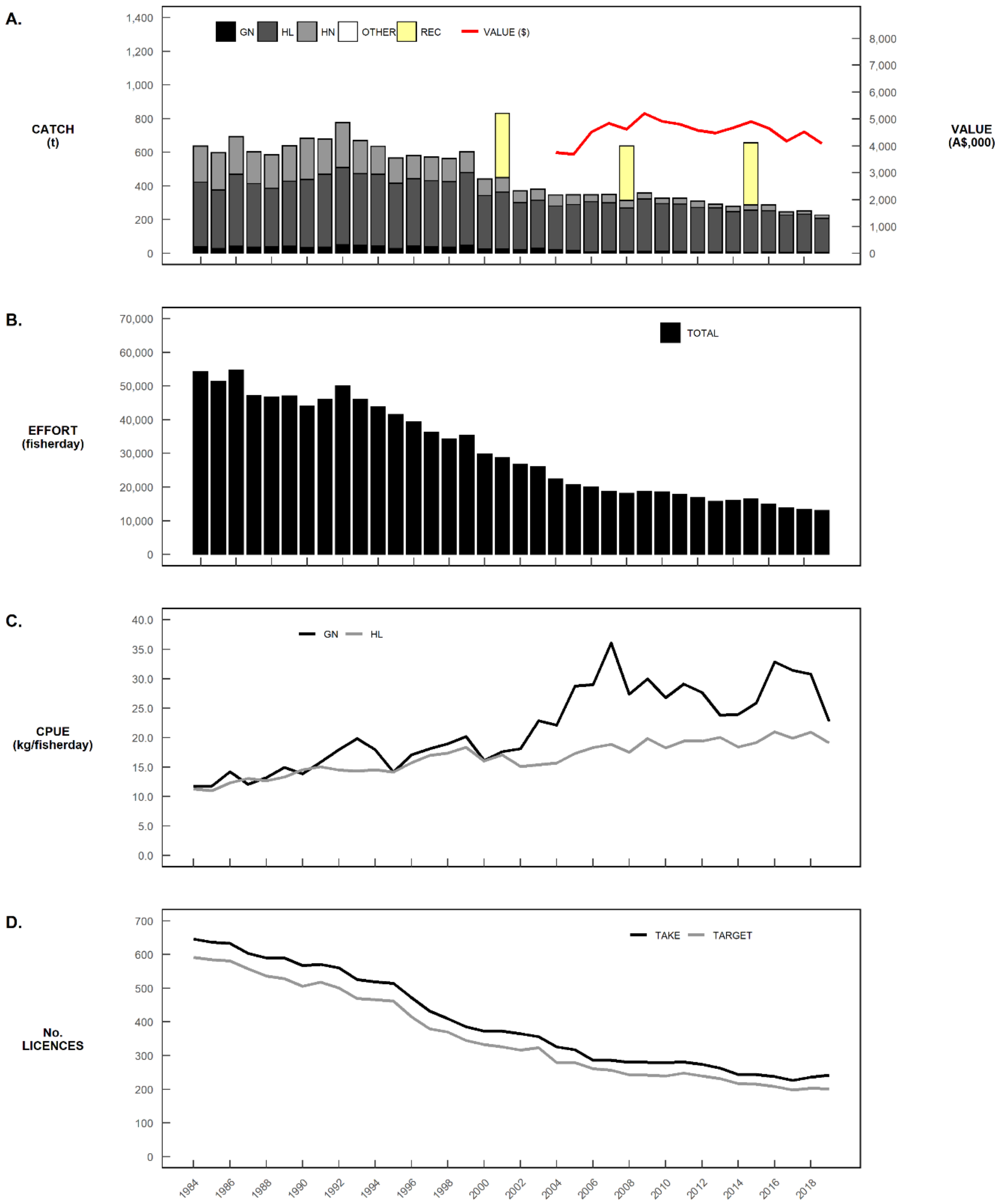

Figure 3-1. King George Whiting. Long-term trends in: (A) total catch of the main gear types (handline, hauling net and gill net), estimate of recreational catch and gross production value; (B) total effort; (C) total catch per unit effort (CPUE) for handline and longline; and (D) the number of active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

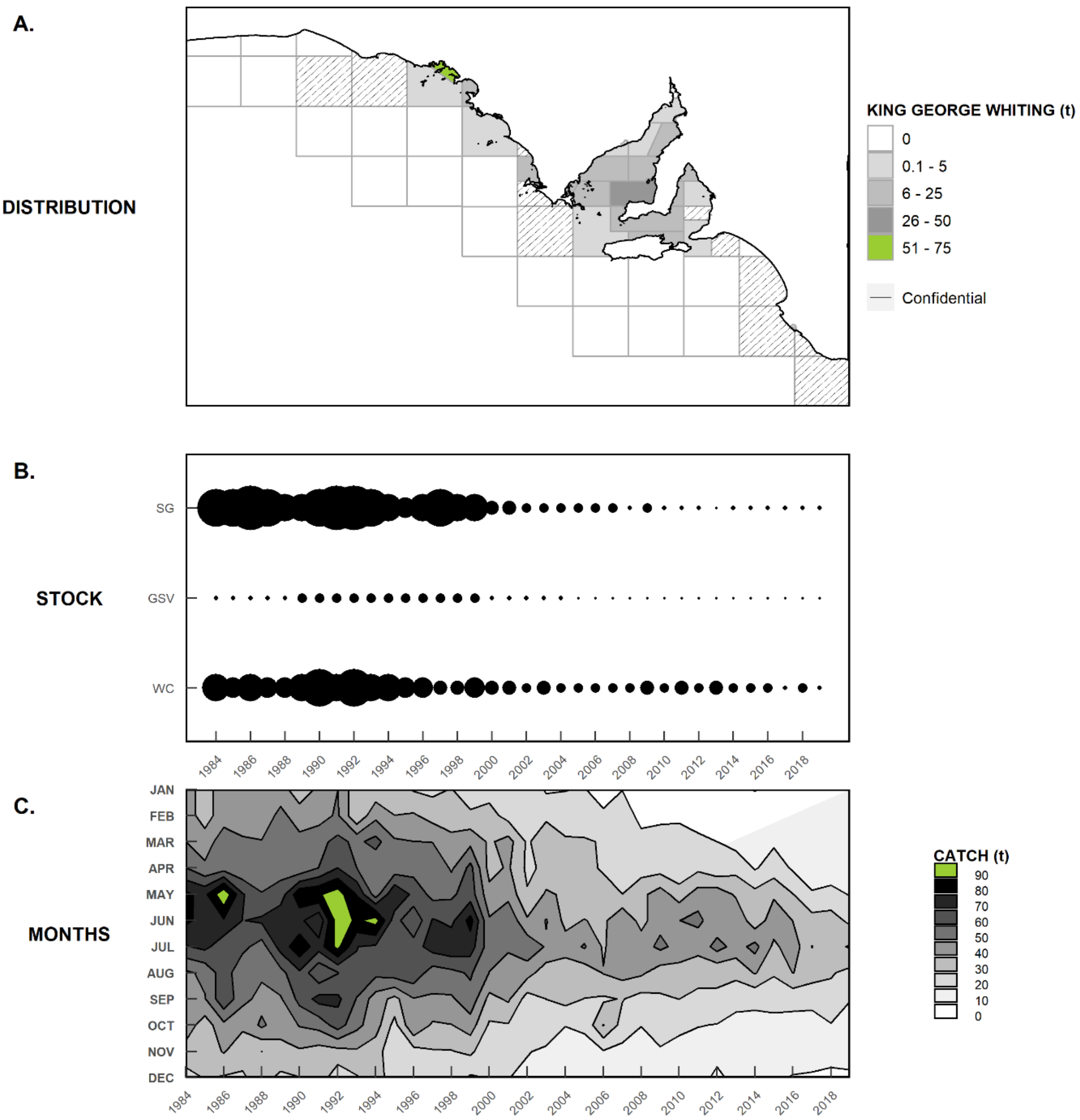

Figure 3-2. King George Whiting. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among stocks, (C) months of the year (t).

West Coast Stock

The west coast stock includes all fish captured in the MFA fishing areas from the southern coastline of Eyre Peninsular to the Western Australian boarder (Figure 2-1). Annual commercial catches from this stock increased between 1984 and 1992 when the highest annual catch of 283 t was taken (Figure 3-3a). From then, total catch gradually declined by 53% to only 134 t in 2002. Subsequently, it increased to 171 t in 2013, before falling to the lowest ever recorded catch of 98 t in 2019.

In all years, handlines were the dominant gear. Targeted handline catches dropped from the high of 216 t in 1999 to 97 t in 2019 (Figure 3-3b). Targeted handline effort has declined relatively consistently from the maximum of 15,827 fisher-days in 1984 to the lowest of 4,322 fisher-days in 2019 (Figure 3-3c). In contrast, handline CPUE has increased considerably in several multi-year steps. It increased between 1987 and 1992 before declining considerably to 1995 (Figure 3-3). It increased again to 1999 before falling from 20.8 to 15.6 kg.fisher-day^{-1} in 2002. Subsequently, CPUE increased to 24.5 kg.fisher-day^{-1} in 2013. Although it dropped considerably in 2014, it recovered and peaked at 25.5 kg.fisher-day^{-1} in 2018. The CPUE then reduced marginally to 22.5 kg.fisher-day^{-1} for 2019. The numbers of fishers taking and targeting King George Whiting from the WCS with handlines have both declined considerably between 1984 and 2019 (Figure 3-3e). The former fell from 197 to 81 fishers, whilst the latter declined from 196 to 79 fishers.

The model-estimated values of West Coast fishable biomass have gradually increased over time, particularly between 1984 and 1999 and again between 2008 and 2013 (Figure 3-3). The general increasing trend in biomass reflects a long-term increasing trend in recruitment, although interrupted by occasional short declines. Biomass has been stable at high levels since 2009. Furthermore, there has been a long-term decreasing trend in exploitation rate, ~50% reduction since the mid-1980s, which relates to the decline in fishing effort, reflecting the declining number of commercial fishers. The long-term increase in biomass is commensurate with this trend of large long-term reductions in exploitation level. The recent age structures for the catches in the bays of the West Coast remain dominated by the 2+ and 3+ age classes. Older King George Whiting, the spawning population of the West Coast, are presumed to reside in deeper waters, outside of the primary inshore fishing areas.

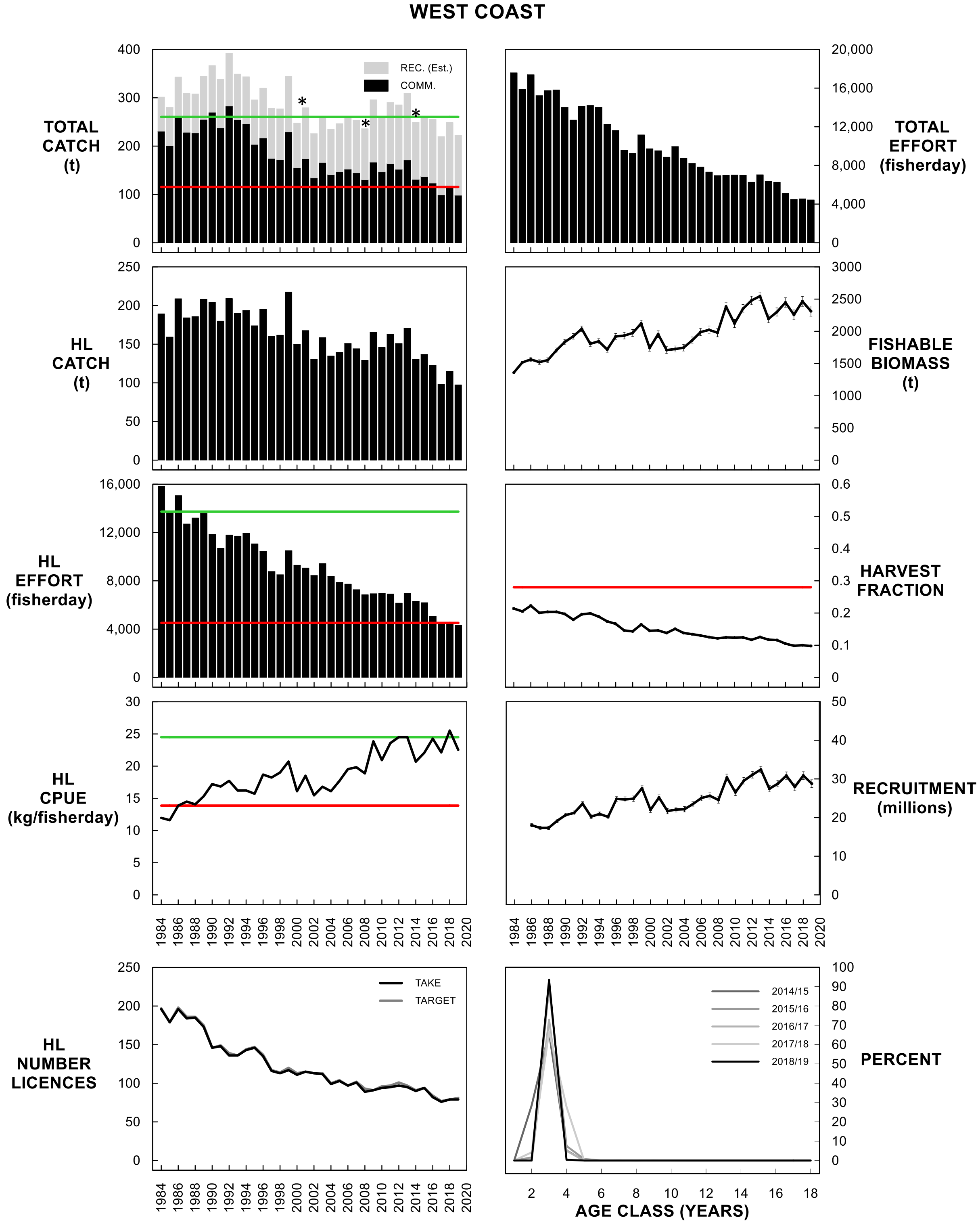

Figure 3-3. Key outputs used to assess the status of the West Coast King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2014/15 to 2018/19. Green and red lines represent the upper and lower trigger reference points outlined in Table 3-1. Asterix identifies years when real estimates of recreational catch were available from recreational fishery surveys.

Spencer Gulf Stock

Total commercial catch of King George Whiting from Spencer Gulf was relatively high and varied cyclically between 1984 and 1997 (Figure 3-4). The highest catch of 346 t was recorded in 1992. From 1997 until 2004, total catch declined by 57% and then further declined by 41% to the lowest recorded amount of 71 t in 2013. From 2014 to 2018, total catch has increased again and has varied at around 100 $t.yr^{-1}$. In 2019, the total catch was the second lowest recorded for Spencer Gulf at 85 t.

Throughout the 2000s, targeted handline catch has been considerably lower than throughout the 1980s and 1990s (Figure 3-4). It was lowest at 57 t in 2013 before increasing by 24% to 75 t in 2019. Handline fishing effort was variable between 1984 and 1992. Between 1992 and 2004, it declined by 58% from 10,727 to 4,530 fisher-days. It was then relatively stable for several years, until declining in 2013 to the lowest level of 3,463 fisher-days, but has since increased by 17% to 4147 fisher-days in 2019 (Figure 3-4). Handline CPUE has shown a long-term increase, although with clear cyclical variation. The cycles have typically involved several years during which CPUE increased quickly, followed by several years of decline. From 2003 to 2007, catch rate increased by 34% from 15.4 to 20.7 $kg.fisher\text{-}day^{-1}$. However, from 2007 to 2013, there was the longest period of decline during which it dropped by 17% to 16.8 $kg.fisher\text{-}day^{-1}$ (Figure 3-4). Then, between 2013 and 2016, it increased again, attaining the highest recorded level of 20.8 $kg.fisher\text{-}day^{-1}$. Handline CPUE has subsequently declined over the past three years to 18.2 $kg.fisher\text{-}day^{-1}$ in 2019. The number of licence holders who took King George Whiting with handlines fell from 237 in 1984 to 110 in 2019 (Figure 3-4), whilst those targeting it fell from 233 in 1984 to 108 in 2019.

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). While the estimates declined marginally between 2007 and 2012, since then they have increased to the highest estimated level. The overall increasing trend in biomass has reached all-time high levels for the last 5 years which 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 and cyclical, but shown no long-term trend. Recruitment was lowest between 2002 and 2004, and then increased considerably up to 2016. It has now declined sharply over the last three years, which isn't reflected in the high overall biomass estimates. The age structures remain dominated by the younger age classes (2–5 years), although a small percentage of older age classes are still present in the catches.

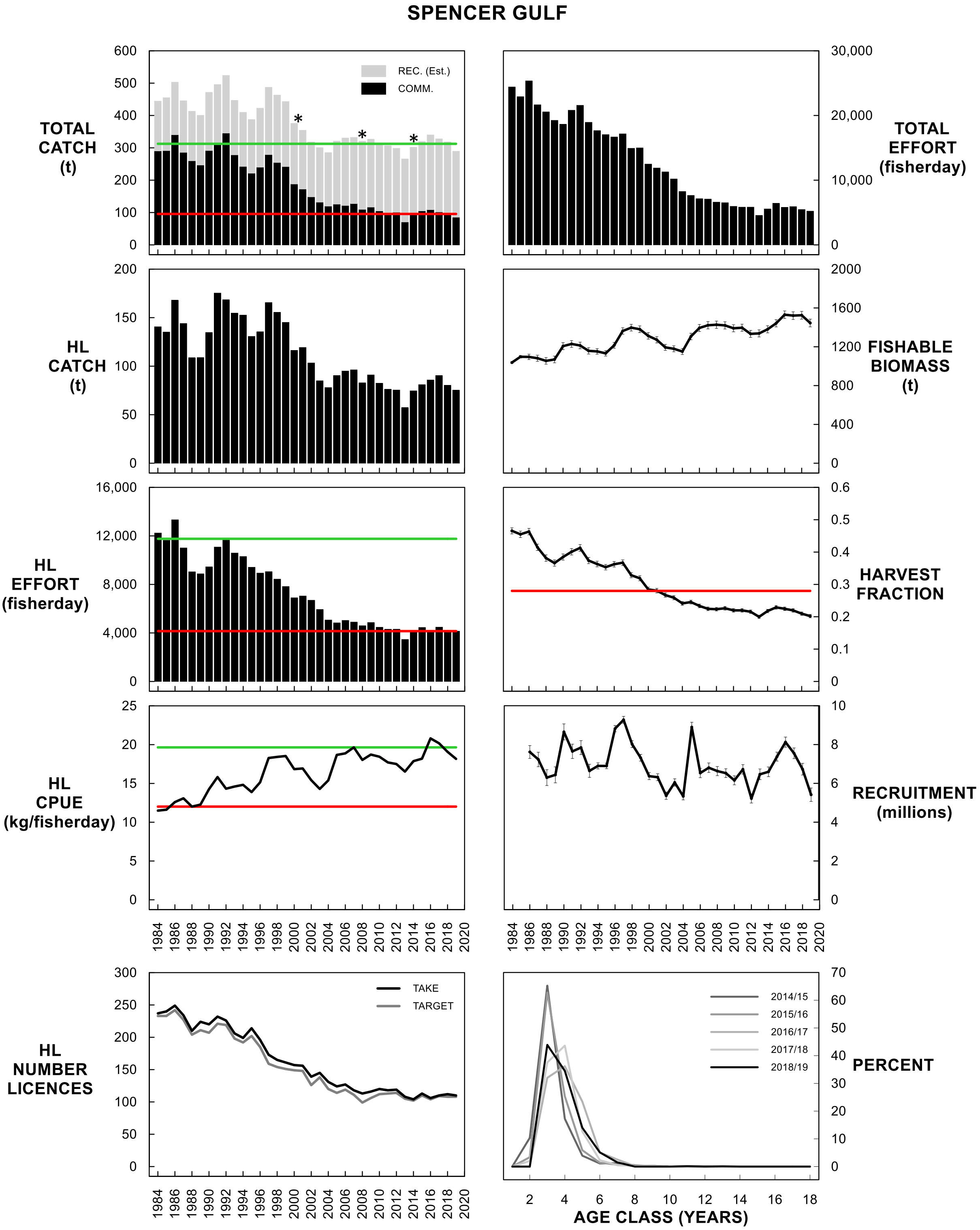

Figure 3-4. Key outputs used to assess the status of the Spencer Gulf King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2014/15 to 2018/19. Green and red lines represent the upper and lower trigger reference points outlined in Table 3-1. Asterix identifies years when real estimates of recreational catch were available from recreational fishery surveys.

Gulf St. Vincent / Kangaroo Island Stock

Total commercial catch from this stock has been consistently lower than for the other two stocks and has varied through several different periods. After declining between 1984 and 1988, catches increased to the record level of 145 t in 1994 (Figure 3-5). Subsequently, it has shown a long-term decline to the lowest annual catch of 39 t in 2018. The total catch for 2019 remained low and was the second lowest recorded at 42 t.

Targeted handline catch largely accounted for the variation in total catch, being highest between 1992 and 1995 before declining to 38 t in 2005 (Figure 3-5). It increased again to 52t in 2010, but has subsequently declined to the lowest level of 28 t in 2019. Handline fishing effort reached its highest level of 7,504 fisher-days in 1992 (Figure 3-5). It subsequently declined to three consecutive years of the lowest targeted effort level recorded, with 2052 fisher-days in 2019. Between 1984 and 2007, handline CPUE was variable but nevertheless increased by 76% from 8.4 to 14.8 kg.fisher-day^{-1} (Figure 3-5). Over the following five years, it declined by 18% to the low value of 12.2 kg.fisherday^{-1} in 2012. It has subsequently increased by 24% over several years to 14.7 kg.fisherday^{-1} in 2017, but then slightly decreased to 13.7 kg.fisherday^{-1} in 2019. The numbers of licence holders who captured or targeted King George Whiting with handlines has declined considerably. In 1984, a total of 128 fishers took King George Whiting, which fell to 46 fishers in 2019 (Figure 3-5). The numbers who targeted this species with handlines fell from 126 to 41 fishers over the same period.

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 stabilised. The decline reflected a period of declining recruitment rates between 2004 and 2010, which have subsequently increased between 2010 and 2016. Recruitment was lower in 2017, but then marginally increased in 2018 and again in 2019 to stabilise at an average level in 2019. The exploitation rate has gradually declined over time, reflecting the State-wide declining numbers of fishers and fishing effort. The age structures of sampled commercial catches remain dominated by fish in the 3+ to 6+ age classes with some representation in older age classes.

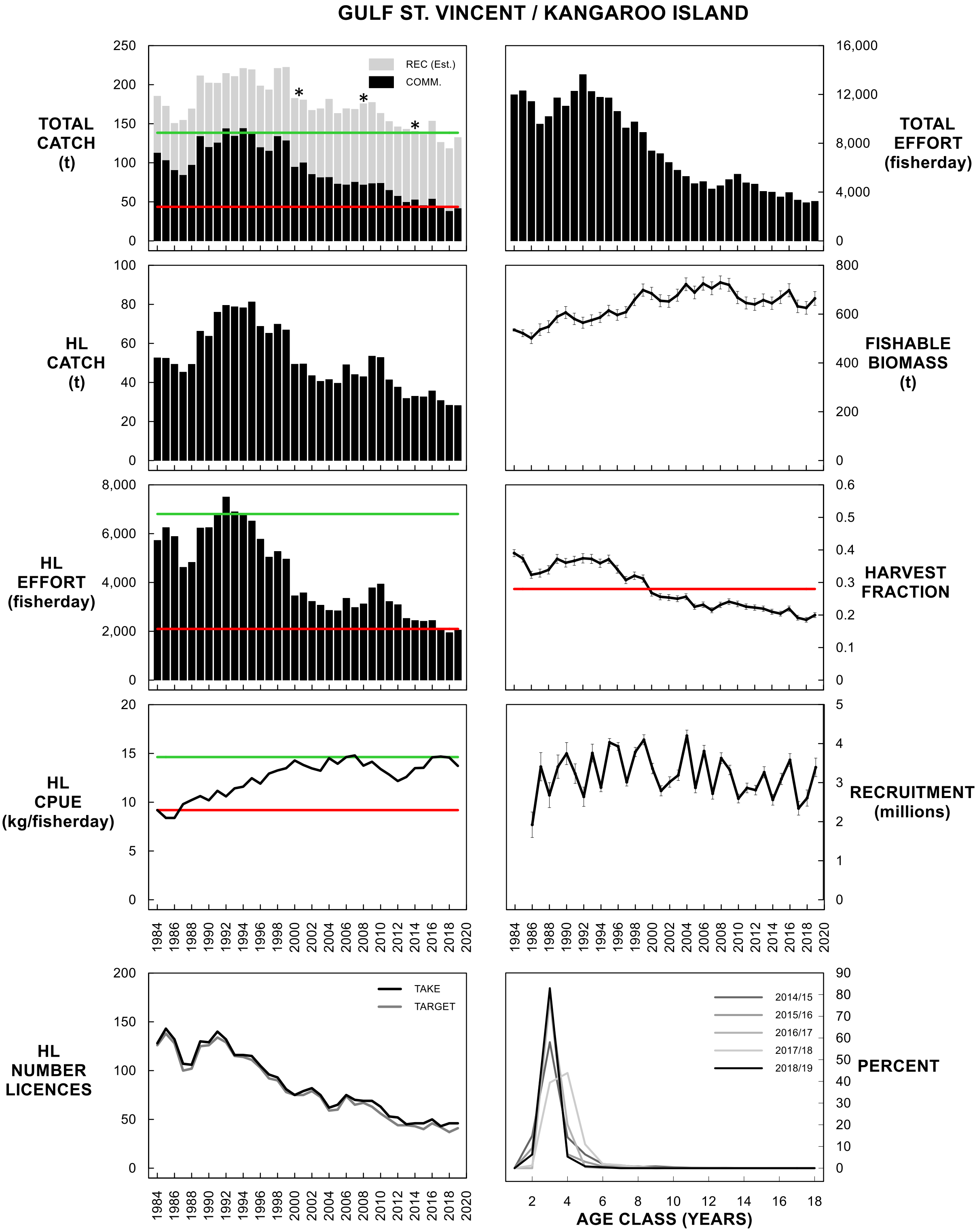

Figure 3-5. Key outputs used to assess the status of the Gulf St. Vincent/Kangaroo Island King George Whiting Stock. (Left) Trends in total catch; target handline (HL) catch, effort and catch rates (CPUE); number of licences targeting and taking KGW. (Right) Trends in total effort; model output: fishable biomass, harvest fraction, and average (± sd) recruitment; population age composition from 2014/15 to 2018/19. Green and red lines represent the upper and lower trigger reference points outlined in Table 3-1. Asterix identifies years when real estimates of recreational catch were available from recreational fishery surveys.

3.3.2. Age and size structures

West Coast (MFAs 7, 8, 9, 10, 15, 16, 17, 18, 27, 28)

Across five years, >9,235 fish captured along the West Coast of Eyre Peninsula, including the Coffin Bay area were measured and 1,192 were sampled for age structure information. Size distributions were consistently characterised by small to medium-sized fish 30 – 35 cm TL, however a few larger (>40 cm TL) fish were sampled in relatively low numbers across years. The age structures across all years were dominated by fish 3+ years, whilst the 2+ age class was most prevalent in 2015 and the 4+ age class was higher in 2017 and 2018. The small variation in age structures between years is most likely a result of reduced sample sizes in recent years and the timing of sampling occurring in relation to the nominated birth date of 1st May.

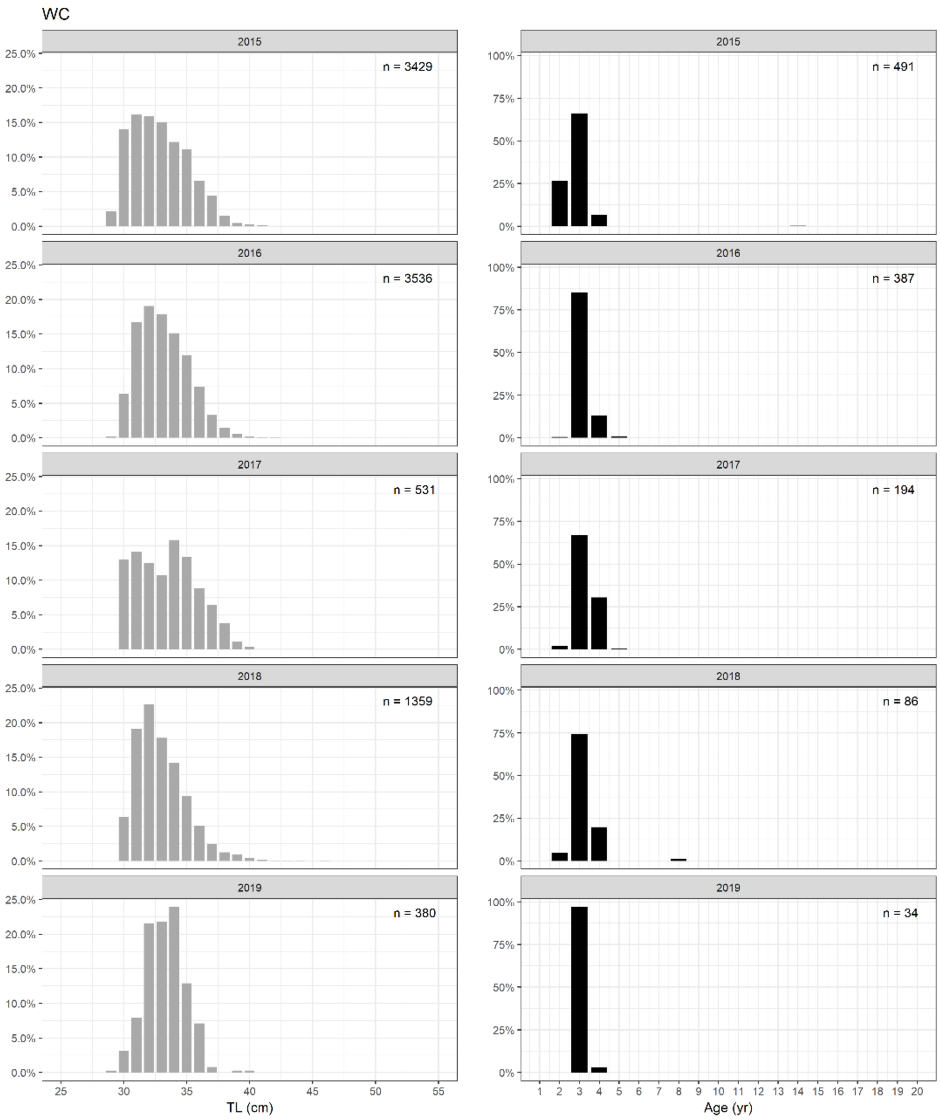

Figure 3-6. Age and total length (TL) structures of samples of King George Whiting collected in 2015, 2016, 2017, 2018 and 2019 from the West Coast of Eyre Peninsula in South Australia.

Northern Spencer Gulf (MFAs 11, 19, 20, 21, 22, 23)

A total of 8,481 fish captured from Northern Spencer Gulf between 2014 and 2019 were measured for the development of size structures, and a further 689 fish were sampled across all years for age structure information. The size structures were relatively consistent between years, with the catches dominated by small to medium fish <40 cm TL and decreasing numbers of larger fish present. A small variation in modal size classes is evident between 2014 and the following years. In 2014, most fish ranged in size from 34 – 37 cm TL, whereas the modal size range of the following years is 31 – 34 cm TL. The reduction of fish measured <32 cm TL after 2016 is the result of an increase to the legal minimum total length. The age structures for all years of sampling were dominated by 3+ and 4+ age classes, these age classes account for ~80% of fish sampled annually.

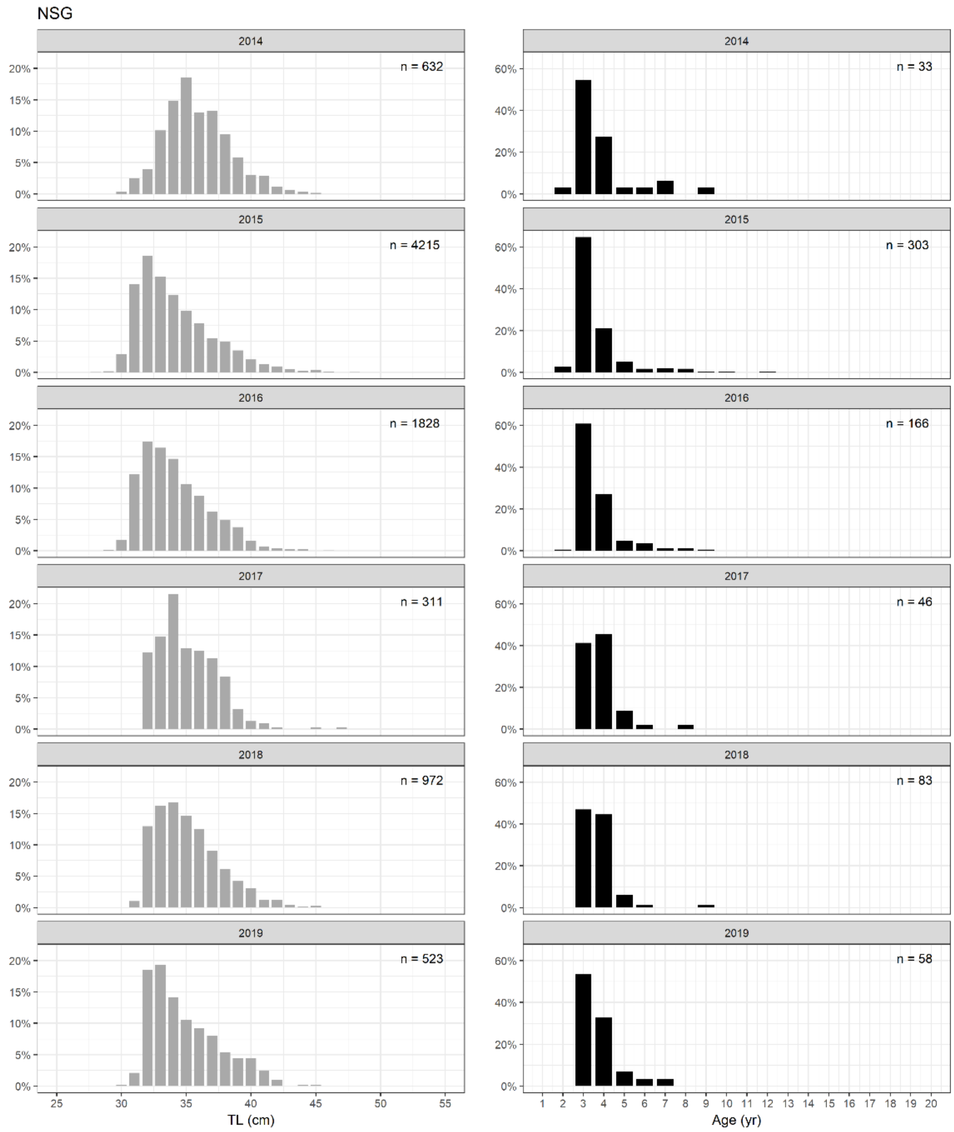

Figure 3-7. Age and total length (TL) structures of samples of King George Whiting collected in 2014, 2015, 2016, 2017, 2018 and 2019 from Northern Spencer Gulf in South Australia.

Southern Spencer Gulf (MFAs 29, 30, 31, 32, 33)

A total of 10,503 fish captured from Southern Spencer Gulf between 2014 and 2019 were measured for the development of size structures, and a further 994 fish were sampled across all years for age structure information. The size distributions were broader and in general larger than those captured in NSG. The modal sizes were between 34 and 37 cm TL across most years. Around 20% of fish measured were 40 cm TL or larger each year for all years sampled. Age distributions were consistent between years and were predominately comprised of 3+, 4+ and 5+ age classes. The presence of older age classes 5+ – 15+ was still relatively low, however they were more numerous than in other regions. The oldest fish in each year was 9+ years or more, with the oldest fish aged 13+ in 2018.

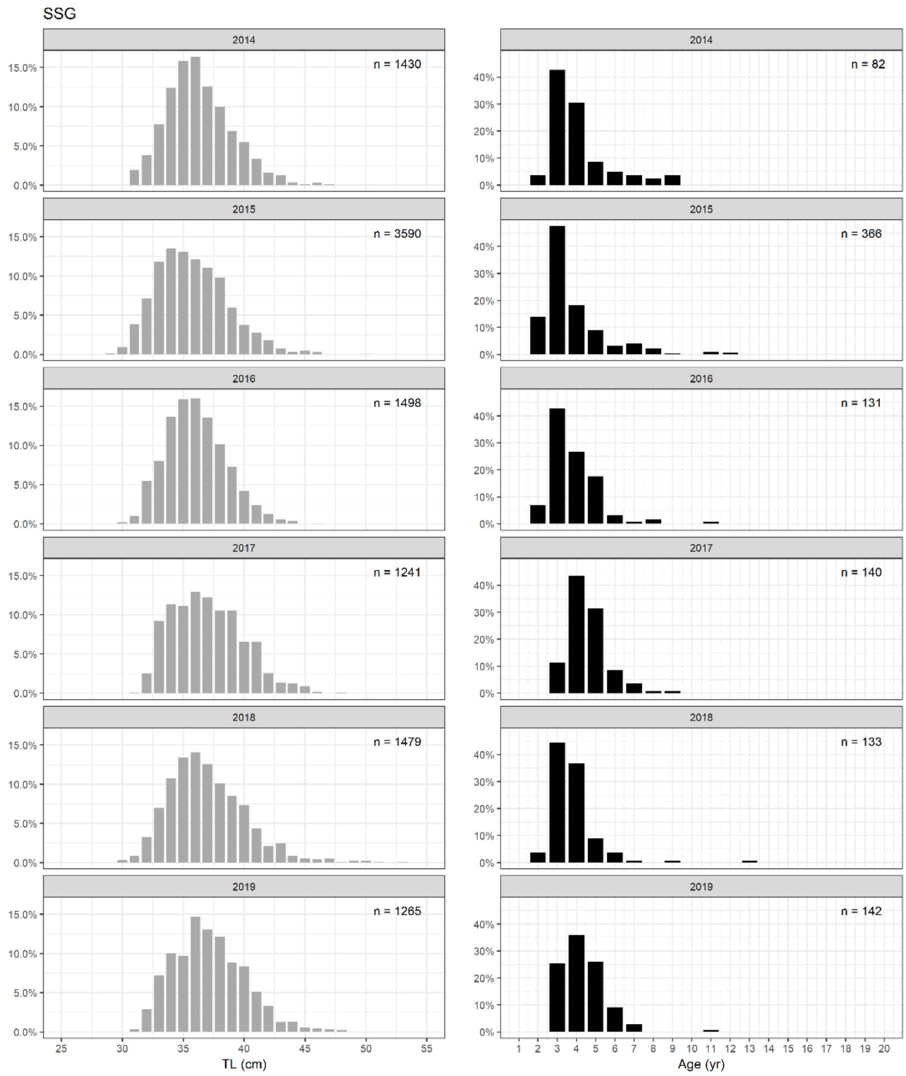

Figure 3-8. Age and total length (TL) structures of samples of King George Whiting collected in 2014, 2015, 2016, 2017, 2018 and 2019 from Southern Spencer Gulf in South Australia.

Northern Gulf St Vincent (MFAs 34, 35, 36)

A total of 5,800 fish captured from Northern Gulf St Vincent between 2014 and 2019 were measured for the development of size structures, and a further 491 fish were sampled across all years for age structure information. The resulting annual length distributions were dominated by small to medium sized fish, with most fish <40 cm TL. The modal sizes varied between 32 and 34 cm TL. Relatively few fish were in the larger (>40 cm TL) size range, however the largest fish recorded was 47 cm TL in 2016. The age structures were dominated by the 3+ age class for all years besides 2014, which was dominated by 2+ year class. There was little representation from older age classes 5+ to 9+ years.

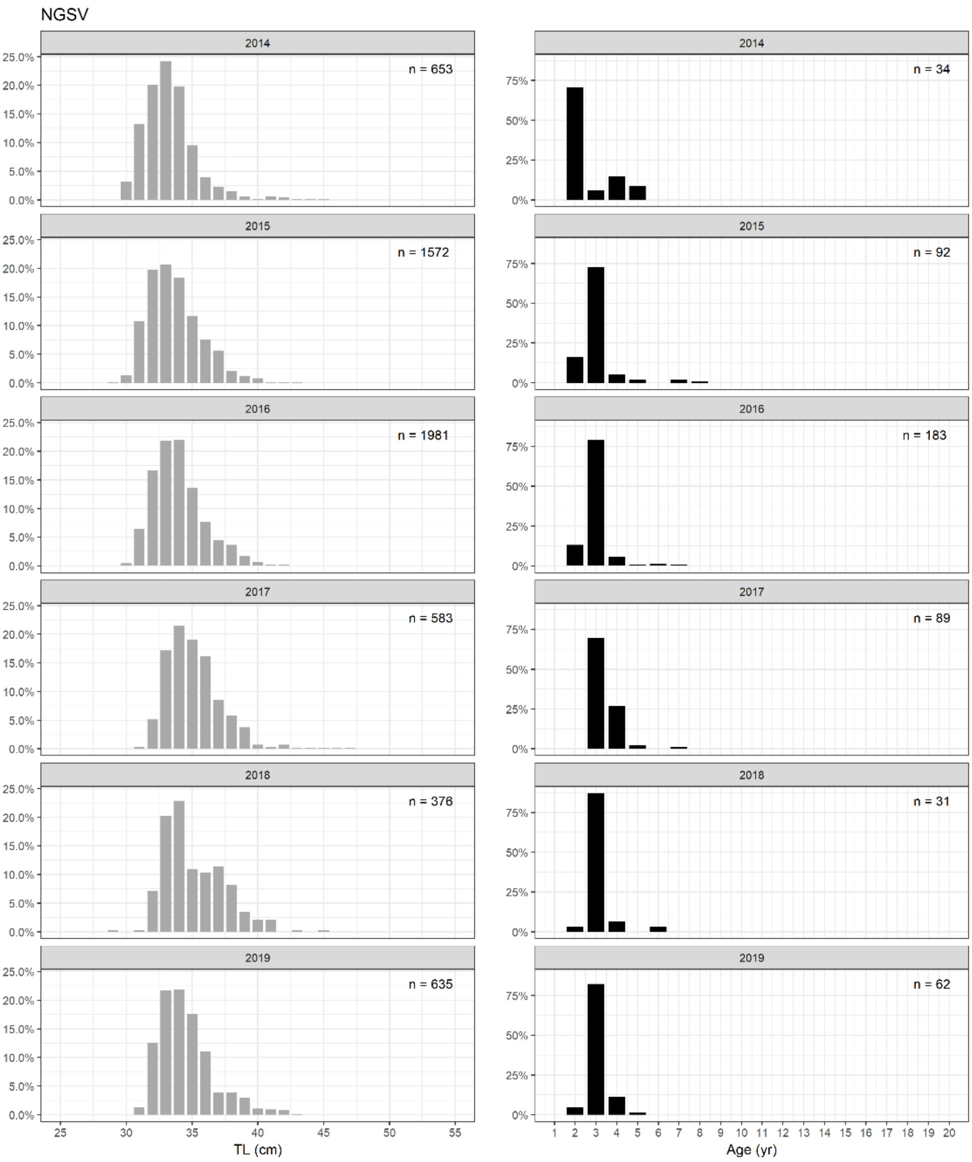

Figure 3-9. Age and total length (TL) structures of samples of King George Whiting collected in 2014, 2015, 2016, 2017, 2018 and 2019 from Northern Gulf St. Vincent in South Australia.

Southern Gulf St Vincent (MFAs 40, 41, 42, 43, 44)

A total of 4,186 fish captured from Southern Gulf St Vincent between 2014 and 2019 were measured for the development of size structures, and a further 874 fish were sampled across all years for age structure information. This region included a complex range of habitats, from inshore bays which are known for small King George Whiting and deep-water reef habitats where larger spawning fish aggregate. Therefore, the resulting size and age structure information is broader and more variable dependent on the locality of fishing than seen in other regions. The length structures were not consistent between years, with the fish collected in 2014, 2015, 2017 and 2018 were medium sized, ranging from 32 to 37 cm TL. Contrastingly, in 2016 the size structure was representative of larger fish, with the majority ranging from 41 to 45 cm TL. This variation in size structure seen in 2016 is likely the result of a small sample size and fish sampled were targeted from deeper water locations. Similar to other regions, the 3+ and 4+ age classes dominated the age structures with adequate sample sizes (2014–2017). However, the age structures were complex and broader with the highest representation of older year classes >5+ for any region. The oldest fish aged in each year with adequate sample sizes (2014–2017) was at least 9+ years, with multiple fish in the 18+ age class captured in 2016.

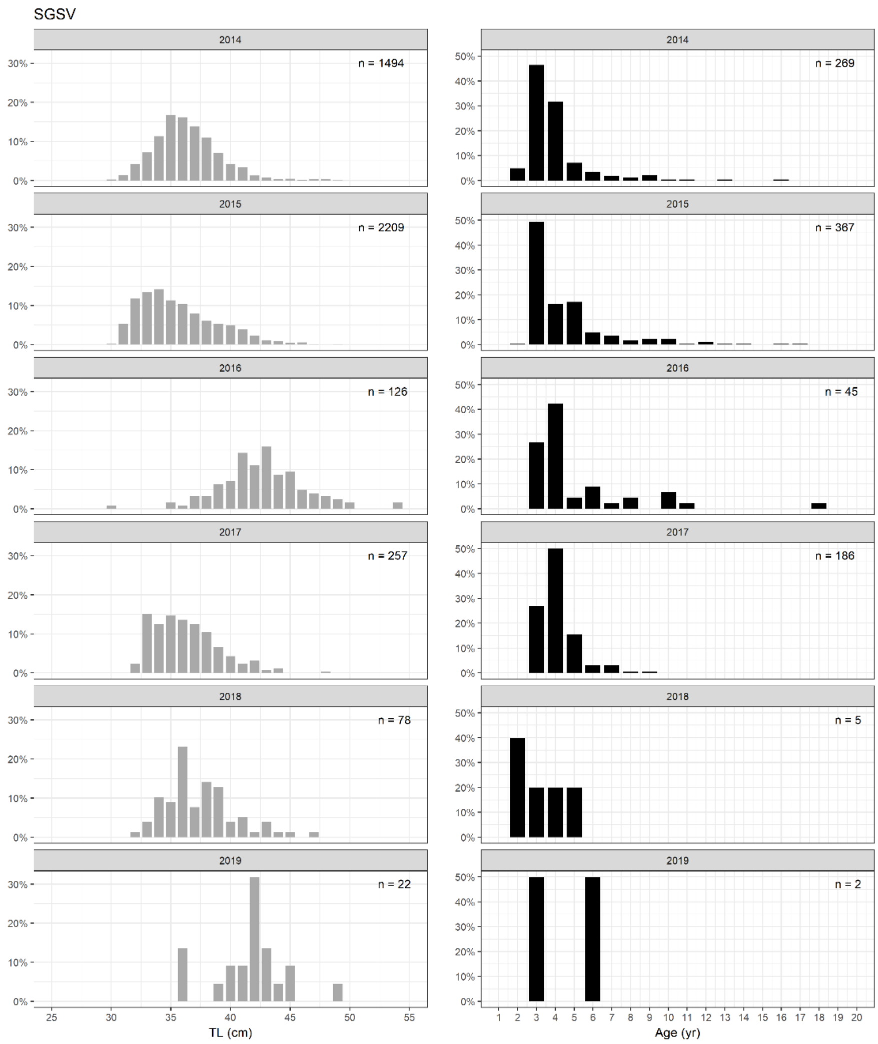

Figure 3-10. Age and total length (TL) structures of samples of King George Whiting collected in 2014, 2015, 2016, 2017, 2018 and 2019 from Southern Gulf St. Vincent in South Australia.

3.3.3. Fishery Performance

The catch data from the three commercial fisheries from 2019 were compared against their allocations using Triggers 2 and 3 as reference points. No negative trigger reference points were breached (Table 3-3).

Table 3-3. Comparisons of percentages of commercial catch of King George Whiting 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. 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%
2015	98.78%	0.00%	1.22%
2016	99.36%	0.00%	0.64%
2017	99.10%	0.00%	0.90%
2018	98.60%	0.00%	1.39%
2019	99.20%	0.01%	0.79%

The general fishery performance indicators were assessed against trigger reference points at the State-level and for each of the three regional stocks. There were nine breaches of general trigger reference points that were consistent at the state-level and regional spatial scales (Table 3-4). For each stock, and at the State-wide scale, the lowest or second lowest total catches were recorded. Similarly, for all regional stocks and at the State-wide scale the lower reference points for handline fishing effort levels were triggered (Table 3-4). Finally, at the State-wide scale there has been a decline for five consecutive years in targeted handline effort.

For the biological indicators, four positive and one negative reference points were breached (Table 3-4). At the State-wide scale and for the WC and SG, the average annual estimates of biomass between 2017 and 2019 were >10% above the long-term averages. For SG and GSV/KI stocks, the estimate of recruitment in 2019 were >10% above the averages from the previous five years.

Table 3-4. Results of the assessment of the performance indicators against their trigger reference points at the biological stock level for King George Whiting.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	STATE	WC	SG	GSV/KI
TOTAL CATCH	G	3rd Lowest / 3rd Highest	LOWEST	LOWEST	2nd LOWEST	2nd 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	3rd LOWEST	2nd 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	×	×	×	×
FISHABLE BIOMASS	B	3 year av. Is +/- 10% of previous years	17% ABOVE	21% ABOVE	18% ABOVE	1% ABOVE
HARVEST FRACTION	B	> 28% (int. standard)	15%	10%	20%	20%
RECRUITMENT	B	+/- 10% of average of previous 5 years	4% BELOW	1% BELOW	26% BELOW	20% ABOVE
AGE COMPOSITION	B	Change in long-term or previous 5 years				

3.4. Discussion

3.4.1. Determination of Stock Status

The status of each of the three South Australian King George Whiting stocks was classified using the national stock status classification system (Stewardson et al. 2018). 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, CPUE and WhitEst outputs (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, 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 pattern of '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 relate 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 are likely to 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, 2015/16, 2017/18, and 2018/19. The age distributions from recent years were considered against historical data. These age and length samples of the commercial catch are also crucial input data to the model.

The 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 long-term 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. A greater source of error in model outputs is the considerable uncertainty about the time-series of catch and effort data from the recreational sector. These primarily relate to the few empirical data available from surveys and the underlying assumptions required to provide estimates for the intervening years. The lack of these data is particularly crucial for King George Whiting with the recreational sector accounting for >50% of the total catch across the State.

3.4.2. Stock Status

West Coast Stock

This stock includes the populations of King George Whiting that inhabit all the bays and offshore areas of the west coast of Eyre Peninsula. In recent years, it has been consistently classified as sustainable (Fowler et al. 2014, Steer et al. 2020, 2018a, b). Nevertheless, over the past seven years total catch dropped by 43%. Handline effort also shows a long-term decreasing trend, consistent with the declining numbers of fishers taking and targeting this species. Handline CPUE has remained relatively high and stable over the past decade, reaching its highest rate recorded in 2018. Outputs from WhitEst show that fishable biomass had gradually increased over time, particularly through the two periods of 1984 to 1999 and 2008 to 2013 (Steer et al. 2018a) and remained largely stable thereafter. This general increasing trend in biomass reflected a long-term increasing trend in recruitment and long-term declining exploitation rate, which is at 10% harvested fraction for 2019. The current low harvest fraction is the result of increased biomass and declining fishing effort relating to the declining numbers of commercial fishers.

The levels of catch and effort for this stock have steadily declined since 2013. This is relatable to reductions in the numbers of commercial fishers. Nevertheless, there is no indication in the estimates of handline CPUE up to 2019 and estimates of fishable biomass, recruitment and exploitation rate up to 2019, to suggest that the biomass has been depleted and that recruitment is likely to be impaired. As such, the West Coast Stock is classified as **sustainable**.

Spencer Gulf Stock

This stock extends throughout the entire northern and southern regions of Spencer Gulf. Throughout the 2000s, total catch and effort have been low relative to the high levels recorded through the 1980s and 1990s (Fowler et al. 2014, Steer et al. 2020, 2018a). Also, handline CPUE has varied cyclically over time, but nevertheless has demonstrated a long-term increasing trend. However, between 2007 and 2013, catch, effort and CPUE all declined (Fowler et al. 2014). The estimates of biomass from the stock assessment model also declined through this period reflecting a significant decline in recruitment. As such, on the basis of these negative fishery performance indicators, this stock was classified as 'transitional depleting' (Fowler et al. 2014). This prompted a review of the fishery management arrangements that resulted in changes to the management regime that were implemented in December 2016.

Between 2013 and 2017, there were notable increases in the commercial fishery statistics. Over this period, total catch increased by 41%, handline effort by 30% and handline CPUE by 20%. Furthermore, the output from the stock assessment model indicated that from 2013 to

2016, there was an upward trend in recruitment that resulted in an 11% increase in fishable biomass (Steer et al. 2018a). Such variable biomass appears typical for this stock, which is evident as cyclical variation in the fishery statistics. It suggests that the population is subject to inter-annual variation in recruitment that impacts on population biomass and fishery productivity over cycles that last a number of years. The fishery statistics to 2017 and outputs from the fishery assessment model to 2016 were not consistent with the biomass at that time being depleted and moving the stock in the direction of being recruitment impaired (Steer et al. 2018b). Rather, they suggested that the biomass had recovered to a level sufficient to ensure that future recruitment was adequate. As such, in that year the stock classification of 'sustainable' was retained.

For this current assessment period of 2017 to December 2019, catch, effort, and CPUE have all marginally declined. Catch has fallen across this period to the second lowest level recorded. Similarly, targeted handline effort has reduced to its third lowest level. As a result of these reductions in catch and effort, CPUE has marginally declined from its second highest peak recorded in 2017. Outputs from the fishery assessment model indicate that between 2016 and 2018 biomass peaked at ~1500 t, with a small decline in 2019. The Harvest Fraction has maintained a relatively constant level since the early 2000s and is currently 20%. Recruitment, which has historically been heavily cyclical in nature, has declined steeply from 2016 to 2019. However, recent lower recruitment is not reflected in lower biomass, implying that lower exploitation rate over the last 5 years permitted the highest estimated biomass levels in recent years to be retained. These marginal declines since 2016 are not sufficient to warrant a downgrade in stock status, since handline CPUE has remained relatively high. As such, here the Spencer Gulf Stock classification remains at **sustainable**.

Gulf St. Vincent / Kangaroo Island Stock

The GSV/KIS occurs throughout Gulf St. Vincent, Investigator Strait and the waters surrounding Kangaroo Island. The recent stock assessments completed in 2014 and 2017 showed that commercial catch and effort for this stock were considerably lower during the 2000s compared to the 1990s, consistent with a long-term decline in the number of fishers participating in the fishery (Fowler et al. 2014, Steer et al. 2018a). In particular, between 2009 and 2013, there were considerable declines in commercial catch and effort (Steer et al. 2018a). Whilst CPUE had shown a long-term increasing trend between 1984 and 2007, this was followed by a period of consistent decline between 2007 and 2012, during which it fell by 18%. Consequently, estimates of biomass for the period of 2007 to 2012 from the stock assessment model showed a considerable decline of 12% (Steer et al. 2018a). This related to a period of declining recruitment. Based on these fishery performance indicators, the fishery was classified as 'transitional depleting' (Fowler et al. 2014). This, in association with the stock status assigned to the SG stock, prompted a review of fishery management arrangements that resulted in the changes that were implemented in December 2016.

For the GSV/KI Stock, total catch, targeted handline catch and effort have been relatively stable since 2013. Handline effort has followed a slowly declining trend, recording three consecutive years of lowest effort from 2016 to 2019. However, handline catch has maintained a relatively consistent level ~38 t since 2013. These relatively stable catches and marginally declining effort levels have resulted in consistent levels of handline CPUE. Between 2016 and 2018, handline CPUE was over 20% higher than the low level in 2012. The estimates of CPUE in these three years are the highest ever recorded for consecutive years. In the recent years leading up to 2019, estimates of biomass from the stock assessment model had marginally decreased and then stabilised, relating to an initial decreasing trend in recruitment. As with the other two stocks, the dominant trend is of on-going long-term reductions in exploitation rate, closely linked to similar long-term reductions in numbers of fishing licences. The recruitment and biomass indicators for the GSV stock are largely stable over the model time frame, with generally higher stable levels of biomass since around 1999. The recent estimates of fishery performance indicators indicate that the biomass of this stock is now unlikely to be depleted and that recruitment is unlikely to be impaired. As such, the GSV/KI Stock is classified as **sustainable**.

3.5. Assessment Uncertainties

The main uncertainty in this 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. 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, but it is unlikely that such interpolated values provide a precise 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.

Previously, there was 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, offshore waters of southern Spencer Gulf and Investigator Strait. In recent years, such places have become increasingly 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. The implementation of the spatial spawning closure for one month in 2017, 2018 and 2019, which incorporated most of Investigator Strait and part of southern Spencer Gulf was designed to relieve the fishing pressure on these fishing areas and support uninterrupted spawning. At this stage, the influence of the spawning closures and their impact on these two gulfs stocks remains unclear, as these fish would not have reached legal-minimum length and entered the commercial fishery. However, peak King George Whiting egg densities combined with bio-physical oceanographic modelling indicated that the implemented closures were located on key spawning locations for both gulf stocks (Drew et al. 2020). Total catches in Spencer Gulf decreased in 2018 and 2019; thus, there is potential that the spatial closure in the southern gulfs influenced catch in over those years.

Over the past decade there has been a decreasing trend in catch and effort combined with increasing levels of estimated fishable biomass for the three King George Whiting stocks. However, the time series of biomass only extends to 1984 at which point King George Whiting stocks had been fished for several decades. Therefore, it’s probable that biomasses prior to the start of this time series were higher than current levels. It is likely that the continuing low levels of catch and effort, despite the increasing estimates of biomass, are closely coupled to the reduction in fishers targeting this species. The reduction of fishers targeting King George Whiting is potentially the result of a combination of licenses being removed from the fishery through time and the shift in effort to other, more cost-effective and profitable emerging species, such as Southern Calamary. This discrepancy should be further explored in the next assessment of King George Whiting.

Research priorities have shifted from King George Whiting in recent years, as the focus has been redirected towards investigating the declining Snapper stocks. Limited sample sizes were obtained for age structures from two regions of southern Gulf St. Vincent and the West Coast in 2019. There will be a greater emphasis over the coming assessment period to obtain sufficient sample sizes from these regions.

3.6. Future Work

Two major projects (FRDC Project 2017/014, Informing the structural reform of South Australia's Marine Scalefish Fishery and FRDC project 2020/056, Evaluation of a smart-phone application to collect recreational fishing catch estimates, including an assessment against an independent probability-based survey, using South Australia as a case study) will improve our understanding of the fishing pressures on King George Whiting and refine key parameters for future WhitEst modelling. One of the most significant requirements to better assess the status of SA's King George Whiting stocks is to improve the estimates of recreational catch and effort. Since more than half of the total catch is estimated to be 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. Currently, a State-wide recreational fisher survey is being implemented utilising a combination of telephone/diary questionnaires supplemented by boat ramp surveys, and the trial and development of a mobile phone application (App). This combined method of recreational fishing survey techniques will lead to an improved understanding of the level of catch and effort within the recreational sector for King George Whiting. The implementation of a phone App has the potential to lead to more frequent and up to date recreational fishing data, which is an integral input and also a source of uncertainty for future stock assessment models.

In July 2021, the MSF underwent the largest fisheries reform in its history. Electronic commercial logbook reporting is likely to occur following the reform. This provides an opportunity to review and revise the fishery information that is collected. It may also allow for assessments to include more up to date data than is currently possible as there will no longer be substantial lags in receiving fishing records via mail. Several licence holders will exit the fishery through a voluntary licence surrender program that is a pillar of the reform. Therefore, substantial updates to future assessments will be required to address changes in catch statistics that will occur to changes in fleet composition, rather than changes in fish stocks. This will include the standardisation of commercial CPUE. Commencing in July 2021, a TACC and ITQ system will be implemented for Tier 1 species in the MSF. King George Whiting has been assigned a provisional Tier 1 status in the new Spencer Gulf and Gulf St. Vincent fishing zones. Therefore, subsequent stock assessments of these stocks will be used to determine the TAC and TACC in subsequent years. A current FRDC funded research project is underway that is providing scientific support to the reform process (FRDC 2017/014). Following the implementation of the fishery reform in July 2021, harvest strategy development of key fish stocks will be required. The model outputs presented in this assessment, and its future iterations, will likely be important for determining harvest control rules for each of the Tier 1 King George Whiting stocks. Subsequently, model updates may be required such as estimating levels of depletion. To accomplish this, the WhitEst models will need to be further developed to estimate unfished biomass and egg production.

A proof of concept for fishery independent biomass estimates has recently been developed for King George Whiting from Daily Egg Production Methods (DEPM) (Drew et al. 2020). This provides future opportunities for fishery independent estimates of biomass to be incorporated into stock assessments for the SGS and GSV/KIS, should future DEPM surveys be undertaken. These fishery-independent biomass estimates have shown great potential in supplementing the recent fishery-dependent based stock assessment models for Snapper and could similarly benefit future King George Whiting assessments (Fowler et al. 2020a).

4. STOCK STATUS OF KEY MARINE SCALEFISH SPECIES

4.1. Introduction

This section of the report uses a weight-of-evidence approach to determine the stock status of 19 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. These data span a 36-year time-series from 1984 to 2019 and were aggregated at either the biological stock, State-wide or regional scales to provide annual estimates of catch and effort for the main gear types (Table 4-1). Data on Snapper catches by the Lakes and Coorong Fishery (LCF) and by-product of Southern Calamari by SA's three Western King Prawn fisheries are also included.

The presentation 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 general performance indicators for 2019 were benchmarked against the trigger reference points calculated from the historical data. The national stock status classification system developed for the assessment of key Australian fish stocks (Stewardson et al. 2018) was used to assign stock status for 2019 (see Table 1-1).

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 (targeted or total).

CATEGORY	SPECIES / TAXON	STOCK	GEAR	TARGETED OR TOTAL
PRIMARY	SNAPPER	Biological	Handline, Longline	Targeted
	KING GEORGE WHITING	Biological	Handline, Hauling Net, Gillnet	Total
	SOUTHERN CALAMARI	State-wide and regional	Squid Jig, Hauling Net	Targeted
	SOUTHERN GARFISH	State-wide and regional	Hauling Net, Dab Net	Targeted
SECONDARY	YELLOWFIN WHITING	Biological	Hauling Net	Targeted
	WA SALMON	State-wide	Hauling Net	Targeted
	AUST. HERRING	State-wide	Hauling Net	Targeted
	SNOOK	State-wide	Hauling Net	Targeted
	BLUE CRABS	State-wide	Crab Net	Targeted
	SAND CRABS	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
	OCEAN JACKETS	State-wide	Fish Trap	Targeted
TERTIARY	BLUETHROAT WRASSE	State-wide	Handline, Longline	Total
	SILVER TREVALLY	State-wide	Handline	Total
	LEATHERJACKETS	State-wide	Hauling Net	Total
	RAYS AND 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

Biology

Snapper (*Chrysophrys auratus*) is a species of teleost fish in the family Sparidae. It is a large, long-lived, demersal, finfish species that is broadly distributed throughout the Indo-Pacific region, where its extensive distribution includes the coastal waters of the southern two-thirds of the Australian 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 to 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 study indicated that there are three stocks that occur in South Australian coastal waters (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 (SA) as far west as Cape Jervis. There are also two wholly South Australian stocks, i.e., the Spencer Gulf / West Coast Stock (SG/WCS) and Gulf St. Vincent Stock (GSVS) (Fowler 2016, Fowler et al. 2017).

The recent study on the stock structure of Snapper was also informative about the demographic processes responsible for the replenishment of the three 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 South East Region (SE), Snapper abundance varies episodically, as fish of a few years of age migrate westwards to this region over hundreds of km from PPB (Fowler et al. 2017). This occurs several years after strong year classes recruit to 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 in SA are independent and self-recruiting. They also experience inter-annual variation in recruitment of 0+ fish (Fowler and Jennings 2003, Fowler and McGlennon 2011), most likely as a consequence of variable larval survivorship (Hamer et al. 2010). Each is an important nursery area that acts as a source of emigration of sub-adult and adult fish that replenish regional populations in adjacent coastal waters (Fowler 2016). NSG is the source region for immigrants to Southern Spencer Gulf (SSG) and most likely also for the West Coast of Eyre Peninsula (WC), whilst NGSV is the source for Southern Gulf St. Vincent (SGSV). As such, the dynamics in the regional populations of SA are primarily driven by temporally variable recruitment and subsequent emigration of fish from the source regions that support the nursery areas to adjacent regional populations (Fowler 2016).

Fishery

Snapper is an iconic fishery resource in each mainland State of Australia (Kailola et al. 2003). Throughout the mid-2000s, SA was the dominant State-based contributor to the national total catches of both the commercial and recreational sectors (Fowler et al. 2016a). 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 region, although the highest abundances have generally been in Spencer Gulf (SG) or Gulf St. Vincent (GSV), which have consequently produced the highest fishery catches (Fowler et al. 2020).

Snapper is a primary target species of the commercial and recreational sectors of SA (PIRSA 2013). Licence 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). The main gear types used to target Snapper by commercial fishers are handlines and longlines, since using hauling nets to take Snapper was prohibited in 1993. For local recreational fishers and others from inter-state, Snapper has been an important species in SA's waters because of their desire to catch the large trophy fish (Fowler et al. 2016a). Such recreational fishers target Snapper using rods and lines, primarily from boats, although jetty and land-based catches do occur. Based on the most recent recreational fishing survey in 2013/14, the contributions to total catch by the commercial and recreational sectors were 62% and 38%, respectively (Giri and Hall 2015, Fowler et al. 2016a).

The spatial structure of SA's Snapper fishery underwent considerable change between 2008 and 2012 (Fowler et al. 2016a). Historically, SG supported the highest catches and CPUE. However, these have declined considerably, whilst contemporaneously those in NGSV and the SE increased to unprecedented levels (Steer et al. 2018a, b). For the three different stocks these changes reflected different, independent demographic processes that related to recruitment and adult migration (Fowler 2016, Fowler et al. 2017). From 2011 onwards, the changes in the spatial structure of the fishery and stock status have caused considerable issues for managing the fishery. This resulted in numerous management changes that were implemented to limit commercial catches and to maximise the opportunities for spawning and recruitment success. Furthermore, several FRDC-funded research projects were undertaken to firstly identify the demographic processes responsible for the observed spatial changes (FRDC 2012/020, Fowler 2016), and also to develop a fishery independent index of fishable biomass (FRDC 2014/019, Steer et al. 2017).

Management Regulations

In the text below there is a description of the broad approach and the historical changes to the management protocols for the commercial, recreational and charter boat sectors of the Snapper fishery. Nevertheless, since 1st November 2019, these protocols have been superseded by the following significant spatial closures to Snapper fishing in SA's waters:

- a total Snapper fishing closure for the waters of the west coast of Eyre Peninsula, Spencer Gulf and Gulf St. Vincent until January 2023;
- an annual closure in the waters of the SE Region, to be applied from 1st November until 31st January each year until 2023. For the remainder of each year, this region will be open to fishing although a total allowable catch will apply, to be shared amongst the commercial, recreational and charter boat sectors.

The spatial closures that were imposed in November 2019 reflect the poor statuses that were assigned to the SG/WCS and the GSVS in the stock assessment undertaken in that year (Fowler et al. 2019). Their purpose is to return these Snapper fisheries to sustainable stock levels. Particularly for the SG/WCS, the 'depleted' status is the culmination of a deterioration in stock status since 2011 (Fowler et al. 2013, 2016, 2019). From then until late 2019, the management strategy was modified numerous times, attempting to redress the deteriorating stock status. Nevertheless, the strategies adopted did not result in recovery of the stock.

Prior to the fishery closures that were imposed in November 2019, regulations for the commercial sector of SA's Snapper fishery involved a suite of input and output controls (PIRSA 2013, 2014). Since 2012, there have been numerous changes to the regulations relating to these input and output controls. 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 38 cm 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. Commercial handline fishers are limited with respect to the numbers of lines and hooks per line that they can legitimately use. With respect to the use of longlines, from December 2012, the number of hooks that could be used was reduced from 400 to 200 in SG and GSV, but remained at 400 for other regions. Also, in 2012 a daily commercial catch limit of 500 kg was introduced for all South Australian waters. In December 2016, this was further reduced due to on-going concerns about the statuses of the different stocks (Fowler et al. 2016a). For the SG/WCS, it was reduced to 200 kg with a limit of two days per trip. For GSV, the daily trip limit was reduced to 350 kg with a trip limit of two days. For the SE Region, the daily trip limit was also reduced to 350 kg, with a five-day trip limit. There is also a 50 kg by-catch trip limit for the Commonwealth-managed Southern and Eastern Scalefish and Shark Fishery.

For the recreational sector, the minimum legal length of 38 cm 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 the spatial structure of the fishery and the classifications of stock status (Fowler 2016, Fowler et al. 2016a). Until that time, the bag and boat limits had differed geographically. However, since 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 38 - 60 cm TL, and bag limit of 2 fish and boat limit of 6 fish for fish >60 cm TL, now apply for all State waters. For the Charter Boat sector, from December 2018, the individual bag limit for Snapper was reduced to three small fish (38-60 cm TL) and one large fish (>60 cm TL), with no boat limit.

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 for all fishing sectors was extended for several weeks until 15th December. 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 Snapper in these areas for most of the reproductive season. The four spatial closures in NSG and one in NGSV were circular in shape with a 4-km radius from a fixed point. In December 2018, the spawning spatial closure in NGSV was removed and replaced with two new closures located in the southern gulf at Tapley Shoal and Sellicks Beach. These closures were extended to the 31st March 2019. For SG, a new closure at Point Lowly was added to the existing four closures.

Commercial Fishery Statistics

State-wide

Estimates of total State-wide commercial catch of Snapper show cyclical variation, with the cycles typically encompassing a number of years (Figure 4-1). Since 2003, State-wide catch increased to a record level of 1,035 t in 2010, before declining by 75.7% to 252 t in 2019, the 2nd lowest recorded. Historically, handlines (HL) were the most significant gear type, whose catches largely accounted for the cyclical variation in total catch until 2008. The proportional contribution of longlines (LL) to total catch increased considerably between 2005 and 2010, becoming the dominant gear type. Both HL and LL catches have declined considerably since 2010.

Between the mid-1980s and 2008 there was a long-term, gradual declining trend in total commercial fishing effort that produced catches of Snapper (Figure 4-1). This was followed by a period of elevated fishing effort between 2009 and 2012 that related to the increase in LL effort. However, since 2010, LL effort has declined, complementing the on-going declining trend in HL effort since 2002. As such, the total fishing effort of 4,336 fisher-days in 2019 was the lowest recorded since 1984. State-wide HL CPUE showed cyclical variation, superimposed on a long-term increasing trend. However, since 2007 it has decreased considerably, concomitant with the emerging dominance of LL fishing. In contrast, LL CPUE increased considerably between 2004 and 2015, before declining in each year between 2016 and 2019.

The total 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 declining from 260 in 2010 to 163 fishers in 2019. The numbers who targeted Snapper varied similarly and fell from 201 in 2009 to 121 in 2019.

In 2019, the commercial catch was dominated by the MSF which contributed 97.7% of the total (Figure 4-2). The SZRLF accounted for most of the remaining catch. Catches by Commonwealth fishers were small in 2019 (<2%).

Regional

The relative contributions of the three stocks to total State-wide annual catches have changed considerably over time particularly with respect to significant change in the spatial structure of the fishery that occurred between 2008 and 2012 (Figure 4-2a). The SG/WCS provided the highest annual catches up to 2009, after which they declined and fell to their lowest levels between 2012 and 2019 (Figure 4-2b). The catches from the GSVS were generally very low until around 2004 after which they 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 2019. The catches from the South East region also increased dramatically between 2007 and 2010, before declining back to a low level in 2017. They increased marginally in 2018 and in 2019.

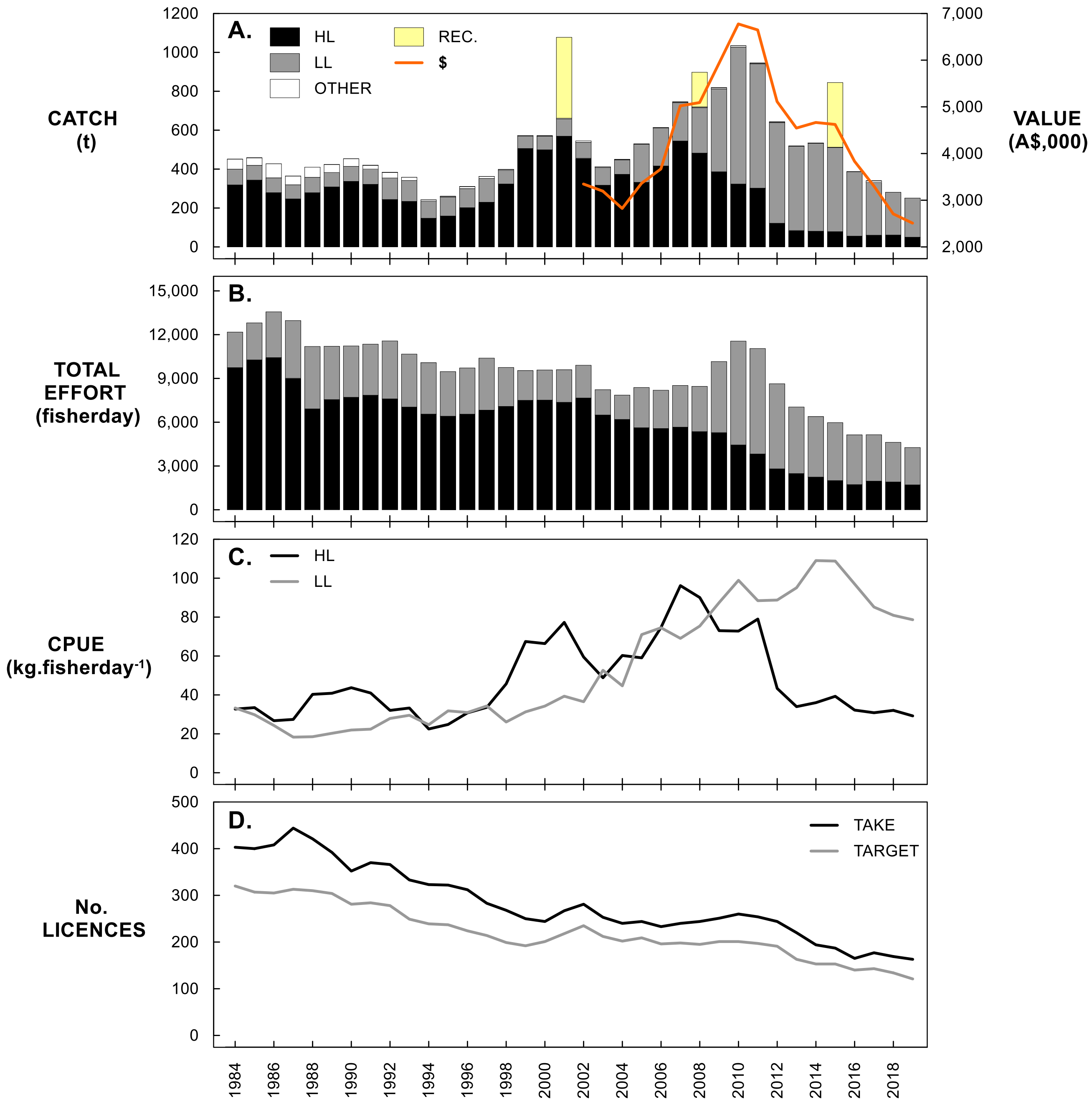

Figure 4-1. Snapper. Long-term trends in: (A) total catch of the main gear types (handlines and longlines) and gross production value; (B) total effort for handlines and longlines; (C) total catch per unit effort (CPUE) for handlines and longlines; and (D) the number of active licence holders taking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

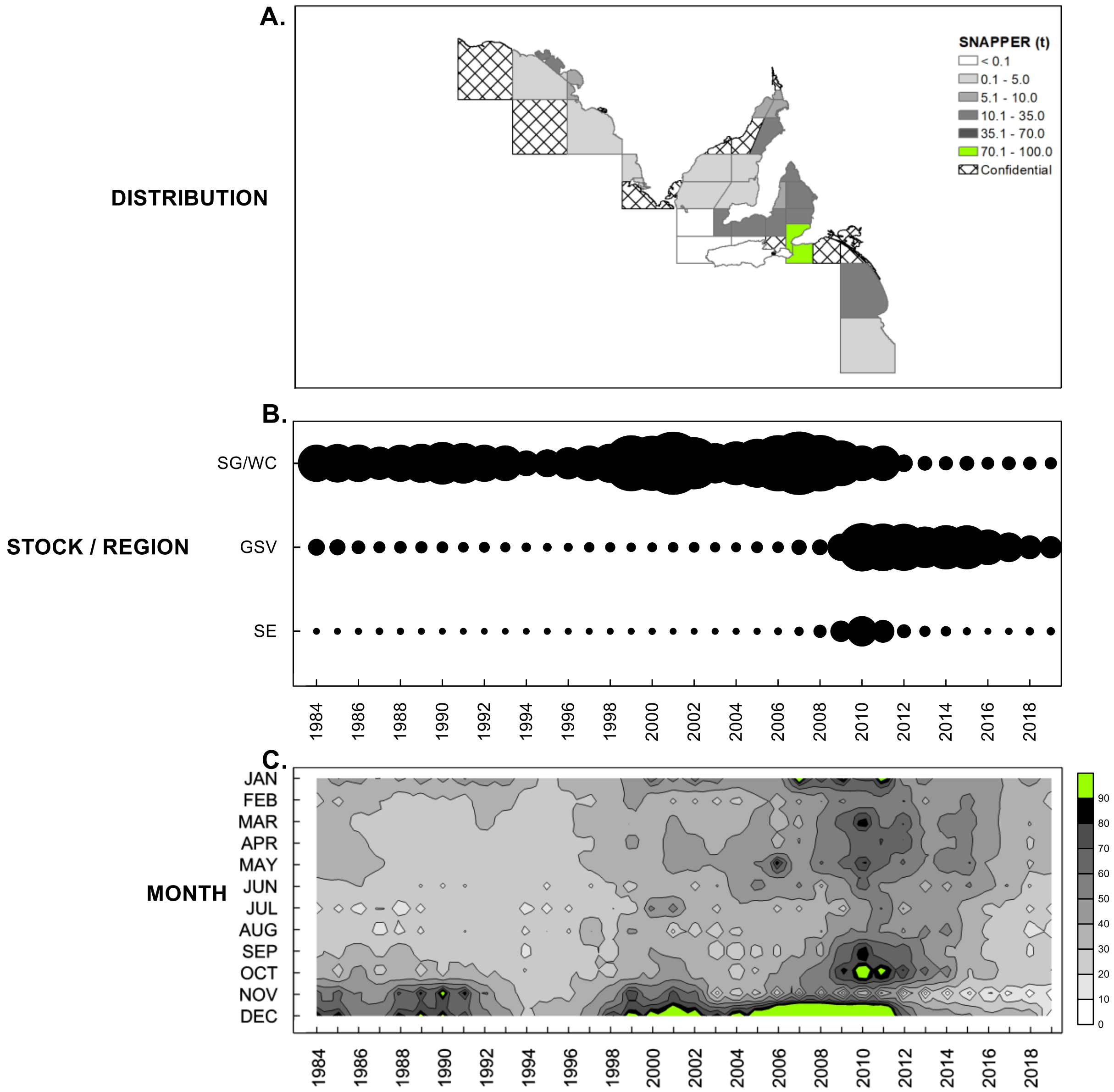

Figure 4-2. Snapper. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among biological stocks, (C) months of the year.

Spencer Gulf/ West Coast Stock

Annual catches from the SG/WCS have varied cyclically with peaks in 1990, 2001 and 2007. The latter year produced the highest catch of 618.3 t (Figure 4-3). From 2007 to 2012, annual catches fell considerably, and have subsequently remained relatively stable at a low level. In 2019, the lowest recorded catch from this stock of 61.7 t was taken.

Targeted HL catches have varied over time. The highest of 516.4 t was taken in 2001, which has since fallen to the lowest of only 26.1 t in 2019 (Figure 4-3). Targeted HL effort increased between 1984 and 2002 to the highest level of 5,142 fisher-days. Since then, it has declined to the lowest level of 459 fisher-days in 2019. Targeted HL CPUE has varied cyclically, but showed a long-term increasing trend to 2011, which peaked in 2007 at 138.1 kg.fisher-day^{-1}, but in 2012 declined steeply to 63.8 kg.fisher-day^{-1}, before dropping to 48.1 kg.fisher-day^{-1} by 2018. It increased marginally to 56.8 kg.fisher-day^{-1} in 2019. The numbers of licence holders who took and targeted Snapper with HLs declined slowly through the 1980s and 1990s but the rates of decline increased through the 2000s. Those taking Snapper with HLs fell from 219 in 1985 to 92 in 2019, and those targeting fell from 177 to 50 over the same period. Between 2004 and 2011, the number of reported daily HL catches (between February and October) declined considerably and from 2012 to 2019 have been relatively low, i.e. generally <400 catches.yr^{-1}. The estimates of Prop200kgHLTar (proportion of daily catches that exceed 200kg) have been variable from year-to-year generally ranging from 0.1 to 0.25, but show no long-term trend (Fowler et al. 2020).

From 1984 to 2004, targeted LL catch for the SG/WCS was relatively flat before it increased and peaked at 154.2 t in 2006, before declining again (Figure 4-3). By 2019, it had fallen to 22.9 t, the 2nd lowest amount. Since targeted LL effort peaked at 2,578 fisher-days in 1997, it has declined considerably. From 2014 to 2018, it was relatively flat and then declined to the lowest level of 523 fisher-days in 2019. Between 2005 and 2008, targeted LL CPUE peaked, with the highest at 98.7 kg.fisher-day^{-1} in 2006. From 2008, it fell considerably and by 2014 had dropped to 33.7 kg.fisher-day^{-1}. Subsequently it increased to 52.8 kg.fisher-day^{-1} in 2018, but fell again to 43.9 kg.fisher-day^{-1} in 2019. Since 1988, the numbers of license holders taking Snapper fell from 118 to 40 and those targeting it fell from 100 to 32 (Figure 4-3). The numbers of reported daily LL catches fell between 2006 and 2011 and have subsequently remained at the relatively low level of <500 catches.yr^{-1}. The annual estimates of Prop200kgLLTar declined to approximately 0.1 in 2011 and have since remained around this low level.

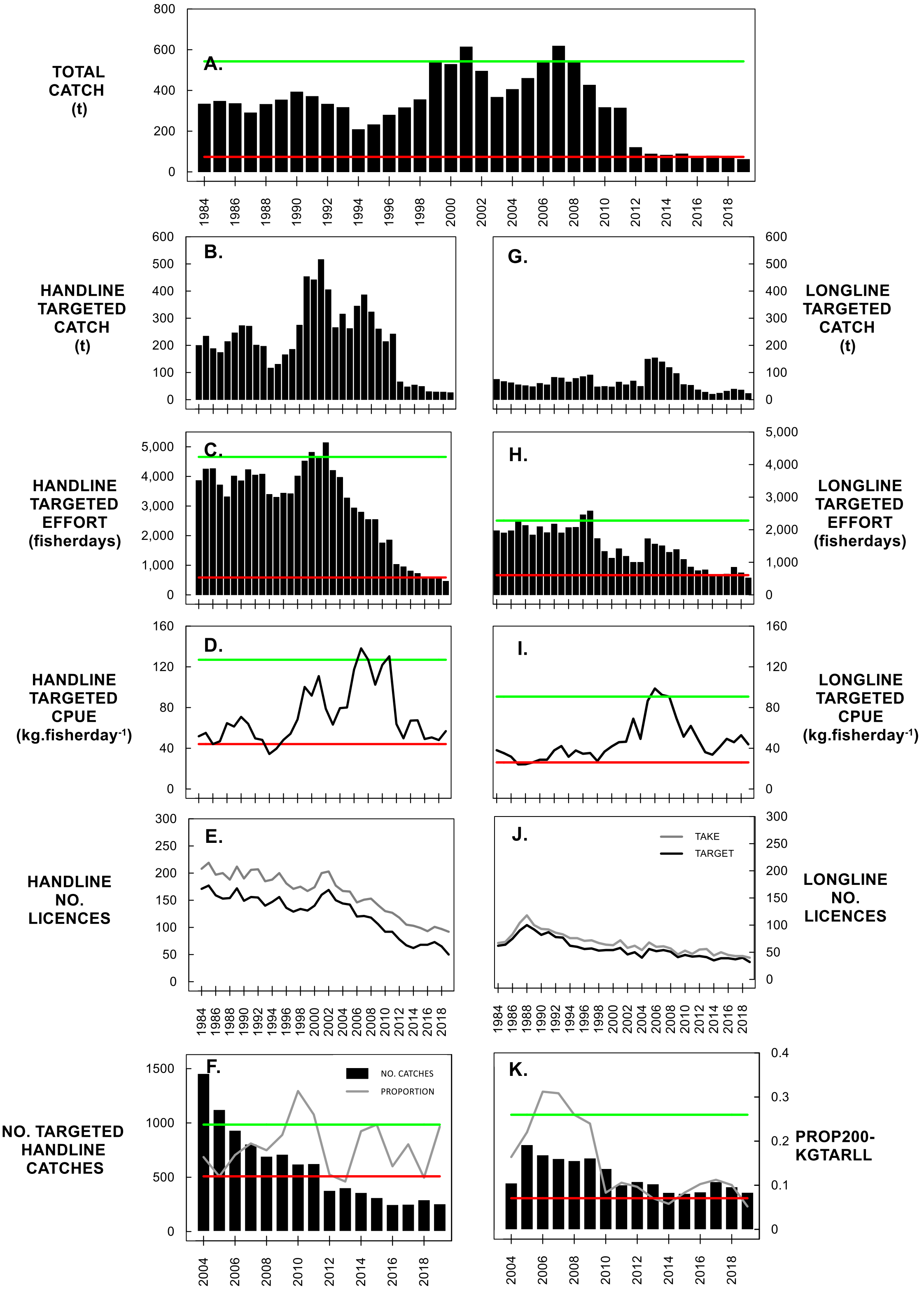

Figure 4-3. Key fishery statistics used to inform the status of the Spencer Gulf/ West Coast Stock of Snapper. Long-term trends in (A) total catch. (Left) trends in (B) targeted handline catch; (C), effort, (D) catch rate; and (E) the number of active licence holders taking and targeting the species; (F) number of targeted daily catches and Prop200kgTarHL. (Right) trends in (G) targeted longline catch; (H), effort, (I) catch rate; and (J) the number of active licence holders taking and targeting the species; (K) number of targeted daily catches and Prop200kgTarLL. Green and red lines represent the upper and lower reference points identified in Table 4-3.

Gulf St. Vincent Stock

Between 1984 and 2006, the GSVS produced relatively low catches (Figure 4-4). However, from 2006 to 2010, total catch increased exponentially culminating in the record catch of 454.1 t. Total catch declined marginally between 2010 and 2015 after which the rate of decline increased. In 2019, total catch was 171.4 t, i.e. 37.7% of the record level, and the lowest since 2008.

Targeted HL catch has generally been low for this stock despite the high effort levels during the early 1980s (Figure 4-4). Targeted effort declined to a low level in 1995 and has since remained low but has varied cyclically. Estimates of annual targeted HL CPUE were low until 2006, before they increased to the highest levels between 2007 and 2013. It has subsequently decreased to a moderate level, with 34.6 kg.fisher-day^{-1} recorded in 2019. The numbers of handline license holders fell considerably through the 1980s and 1990s. The number that reported taking Snapper in 1984 was 96, which fell to 41 in 2019. Similarly, the number who targeted Snapper fell from 89 to 28. The numbers of reported daily handline catches have generally been <300.yr^{-1} since 2004. The estimates of Prop200kgTarHL were <0.2 between 2007 and 2010, but since 2014 have been low at <0.1.

The LL fishery for the GSVS largely accounted for the recent rapid increase in total catches. Between 2008 and 2015, targeted LL catch increased from 46.7 t to 388.2 t (Figure 4-4). This increase was associated with a 334.1% increase in targeted longline fishing effort from 657 to 2,852 fisher-days. Nevertheless, targeted fishing effort declined between 2016 and 2019 from 2,558 to 1,487 fisher-days. Between 2000 and 2010, LL CPUE increased considerably, peaking at 145.7 kg.fisher-day^{-1}. Since 2015, it has declined consistently to 100.4 kg.fisher-day^{-1} in 2019. The numbers of LL license holders who took and targeted Snapper peaked in 2012 at 66 and 64, respectively and have since declined considerably to 29 and 28 in 2019. The numbers of daily longline catches increased from 2007, peaked in 2012 at 1,448 catches and then declined considerably between 2016 and 2019 to 693 catches. The Prop200kgTarLL was low from 2004 to 2008 but then increased up to 0.57 in 2014. Since then there has been a general decline to 0.43 in 2019.

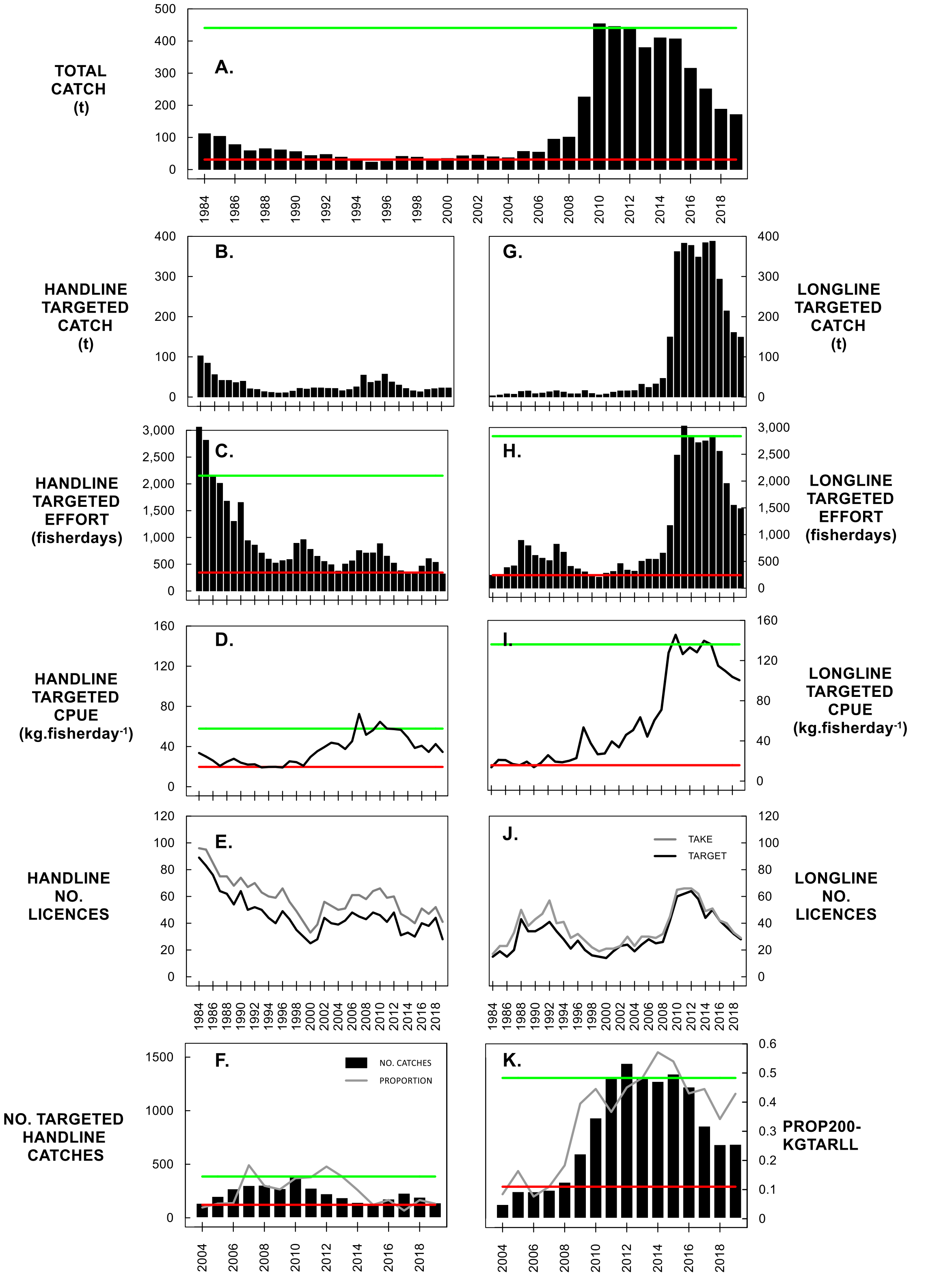

Figure 4-4. Key fishery statistics used to inform the status of the Gulf St. Vincent Stock of Snapper. Long-term trends in (A) total catch. (Left) trends in (B) targeted handline catch; (C), effort, (D) catch rate; and (E) the number of active licence holders taking and targeting the species; (F) number of targeted catches and Prop200kgTarHL. (Right) trends in (G) targeted longline catch; (H), effort, (I) catch rate; and (J) the number of active licence holders taking and targeting the species; (K) number of targeted catches and Prop200kgTarLL. Green and red lines represent the upper and lower reference points identified in Table 4-3.

South East Regional Population

The SE region has generally produced low catches of Snapper (Figure 4-5). However, from 2006 to 2010 there was an exponential increase in catch that peaked in 2010 at 260.9 t. It then fell consistently and in 2016 was only 3.5 t. It has since increased to 19.1 t in 2018 and 18.4 t in 2019.

Targeted HL catch in the SE has always been low. There was an increase between 2006 and 2009, which peaked in 2007 at 12.4 t, but which has subsequently declined (Figure 4-5). Such catches reflect low but variable fishing effort, which peaked at 316 fisher-days in 2007. Up to 2003, targeted HL CPUE was generally <20 kg.fisher-day^{-1}. It then increased to its highest levels from 2006 to 2009, peaking at 68.6 kg.fisher-day^{-1} in 2008. From then, HL CPUE declined to the lowest level in 2017 before increasing sharply in 2019. The numbers of HL fishers who took and targeted Snapper peaked in 2009, at 16 and 13, respectively. They have subsequently declined and were at seven and six fishers, respectively in 2019. Since 2004, the numbers of reported daily catches have been consistently low having declined from a peak of 93 catches in 2007 to only seven catches in 2019. Prop200kgTarHL was highest from 2006 to 2009, but subsequently has generally been zero.

Up to 2007, targeted LL catches were generally less than one tonne.yr^{-1}. After this, there was a rapid increase to the maximum level of 239.2 t in 2010 (Figure 4-5). It then declined to 9.0 t in 2017 before increasing to 18.6 t in 2018 and then to 16.6 t in 2019. There was a considerable increase in targeted LL effort that peaked in 2010 at 2,614 fisher-days. This subsequently declined to only 162 fisher-days in 2017 but has increased marginally to 203 fisher-days in 2019. Targeted LL CPUE also increased considerably between 2007 and 2010, peaking at 91.5 kg.fisher-day^{-1}. Since then it has been variable, but shown no long-term trend. The numbers of LL fishers who took and targeted Snapper increased dramatically from 2005 and peaked in 2010 at 35 and 27, respectively. They declined to 11 and 10 in 2019. The reported numbers of daily catches increased from 2007, peaked in 2010 at 699 catches and subsequently declined to a minimum of 43 in 2016, before increasing marginally in 2017, 2018 and 2019. Prop200kgTarLL also peaked in 2010 at 0.52 and declined to 0.02 in 2016. It has risen again to 0.28 in 2018 and 0.44 in 2019.

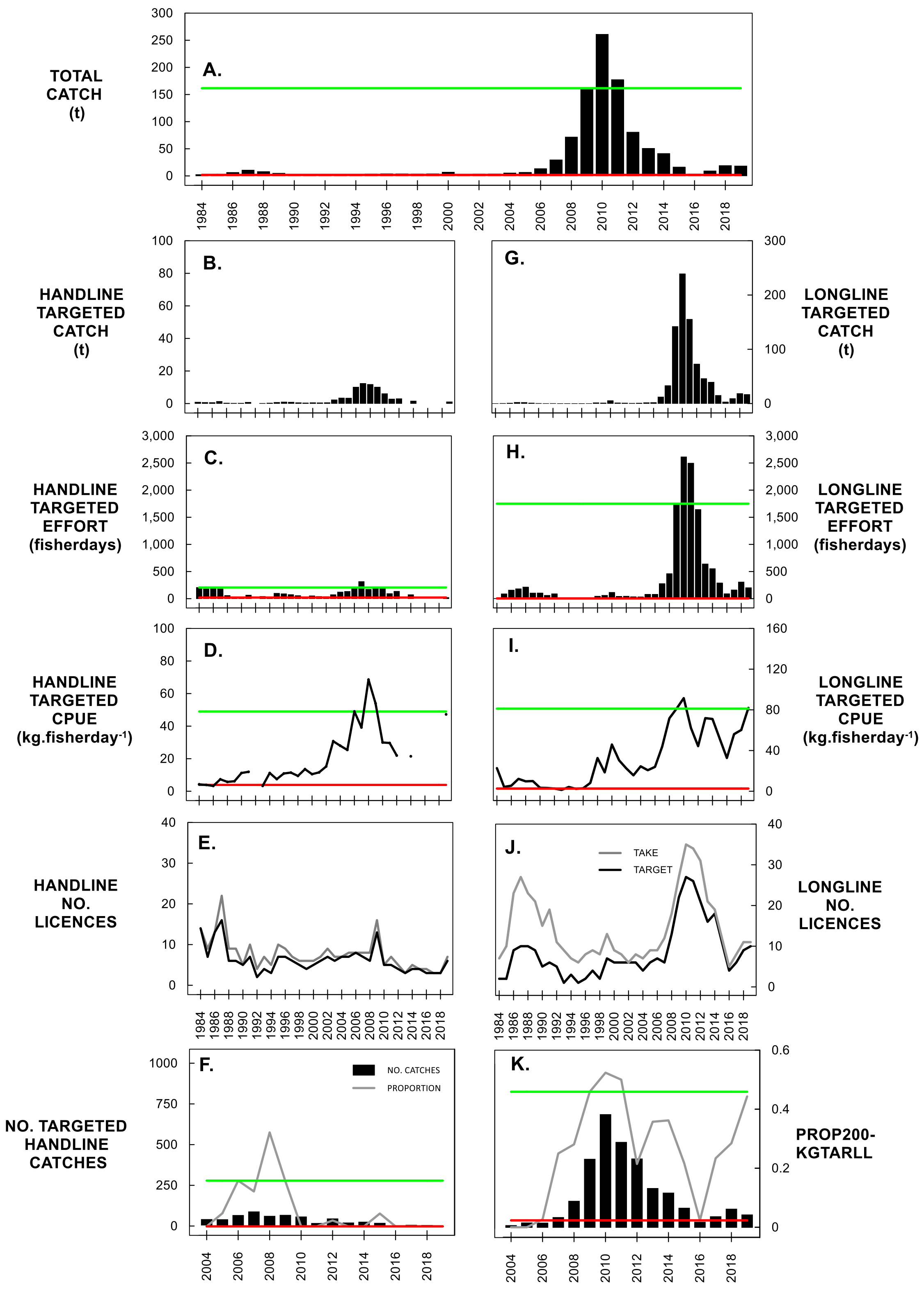

Figure 4-5. Key fishery statistics used to inform the status of the South East regional population of Snapper. Long-term trends in (A) total catch. (Left) trends in (B) targeted handline catch; (C), effort, (D) catch rate; and (E) the number of active licence holders taking and targeting the species; (F) number of targeted catches and Prop200kgTarHL. (Right) trends in (G) targeted longline catch; (H), effort, (I) catch rate; and (J) the number of active licence holders taking and targeting the species; (K) number of targeted catches and Prop200kgTarLL. Green and red lines represent the upper and lower reference points identified in Table 4-3.

Fishery Performance

The proportions of the total commercial catches taken by the different commercial fisheries are presented for each year from 2015 to 2019 in Table 4-2. For 2019, the relative catches from the four fisheries in 2019 were compared against their allocations using Triggers 2 & 3 as reference points (Table 4-2). No trigger reference point was exceeded.

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. Green colour – allocation not exceeded, red colour – allocation trigger activated.

	MSF	SZRLF	NZRLF	LCF
Commercial allocation	*97.5*	*1.78*	*0.68*	*0.04*
Trigger 2 (%)	*na*	*2.68*	*1.3*	*0.75*
Trigger 3 (%)	*na*	*3.58*	*2.0*	*1.0*
% total 2015	99.37	0.46	0.18	0
% total 2016	99.90	0.05	0.06	0
% total 2017	98.75	1.10	0.16	0
% total 2018	96.35	3.59	0.06	0
% total 2019	97.67	2.11	0.12	0.11

The general fishery performance indicators were assessed for the SG/WCS, GSVS and the SE Region, based on the estimates for 2019. Overall, there were 11 breaches of trigger reference points (Table 4-3), although not all are considered negative breaches. For the SG/WCS, there six breaches, including for the lowest estimates of total catch, targeted HL and LL effort and Prop200kgTarLL. For the GSVS, there two breaches: for decreasing annual catches over five consecutive years; as well as for the lowest targeted HL effort yet recorded. For the SE, there were three breaches, of which several were positive indicators for the stock status. These were: the highest inter-annual increase in HL CPUE; and the 2nd highest estimate of LL CPUE. Nevertheless, the lowest estimate of Prop200kgTarHL was also recorded.

Table 4-3. Results of the assessment of fishery performance indicators against their trigger reference points for the two stocks of SG/WCS and the GSVS and the SE Region population for Snapper in 2019.

Performance Indicator	Type	Trigger Reference Point	SG/WC	GSV	SE
Total catch	G	3rd lowest/3rd highest	Lowest	×	×
		Greatest inter-annual change (±)	×	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	y	×
Targeted handline effort	G	3rd lowest/3rd highest	Lowest	Lowest	×
		Greatest inter-annual change (±)	×	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×
Targeted longline effort	G	3rd lowest/3rd highest	Lowest	×	×
		Greatest inter-annual change (±)	×	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×
Targeted handline CPUE	G	3rd lowest/3rd highest	×	×	×
		Greatest inter-annual change (±)	×	×	Highest
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×
Targeted longline CPUE	G	3rd lowest/3rd highest	×	×	2nd
		Greatest inter-annual change (±)	×	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×
Prop200kgTarHL		3rd lowest/3rd highest	3rd	×	Lowest
		Greatest inter-annual change (±)	2nd	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×
Prop200kgTarLL		3rd lowest/3rd highest	Lowest	×	×
		Greatest inter-annual change (±)	×	×	×
		Greatest 5-year trend (±)	×	×	×
		Decrease over 5 consecutive years?	×	×	×

Stock Status

A full stock assessment for Snapper where the statuses of South Australia's stocks were determined using a combination of fishery-dependent and fishery-independent data sources was undertaken in 2020 and has been published separate to this report (Fowler et al. 2020a). It included updated commercial fishery statistics as well as population size and age structures. Furthermore, it reported on results of all DEPM surveys undertaken since 2013 including those done in December 2019 and January 2020. Also, for this stock assessment, the fishery model SnapEst was upgraded and run for the first time at the scale of biological stock for the SG/WCS and the GSVS and at the regional scale for the SE Region. For each, the model integrated all available data sources and generated time series of fishery performance indicators that were interpreted as fishery performance indicators (Fowler et al. 2020a).

Spencer Gulf / West Coast Stock (SG/WCS)

For this stock there were several independent sets of data that indicated that the fishable biomass was low (Fowler et al. 2020a). In 2019, the estimates of commercial catch, effort and CPUE remained at historically low values. The age structures from commercial market sampling suggested that the regional population in NSG was severely truncated and provided no evidence of recent recruitment of any new strong year classes. These observations were consistent with this population being recruitment-impaired. The results from the Daily Egg Production Method (DEPM) undertaken in 2018 and 2019 suggested that the spawning biomass declined from the low level in 2013, for which it is now apparent that the spawning biomass was already compromised.

The outputs of fishery performance indicators from the SnapEst model suggested that the fishable biomass of the SG/WCS declined by 91% between 2005 and 2020, to the lowest estimated level. Model outputs indicated that the decline in fishable biomass related to poor recruitment throughout the 2000s, as well as increasing harvest fractions caused by the continuation of fishing of a depleted stock. The model outputs also showed that egg production was very low. The evidence indicated that the harvestable biomass of the SG/WCS was likely to be depleted and that recruitment was likely to be impaired. Consequently, at the end of 2019, the SG/WCS was classified as **depleted** under the NFSRF (Fowler et al. 2020a). This status was unchanged from that in 2017 and 2018.

Gulf St. Vincent Stock (GSVS)

The commercial fishery statistics for the GSVS, particularly for the LL sector, increased to unprecedented levels between 2007 and 2010, and then remained near these high levels until 2015. However, since then, there have been substantial declines in total catch, targeted LL catch, effort, CPUE, the number of LL fishers targeting and taking Snapper, the number of their reported daily catches, and Prop200kgTarLL. Two reference points for general performance indicators were negatively triggered. These trends in the fishery statistics are first of all consistent with an increase in biomass until around 2015, followed by a rapid decline. The fishery-independent estimates of spawning biomass from applications of the DEPM in 2014, 2018 and 2020 confirm the decline in biomass.

Estimates of outputs from SnapEst show fishable biomass increased from low levels in the 1990s to a record level in 2011, before declining by 90% between 2011 and 2020 to the lowest recorded value. The increase in biomass through the 2000s reflected recruitment of numerous strong year classes to the population. The subsequent reduction related to relatively poor recruitment from 2009 to 2017, when catches remained high and harvest fractions increased.

In 2019, the status of the GSVS was changed from ‘sustainable’ to ‘depleting’ (Fowler et al. 2019). This reflected the decline in spawning biomass estimated from DEPM surveys that had occurred since 2014, poor recruitment since 2009, and persistent high targeted fishery catch and effort. The evidence in 2020 demonstrates ongoing deterioration of this stock: (i) commercial fishery statistics show further decline in 2019; (ii) the 2019 DEPM estimate confirmed the low level of spawning biomass; (iii) poor recruitment between 2010 and 2017, despite the moderate 2014 year class; and (iv) model-estimated fishable biomass and egg production have declined since 2011, and were at their lowest estimated levels in 2020. There is compelling evidence that the biomass and recruitment of the GSVS are at their lowest recorded levels. The fishable biomass is depleted and recruitment is likely to be impaired. Consequently, to the end of 2019, the GSVS is classified as ‘**depleted**’, reflecting a change from ‘depleting’ in 2018 (Fowler et al. 2020a).

South East Regional Population

The Snapper population in the SE Region in SA is the western extremity of the cross-jurisdictional Western Victorian Stock (Fowler 2016, Fowler et al. 2017). Which takes into consideration the fishery data from the South Australian part of the stock. This population is sustained through emigration of fish from the main nursery area, which is located in PPB, Victoria, i.e. approximately 600 km to the east. This SE region remains open to fishing (1st February – 31st October) with a TAC for 2020 of 75 t.

For this regional population, substantial increases in annual fishery catches, effort and CPUE occurred primarily between 2008 and 2012, but these have subsequently declined. Outputs from SnapEst indicate that this reflected a substantial increase in fishable biomass following recruitment of two strong year classes in PPB in 2001 and 2004 and their subsequent emigration from PPB to the SE Region (Fowler et al. 2017). However, fishable biomass has subsequently declined, due to reduced recruitment into PPB since 2004. Model-estimated fishable biomass increased slightly between 2018 and 2020, reflecting recruitment of the strong 2014 year class.

In 2016 (Hamer and Conron 2016) and 2018 (Stewardson *et al.* 2018), the WVS was classified as ‘**sustainable**’. The annual 0+ recruitment survey showed that over the 12 years to 2016, there had been six years for which recruitment was at, or above, the long-term average. Furthermore, the 2018 year class in PPB was the largest yet recorded. This evidence shows that the adult biomass is at a level sufficient to ensure that, on average, future levels of recruitment are adequate, i.e. recruitment is not impaired, and fishing mortality is adequately controlled to avoid the stock from becoming impaired.

4.3.2. SOUTHERN GARFISH

Biology

Southern Garfish (*Hyporhamphus melanochir*) are distributed from Shark Bay in Western Australia, along the southern coast of Australia including Tasmanian waters, and as far east as Eden in New South Wales (Kailola 1993, Noell and Ye 2008). The species forms schools in sheltered bays and shallow, inshore, marine waters to depths of ~20 m. They are particularly abundant throughout the gulf regions of South Australia.

Southern Garfish have an extended spawning season that spans approximately six months from October to March. Within this season only a small proportion (10–20%) of the population are in spawning condition at any given time (Giannoni 2013) indicating that reproductive activity is asynchronous with small pulses of spawning activity. The estimated length-at-50%-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).

During the 1990s, a total of 2,079 Southern Garfish from commercial catches in South Australia were aged for a study on age and growth (Ye et al. 2002). There were seven age classes (0+ to 6+ years) that contributed to the commercial catches; 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+ year olds, but the age structure has become considerably truncated to consist of primarily one- and two-year-olds (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, 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 requiring them to be considered 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 restructure the historical management framework of two discrete, gulf-specific, stocks to a structure of five smaller, semi-discrete, regional units.

Fishery

Southern Garfish is a significant inshore fishery species of southern Australia, with fisheries also existing 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 M (Econsearch 2020). 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. These are the Marine Scalefish Fishery, Northern Zone Rock Lobster Fishery and Southern Zone Rock Lobster Fishery. The Southern Garfish fishery is principally located in Spencer Gulf and Gulf St. Vincent 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 (Steer et. al. 2015).

In 2001, the legal minimum length (LML) for Southern Garfish was increased from 210 mm to 230 mm 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 strategy 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 was subsequently increased to 38 days in 2013, 40 days in 2014, 60 days in 2016, 80 days in 2018, and 80 days in 2019 for Gulf St. Vincent. 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 190 t in 2019 (*c.f.* 176 t in 2018) (Figure 4-6a). The 2019 season was the fifth consecutive year with total catches below 200 t. The economic value of the commercial catch of Southern Garfish in 2019 was approximately $ 1.8 M (*c.f.* $ 1.7 M in 2018) (Figure 4-6a).

The hauling net sector has accounted for ~90% of the State-wide harvest since 1984 (Figure 4-6a). Catches in this sector varied between 325 t and 500 t from 1984 to 2002, averaging

413 t.yr^{-1}, before declining to ~131 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 4-6a), and was 23 t in 2019.

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 4-6b). This represents a 73% decrease over 28 years declining at a rate of 474 fisher-days.year^{-1}. This decline can largely be attributed to a consistent reduction in hauling net effort. Since then fishing effort has stabilised and maintained consistent levels of targeted effort, and was 4,726 fisher-days in 2019 (*c.f.* 4,816 fisher-days in 2018). This trend was consistent for hauling net and dabbing gear types.

CPUE of Southern Garfish 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 CPUE of the preceding decade (Figure 4-6c). Since 2014, catch rate for non-target hauling net effort has declined and averaged 34.2 kg.fisherday^{-1}, and in 2019 was 39.4 kg.fisherday^{-1}. Dab net CPUE 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 4-6c). This increase was not sustained as it dropped to 31.9 kg.fisherday^{-1} in 2007. CPUE in the dab net sector since 2014 has ranged between 37.7 and 49.5 kg.fisherday^{-1}. In 2019, the catch rate of 47.2 kg.fisherday^{-1} was ~10 kg.fisherday^{-1} higher than the previous year (*c.f.* 37.7 kg.fisherday^{-1} in 2018) and higher than the 15-year average (38.7 kg.fisherday^{-1}).

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 4-6d). 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 4-7a, b). 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 4-7c). 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 4-7c).

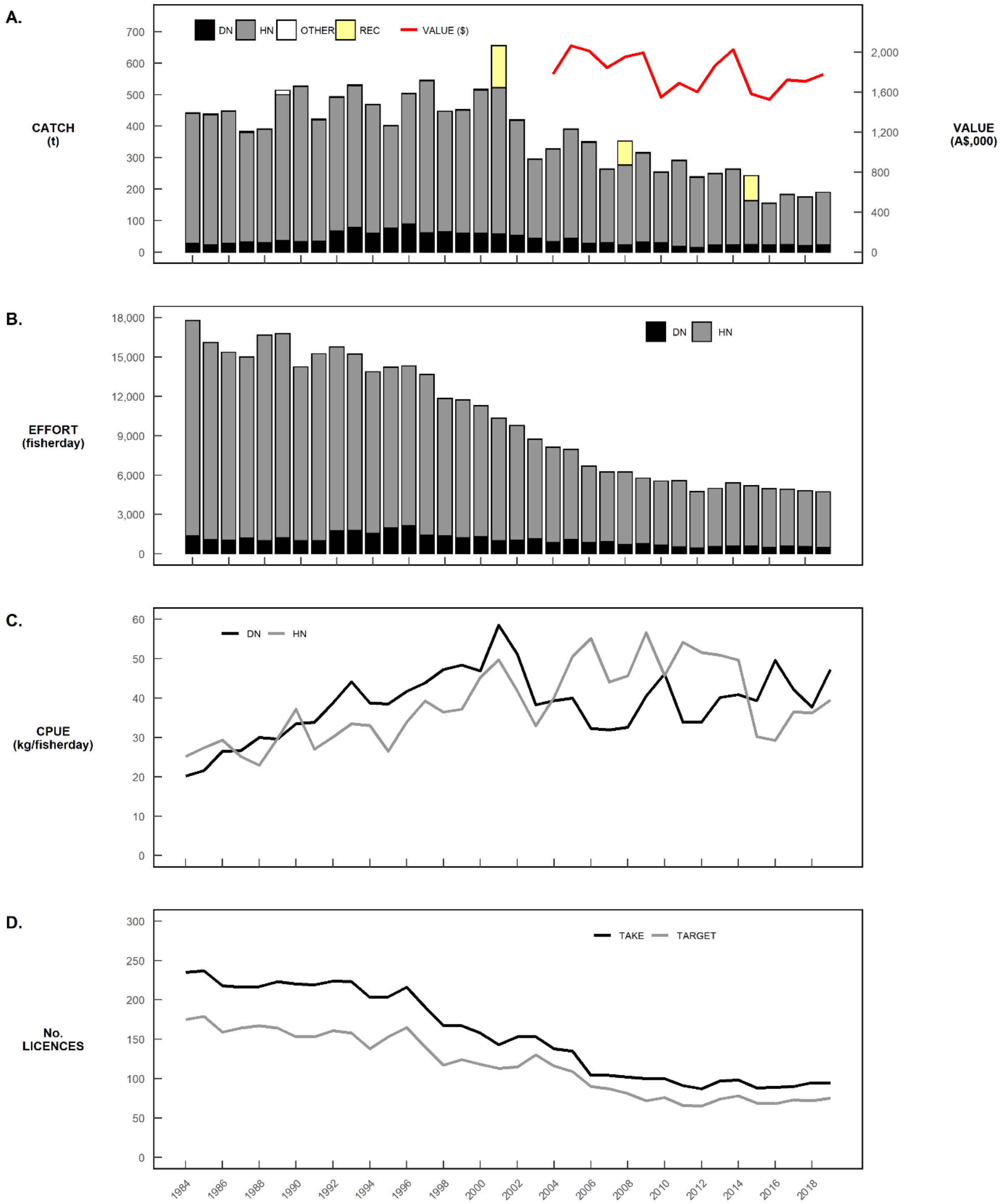

Figure 4-6. Southern Garfish. (A) Catch distribution for 2019; Long-term trends in: (B) total catch for the main gear types (hauling and dab nets) and gross production value; (C) Long-term total effort for hauling and dab nets; (D) total catch per unit effort for hauling and dab nets; and (E) the number of active licence holders taking or targeting the species.

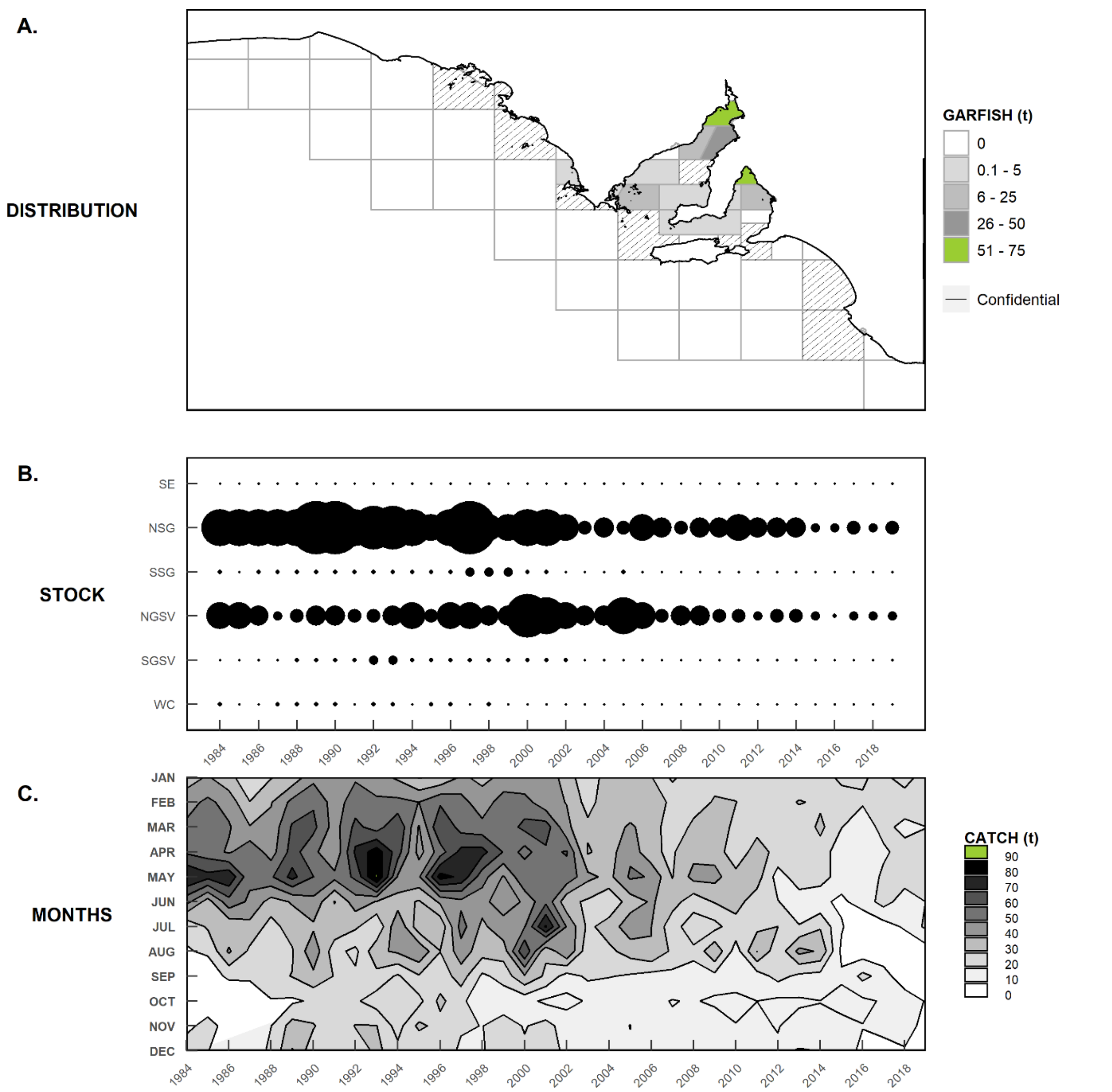

Figure 4-7. Southern Garfish. (A) The proportion of catch distributed among the commercial sector in 2019; (B) Long-term trends in the annual distribution of catch among biological stocks; and (C) months of the year.

West Coast

From 1984 to 1999, the annual commercial catch of Southern Garfish from the West Coast accounted for approximately 7% of the State's catch. This has since declined to 2 t or 1.0% of the state catch in 2019. This has been driven by a continuous reduction in hauling net effort through the implementation of commercial netting restrictions (Figure 4-8b). Annual Southern Garfish catch peaked at 37.2 t in 1992 of which hauling net sector landed 86% (Figure 4-8a). Over the past nine years, catches have remained below 5 t and fell to the equal lowest recorded level of 1.3 t in 2013 and 2018. Total fishing effort has declined 91% since 1984, with fishers expending 104 days catching Southern Garfish in 2019, which was three times the effort in 2018. Dab nets emerged as the dominant gear type in 2006, however, targeted dab net effort has reduced to 15 days in 2019 (Figure 4-8f). The targeted CPUE in the hauling net sector peaked at 77.1 kg.fisher-days^{-1} in 1999 (Figure 4-8d). Since 2005, less than five hauling net fishers have operated in this region per year (Figure 4-8e). Targeted CPUE in the dab net sector ranged from 16.7–62.2 kg.fisher-days^{-1}, with the highest peak occuring in 2018. Targeted CPUE for 2019 has declined by 43% to 35.31 kg.fisher-days^{-1} (Figure 4-8h).

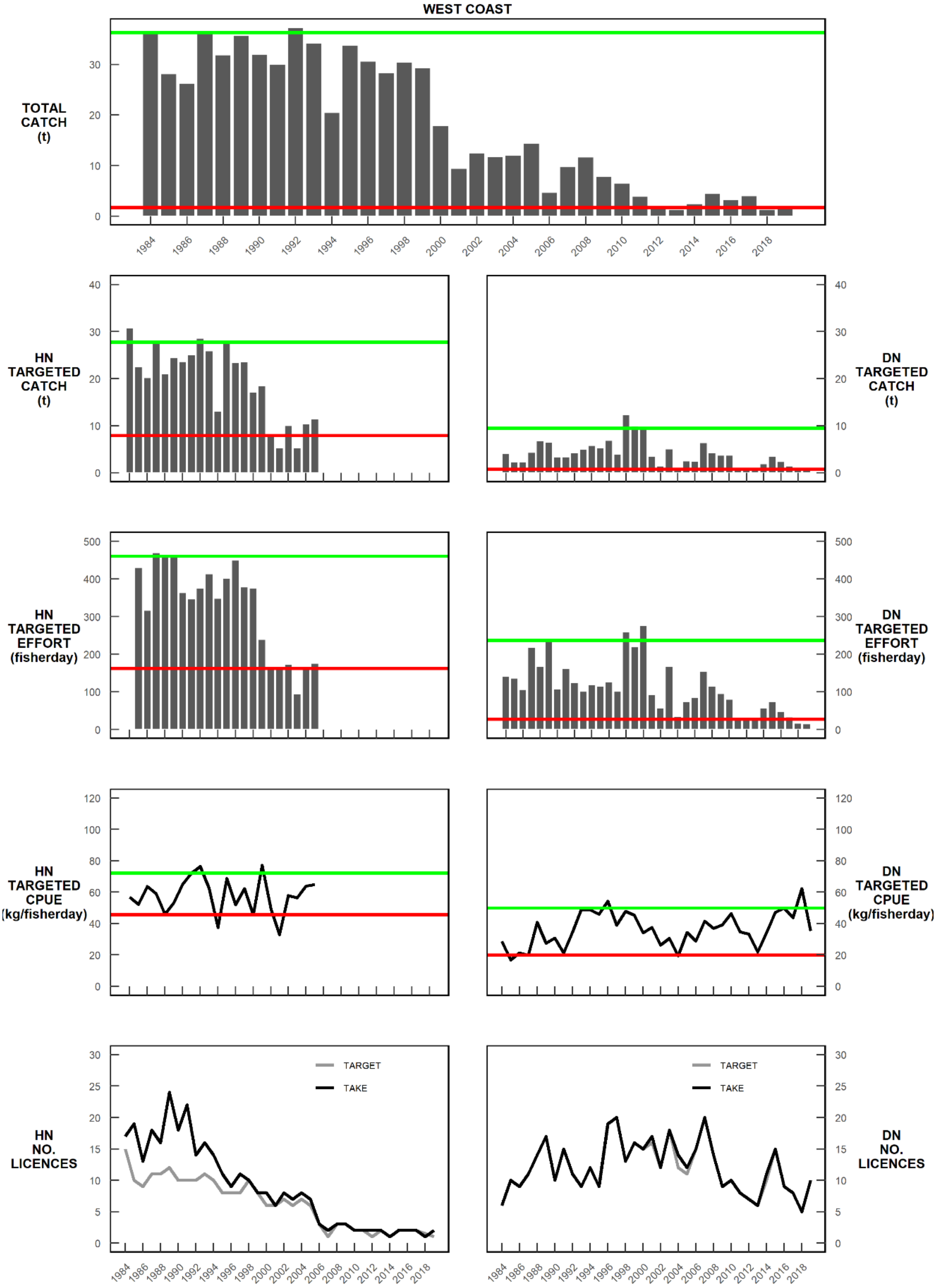

Figure 4-8. Key fishery statistics used to inform the status of the West Coast stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern 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 4-9a). 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 between 142 and 150 t from 2012 to 2014, before decreasing below 100 t from 2015 to 2018. The total catch of Garfish in northern Spencer Gulf was 101 t in 2019.

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 ~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 (Figure 4-9c). CPUE 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 (Figure 4-9d). CPUE subsequently fell from a peak in 101.8 kg.fisher-days^{-1} 2014 to 67.7 kg.fisher-days^{-1} in 2019 (Figure 4-9d). Few dab net fishers (<13) have historically targeted Southern Garfish in this region each year, catching on average 36 kg.fisherday^{-1} (Figure 4-9e).

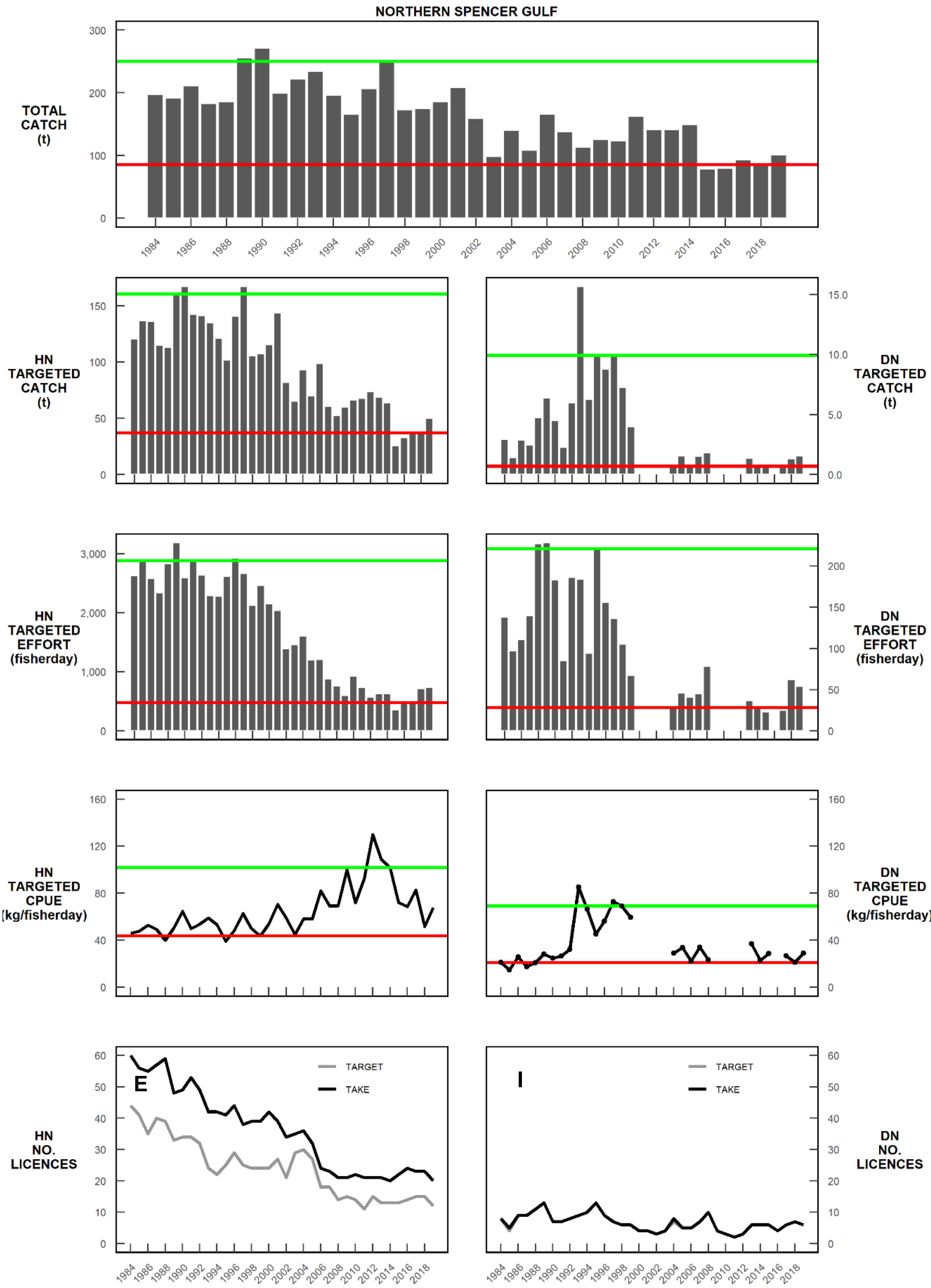

Figure 4-9. Key fishery statistics used to inform the status of the Northern Spencer Gulf stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-5

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 ~10% up to 2005 to 3% over the past decade (Figure 4-10a). Approximately half of the hauling net fishers who operated in this region specifically targeted Southern Garfish. This sector historically accounted for ~30% of the total catch of the species, which peaked at 71 t in 1998. However, it has been reduced through spatial restrictions imposed in 2005 and is now almost exclusively fished by the dab net sector.

Total catch of Southern Garfish in this region ranged between 9.3 and 12 t in the past 5 years (Figure 4-10a). Total catch was 11 t in 2019 (*c.f.* 11 t in 2018).

Targeted dab net effort remained relatively stable at ~121 fisher-days from 2011 to 2014, before increasing to reach a peak of 237 fisher-days in 2015, before declining to 174 fisher-days in 2019 (Figure 4-10f).

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 51.4 kg.fisher-days^{-1} in 2019 (Figure 4-10h).

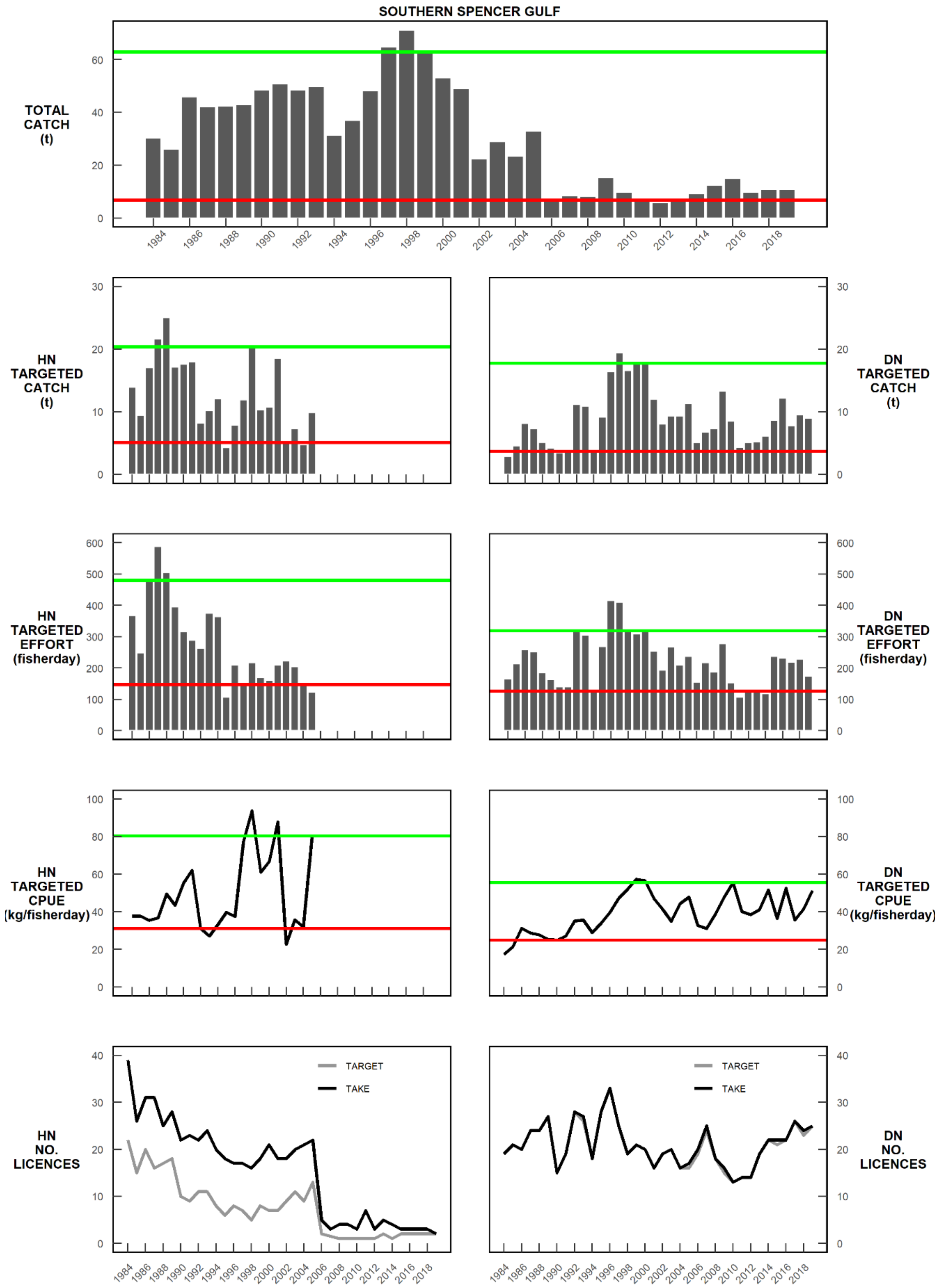

Figure 4-10. Key fishery statistics used to inform the status of the Southern Spencer Gulf stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern 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 commercial fishing region in South Australia for Garfish. Annual catches of Garfish were > 200 t twice in the past 31 years; 221 t in 2000 and 210 t in 2005, before declining to a record low of 53 t in 2016. Catches then stabilised at low levels have averaged 70 t since 2016, and was 70 t in 2019 (Figure 4-11a). This represents a 52% decline over the past 10 years, which corresponds with decreases in hauling net targeted effort, and overall declines in targeted CPUE from its peak of 110 in 2001 to 49 kg.fisher-day^{-1} in 2019 (Figure 4-11d).

Conversely, levels of annual targeted catch and effort in the dab net sector have increased and were > 5 t and 110 fisher-days over the past five years, respectively (Figures 4-11f, g). This level of dab net activity has not occurred since 2006. Targeted CPUE in this sector were 34 to 45 kg.fisher-days^{-1} between 2009 and 2018, and has increased to its second highest peak of 51.1 kg.fisher-days^{-1} in 2019 (Figure 4-11h).

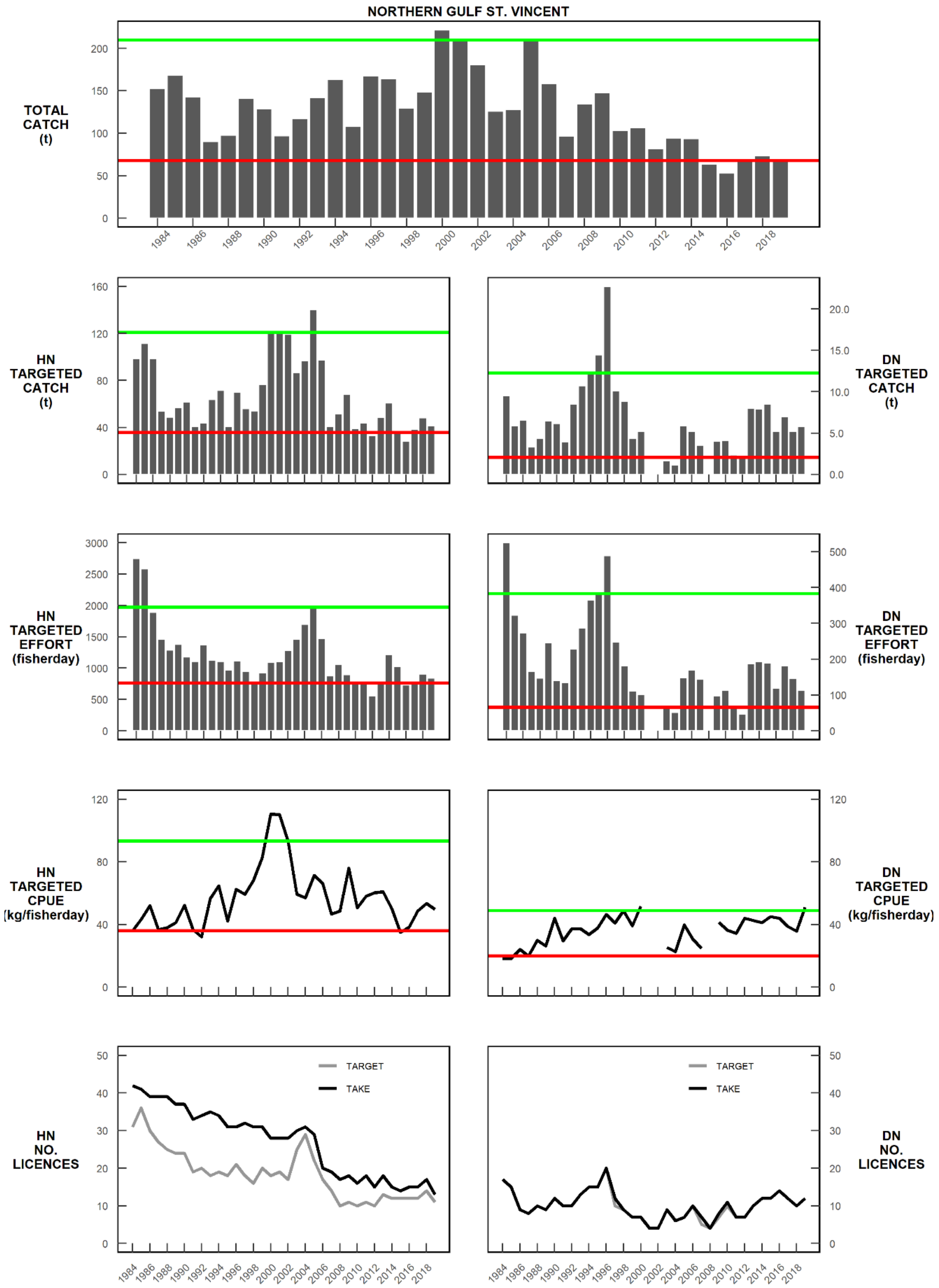

Figure 4-11. Key fishery statistics used to inform the status of the Northern Gulf St. Vincent stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern 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 4-12a). From 1993, the contribution of Southern Garfish catch by the hauling net sector declined in line with steady reductions in effort (Figure 4-12b). From 2005 onwards the dab net sector accounted for >75% of annual commercial fishing effort in Southern Gulf St. Vincent as the implementation of netting restrictions virtually removed all hauling net activity from the region. Targeted dab net effort declined from 558 fisher-days in 2005 to a record low of 39 fisher-days in both 2015 and 2016. In 2017, targeted dab net catches increased to 7 t, before decreasing to 5 t in 2019 (Figures 4-12f, g). CPUE in the dab net sector fluctuated since 1984 between 20.96 and 72.20 kg.fisher-days^{-1}, with the overall mean target dab netting CPUE for the region equalling 44.05 kg.fisher-days^{-1} (Figure 4-12h). The targeted dab net catch rate for 2019 was 58.81 kg.fisher-days^{-1} (Figure 4-12h).

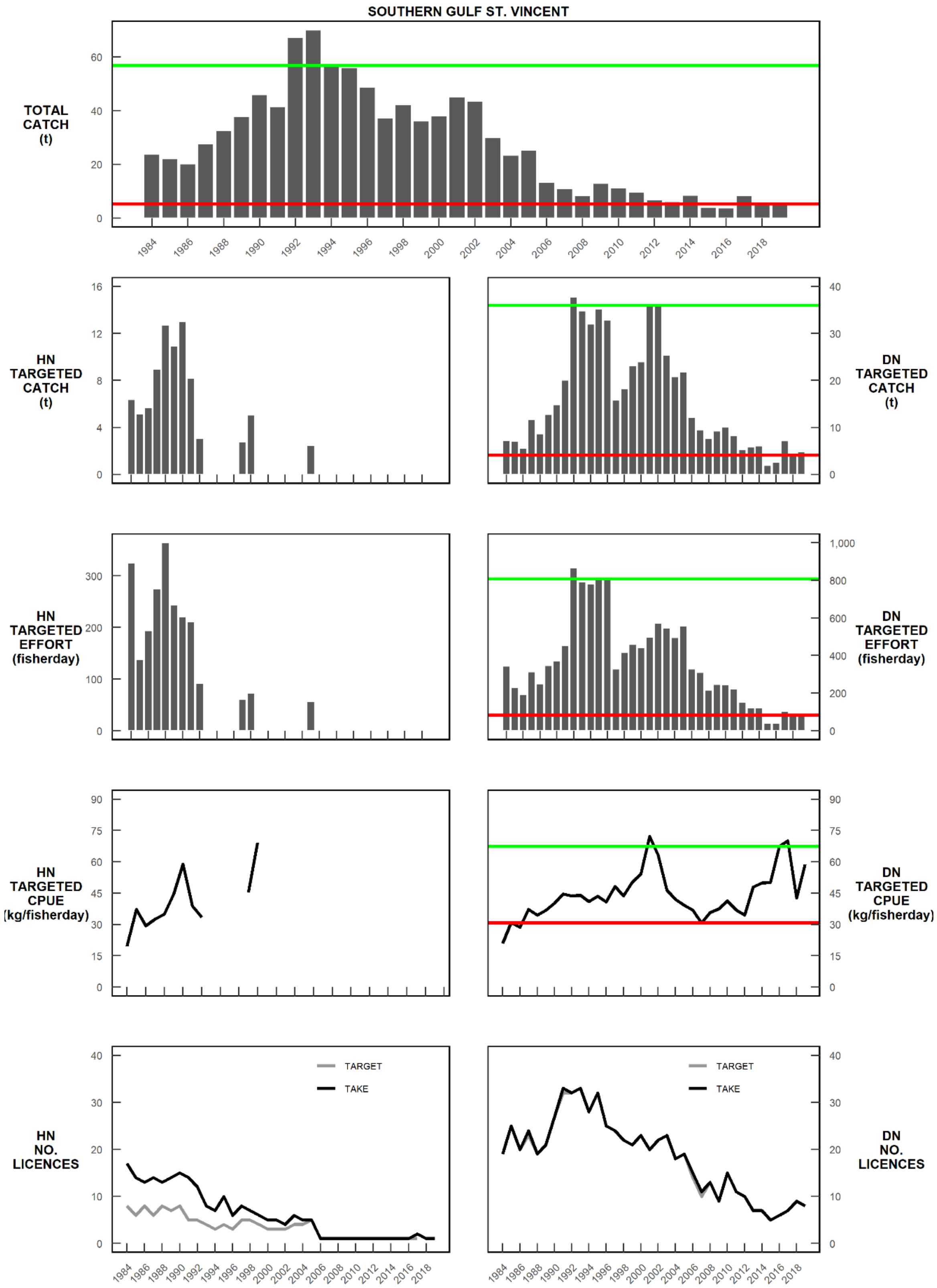

Figure 4-12. Key fishery statistics used to inform the status of the Southern Gulf St. Vincent stock of Southern Garfish. (Left) Trends in total catch, hauling net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with hauling nets. (Right) Trends in total effort; dab net targeted catch, effort and catch rates (CPUE); The number of active licence holders taking or targeting Southern Garfish with dab nets. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-5.

South East

A negligible amount of Southern Garfish is landed by the commercial sector in the South East, with only 30 t landed in the region across the 36-year time-series. Total number of fishers has been < 5 in several years, resulting in catch and effort data being confidential, this is the circumstance for 2019 (Figure 4-13).

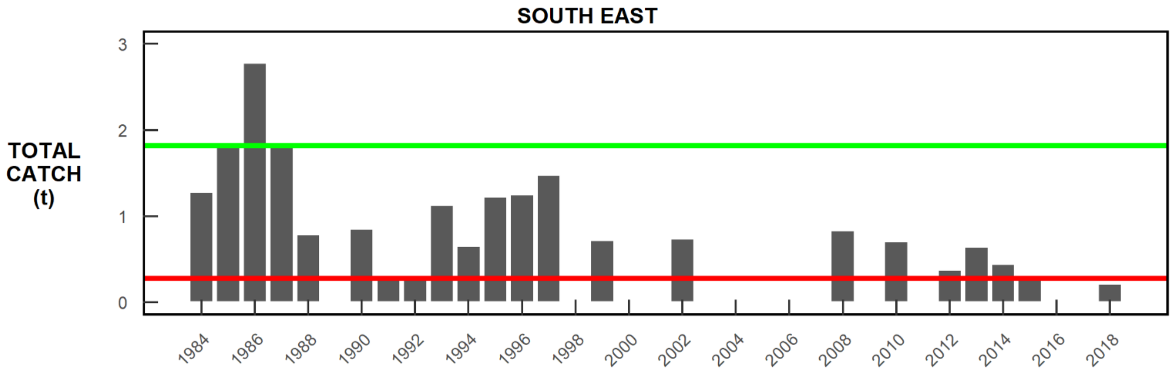

Figure 4-13. Key fishery statistics used to inform the status of the South Eastern stock of Southern Garfish. (Left) Trends in total catch; (Right) Trends in total effort. Green and red lines represent the upper and lower trigger reference points outlined in Table 4-5.

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 2019, neither Trigger 2 nor Trigger 3 was breached (Table 4-4).

The general performance indicators were assessed at the biological stock level. There were 5 breaches of trigger reference points across the six stocks (Table 4-5). In 2019, targeted dab net effort was the lowest and second lowest recorded in the WC and SGSV. Furthermore, in the WC, targeted dab net effort has declined for five consecutive years and recorded the largest annual change in targeted dab net CPUE. Northern Gulf St Vincent reached its second highest targeted dab net CPUE.

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%
2015	99.89%	0.11%	0.00%
2016	99.95%	0.03%	0.02%
2017	99.81%	0.19%	0.00%
2018	99.92%	0.08%	0.01%
2019	99.91%	0.09%	0.00%

Table 4-5. Results of 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	×	×	×	×	×	
	G	Greatest % interannual change (+/-)	×	×	×	×	×	
	G	Greatest 5 year trend	×	×	×	×	×	
	G	Decrease over 5 consecutive years	×	×	×	×	×	
TARGET HAULING NET EFFORT	G	3rd Lowest / 3rd Highest		×		×		
	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		×	×	2nd 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	×		×	2nd HIGHEST	×	
	G	Greatest % interannual change (+/-)	✓		×	×	×	
	G	Greatest 5 year trend	×		×	×	×	
	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 SA WC, 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 off the WC is unlikely to cause the biological stock to become recruitment overfished. On this basis the WC Southern Garfish stock is classified as **sustainable**.

Northern Spencer Gulf Stock

From the stock assessment in 2017, the NSG stock of Southern Garfish was assigned the status of ‘recovering’ (Steer et al. 2018b). This status reflected favourable reductions in the exploitation rate which has continued to track below the operational target trajectory of reaching ≤ 30% by 2020. Egg production and fishable biomass had remained relatively stable since the previous stock assessment undertaken in 2015 (Steer et al. 2016), and there were positive signs of an increase in population age structure.

Targeted CPUE in the hauling net sector has increased to 67.65 kg.fisherday^{-1} in 2019, representing a 32% increase on the previous year. This increase in CPUE is the result of a five-year high in catches and relatively stabilised effort. However, the lower catches over the past few years was likely a result of management intervention, where a 60-day closure, was implemented to reduce catches and CPUE during the peak of the Garfish fishing season.

Based on the fishery statistics presented here up to and including December 2019 for NSG in association with the most recent management arrangements, there is not enough evidence of any change in the status of this stock. A full stock assessment for Southern Garfish will be conducted in 2021 when the fishery will be assessed against modelled biological performance indicators. It appears that the appropriate management is currently in place and the stock biomass is continuing to recover. On this basis, the current status of the NSG Garfish stock remains classified as **recovering**.

Southern Spencer Gulf Stock

Large areas of SSG 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. Targeted dab net fishing effort has remained moderately high and stable (~200 fisherdays^{-1}) over the past 5 years and associated CPUE has remained within the general performance trigger reference points. This indicates that the biomass is at a sufficient level to ensure that future levels of recruitment are adequate (i.e. not recruitment impaired) and fishing mortality is adequately controlled to avoid the stock becoming recruitment impaired. Consequently, the SSG Garfish 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 ‘depleted’ (Steer et al. 2018b). This assessment indicated that targeted CPUE in NGSV increased in the hauling net sector; harvest fraction had trended downwards; fishable biomass, egg production and recruitment had remained relatively stable; older Southern Garfish appeared in the population age structure, and that current fishing mortality appeared to be constrained by management to a level that should allow the stock to recover from its recruitment impaired state. Despite these positive signs, measurable improvements were yet to be detected to alter stock status. Furthermore, 2017 was the first year the fishing closure extended into October, increasing the opportunity for Southern Garfish schools to disperse, reducing their vulnerability to the hauling net fishers. Despite these extended closures that aimed to reduce catches during the peak fishing season, targeted catches and CPUE in the hauling net sector have increased since 2016. A full stock assessment for Southern Garfish will be conducted in 2021 when the fishery is assessed against modelled biological performance indicators. Until this is undertaken, the NGSV stock will remain classified as **depleted**.

Southern Gulf St. Vincent Stock

Prior to 1993, the commercial catch of Southern Garfish from SGSV 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. The relatively low levels of exploitation in SGSV indicate that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. Furthermore, the above evidence indicates that the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On this basis, the SGSV biological stock is 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

Biology

Southern Calamari (*Sepioteuthis australis*) 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.

The life-history of Southern Calamari is characterised by rapid growth and a sub-annual life-span (Jackson 2004). In South Australia, adults and juveniles are predominantly found in shallow, inshore waters. Offshore waters to depths <70 m tend to be occupied by sub-adults (Winstanley et al. 1983). The patterns of distribution and abundance of adult Southern Calamari in South Australia's gulfs tends to be seasonal and consistent amongst years (Triantafillos 2001). Adult abundance typically increases for six months to a peak and declines for the remainder of the year. Timing of these peaks varies among regions and follows an anti-clockwise progression around the gulfs. This cycle starts in the south-east during late spring and concludes along the western coasts during late winter. Seasonal patterns in water clarity, associated with the prevailing cross-offshore winds, appear to drive this progression as Southern Calamari spawn in shallow seagrass habitats found along protected leeward shores (Triantafillos 2001; Steer et al. 2007). Spawning occurs throughout the year and recruitment to the fishery is continuous.

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 are assessed at the regional scale to match the spatial dynamics of the fishery.

Fishery

In South Australia, the Southern Calamari resource is shared by three sectors. Adult Southern Calamari are targeted by commercial MSF fishers, charter fishery clients, 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 target Southern Calamari from jetties, breakwaters and rocky shorelines. Most of the catch is landed by handlines and rods and reels using squid jigs that are shaped like a prawn. Commercial fishers also mostly use these jigs, but 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 Southern 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 Southern Calamari. These concerns resulted in the implementation of recreational bag and boat limits in 1995 (i.e. 15 per bag and a maximum of 45 per boat per day with 3 people onboard) 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 Southern Calamari. Restrictions currently prevent netting in all metropolitan waters and in waters >5m 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 Southern Calamari.

Commercial Fishery Statistics

State-wide

The total reported commercial catch of Southern Calamari remained relatively stable (>350 t) over the last six years (Figure 4-14a). The economic value of the commercial catch of Southern Calamari in 2019 was approximately $ 5.4 M (*c.f.* $ 5.5 M in 2018) (Figure 4-14a). Therefore, Southern Calamari now has the highest economic value in the fishery. Southern Calamari is taken as by-product in all three South Australian commercial prawn fisheries and has consistently accounted for <10% of total state-wide catches since it was first reported in 2004; however, it increased to 10.5% and 11.3% in 2016 and 2017, respectively.

In 2019, the prawn fisheries by-product component equated to 9.9% of the total statewide commercial catch, noting, however, that the size structure of the catch of Southern Calamari differs in the MSF and prawn fleets, with the latter mostly taking sub-adults in deeper water.

Total State-wide catch of Southern Calamari inclusive of the prawn fisheries was 363 t in 2019, and 327 t in the MSF (*c.f.* 371 t in the MSF in 2018). In the past 5 years, fishers using hauling nets have taken 18.8–30.6% of the MSF catch (21.4% in 2019). Fishers using jigs have taken 69.2–81.0% of the total catch in the MSF (78.5% in 2018). 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 70–80% of the annual catch. Total fishing effort combined for both jig and hauling net fishers had remained relatively stable from 2005 until 2016 ranging between 11,461 fisher-days in 2008 to 14,487 fisher-days in 2011. In 2019, 13,642 fisher-days (*c.f.* 14,330 fisher-days in 2018) were spent catching Southern Calamari within the MSF (Figure 4-14b). CPUE has gradually increased over the past 35 years for both gear types, at a rate of 0.51 kg.fisher-day.year^{-1} (Figure 4-14c). Since the implementation of the licence amalgamation scheme in 1994, the number of licence holders taking Southern Calamari has declined from 355 to 209 in 2017, with 215 licence holders taking the species in 2019. The number of licence holders specifically targeting Southern Calamari has remained relatively stable, averaging 212 licences per year (Figure 4-14d).

Regional

Southern Calamari is caught throughout the State with the majority landed within the gulfs (Figure 4-15a). Catches have increased in NSG, SSG and NGSV since 2008, with all three regions accounting for similar proportions of the State-wide commercial total (Figure 4-15b). Although, Southern Calamari can be caught throughout the year, catches tend to peak during late spring and late autumn (Figure 4-15c). In 2019, the commercial catch of Southern Calamari was dominated by the MSF fishers (~90%), prawn fleets (9.9%) and Northern Zone Rock Lobster fishers accounted for <1%.

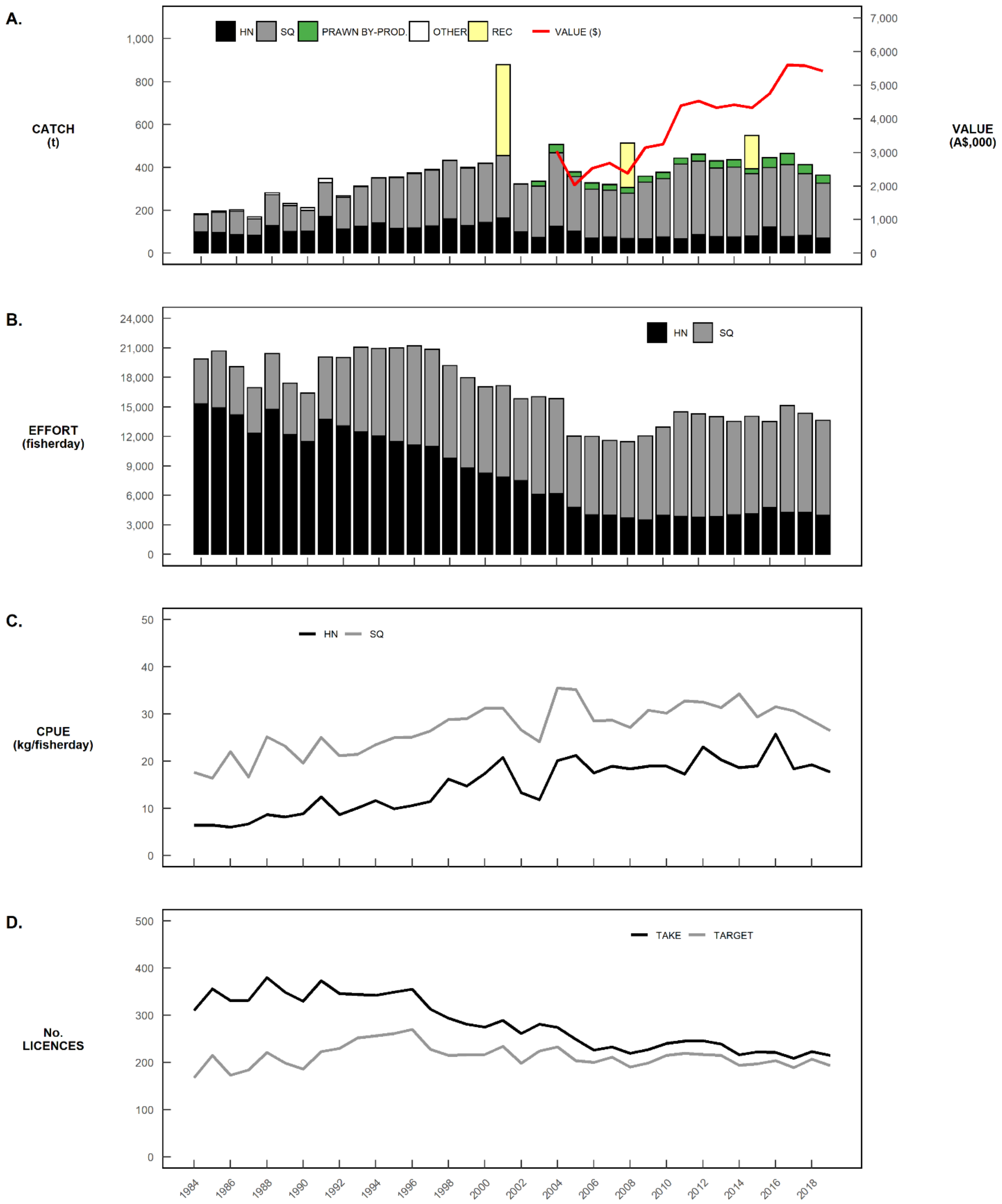

Figure 4-14. Southern Calamari (A) Long-term trends in total catch for the main gear types (squid jig, hauling net, prawn bycatch), estimated recreational catch and gross production value; (B) Long-term total effort for squid jigs and hauling nets; (C) total catch per unit effort for squid jigs and hauling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

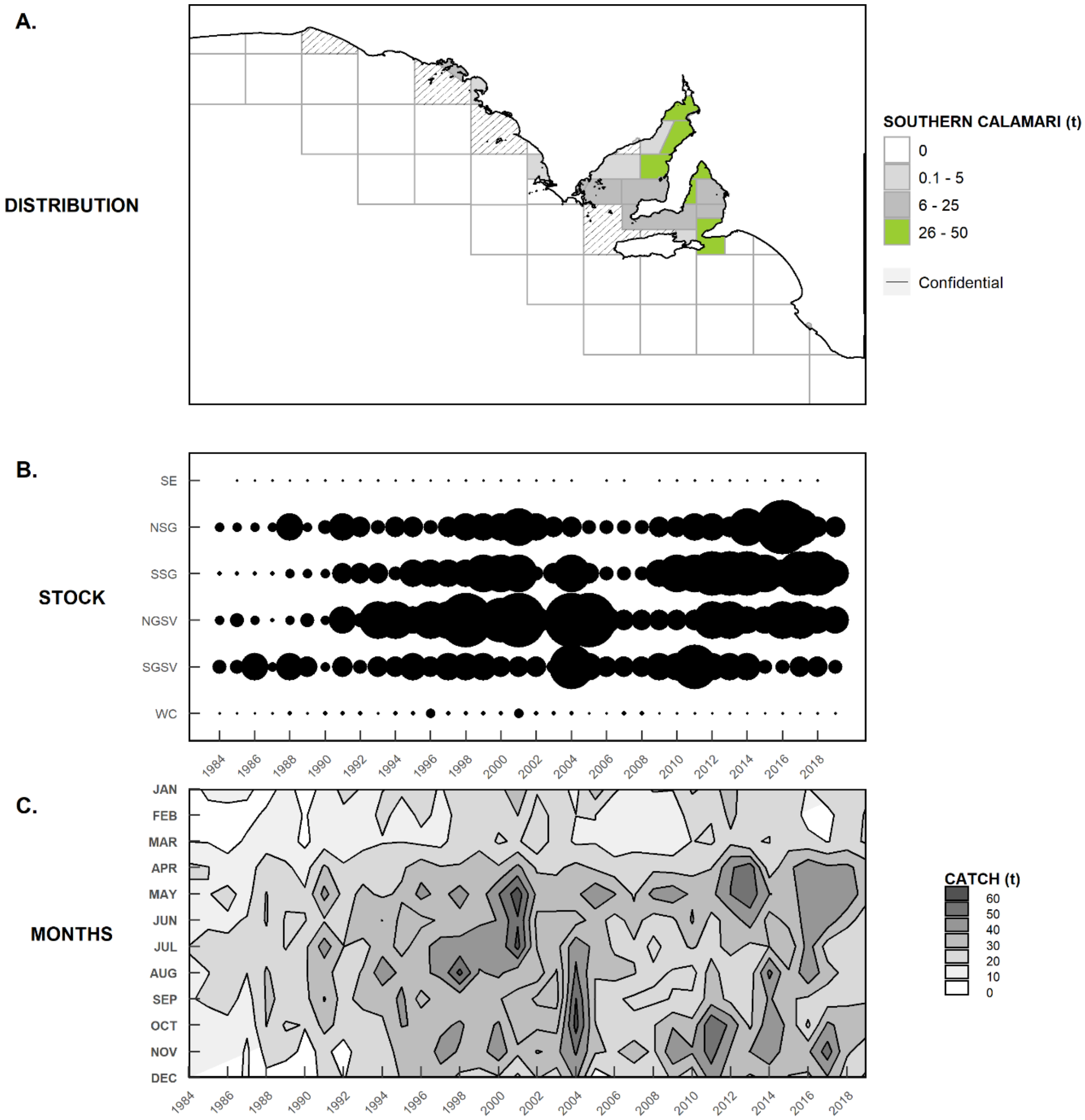

Figure 4-15. Southern Calamari. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

West Coast

The annual commercial catch of Southern Calamari from the WC has rarely exceeded 10% of the State's catch. Total catches declined from a peak of 37.2 t in 1996 to its lowest catch of 5.2 t in 2014 (Figure 4-16a). Annual catch of Southern Calamari in the WC decreased from 10.7 t in 2015 to 8.4 t in 2019. Targeted jig effort in this region declined from a historic peak of 1,343 fisher-days in 2001 to 277 fisher-days in 2009, decreasing at a rate of 94 fisher-days.year^{-1} over eight years (Figure 4-16c). Targeted jig effort remained below 430 fisher-days.year^{-1} since 2014, and was 402 fisher-days in 2019. Targeted jig CPUE has marginally decreased over the past four years from 26 kg-fisherday^{-1} in 2016 to 21 kg-fisherday^{-1} in 2019.

Most of the fishing for Southern Calamari in this region has been targeted using jigs. The number of licences targeting Southern Calamari using jigs has ranged from 32 to 55 over the past decade, and was 40 fishers in 2019. (Figure 4-16e).

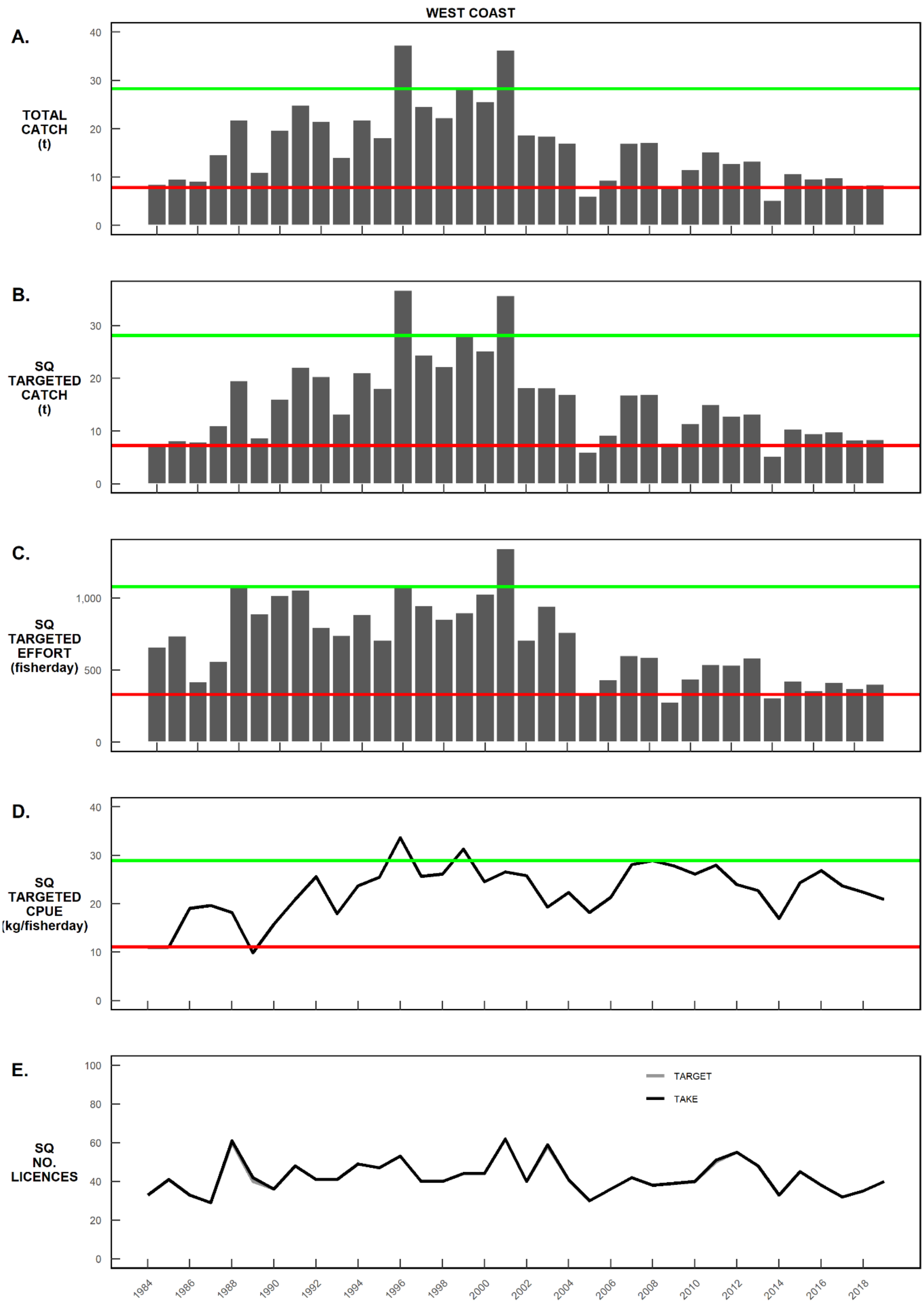

Figure 4-16. Key fishery statistics used to inform the status of Southern Calamari in the West Coast. Long-term trends in (A) total catch; (B) targeted squid jig catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-7.

Northern Spencer Gulf

Total catch of Southern Calamari in NSG has typically accounted for 25% of the State's catch. The annual total catch for NSG decreased by 5 t from 2018 to 71.7 t in 2019 (Figure 4-17a). The targeted hauling net catch had decreased from 7.9 t in 2018 to 5.8 t in 2019, however, this catch is still above the historical average of >3 t per year (Figure 4-17c). Targeted jig catch has stabilised in 2019 to 38 t (*c.f.* 39 t). Targeted jig effort in NSG decreased from 1,689 fisher-days in 2018 to 1,532 fisher-days in 2019. Targeted jig CPUE in 2019 marginally increased from 2018 to 24.9 kg fisher-day^{-1} (*c.f.* 23.2 kg fisher-day^{-1} in 2018) (Figure 4-17d). The number of licence holders targeting Southern Calamari using jigs has declined from a peak of 45 fishers in 2011 to 34 in 2019 (Figure 4-17e).

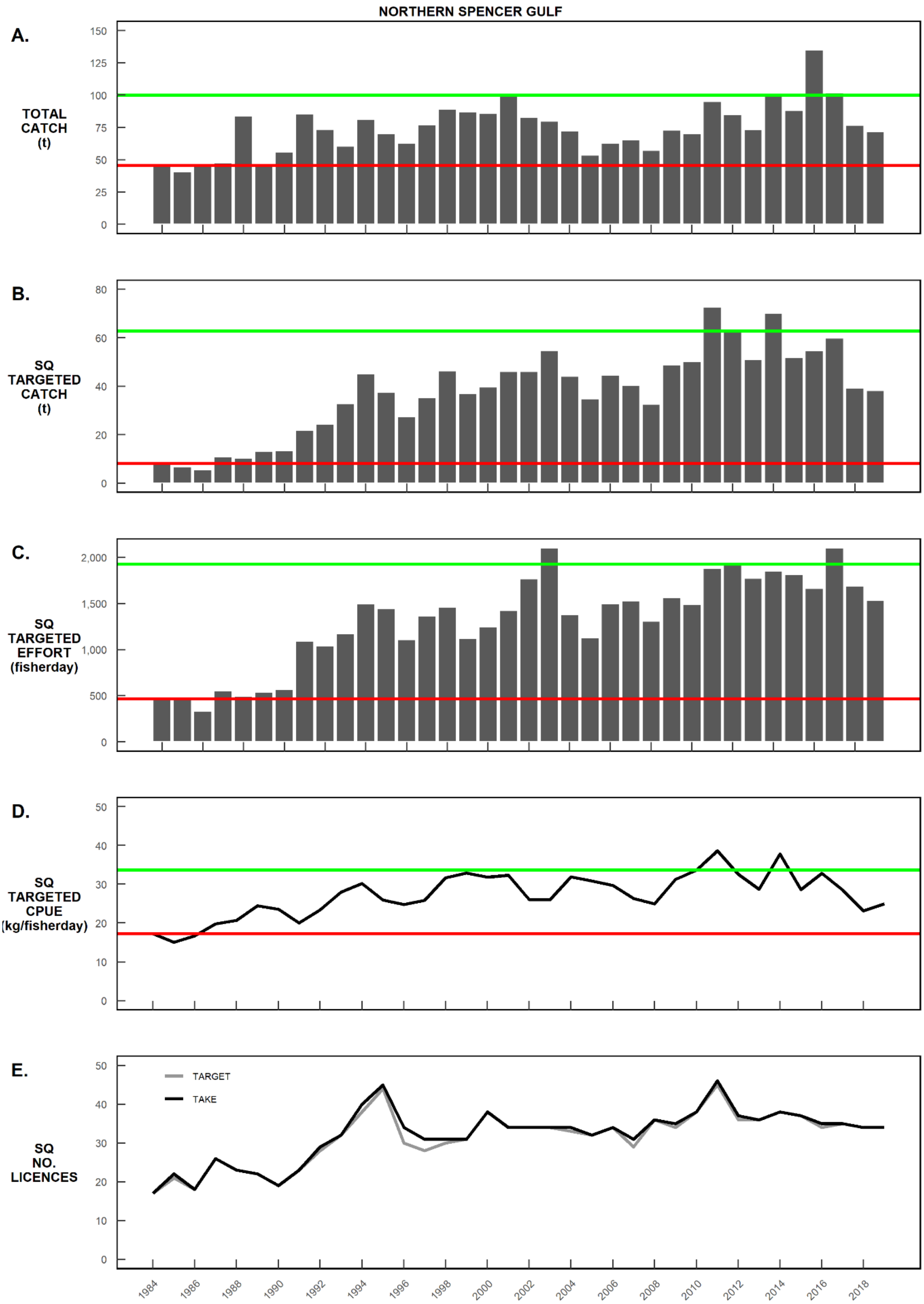

Figure 4-17. Key fishery statistics used to inform the status of Southern Calamari in Northern Spencer Gulf. Long-term trends in (A) total catch; (B) targeted squid jig catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-7.

Southern Spencer Gulf

Total catch of Southern Calamari in the MSF in SSG has accounted for 30% of the State-wide MSF catch. Total catches reached a record high of 123.7 t in 2017, before stabilising at 120.8 t in 2018 (Figure 4-18a). The total catch has since declined by 25% to 92 t in 2019. Effort levels followed a similar trend, with targeted jig effort rising to a peak of 3,599 fisher-days in 2012. Targeted jig effort then decreased to 2,790 fisher-days in 2016 before peaking at the highest effort recorded of 4,058 fisher-days in 2018 (Figure 4-18c). Targeted jig effort decreased to 3680 fisher-days in 2019, however, it was still the third highest targeted effort recorded. Almost all fishing of Southern Calamari in SSG consisted of jigs, as area available for hauling netting is limited. Targeted jig CPUE peaked at 36.3 kg.fisher-day^{-1} in 2013 and have since declined over the past seven years to 25 kg.fisher-day^{-1}.year^{-1} in 2019 (Figure 4-18d). The number of licence holders using jigs to target Southern Calamari in this region remained relatively stable since 2010, ranging from 90–103 fishers per year (Figure 4-18e).

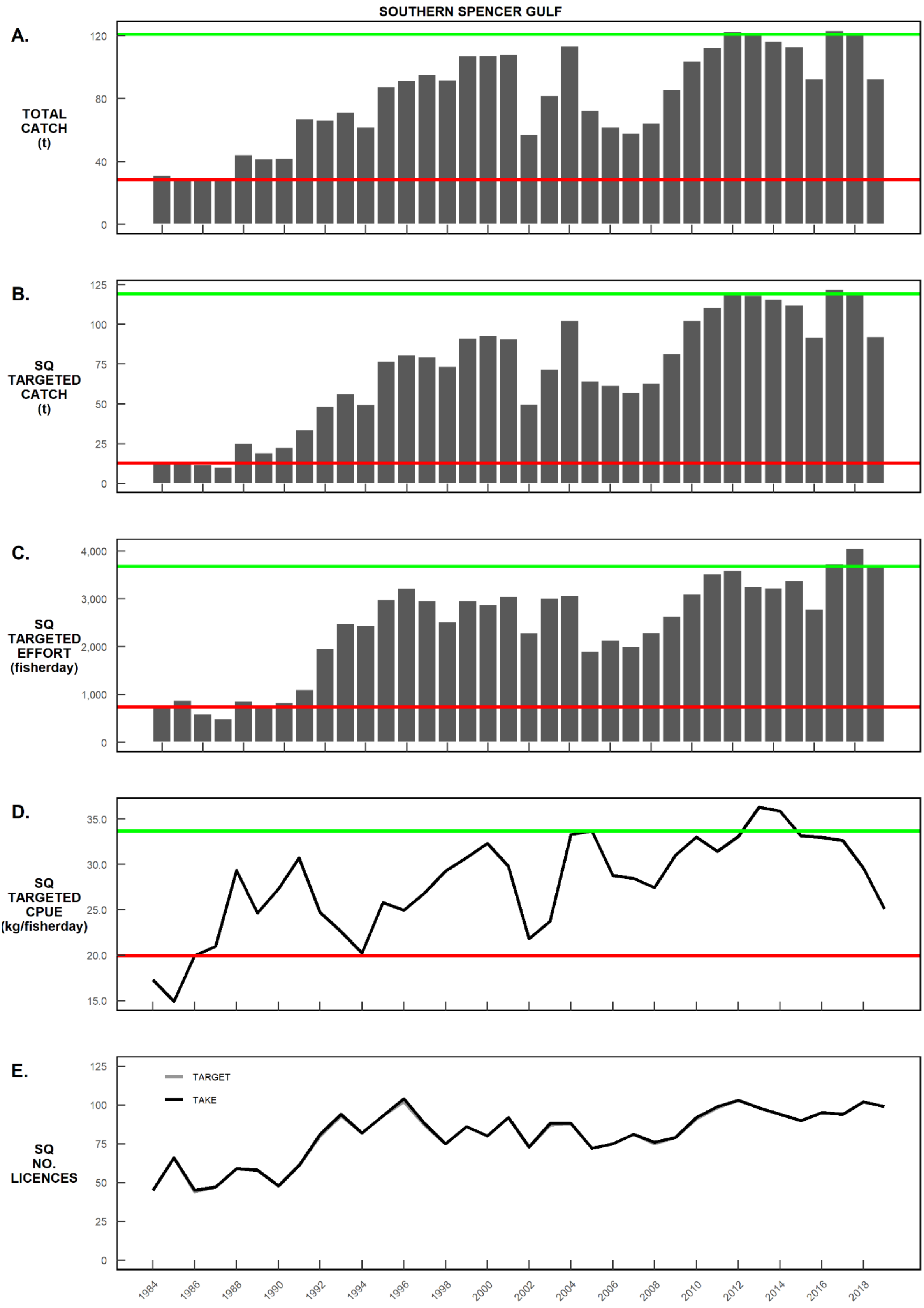

Figure 4-18. Key fishery statistics used to inform the status of Southern Calamari in Southern Spencer Gulf. Long-term trends in (A) total catch; (B) targeted squid jig catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-7.

Northern Gulf St. Vincent

The relative contribution of the commercial Southern Calamari catch from NGSV to the annual State-wide total is ~25%. Annual catches have decreased from a peak of 148 t in 2004 to the most recent low of 69 t in 2009 (Figure 4-19a). Since then, annual total catch has remained relatively stable, averaging ~94 t per year. A total of 88% of the catch is targeted, of which 27% and 61% are taken using hauling nets and jigs, respectively. Targeted jig effort fluctuated annually following an increasing trend that ranged from 503 to 1,546 fisher-days.year^{-1} from 1984 to 2012 (Figure 4-19c). Target effort then increased sharply, ranging between 1,409 and 2,207 fisher-days.year^{-1} between 2012 and 2017. Targeted jig effort reached the third highest recorded effort in 2019 at 1,924 fisher-days.year^{-1} (Figure 4-19c). CPUE has been relatively stable between 2011 and 2019, ranging from 28.5 to 33.5 kg.fisher-day.year^{-1} (Figure 4-19d). The number of licence holders using jigs to target Southern Calamari in NGSV was stable with a slightly upward trend since 1992, averaging 43 per year (Figure 4-19e).

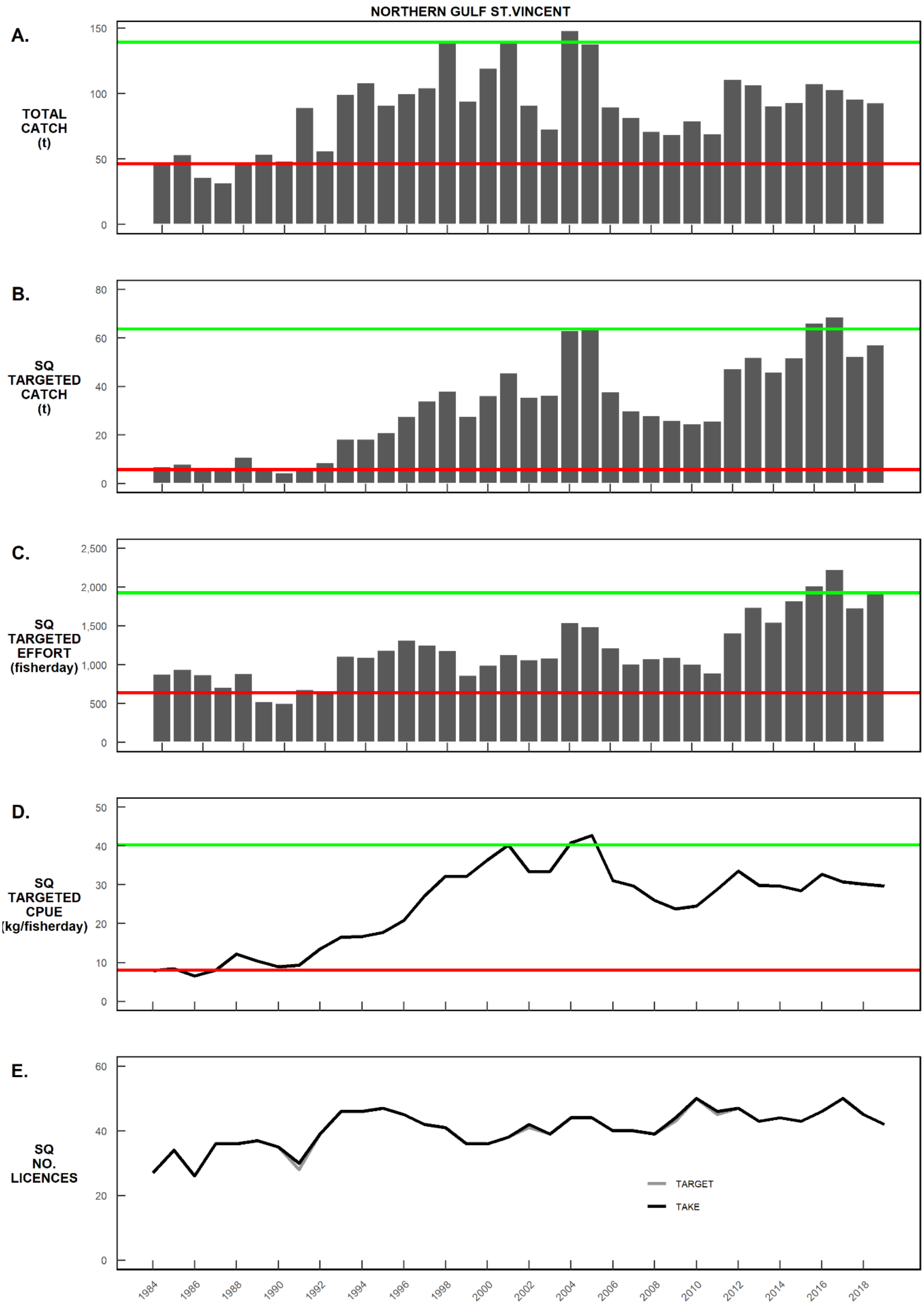

Figure 4-19. Key fishery statistics used to inform the status of Southern Calamari in Northern Gulf St. Vincent. Long-term trends in (A) total catch; (B) targeted squid jig catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-7.

Southern Gulf St. Vincent

Southern Gulf St. Vincent accounts for ~20% of the State-wide catch of Southern Calamari, in the MSF with almost all (>98%) of it targeted by jig fishers. Total catch peaked at 122.7 t in 2011 (Figure 4-20a). Total catch of Southern Calamari in SGSV was 61 t in 2019, representing a decrease in total catch of ~50% in the last 9 years (Figure 4-20a). This decreasing trend has been driven by a concomitant decrease in targeted jig effort, declining from 3,683 fisher-days in 2011 to a record low of 1,857 fisher-days in 2016 (Figure 4-20c). Targeted jig effort levels decreased marginally from 2176 fisher-days in 2018 to 2,135 fisher-days in 2019. Targeted jig CPUE has been moderate and relatively consistent since 1984, averaging 28.5 kg.fisher-day.year^{-1} (Figure 4-20d). The number of licence holders using jigs to target Southern Calamari in this region peaked at 69 in 1996, and remained stable, ranging between 42 and 47 in the past 7 years (Figure 4-20e).

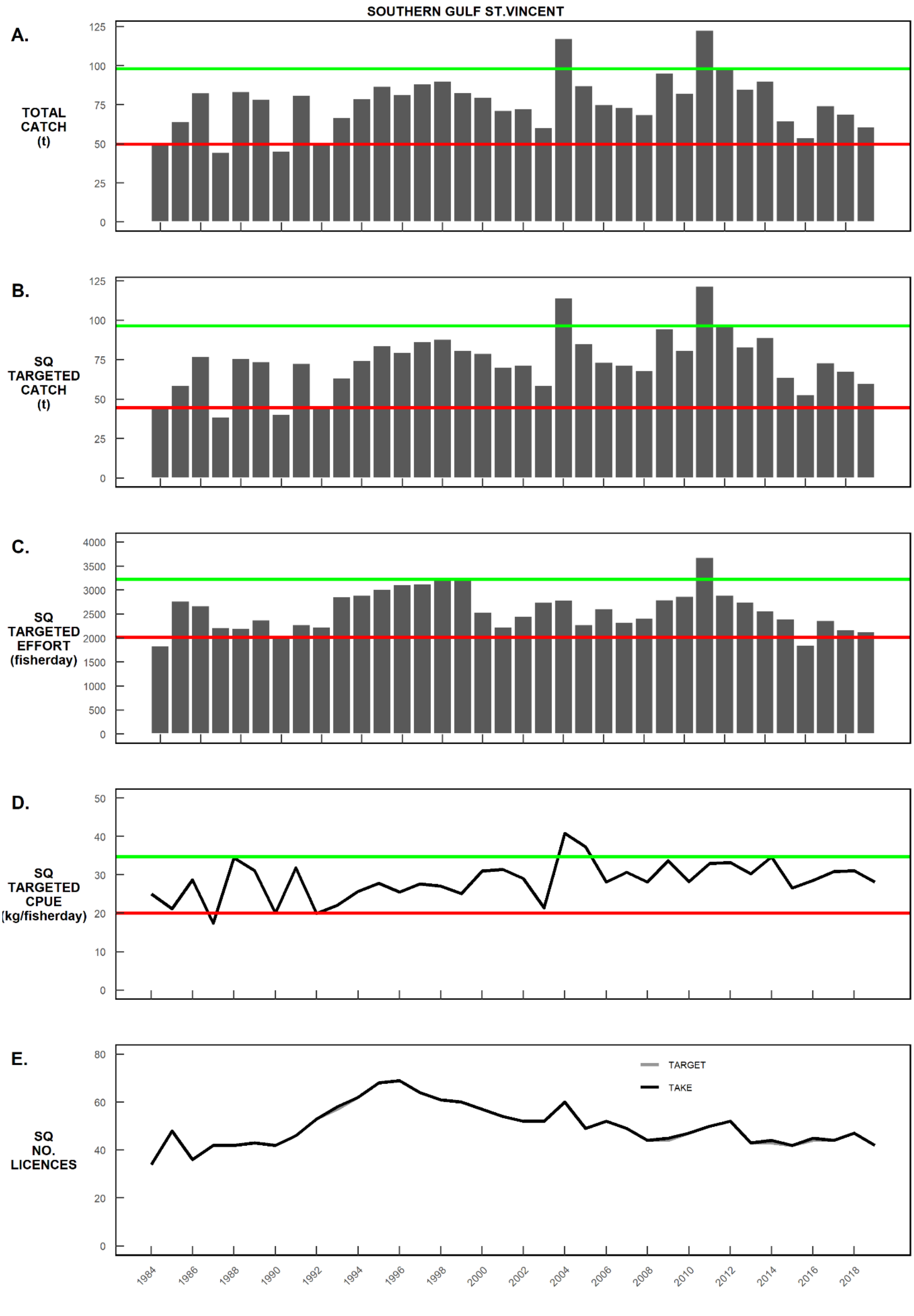

Figure 4-20. Key fishery statistics used to inform the status of Southern Calamari in Southern Gulf St. Vincent. Long-term trends in (A) total catch; (B) targeted squid jig catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-7.

South East

A negligible proportion of the catch (<1%) of Southern Calamari in the MSF was landed in the SE.

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 for 2019. There were three breaches of trigger reference points (Table 4-7), two in SSG and one in NGSV. Southern Spencer Gulf yielded the third highest targeted jig effort and declines in catch rate over five consecutive years. Contemporaneously, NGSV recorded the third highest targeted jig effort.

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. Trigger 2 is breached if the respective sector allocation is breached for three consecutive years. Trigger 3 is breached if the respective sector allocation is breached in any one year.

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%
2013	91.98%	-	0.66%	0.00%	7.23%	conf.
2014	91.87%	-	0.34%	0.04%	7.62%	conf.
2015	93.97%	-	0.21%	0.51%	5.23%	conf.
2016	89.18%	-	0.34%	0.77%	9.65%	conf.
2017	88.65%	-	0.11%	0.77%	10.35%	conf.
2018	89.81%	-	0.14%	1.01%	8.85%	conf.
2019	90.02%	-	0.05%	0.70%	9.08%	conf.

Table 4-7. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the regional spatial scales for Southern Calamari in 2019.

PERFORMANCE INDICATOR	TYPE	TRIGGER REFERENCE POINT	WC	NSG	SSG	NGSV	SGSV	SE
TOTAL CATCH	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 JIG EFFORT	G	3rd Lowest / 3rd Highest	×	×	3rd HIGHEST	3rd HIGHEST	×	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.

Stock Status

In the absence of conclusive evidence on the biological stock boundaries of Southern Calamari throughout its geographical range the assessment of stock status is ascertained at the State-wide level. The primary measure for biomass and fishing mortality is targeted CPUE from jig and hauling net fishers. The total reported commercial catch of Southern Calamari in 2019, combined across all fisheries was 363 t, with 327 t taken in the MSF (*c.f.* 370 t in 2018). Commercial CPUE has remained relatively high in both the jig and the hauling net sectors of the fishery.

Southern Calamari has established itself as an alternate target species as fishers have shifted their effort away from other primary species (Figure 2-4). Although the biological stock of Southern Calamari encompasses the State, there appears to be evidence of regional depletion. This is particularly evident in SSG where targeted jig CPUE has consistently declined over the past 7 years, reducing from a peak of 36.3 kg.fisherday^{-1} in 2013 to 25.1 kg.fisherday^{-1} in 2019, representing an 31% reduction, and breaching the associated trigger point. Northern SG has displayed similar reductions with targeted jig CPUE in 2018 and 2019 being the lowest recorded since 2008. The sharp declines in CPUE over the past three to five years in Spencer Gulf raises uncertainty about the sustainability of increased effort on regional populations. There are also concerns within industry regarding local productivity with anecdotal reports suggesting that some areas are displaying signs of localised depletion. These inferences have been based on Southern Calamari being 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. This declining trend was not evident in either northern or southern GSV as target CPUE in both regions has remained relatively stable over the past decade.

There now appears to be some impacts on the regional sustainability of the resource and this is likely a result of increased pressure from both commercial and recreational fishers. Although localised depletion can occur through intense fishing pressure on spawning aggregations, the species' high paced life-history, dynamic spawning behaviour, and movement potential, favours population replenishment at the broader biological stock level (Pecl et al. 2006).

The above evidence indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired at the biological stock level. However, there are concerns regarding levels of fishing activity on regional populations, particularly within Spencer Gulf. That withstanding, the current level of fishing mortality is unlikely to cause the biological stock to become recruitment impaired. On this basis, South Australia's Southern Calamari stock is classified as **sustainable**.

4.3.4. YELLOWFIN WHITING

Biology

The Yellowfin Whiting (*Sillago schomburgkii*) is endemic to Australian coastal waters from Dampier to Albany in Western Australia and in 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. The life history of this species appears particularly adapted to habitation of relatively protected, shallow, near-shore gulf and coastal waters. Adults are generally associated with shallow, tidal creeks and coastal sand flats 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. Age estimation of Yellowfin Whiting using otoliths has indicated a longevity of ~12 years, although most fish taken in the commercial fishery were 2 to 4 years old (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 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). As the Yellowfin Whiting is a schooling species that occupies sandy, shallow habitats predominantly in the northern gulfs, it is particularly vulnerable to net gear types used in 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. 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

There is a minimum size limit of 240 mm TL for Yellowfin Whiting that applies to the commercial and recreational sectors. A bag limit of 20 fish and boat limit of 60 fish is in place for the recreational sector. Furthermore, for the commercial sector, the many regulations that are input controls for the net gear types contribute to minimising fishing effort directed at Yellowfin Whiting. These include restrictions to net lengths and mesh sizes, extensive spatial closures and temporal restrictions that limit net fishing activities.

Commercial Fishery Statistics

State-wide

Estimates of State-wide commercial catches of Yellowfin Whiting ranged from 14.5 t in 1988 to 179 t in 2001 (Figure 4-21a). In 2019, the total catch was 140.2 t. The economic value of the commercial catch of Yellowfin Whiting in 2019 was approximately $ 1.1 M (*c.f.* $ 1.1 M in 2017) (Figure 4-21a). Total commercial catches increased between 2014 and 2016, but were consistent at ~140 $t.yr^{-1}$ from 2017 to 2019. Combined hauling net and gillnet effort declined between 2002 and 2007, and has been relatively flat since then (Figure 4-21b). Hauling nets account for most of the fishing effort that produces catches of this species. State-wide estimates of CPUE for Yellowfin Whiting taken using hauling nets have been highly variable, with an increasing trend from 1984 to 2019, with the estimate in the latter year being 53.5 $kg.fisherday^{-1}$ (Figure 4-21c). Also, from 1984 to 2019, the total number of licence holders who reported taking Yellowfin Whiting declined from 129 to 44 (Figure 4-21d). Most of these did not target this species.

Regional

Although the annual catches of Yellowfin Whiting in NSG have been variable since 1984, they have always been higher than in the other SA regions (Figure 4-22a, b). Since the early 1990s, NGSV has been the second most productive region, whilst lower catches have come from the southern gulfs. Only incidental catches have been recorded from the SE and WC.

Northern Spencer Gulf continues to be the region where most of the State's commercial catch of Yellowfin Whiting comes from (Figure 4-22b).

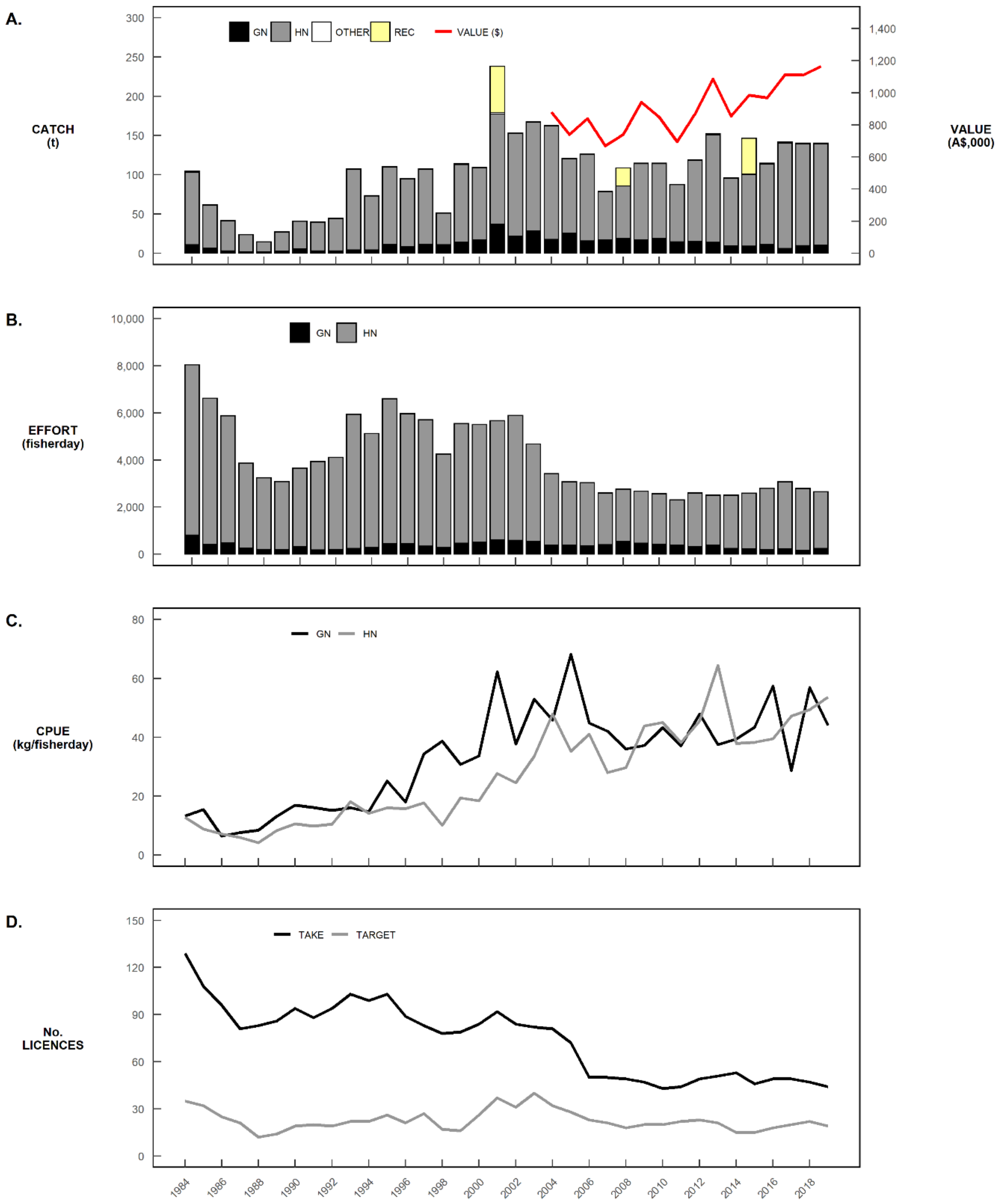

Figure 4-21. Yellowfin Whiting. Long-term trends in: (A) total catch of the main gear types (hauling and gillnets), estimates of recreational catch and gross production value; (B) total effort for hauling and set nets; (C) total catch per unit effort (CPUE) for hauling and dab nets; and (D) the number of active licence holders taking or targeting the species.

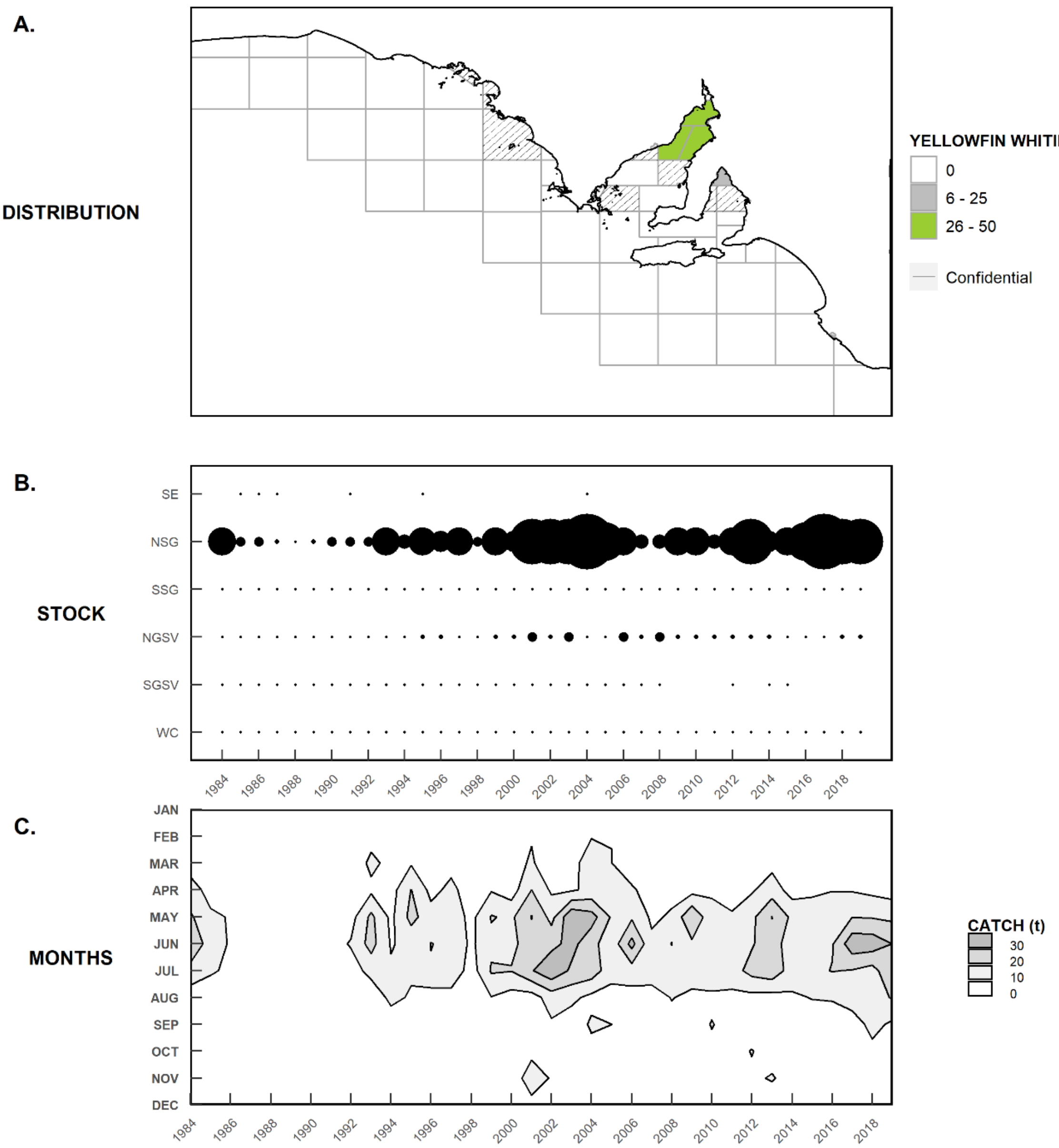

Figure 4-22. Yellowfin Whiting. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Spencer Gulf / West Coast Stock

Total catch of Yellowfin Whiting from WC/SGS has varied considerably over the years. The lowest catch of 13.1 t was taken in 1988 and the highest of 148 t was taken in 2004. The total catch of 122 t in 2019 was the sixth highest reported since 1984 (Figure 4-23a).

Targeted hauling net catches have been highly variable, with the highest catches taken between 2001 and 2004 (Figure 4-23b). Targeted hauling net effort peaked at 826 fisher-days in 2004, but subsequently decreased to 161 fisher-days in 2014, prior to increasing again to 295 fisher-days in 2019 (Figure 4-23c). Targeted hauling net CPUE has been variable but showed no long-term trend from 1984 to 2008, but has increased considerably since then, peaking in 2013 and 2014 at 165.0 and 169.6 kg.fisherday^{-1}, respectively (Figure 4-23d). In 2019, the hauling net CPUE was at 159.4 kg.fisher-day^{-1}. The number of licence holders who took Yellowfin Whiting with hauling nets was highest at 71 in 1984, which by 2019 had declined to 21. The number of fishers who targeted this species with hauling nets has been variable and ranged from 8 to 24, with 10 licence holders targeting this species in 2019 (Figure 4-23e).

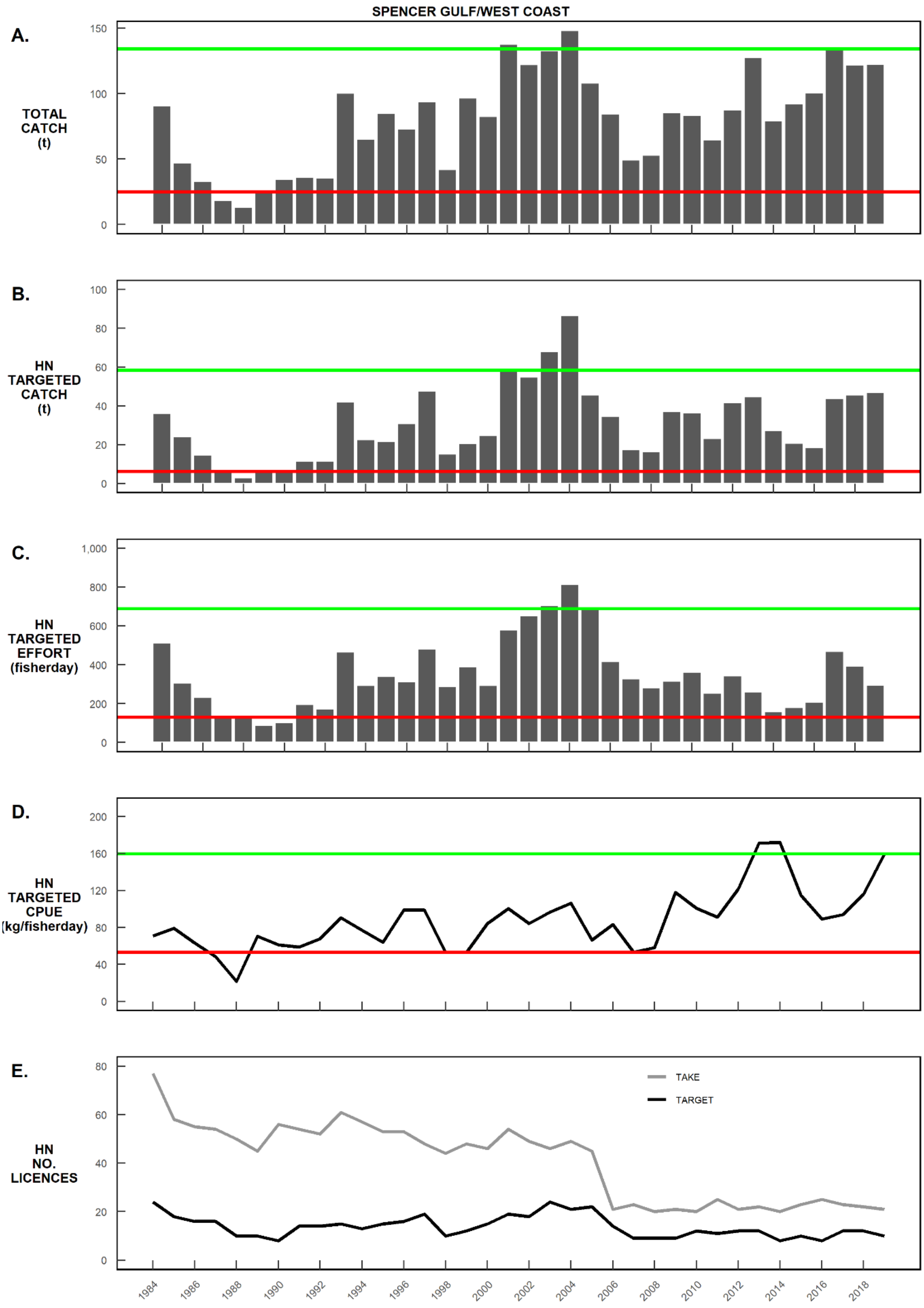

Figure 4-23. Key fishery statistics used to inform the status of Yellowfin Whiting in Spencer Gulf / West Coast. Long-term trends in (A) total catch; (B) targeted hauling net catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-8.

Gulf St Vincent Stock

In GSV, total annual catches of Yellowfin Whiting were highest between 2002 and 2012, when they generally ranged between 20 and 40 $t.yr^{-1}$ (Figure 4-24a). They subsequently declined to 7.5 t in 2017, but have risen again to 17.9 t in 2019. Targeted hauling net catches have been <5 $t.yr^{-1}$ in the past seven years (Figure 4-24b). These low levels of targeted catch were associated with low levels of targeted hauling net effort, which in 2019 was at 44 fisher-days (Figure 4-24c). Furthermore, targeted hauling net CPUE levels have been variable, and in 2019 was 106.8 $kg.fisherday^{-1}$ (Figure 4-24d). Relatively few fishers that took Yellowfin Whiting with hauling nets in NGSV targeted this species. Confidentiality issues prevent presenting the full time-series of commercial catch and effort data (Figure 4-24e).

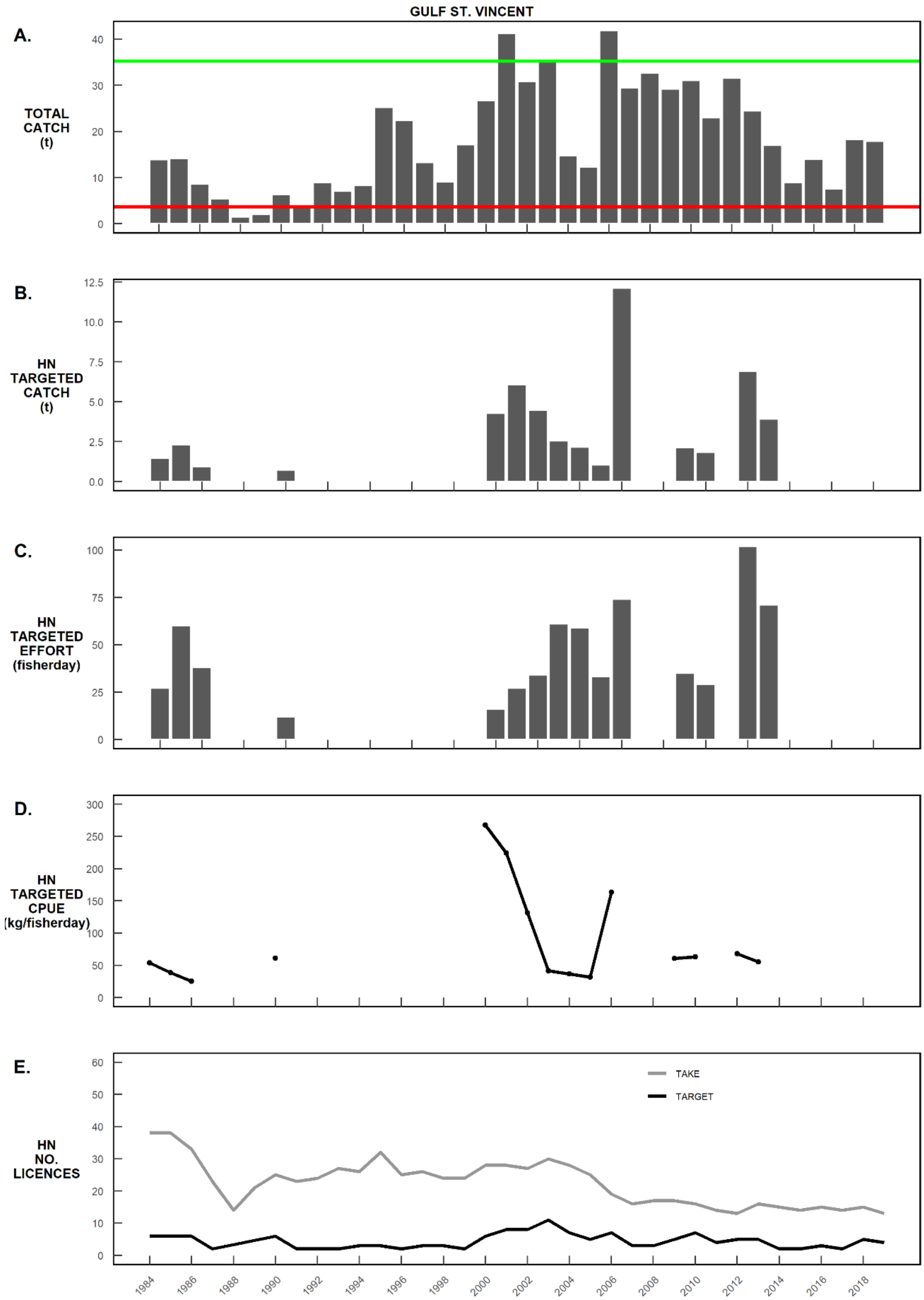

Figure 4-24. Key fishery statistics used to inform the status of Yellowfin Whiting in Gulf St. Vincent. Long-term trends in (A) total catch; (B) targeted hauling net catch; (C) effort; (D) catch rate; and (E) the number of active licence holders taking and targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-8.

Fishery Performance

The general fishery performance indicators for Yellowfin Whiting were assessed for 2019 for both the SG/WC and GSV stocks. For the former, one trigger reference point was breached, i.e. the estimate of targeted hauling net CPUE in 2019 was the third highest recorded (Table 4-8). No trigger reference points were breached for the NGSV stock.

Table 4-8. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the regional spatial scales for Yellowfin Whiting in 2019.

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	3rd HIGHEST	×
	G	Greatest % interannual change (+/-)	×	×
	G	Greatest 3 year trend	×	×
	G	Decrease over 5 consecutive years	×	×

Stock Status

The South Australian catches of Yellowfin Whiting were dominated by those from Spencer Gulf, although the fishery performance indicators for this region are characterised by high levels of variability. This may reflect the transient nature of targeted fishing effort, with fishers either opportunistically targeting Yellowfin Whiting due to market demands, or when the availability of higher value species is low. There was a long-term declining trend in targeted fishing effort for Yellowfin Whiting, between 2005 and 2016. This decline, however, was not reflected in the trends in total catch, targeted catch or targeted CPUE. Then, targeted effort increased again in 2017, 2018, and 2019 and was associated with increases in total catch, targeted catch and CPUE. Such evidence indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. Furthermore, the current level of fishing mortality is unlikely to cause the stock to become recruitment-impaired. On this basis, the Spencer Gulf population is classified as a **sustainable** stock.

The Gulf St. Vincent population has produced considerably lower annual catches than those from Spencer Gulf. The targeted catches from the netting sector in this region have been variable over time reflecting variable effort. The above evidence indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired.

Furthermore, the above evidence indicates that the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On the basis of the evidence provided above, the Gulf St. Vincent stock is classified as a **sustainable** stock.

4.3.5. WESTERN AUSTRALIAN SALMON

Biology

The Western Australian Salmon (*Arripis truttaceus*) (hereafter referred to as 'Salmon') comprises a migratory biological stock that extends from southern Western Australia to the east coast of Tasmania, with each State jurisdiction harvesting different life-history stages. Western Australian Salmon intermix with Eastern Australian Salmon (*A. trutta*) in eastern Victorian waters and around Tasmania. The Western Australian fishery typically targets adult fish that aggregate around the south-western coastline, 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).

Salmon form large spawning schools in coastal waters between Cape Leeuwin and Busselton, Western Australia, during late autumn and early winter when the eastward flow of the Leeuwin Current is strongest. Developing larvae settle along the entire southern coastline of Australia, with the main nursery grounds located along the south-eastern coast. Juveniles 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 and Australian anchovies. Salmon attain a maximum age of ~12 years and can reach a maximum size of 850 mm FL (Cappo 1987).

Fishery

Historically, the harvest of Salmon in South Australia has been confined to gulf and coastal waters and targeted by hauling net fishers and dedicated seine net fishers within the MSF. The Southern and Northern Zone Rock Lobster fisheries and Miscellaneous Fishery have reported negligible catches of Salmon over many years.

Salmon is an iconic recreational fishery species in South Australia and is targeted with rod and line. The product is used for lobster bait and human consumption. The State-wide recreational survey in 2013/14 estimated that 220,332 Salmon were captured, of which 148,361 fish were harvested (Giri and Hall 2015). The estimated total recreational harvest weight was 56.2 t, which was ~48% of the State's total catch in 2013/14.

Management Regulations

Since 1984, the commercial harvest of Salmon in South Australia 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). Other regulations that are in place for this sector include temporal and spatial netting closures, and restrictions to net lengths and mesh sizes, and a minimum legal size of 210 mm TL (PIRSA 2016).

There are multiple management regulations in place for Salmon 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. The minimum legal length of 210 mm (TL) applies for recreational fishers. Daily size, bag and boat limits were implemented for the recreational sector in 1995. 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

Historically, the commercial MSF for Salmon has involved a hauling net component and a specialist purse seine (i.e. Salmon net) component. From 1984 to 2003, the annual commercial catches fluctuated around 600 t per year, with most taken by a small number of purse seiners operating throughout the West Coast and Kangaroo Island/Investigator Strait of Southern Gulf St. Vincent (SGSV) (Figure 4-25a). From 2004 to 2013, catch was considerably lower, ranging from 59–262 $t.yr^{-1}$, as purse seiners exited the fishery. During that period, hauling net fishers landed most (up to 90%) of the annual catch. Since 2013, catch has progressively increased in response to a developing market. A total catch of 228.7 t was taken in 2019, representing a 32% increase in the catch of 156.3 t in the previous year. The total commercial catch of Salmon taken in the Lakes and Coorong was negligible. The economic value of the commercial catch of Salmon in 2019 was approximately $ 299 K (*c.f.* $ 251 K in 2018) (Figure 4–25a).

Targeted effort levels in the hauling net sector have remained relatively stable (~57 fisher-$days.yr^{-1}$) since 2008, increasing to an 11 year high of 94 $fisherdays.yr^{-1}$ in 2019 (Figure 4-25b). Prior to this, fishing activity has steadily declined from a peak of 807 fisher-days in 1992. Associated CPUE peaked at 1,721 $kg.fisher\text{-}day.year^{-1}$ in 2009 (Figure 4-25c). This peak was uncharacteristically high as CPUE has rarely exceeded 450 $kg.fisher\text{-}day.yr^{-1}$, and has typically ranged between 100 and 500 $kg.fisher\text{-}day.year^{-1}$. Hauling net CPUE had decreased to 275 $kg.fisher\text{-}day^{-1}$ in 2019 (*c.f.* 302 $kg.fisher\text{-}day^{-1}$ in 2018).

Regional

Up to the early 2000s, the highest catches were recorded from the West Coast or SGSV, with intermediate contributions from Southern Spencer Gulf (SSG) (Figure 4-26b). From 2004 to 2013, the highest catches were taken in SSG. However, since 2013, the contributions from the West Coast and SGSV have increased, with catches from SSG remaining relatively stable. Most of the catch taken in each year has been landed throughout spring and summer (Figure 4-26c).

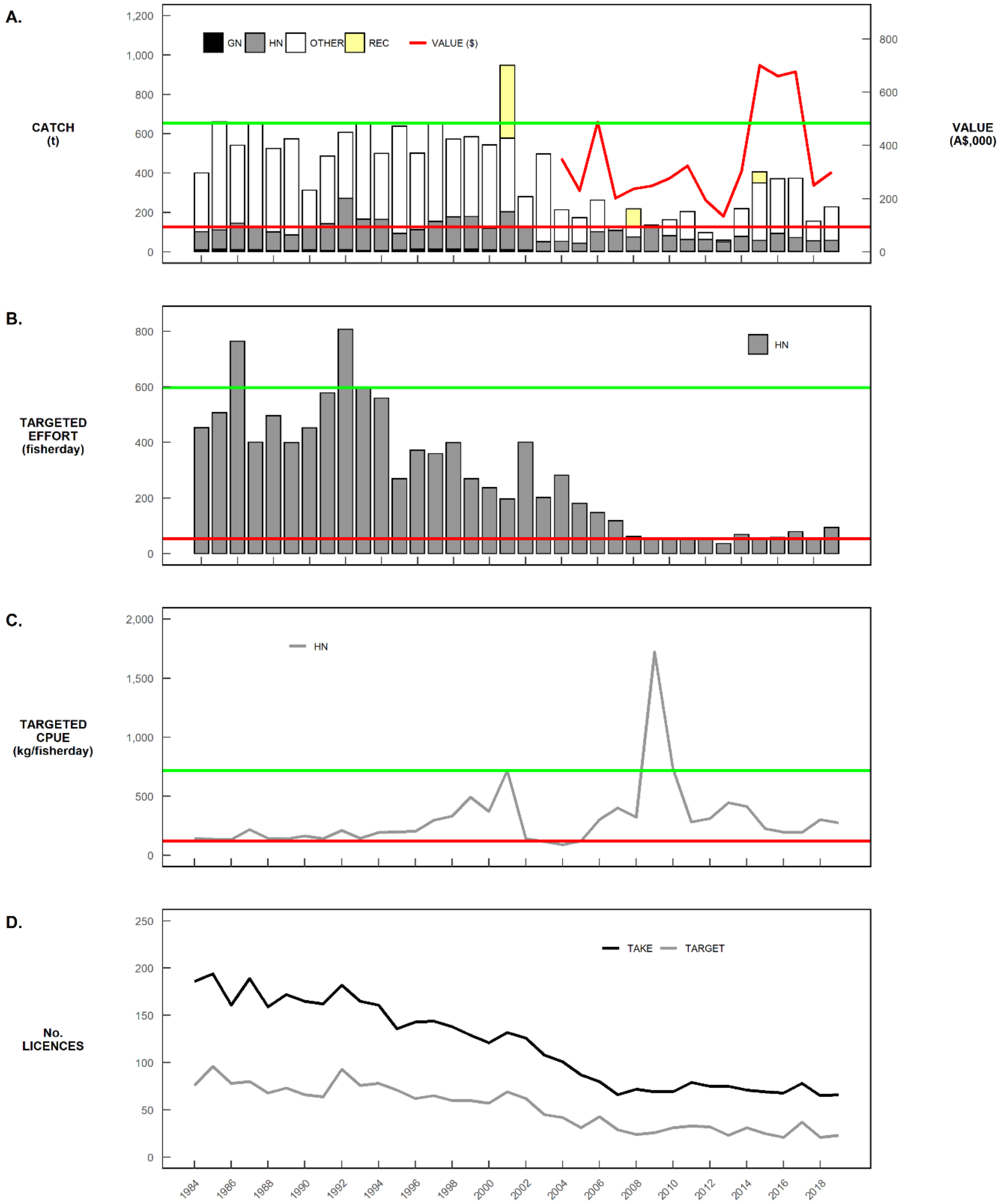

Figure 4-25. Salmon. Long-term trends in: (A) total catch of the main gear types (hauling and set nets), estimates of recreational catch, and gross production value; (B) targeted effort for hauling nets; (C) total catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-9.

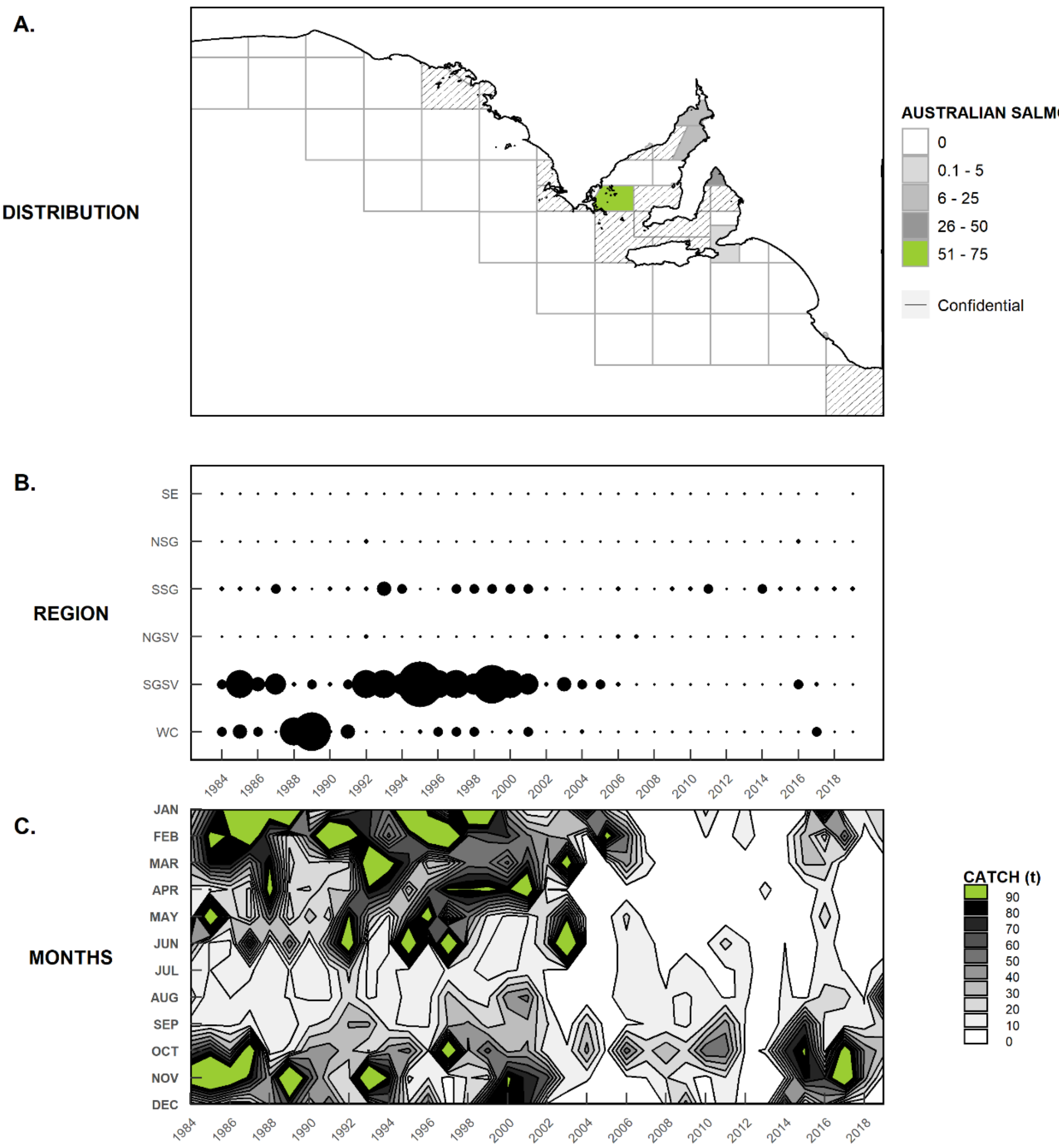

Figure 4-26 Salmon. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general performance indicators for Salmon were assessed for 2019 at the State-wide scale. No trigger reference points were activated was the greatest negative inter-annual change in total catch (Table 4-9).

Table 4-9. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Salmon in 2019.

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 biological stock of Salmon 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 the 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. 2016). Trends in catch and effort of Salmon 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 purse seiners is indicative of a weak market; however, the increase in annual catches from 2015 to 2017 and escalating value suggest a new emerging markets for this species. However, catches then dropped considerably in 2018 but increased by 32% to moderate levels of catch in 2019. The recent medium-level catches and associated CPUE since 2014 indicate that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. On this basis, the Salmon fishery is classified as **sustainable**.

4.3.6. AUSTRALIAN HERRING

Biology

Australian Herring (*Arripis georgiana*) (hereafter referred to as 'Herring') is 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 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 relates to the relative strength of the Leeuwin Current which transports warm tropical water southward in the Indian Ocean and eastward along Australia's southern coastline during autumn and winter. 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 and Blue Sprats), larger crustaceans and surface insects. Herring attain sexual maturity at two to three years of age and ~200 mm in length and typically return to southwestern Australia where they contribute to the spawning population (Smith et al. 2013).

Fishery

The schooling behaviours 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. 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

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 2019 was 99.8 t, which represented a minimal decrease from the previous year (*c.f.* 104.5 t in 2018) (Figure 4-27a). Annual catches have remained below 200 t since 2003. The economic value of the commercial catch of Australian Herring in 2019 was approximately $ 342 K (*c.f.* $ 331 K in 2018) (Figure 4-27a).

Netting closures have contributed to reductions in fishing effort, with hauling net fishers rarely exceeding 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 (Figure 4-27b).

Target CPUE of Herring in the hauling net sector has been highly variable over the past 35 years ranging from 53.4 kg.fisher-day^{-1} in 2003 to 216.5 kg.fisher-day^{-1} in 1999 (Figure 4-27c). Targeted hauling net catch rate of Herring in 2019 is confidential. Despite such high variability, the long-term trend has been relatively stable. Approximately 10–20% of fishers that take Herring actively target the species, and this has remained relatively consistent over the last 35 years (Figure 4-27d).

Regional

Prior to the implementation of the netting closures in 2005, the highest catches for Herring were shared amongst NSG, SSG, and NGSV (Figure 4-28b). 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 4-28b). Most of this catch has been historically landed throughout spring and autumn (Figure 4-28c).

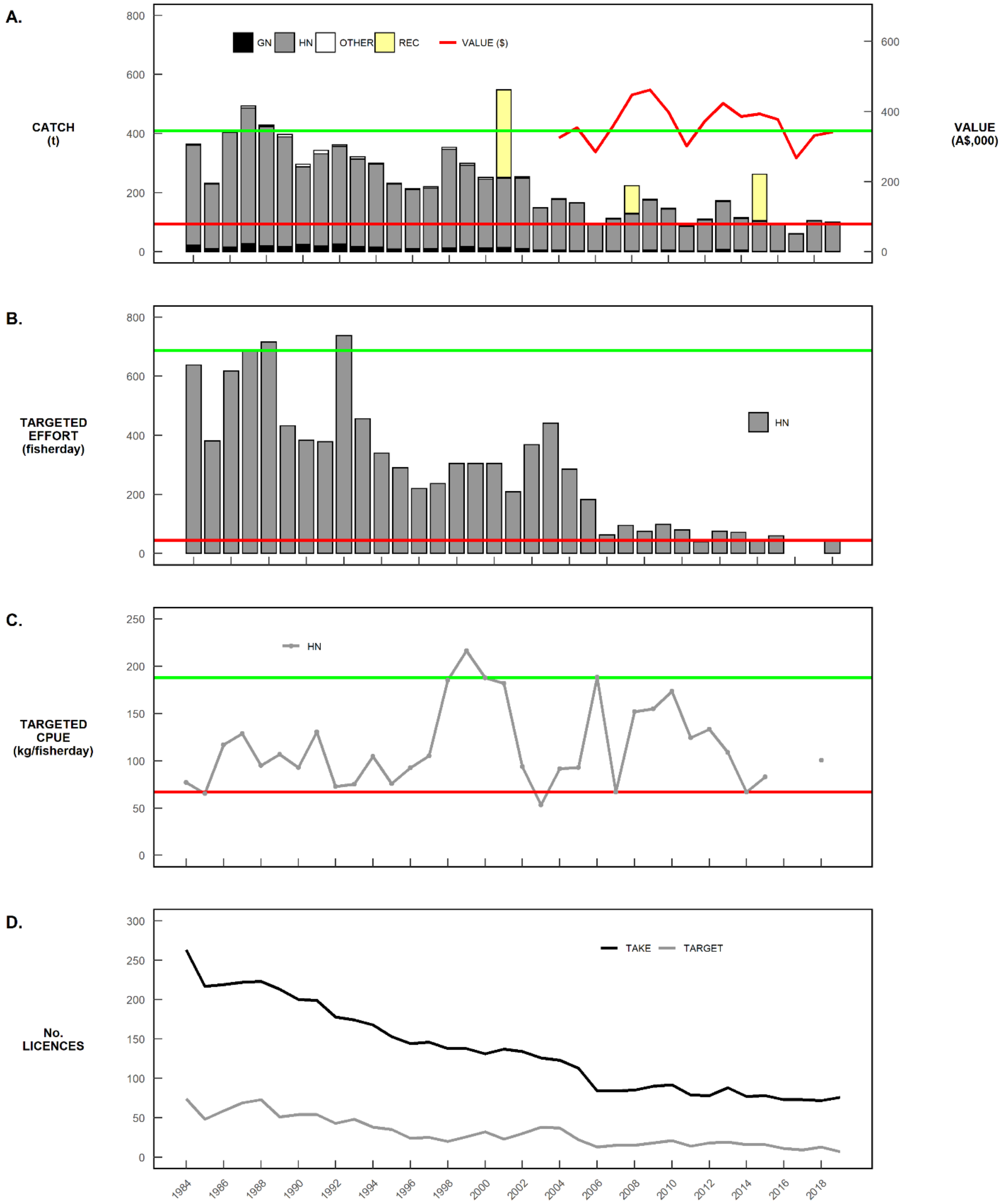

Figure 4-27. Australian Herring. Long-term trends in: (A) total catch of the main gear types (hauling and set nets), estimates of recreational catch, and gross production value; (B) targeted effort for hauling nets; (C) total catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-10.

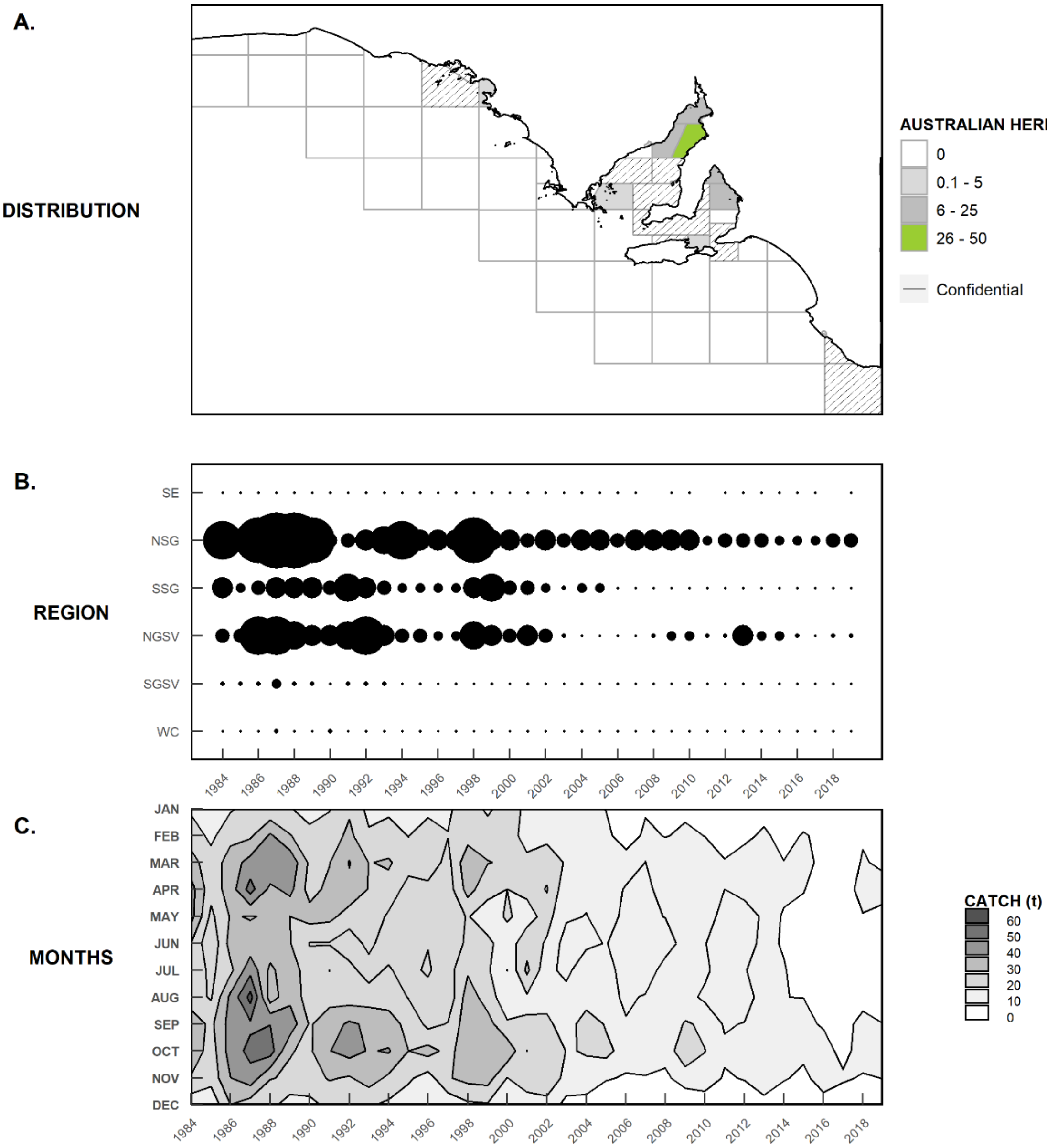

Figure 4-28. Australian Herring. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among regions, (C) months of the year (t).

Fishery Performance

The general performance indicators for Herring were assessed for 2019 at the State-wide scale, using the reference period 1984 to 2019. The resolution of the targeted effort and associated CPUE for hauling net fishers were confidential due to the <5 fisher rule. No trigger reference points were breached (Table 4-10).

Table 4-10. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State scale for Australian Herring in 2019. CONF. denotes confidential data, <5 fishers.

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 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

The levels of fishing effort and subsequent catch of Herring in South Australia have declined over the past 35 years, which was partly due to implementation of a series of netting closures in 2005. During 2019, total catch of Herring remained low and had marginally decreased from the previous year to 99.8 t, reflecting continuing low effort levels. CPUE within the hauling net sector remained highly variable with no clear, long-term trend. This is most likely due to this species being infrequently targeted by the commercial sector. The species is a popular target within the State's recreational fishing sector.

The productivity of the species and the management arrangements introduced in WA in 2015, has contributed to the recovery of the resource (DPIRD 2017). Consequently, the status of the South Australian Herring Fishery should reflect the Western Australian assessment.

The current level of fishing mortality of Herring in South Australia is unlikely to cause the stock to become recruitment impaired. On the basis of the evidence provided above, the Australian Herring biological stock is classified as **sustainable**.

4.3.7. SNOOK

Biology

Snook (*Sphyraena novaehollandiae*) are elongate predators that occur over seagrass beds and kelp reefs in inshore and offshore waters (Emery et al. 2016). They prey on pelagic and demersal teleost fishes, crustaceans and cephalopods (Bertoni 1994). The species is 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 the stock structure of Snook throughout its broad Australasian distribution (Emery et al. 2016).

A study in Gulf St. Vincent and Spencer Gulf during 2002 (O'Sullivan and Jones 2003) found that the largest fish was 820 mm TL, although most fish measured were in the size range of 300 to 500 mm TL. The modal age was 2+ years and the oldest fish were 12 years old. Males and females have similar growth patterns, with a strong bias in the sex ratio towards females. Snook were reproductively active during late spring-summer (Bertoni 1994). They are multiple batch spawners with indeterminate fecundity. The length-at-50%-maturity (L_{50}) is 391 mm and 403 mm TL for males and females, respectively, at two years of age.

Fishery

Snook are taken by both the commercial and recreational sectors of the MSF. 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 using lures. Recreational fishers target Snook with rods and lines. The State-wide recreational survey done in 2013/14 estimated that 187,165 Snook were captured, of which 12,941 were released, leaving 174,224 fish that were retained (Giri and Hall 2015). The latter provided an estimated State-wide recreational harvest of 126.3 t.

Management Regulations

For the commercial sector, the many input controls for the netting gear types contribute to limiting fishing effort. The minimum size limit for Snook was increased from 360 to 450 mm TL in July 2001. However, a reduction in size limit to 410 mm TL came into effect in 2017, to align with the estimated length-at-maturity (Bertoni 1994). For 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 remained the same after 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 of 147.3 t in 1995, before declining to the lowest level of 38.9 t in 2017 (Figure 4-2929a). In 2019, the annual commercial catch was marginally higher at 40.5 t. The economic value of the commercial catch of Snook in 2019 was approximately $ 256 K (*c.f.* $ 231 K in 2018) (Figure 4-29a).

Hauling nets have generally accounted for at least half of the annual catches, whilst troll lines and gill nets have been the second and third most important gear types (Figure 4-29a). Targeted hauling net fishing effort has declined since 2005, falling to the lowest recorded level in 2010, after which it has been variable but increased to 53 fisher-days in 2019 (Figure 4-2929b). Targeted hauling net CPUE has been highly variable, often fluctuating by >30 kg.fisher-day^{-1} between years. During the 1980s and 1990s, annual targeted hauling net CPUE ranged from 14 to 62.1 kg.fisher-day^{-1}. Through the 2000s, CPUE has generally been >50 kg.fisher-day^{-1}. The catch rate in 2019 was 63.0 kg.fisher-day^{-1} (Figure 4-2929c). The number of MSF fishers taking Snook decreased from 318 in 1984 to 127 in 2005, and then fell further to 96 in 2019 (Figure 4-2929d). The numbers of fishers targeting Snook have fallen from 143 in 1984 to 65 in 2019.

Regional

Catches of Snook have been reported from all six geographic regions of South Australia's marine waters (Figure 4-30a). The highest regional catches were mainly taken from NSG and NGSV during the 1990s, with intermediate catches from SSG and the WC (Figure 4-30b). Catches from all regions have been lower during the 2000s. The fishery is seasonal with highest catches generally taken between July and November. Marine Scalefish Fishery licence holders accounted for all of the State-wide commercial catch in 2019 (Figure 4-30c). The commercial sector landed 27% of the total State-wide catch in 2013/2014 with the recreational sector accounting for the remaining 73% (Figure 4-300d).

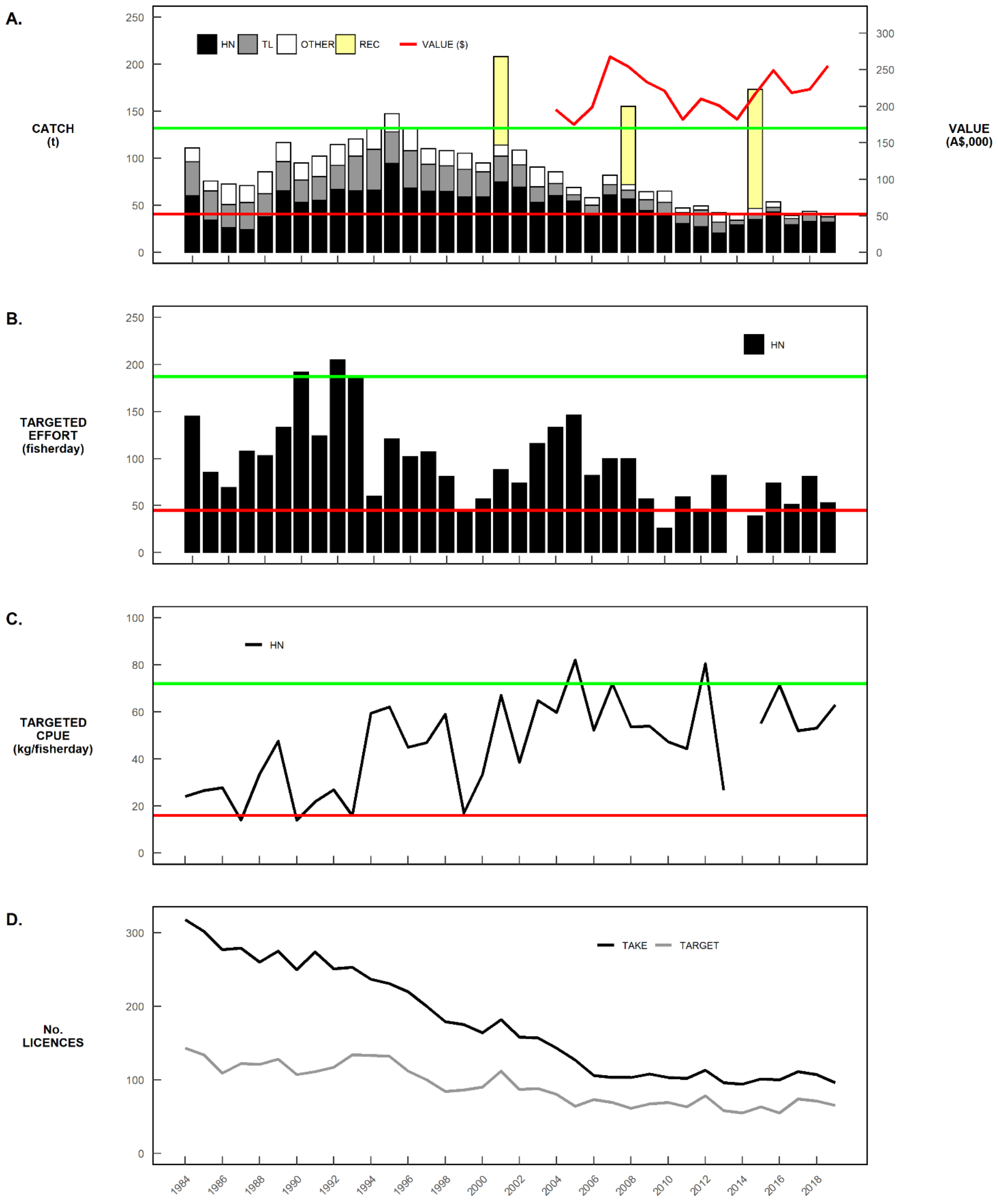

Figure 4-2929. Snook. Long-term trends in: (A) total catch of the main gear types (hauling net and troll line), estimates of recreational catch, and gross production value; (B) targeted effort for hauling nets; (C) total catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-11.

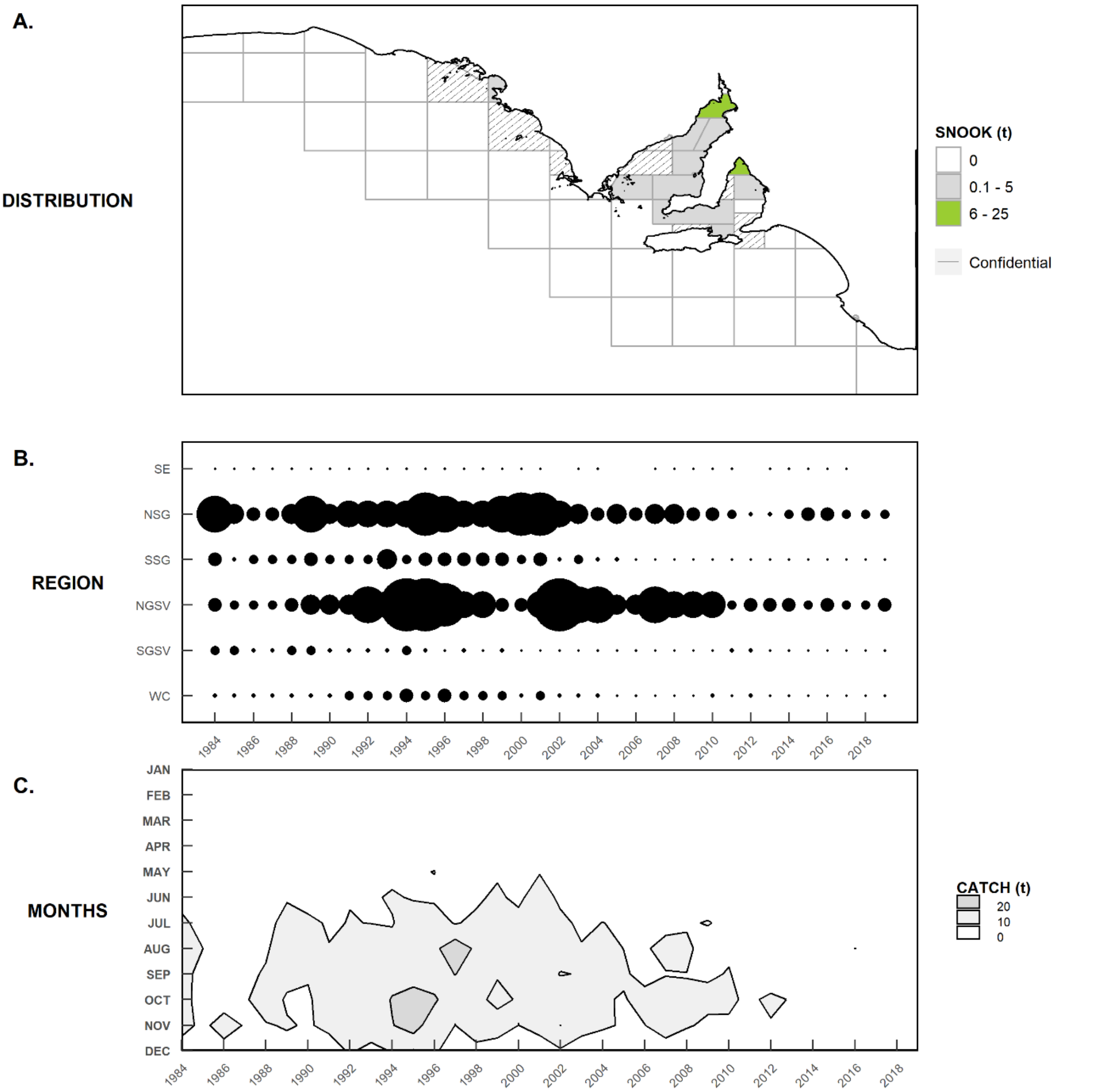

Figure 4-300. Snook. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Snook were assessed for 2019 at the State-wide scale. There was one breach of the trigger reference points, with the third lowest total catch of Snook being recorded (Table 4-11).

Table 4-11. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide scale for Snook in 2019.

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	×
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 is reflected by the relatively high numbers of fishers who report taking Snook, but the considerably fewer fishers who report targeting it.

Total catches of Snook 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 period. Nevertheless, from 1984 to the early 2000s, despite that targeted hauling net CPUE was variable they showed an increasing trend. Since then, the annual CPUE has continued to be variable with no long-term trend. The 2019 estimate indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. Furthermore, the relatively low recent catches and low targeted hauling net effort suggest that it is unlikely that the populations in the gulfs will become recruitment limited. On this basis, Snook in South Australia is classified as a **sustainable** stock.

4.3.8. BLUE CRAB

Biology

The Blue Crab (*Portunus armatus*) is distributed within near-shore, marine bays and estuarine systems in Australia and New Caledonia (Lai et al. 2010). The species occurs in a wide range of inshore habitats to a depth of at least 50 m (Williams 1982; Edgar 1990). Blue Crabs generally reach sexual maturity at carapace widths of between 70 and 90 mm (Smith 1982).

The spawning season lasts for three to four months over the summer/autumn period (Kumar et al. 2000). In South Australian waters, Blue Crabs near the Minimum Legal Size (MLS = 110 mm carapace width) have reached sexual maturity and are ~14 to 18 months old. Females produce at least two batches of eggs within a single season. Fecundity of females is size-dependent, increasing up to a carapace width of 134 mm and decreasing thereafter. Between 650,000 and 1,760,000 eggs are produced per spawning event (Kumar et al. 2000; 2003). Using allozyme markers, Bryars and Adams (1999) determined that the populations of *P. armatus* within Spencer Gulf, Gulf St Vincent and West Coast regions of South Australia represented separate sub-populations with limited gene flow.

Fishery

Blue Crabs were first harvested as by-product in South Australian Prawn and Marine Scalefish Fisheries in the 1970s. In 1981, an experimental trawl fishery with four licensed fishers was established in northern Spencer Gulf. This approach was later abandoned, and in 1983, six experimental pot fishing permits were offered to licence holders in the MSF. In 1985/86 the number of experimental licences was increased to 12, i.e. four on the West Coast, six in Spencer Gulf, and two in Gulf St Vincent. In 1986, the West Coast fishery declined and the four licence holders surrendered their entitlements. Also during 1986, the sale of Blue Crabs as by-product from the prawn fishery was prohibited.

During the early years the fishery was primarily based on the use of specialised crab pots. However, from 1998, crab pots were no longer used by the MSF as effort was transferred to the pot fishing sector of the Blue Crab Fishery (BCF).

In June 1996, management arrangements for a separate commercial BCF in South Australia were established. The BCF is based on the capture of a single species (*P. armatus*), although other crab species may also be landed. The BCF comprises two fishing zones, i.e. the Spencer Gulf and Gulf St Vincent fishing zone. An annual total allowable commercial catch (TACC) or ‘quota’ is determined for the BCF for the 12-month period from 1 July to 30 June, with separate quota units allocated for each fishing zone. Almost all of the TACC (99%) is allocated among the BCF licence holders (also referred to as ‘pot fishers’), with the remainder allocated to some

MSF licence holders. Following this, crab nets became the predominant gear type used in the MSF. Fishery-independent surveys are conducted to inform stock assessment of the BCF with the most recent report classifying the Gulf St Vincent and Spencer Gulf biological stocks as sustainable (Beckmann and Hooper 2018). The statistics in this report refer to the MSF component of the Blue Crab catch and exclude the BCF catches from 1996 onwards.

Management Regulations

Current output controls for Blue Crabs caught in South Australia include restrictions on the total commercial catch through a quota system (BCF), spatial and temporal commercial closures, bag and boat limits for recreational fishers, a minimum legal size limit (MLS) of 110 mm carapace width measured from the anterior base of the first spine, and restrictions on taking berried females.

The *Fisheries Management (General) Regulations 2007* state that Blue Crabs may also be taken from State waters within three nautical miles of the coast west of longitude 135°E, although this WC region of South Australia is not subject to quota management arrangements. Commercial pot fishers generally haul their gear once or twice every 24 hours using specifically designed crab pots covered with mesh. MSF fishers use either hoop or drop nets hauled every 20-30 minutes. Recreational fishers target Blue Crabs mostly using hoop/drop nets or hand held rakes. The most recent estimate of recreational catch was 376 t between December 2013 and November 2014 (Giri and Hall 2015).

Formalised management arrangements for the BCF include pot dimension restrictions, pot to quota unit ratios, delineation of two fishing zones in SG and GSV, and a single TACC with quota units allocated separately for each zone. Quota is transferable between the pot fishers of the BCF and eligible MSF licence holders, but only within the same zone.

The State-wide TACC for the BCF was initially set at 520 t for the 1996/97 fishing season (325 t in SG and 194 t GSV). Over the following four quota years the TACC was gradually increased to 627 t (382 t in SG and 245 t in GSV) in 2000/01, where it remained until 2012/13. In 2013/14 and 2014/15, the TACC for the GSV zone was reduced to 196 t due to stock sustainability concerns. A voluntary commercial closure in GSV was also implemented from 1 July 2013 to 15 January 2014. From 2015/16, the TACC for the GSV zone was increased to 245 t, resulting in an overall TACC of 627 t (382 t in SG and 245 t in GSV).

Since December 2016, recreational fishers have been restricted to a bag limit of 20 crabs (Blue Crabs and/or Sand Crabs combined) per person per day and a boat limit of 60 crabs per day (where 3 or more people are on board).

Commercial Fishery Statistics

State-wide

Estimates of annual, State-wide commercial catches of Blue Crabs in the MSF have been variable since the fishery commenced in 1984 (Figure 4-311a). Annual catches were comparatively low until 1988. Catches then increased between 1989 and 1995 and reached a peak of 692.9 t, before falling to 74.3 t in 1998. The total annual catch then increased to 123.9 t in 1999, declined to a minimum of 31.2 t.yr^{-1} in 2016. The total annual catch increased by 50% to 53.4 t in 2019 (*c.f.* 35.6 t in 2018). The economic value of the commercial catch of Blue Crabs in the MSF in 2019 was approximately $ 467 K (*c.f.* $ 312 K in 2018) (Fig. 4-31a).

Targeted crab net effort peaked at 5,000–7,000 fisher-days during the 90s. In the past decade, targeted effort ranged between 556 fisher-days in 2016 and 1,106 in in 2013. In 2019, target effort for Blue Crabs was 843 fisher-days (*c.f.* 688 in 2018) (Figure 4-311b).

Targeted crab net CPUE has increased from approximately 40 kg.fisher-day^{-1} in 1985 to 94.8 kg.fisher-day^{-1} in 1995, before declining to 51.8 kg.fisher-day^{-1} in 2000 (Figure 4-311c). Since then, CPUE has remained relatively stable and was 61.0 kg.fisher-day^{-1} in 2019 (*c.f.* 51.7 kg.fisher-day^{-1} in 2018). Since 1989, the numbers of fishers taking and targeting Blue Crabs have been closely linked, which indicates that this species is specifically targeted rather than being a by-product species. The number of fishers targeting Blue Crabs using pots and nets peaked in 1988, and has declined to 31 in 2019.

Regional

From 1985 to 2005, Blue Crabs were primarily harvested from NSG and NGSV (Figure 4-2a, b). Catch in NSG was highest from 1985–1997, while NGSV was highest from 1998–1997. Outside of this region, the highest catches have been taken from the WC and from 2006 onwards, a majority of the catch was harvested from this region. Lower annual catches occurred in SSG and SGSV, while no catch has been recorded the SE. From 1984–1996, the Blue Crabs were harvested all year round, with highest catches during February and March (Figure 4-32c). Since 1997 Blue Crabs harvests have been seasonal with highest catches taken between January and March.

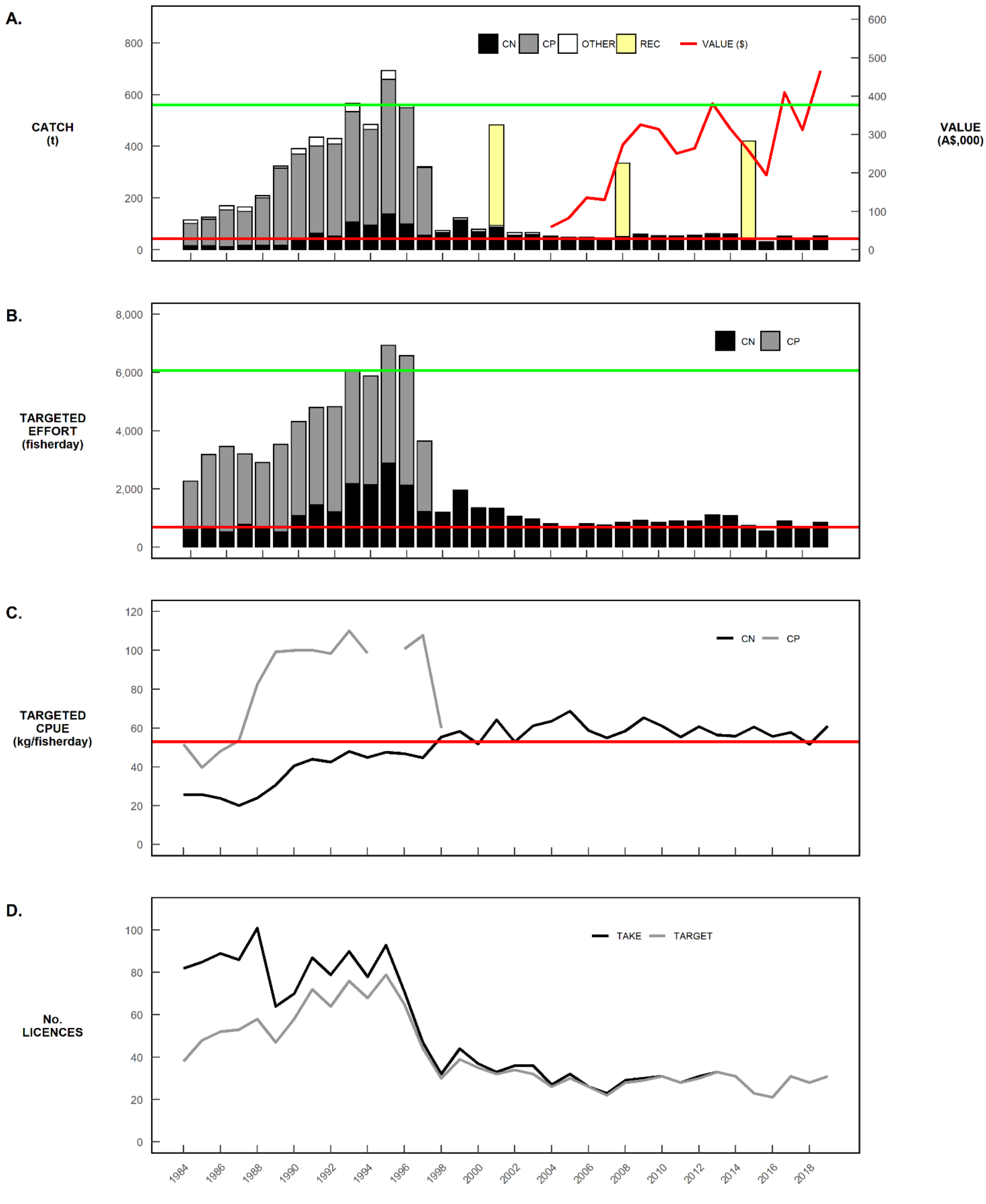

Figure 4-311. Blue Crab catch within the MSF. Long-term trends in: (A) total catch of the MSF for its main gear types (crab net/pot and other), estimates of recreational catch, and gross production value for the MSF component; (B) MSF targeted effort crab net/pots; (C) MSF total catch per unit effort (CPUE); and (D) the number of active licence holders in the MSF taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-12.

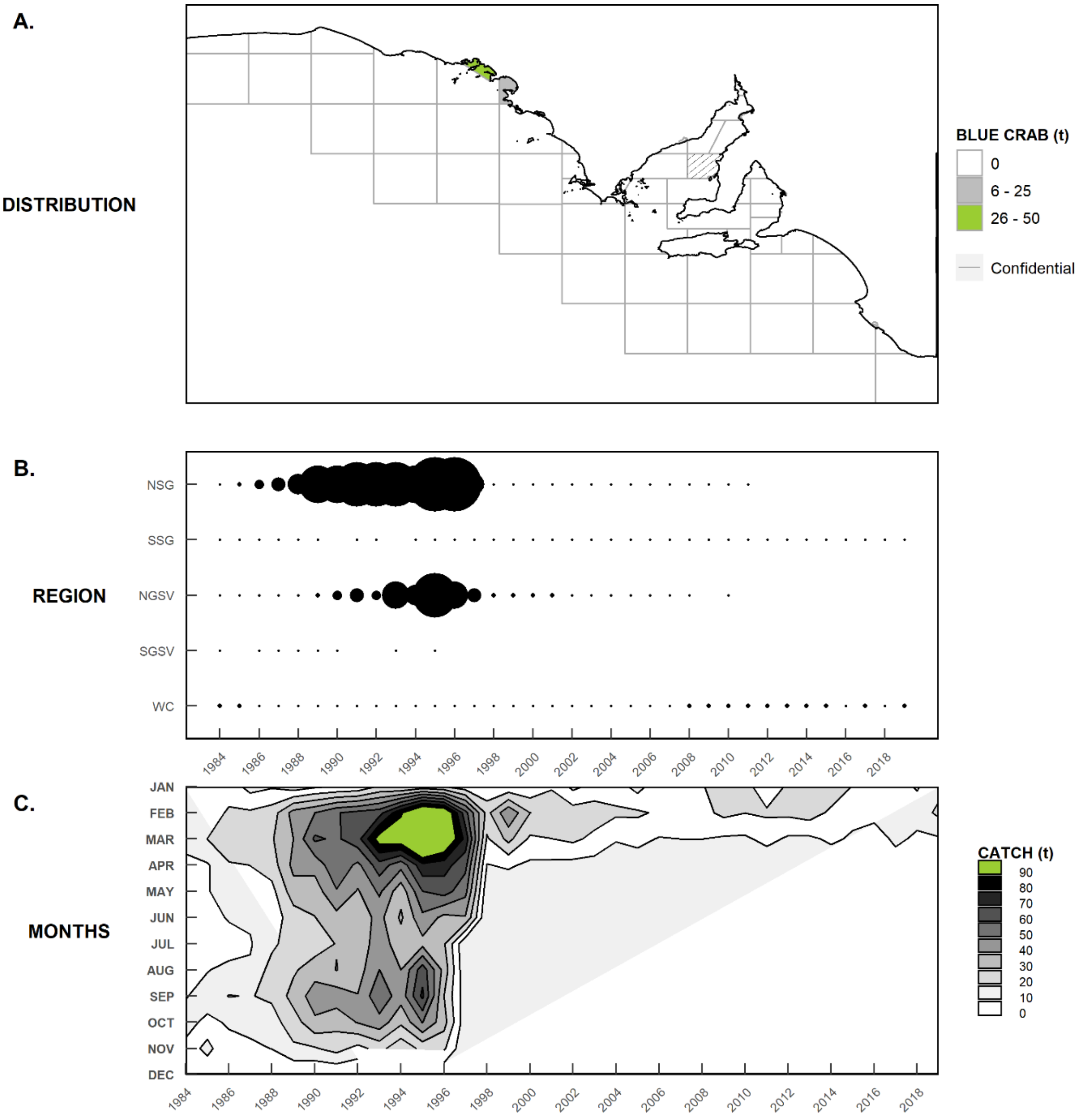

Figure 4-32. Blue Crabs catch within the MSF. (A) MSF Catch distribution for 2019. Long term trends in: (B) the annual distribution of MSF catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Blue Crabs were assessed for 2019 at the State-wide scale. No trigger reference points were activated for 2019 (Table 4-12).

Table 4-12. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide scale for Blue Crab in 2019.

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 Blue Crab resource is accessed by specialist fishers that require endorsed net or pot types on their MSF 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 transfer of MSF effort to the pot fishing sector in the gulfs. This is reflected by low catches from the Spencer Gulf and Gulf St Vincent since 2008. For the WC zone, recent catches and targeted crab net effort levels are relatively high compared to those in the past. Relatively stable CPUE and consistent catches over the past decade indicate that the biomass of this management unit (stock) is unlikely to be depleted and that recruitment is unlikely to be impaired. On this basis, the Blue Crab stock available to the MSF is classified as **sustainable**.

4.3.9. SAND CRAB

Biology

The Sand Crab (*Ovalipes australiensis*) is a medium-sized crab species with a broad distribution across southern Australia from Wide Bay in Queensland to Rottnest Island in Western Australia, including the waters of Tasmania (Kailola et al. 1993). They occur along surf beaches, in sandy bays and inlets, and in offshore waters to ~100 m depth. In South Australia, they are found in most inshore waters except the northern gulfs and west coast bays (Jones 1995), where Blue Crabs are more abundant. The stock structure of Sand Crabs is unknown.

A study into the reproductive biology of Sand Crabs in Coffin Bay determined that they are winter spawners for which reproductive activity peaks in July, with berried females present until late August (Deakin 1996). Female Sand Crabs attain sexual maturity at a smaller size than males. A measuring program undertaken in Coffin Bay during the late 1990s determined that all sampled females were below the minimum legal size of 100 mm, indicating that the regional Sand Crab fishery was essentially based on males (Jones and Deakin 1997, Jones 2000).

Fishery

In South Australia, the commercial fishery for Sand Crabs initially developed in Coffin Bay in 1982 and subsequently extended to southern coastal areas. It started as an experimental trap or pot fishery. The fishery expanded outside of Coffin Bay as fishers: began using more efficient hoop and drop nets; actively targeting Sand Crabs during the night; and implementing mechanical net haulers (Jones 1995, Jones and Deakin 1997).

Recreational fishers target Sand Crabs using hoop or drop nets from jetties along the southern metropolitan Adelaide coast and from small vessels in southern coastal waters. Approximately 52,557 Sand Crabs were captured by the recreational sector in 2013/14, 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). Commercial fishers require a specific licence endorsement to target Sand Crabs and are restricted to a nominated quantity of crab net/pots. Within the MSF there are four dedicated Sand Crab licence holders who have a combined access to 400 crab net/pots. Recreational fishers have a combined Sand/Blue Crab bag and boat limit of 20 and 60 crabs, respectively (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 4-323a). Annual catches were comparatively low until 1988. They then increased considerably between 1989 and 1990 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 these declined over the long-term to 44.2 t in 2018 before increasing to 58.8 t in 2019. During the early years the fishery was based on the use of crab pots. However, in 1989, crab nets (hoop and drop nets) were more prevalent. In the following years, the use of crab nets gradually increased, and since 1991 have dominated the fishery. The economic value of the commercial catch of Sand Crabs in the MSF in 2019 was approximately $ 452 K (*c.f.* $ 317 K in 2018) (Fig. 4-33a).

There have been three peaks in targeted fishing effort on Sand Crabs during which the effort level exceeded 1,000 fisher-days.yr^{-1} (Figure 4-33b). These were in 1989-1991, 1997-2000, and in 2005 and 2006. Since 2006, there has been a gradual decline in targeted effort, which dropped to 335 fisher-days in 2018 before increasing again to 460 fisher-days in 2019.

Targeted crab net and pot CPUE has been variable but nevertheless demonstrated a gradual, long-term increase from 76.5 kg.fisherday^{-1} in 1992 to 131.0 kg.fisherday^{-1} in 2018 before declining marginally to 127.5 kg.fisher-day^{-1} in 2019 (Figure 4-323c). 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 commercial fishers who reported taking sand crabs increased up to 45 in 1997 but have since declined to 18 in 2019. A total of 17 fishers reported targeting this species in 2019.

Regional

The fishery has been heavily concentrated in and around Coffin Bay on the West Coast (Figure 4-334a). Outside of this region, the highest catches have been taken from SSG and was where catch was concentrated in 2019. Lower annual catches have occurred in SGSV and NGSV (Figure 4-34b), 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 4-34c).

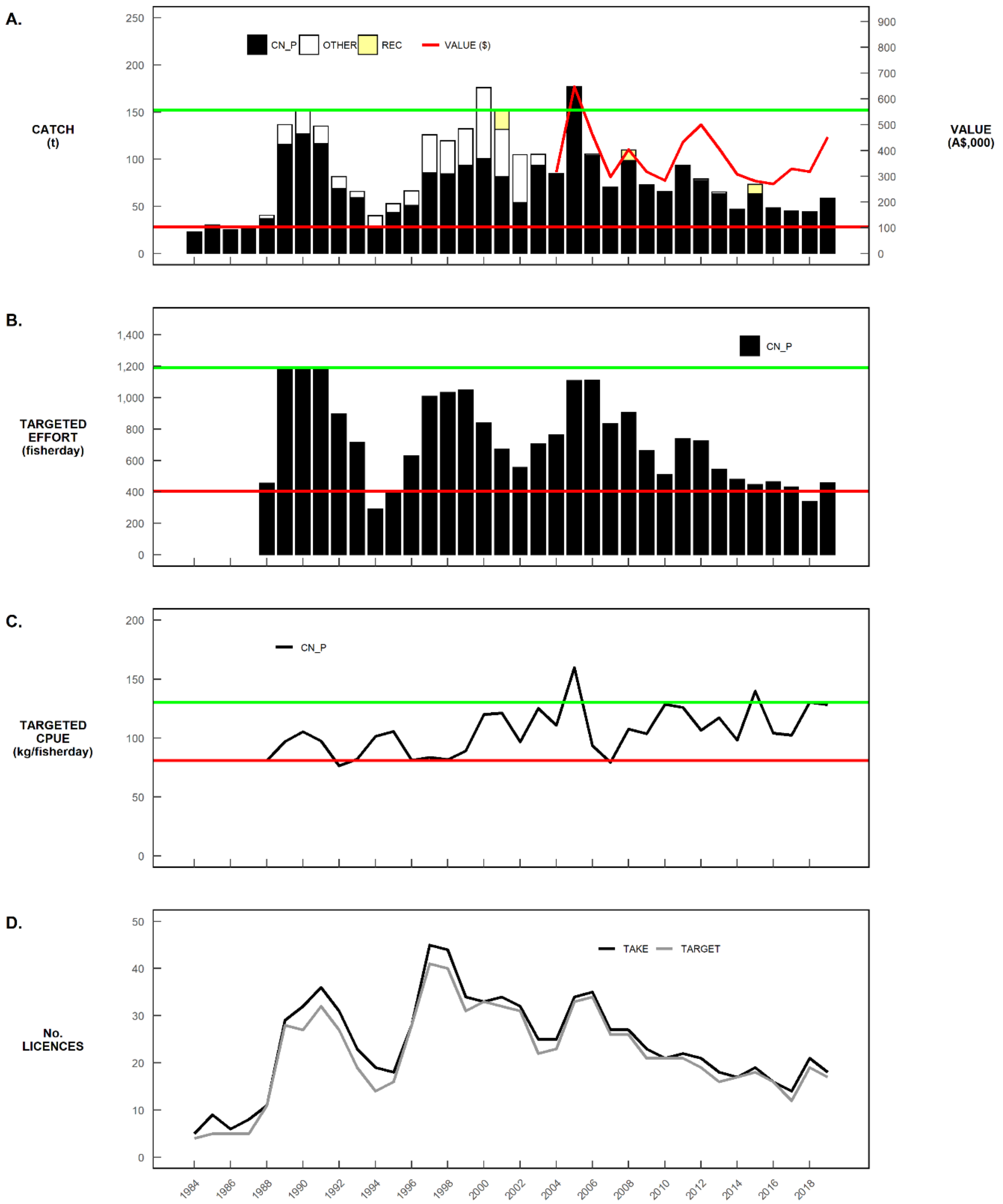

Figure 4-323. Sand Crab. Long-term trends in: (A) total catch of the main gear types (crab net/pot and other), estimates of recreational catch, and gross production value; (B) targeted effort crab net/pots; (C) targeted catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-13.

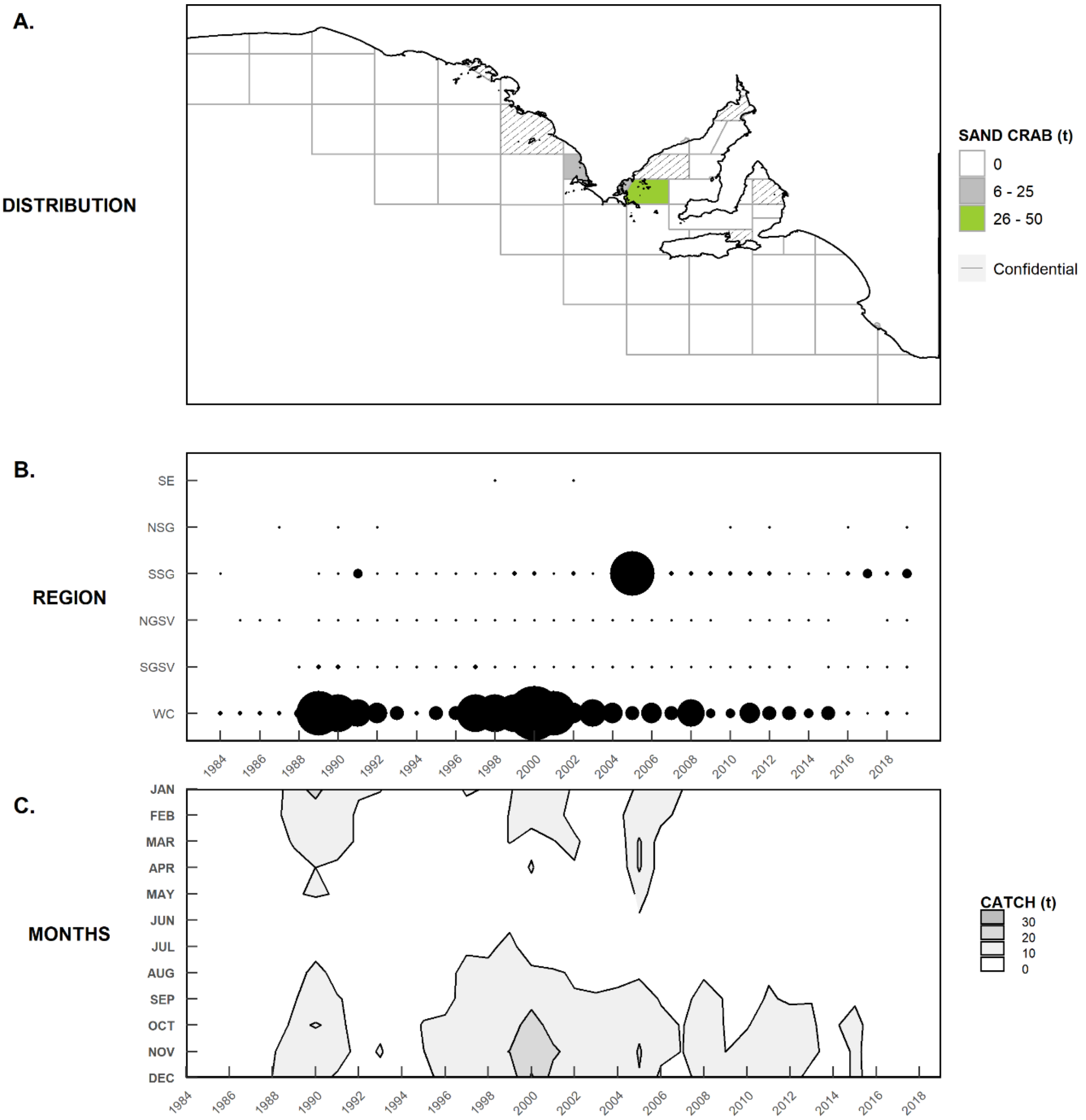

Figure 4-334. Sand Crab. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Sand Crabs were assessed for 2019 at the State-wide scale. The reference period was from 1989 onwards, when the fishers starting to target Sand Crabs with crab nets. No trigger reference points were activated.

Table 4-13. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide scale for Sand Crab in 2019.

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 commercial Sand Crab fishery involves specialist fishers that require endorsed net or pot types on their licences to target the species. Consequently, the fishery statistics considered here at the 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 to use 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 began to use portable, mechanical net haulers, allowing further modifications to net design. The commercial fishery statistics for Sand Crabs are characterised by significant inter-annual variation, although long-term trends are apparent. The trends in State-wide catch statistics are largely driven by those from the West Coast, dominated by the Coffin Bay fishery. However, catches have increased in SSG over the past three years. The recent catches and targeted crab net effort levels are relatively low compared to those in the past, whilst targeted CPUE has slowly increased throughout the 2000s. As such, these data show evidence of the increases in efficiencies in the fishery but no indication that it is becoming recruitment limited. Based on these data, South Australia's Sand Crab fishery is classified as **sustainable**.

4.3.10. YELLOWEYE MULLET

Biology

The Yelloweye Mullet (*Aldrichetta forsteri*) is a small, schooling species that inhabits estuaries and nearshore coastal waters along Australia's southern coast from Kalbarri in Western Australia to the Hunter River in New South Wales, and around Tasmania (Gomon et al. 2008; Earl et al. 2016a). Yelloweye Mullet occur over sandy and muddy substrates to depths of 20 m, and are often abundant in estuaries (Kailola et al. 1993). This species is considered a marine estuarine-opportunist, i.e. spawns at sea; regularly enters estuaries, particularly as juveniles, but also uses coastal marine waters as alternative nursery areas (Potter et al. 2015).

The biological stock structure of Yelloweye Mullet throughout southern Australia is poorly understood. Available data suggest the populations in this geographic region form two discrete biological stocks, i.e. the Western and Eastern Stocks. The South Australian populations on the Far West Coast are thought to contribute to the Western Stock (Smith et al. 2008), while populations in Spencer Gulf, Gulf St Vincent and the South East are thought to be part of the Eastern Stock (Thomson 1954; Pellizzari 2001).

In South Australia, the Yelloweye Mullet is a fast growing, short-lived species that attains a maximum length of 440 mm TL and maximum age of 10 years. Females mature at around 240 mm TL, while males mature at around 250 mm TL (Earl and Ferguson 2013). They have a protracted spawning season from winter to early autumn, with spawning most frequent during December–February.

Fishery

Yelloweye Mullet are taken by both the commercial and recreational sectors of the MSF. In the commercial sector, they are targeted and taken as by-product with hauling nets and set nets. However, 80–90% of annual State-wide commercial catches over the past decade have been taken by the Lakes and Coorong Fishery, which is not considered in this report (Earl and Bailleul 2021).

Recreational fishers target Yelloweye Mullet with rod and line. The State-wide recreational survey in 2013/14 estimated that 100,876 Yelloweye Mullet were captured, 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.

Management Regulations

Mullet spp. are considered a secondary taxa of the commercial MSF, being of medium value and making a relatively small contribution to the total production value of the fishery (PIRSA 2013). For the commercial sector, regulations are in place to manage fishing effort and limit the take of Mullet spp. These include temporal and spatial netting closures, restrictions to net lengths and mesh sizes, and a minimum legal size of 210 mm TL (PIRSA 2016).

There are multiple management regulations in place for Mullet spp. 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. These include a daily recreational bag limit of 60 fish and boat limit of 180 fish, and gear restrictions. The minimum size limit of 210 mm TL also applies to this sector.

Commercial Fishery Statistics

State-wide

The total commercial catch of Yelloweye Mullet peaked at 175 t in 1990, before declining to an historic low of 12.5 t in 2016. Catch increased marginally to 13.9 t in 2019 (*c.f.* 19.7 t in 2018). The economic value of the commercial catch of Yelloweye Mullet in 2019 was approximately $ 78 K (*c.f.* $ 110 K in 2018) (Fig. 4-35a). In recent years, 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 have been dominated by hauling nets. Total hauling net fishing effort declined from a peak of almost 6,000 fisher-days in 1984 to <500 fisher-days in 2009 (Figure 4-35b). Hauling net effort has been low yet stable and ranged between 400 and 694 fisher-days between 2014 and 2019, with 567 fisher-days recorded in 2019 (*c.f.* 658 in 2018).

Hauling net CPUE was relatively stable in the 1980s and 1990s, before it increased substantially from 22 to 50 kg.fisher-day^{-1}between 2003 and 2005 (Figure 4-35c). It remained high (30–55 kg.fisherday^{-1}) until 2012 with that period including the highest value on record (55.1 kg.fisherday^{-1}) in 2011. The hauling net CPUE has decreased to 20.3 kg.fisher-day^{-1} in 2019 (*c.f.* 26.1 kg.fisher-day^{-1} in 2018). The numbers of fishers who reported taking and targeting Yelloweye Mullet have both decreased (37 in 2019) over the time-series.

Regional

Historically, catches of Yelloweye Mullet have been reported from each of the six geographic regions of South Australia's marine waters Figure 4-36a, b). Between 1984 and 1992, the highest catches were taken in Northern and Southern Gulf St Vincent, the former remaining the major contributor since 2003. Catches in the other five regions have been low over the past decade.

Prior to 2005, the fishery was seasonal, with most catches taken between January and April of each year. There has been no clear seasonality of Yelloweye Mullet catches by the MSF during the past decade (Figure 4-36c). In 2019, MSF licence holders accounted for 95.27% of the commercial catch, with the remainder taken by SZRLF licence holders.

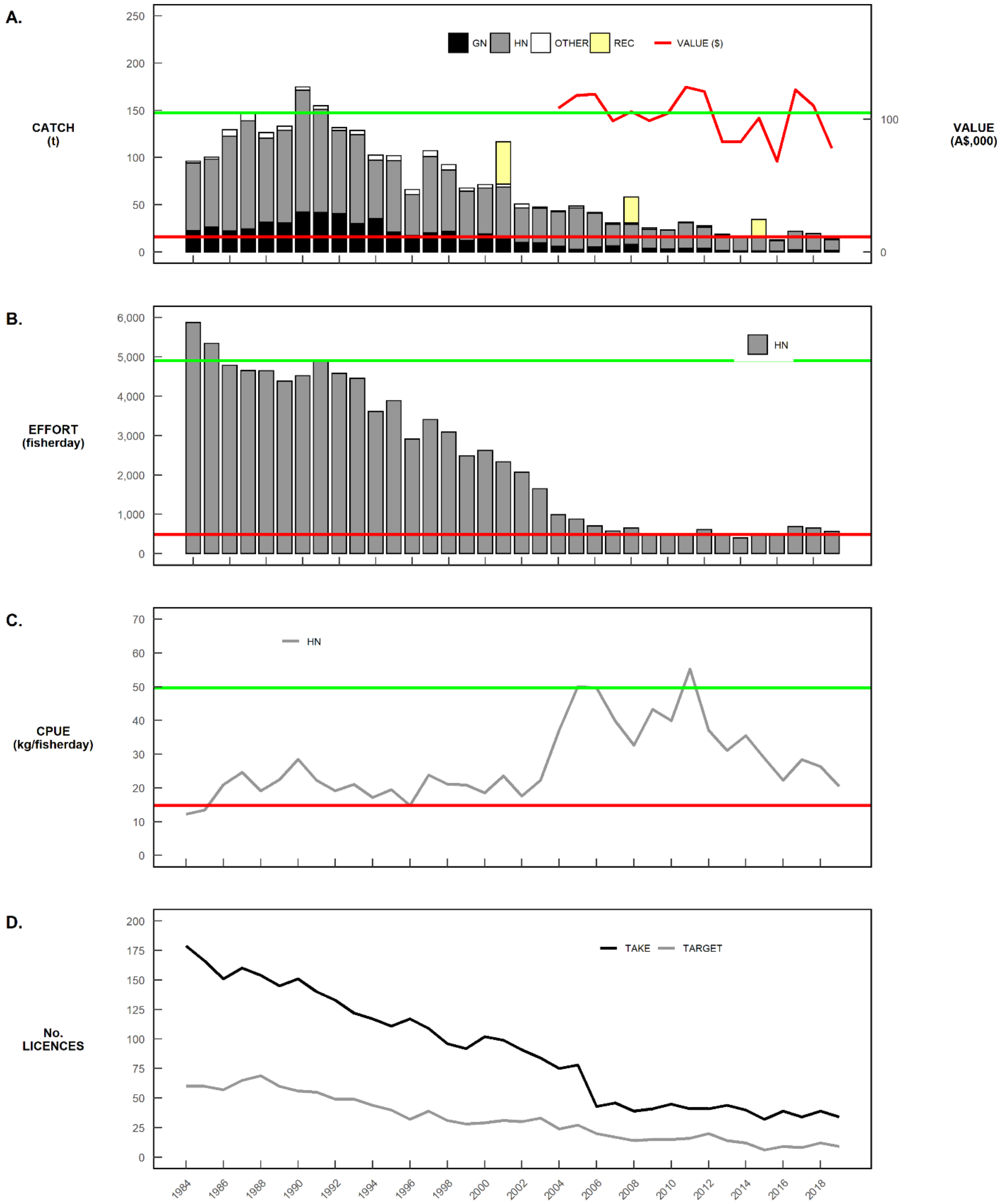

Figure 4-34. Yelloweye Mullet in the Marine Scalefish Fishery. Long-term trends in: (A) total catch in the MSF for the main gear types (hauling net and set net), estimates of recreational catch, and gross production value for the MSF; (B) MSF total effort hauling net; (C) MSF total catch per unit effort (CPUE); and (D) the number of active MSF licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-14.

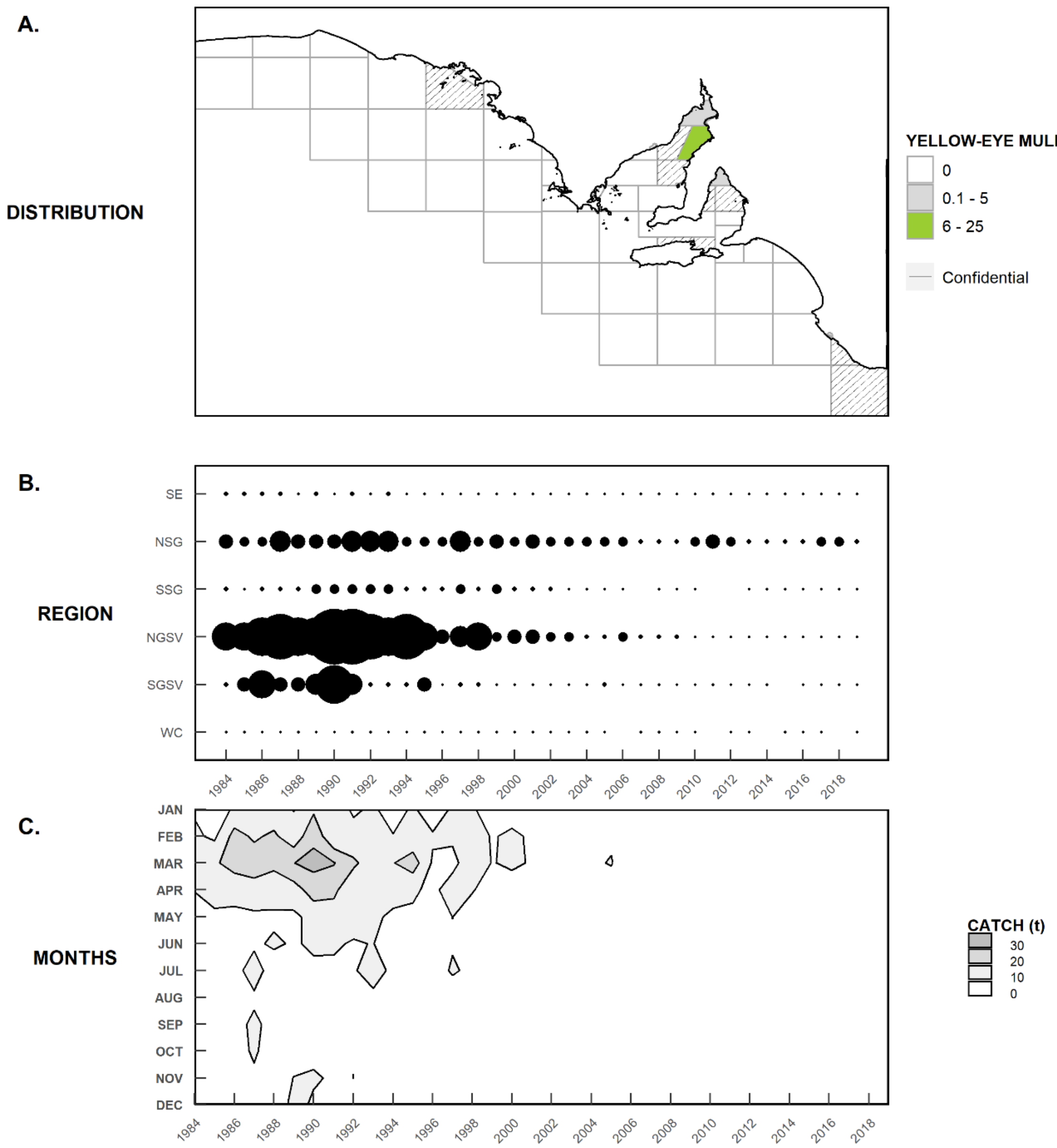

Figure 4-35. Yelloweye Mullet catches in the MSF. (A) MSF Catch distribution for 2019. Long-term trends in: (B) the annual MSF distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Yelloweye Mullet were assessed for 2019 at the State-wide scale. One trigger reference point was activated with the second lowest total catch recorded (Table 4-14).

Table 4-14. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Yelloweye Mullet in 2019.

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	×
	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 of the MSF when other species are targeted. Annual catches of Yelloweye Mullet have been low and stable for a considerable period, which reflects the declines in fishing effort in the hauling net sector of the 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. Yelloweye Mullet is predominantly caught in the Lakes and Coorong Fishery where it was recent classified as sustainable (Earl and Bailleul 2021). The above evidence indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. On this basis, the Yelloweye Mullet fishery is classified as **sustainable**.

4.3.11. MULLOWAY

Biology

Mulloway (*Argyrosomus japonicus*) is a large, schooling species that inhabits estuaries and nearshore coastal waters in subtropical to temperate regions of the Atlantic, Pacific and Indian Oceans including around southern Australia, Africa and India (Silberschneider and Gray 2008; Gomon et al. 2008). In Australia, Mulloway occur from North West Cape, Western Australia, to the Burnett River, Queensland, excluding Tasmania (Kailola et al. 1993). Juveniles are often abundant in estuaries, while adults are predominantly found in nearshore coastal waters, including the surf zone and around the mouths of rivers (Griffiths 1997).

Mulloway is a late-maturing species that can attain a maximum age of 42 years and maximum length of 2000 mm TL. In South Australia, Mulloway mature at ~780 mm TL and five years of age for males and 850 mm TL and six years of age for females (Ferguson et al. 2014). Spawning occurs from October to January each year (Ferguson et al. 2014). Regional differences in otolith morphology and chemistry, and genetic characteristics suggest distinct populations of Mulloway along the eastern and western coasts of South Australia (Ferguson et al. 2014; Barnes et al. 2015).

Fishery

In South Australia, most of the commercial catch of Mulloway is taken by the Lakes and Coorong Fishery (Earl and Ward 2014; Earl and Bailleul 2021), which is not considered in this report. However, this species is also taken by the commercial and recreational sectors of the MSF. In the commercial sector, Mulloway are taken with multiple gear types that include set nets, fishing rods and handlines. For the recreational sector, Mulloway is an iconic species that is targeted with rod and line. The State-wide recreational survey in 2013/14 estimated that 47,238 Mulloway were captured by the recreational sector of which 37,354 fish were released, leaving 9,833 fish harvested (Giri and Hall 2015). The estimated total harvest weight was 59.5 t, which was considerably higher than the annual catches of the commercial sector.

Management Regulations

Mulloway can be taken by the commercial MSF fishers in all coastal waters of South Australia, except those accessible to the commercial Lakes and Coorong Fishery (PIRSA 2014). No specific harvest strategy exists for Mulloway in the MSF (PIRSA 2013). However, multiple management regulations are used to ensure the sustainable harvest of the species. 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 applies for both sectors. For the recreational sector, a bag limit of two fish and boat limit of six fish applies in marine waters.

Commercial Fishery Statistics

State-wide

During the mid-1980s and early 1990s, total annual commercial catch of Mulloway by the MSF fluctuated between 7–15 $t.yr^{-1}$ with a peak of 24.2 t in 1995 (Figure 4-37a). Catches declined during the late 1990s, remained low during the 2000s, and then declined to a low of 1.1 t in 2016. The total commercial MSF catch of Mulloway was 5.2 t in 2019. The economic value of the commercial catch of Mulloway in 2019 was approximately $ 45.6 K (*c.f.* $ 80.8 K in 2018) (Figure 4-37a).

From 1984 to 2001, total catch was dominated by set nets and handlines. Since then, hauling nets have accounted for proportionally higher catches (Figure 4-37b). CPUE for set nets was relatively stable between 2000 and 2009, but became highly variable between 2010 and 2018 (Figure 4-37c). CPUE for handlines has shown no long-term trend from 1984 to 2018. In 2019, the CPUE for set nets and handlines were confidential.

The number of licence holders who reported taking Mulloway has declined over the long-term at a faster rate than the lower number of fishers who reported targeting the species (Figure 4-37d). The higher numbers of fishers taking (17 in 2019) Mulloway compared to those targeting the species (7 in 2019), suggests it is largely a by-product when fishing 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, with most having been taken in the South East (Figure 4-38a, b). In recent years, small catches have been reported from NGSV. Historically and overall, there is no clear seasonality for Mulloway catches by the MSF (Figure 4-38c).

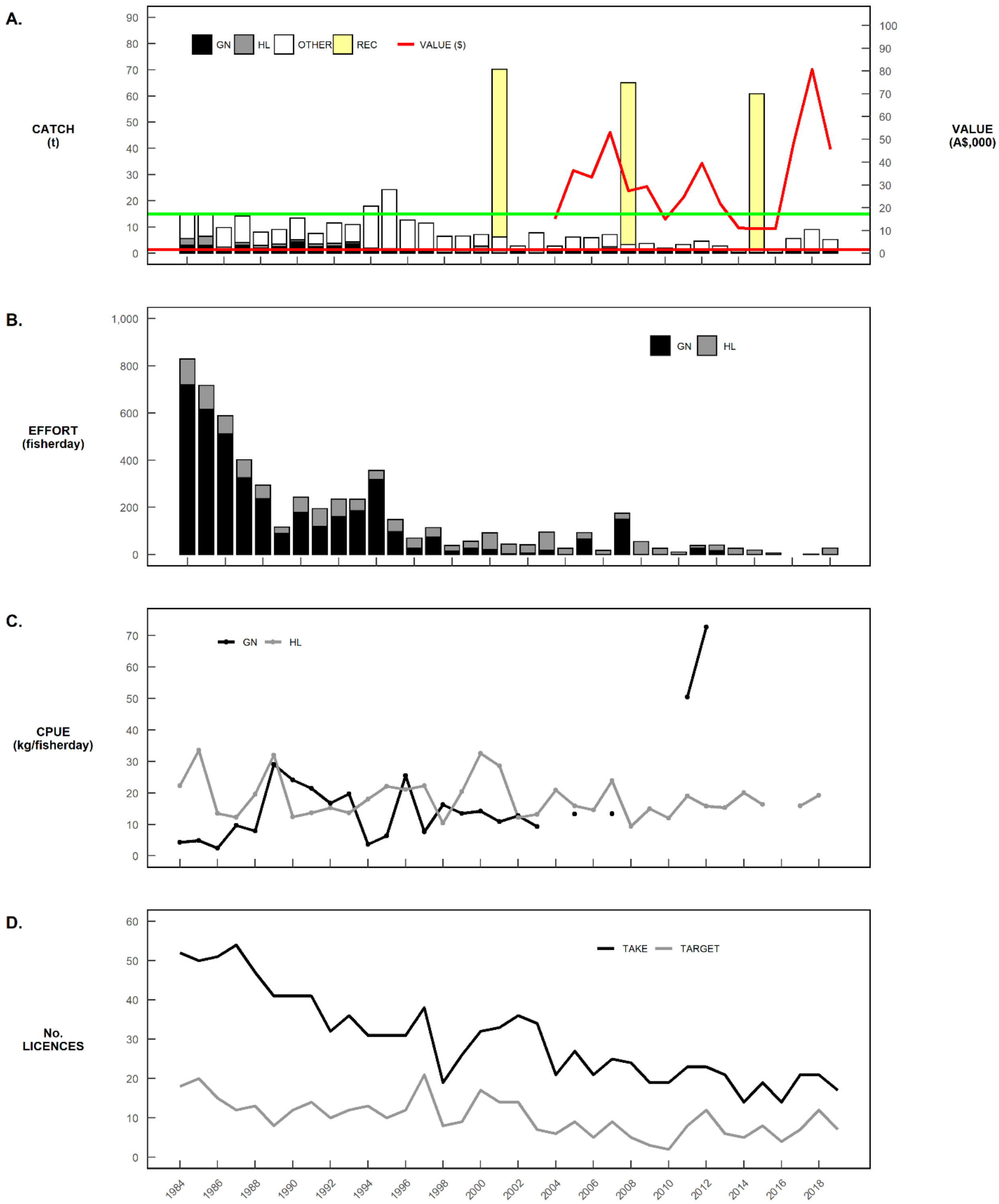

Figure 4-367. Mulloway in the Marine Scalefish Fishery. Long-term trends in: (A) MSF total catch of the main gear types (handline and set net), estimates of recreational catch, and gross production value for MSF; (B) total effort; (C) total catch per unit effort (CPUE); and (D) the number of active licence holders in the MSF taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-15.

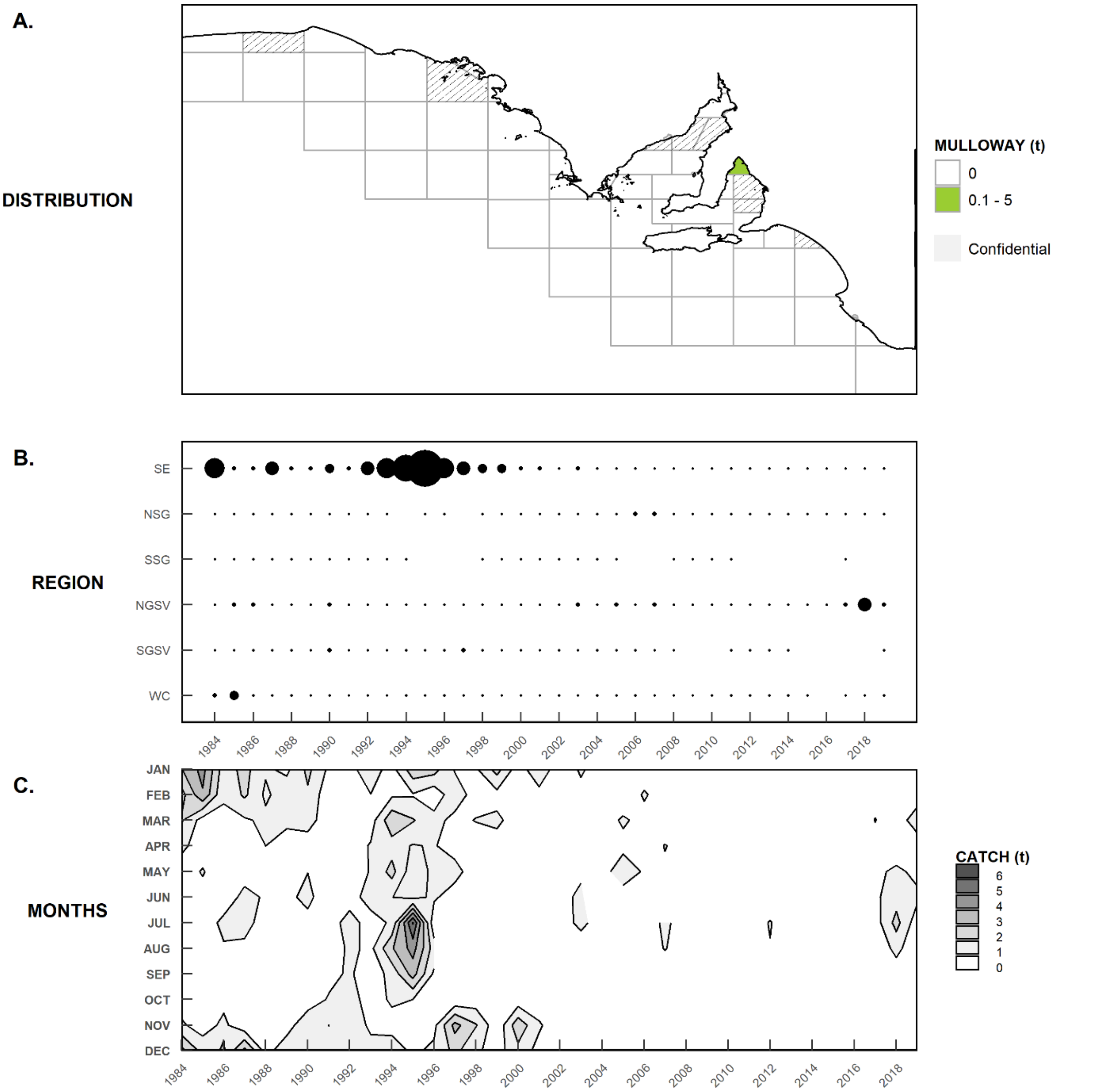

Figure 4-37. Mulloway catch in the Marine Scalefish Fishery. (A) MSF Catch distribution for 2019. Long-term trends in: (B) the annual MSF distribution of catch among regions, (C) months of the year (t), (D) the proportion of catch distributed among the marine waters commercial sector in 2019; and (E) among the State-wide MSF in 2013/14 ascertained from the latest recreational fishing survey (Giri and Hall, 2015).

Fishery Performance

The general fishery performance indicators for Mulloway were assessed for 2019 at the State-wide scale. No trigger reference points were breached (Table 4-15).

Table 4-15. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide spatial scale for Mulloway in 2019.

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	CONF.
	G	Greatest % interannual change (+/-)	CONF.
	G	Greatest 3 year trend	CONF.
	G	Decrease over 5 consecutive years	CONF.
TOTAL HAND LINE 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.
TOTAL SET 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.
TOTAL SET 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

Mulloway is of medium-high value but makes a relatively minor contribution to the commercial MSF total production value because of the low volume taken. 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. Mulloway is predominantly caught in the Lakes and Coorong Fishery where it was recent classified as sustainable (Earl and Bailleul 2021). Total commercial catch of Mulloway in the MSF 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 CPUE has generally remained consistent over the same period. The recent high CPUE indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. On this basis, the Mulloway fishery is classified as **sustainable**.

4.3.12. WHALER SHARKS

Biology

Two species of 'Whaler Sharks' including the Bronze Whaler (*Carcharhinus brachyurus*) and the Dusky Shark (*C. obscurus*) are taken in the MSF. The species can be differentiated by their physical characteristics. Bronze Whalers are copper coloured, have non-serrated teeth and lack an inter-dorsal ridge, whereas Dusky Sharks are dark brown in colour, have serrated teeth and an inter-dorsal ridge located between the first and second dorsal fin.

Female Bronze Whalers live up to 31 years and males have similar lifespans of up to 25 years. Males and females both reach sexual maturity at 16 years of age at lengths of 2.2 and 2.7 m TL, respectively (Drew et al. 2016). The breeding frequency of Bronze Whalers is poorly understood in Australian waters, yet females produce 16–24 pups per litter.

Dusky Sharks are long-lived (max ~50 years), slow growing, have a 3-year breeding frequency and only produce 3–12 pups per litter (Romine et al. 2009; McAuley et al. 2007). Large juvenile Dusky Sharks (>2.0 m) migrate between Western Australia and South Australian waters (Rogers et al. 2012). Similarly, there is preliminary evidence of east-ward and west-ward movements of Bronze Whalers between state jurisdictions (Rogers et al. 2012; 2013; Drew et al. 2019).

Fishery

Catches of Whaler Sharks in the MSF are not currently resolved to the species level and the Bronze Whalers and Dusky Sharks are combined in the logbooks. The MSF mostly uses longlines to target Whaler Sharks and in the last decade 70–90% of the total annual catches were taken using that gear type. During the years prior to the Offshore Constitutional Settlement with AFMA (pre-1999), a larger proportion (45–92%) of the catch of Whaler Sharks was taken using demersal-set gillnets.

Preliminary data suggest catch contributions of the two Whaler Shark species are spatially and temporally variable, and MSF longline catches are mostly (>90%) comprised of juvenile Bronze Whalers. The MSF predominantly targets Whaler Sharks during spring–autumn using floating and demersal set longlines in Spencer Gulf, Gulf St Vincent and along the West Coast.

Recreational fishers target Whaler Sharks during spring and summer from boats, jetties and the shore in South Australia (Jones 2008). A small number (<40 per annum) are also taken by recreational fishers in the South Australian Charter Boat Fishery (Rogers et al. 2017), and by fishers targeting Mulloway from the shore on the West Coast (Rogers et al. 2014).

Given the Dusky Shark stock (early juveniles and adults) is mostly distributed off Western Australia, the status of the biological stock is determined from assessments during the

National Status of Australian Fish Stocks (SAFS) process for the Western Australia jurisdiction. For the first time in SAFS 2020, Bronze Whalers were assessed at the single-species level. The stock has been previously assessed at the state level in the MSF based on the combined Whaler Shark catch statistics (Steer et al. 2018a, b).

Management Regulations

Whaler Sharks in the MSF are managed under input controls on longlines, set nets, drop lines and handlines. There is no commercial size limit. Management measures aimed at limiting fishing effort and mortality of larger mature individuals include, limits on the daily number of hooks that can be set (n = 200), limits on hook leader diameter (2 mm) for longlines, and mesh size restrictions (150 mm) for demersal gill nets. South Australian recreational fishery regulations for Whaler Sharks (both species) include a daily bag limit of one shark per fisher and a daily boat limit of three sharks, when there are three or more fishers on-board.

Commercial Fishery Statistics

State-wide

Annual patterns in catches of Whaler Sharks have been highly variable since 1983. Prior to 2010, peaks in total annual catches ranged between 77 and 121 t per annum (Figure 4-39a). Since 2013, annual catches have stabilised and have ranged from 45 to 63 t. The annual total commercial catch was 62.7 t in 2019 (*c.f.* 45.1 t in 2018). The economic value of the commercial catch of Whaler Sharks in 2019 increased to approximately $ 255 K (*c.f.* $ 176 K in 2018) (Figure 4-39a).

Catch trajectories were stable in the last five-year period, yet considerably lower than the last peak in 2010 (Figure 4-39a). Longlines have been the dominant gear type for taking these shark species since 2000 and comprised ~90% (40–56 t) of annual catches between 2014 and 2019. Catches taken using the net gear types have been < 3 t in the past 5 years. As with the other species assessed in this report, available data on the recreational component of the catch are scant and were based on two surveys.

Annual targeted longline effort was highly variable and increased from 35 fisher-days in 1993 to a peak of 571 fisher-days in 2010 (Figure 4-39b). Since 2014, target effort has stablised between ~150 and 300 fisher-days, and was 270 fisher-days in 2019. Targeted longline CPUE has maintained a stable trend since 1997, ranging from 104 to 215 kg.fisher-day^{-1} (Figure 4-39c). In 2019, the targeted longline catch rate was 136 kg.fisher-day^{-1}. The number of licences taking and targeting Whaler Sharks have each remained relatively stable since 2002 and have followed the same trajectories (Figure 4-39d).

Regional

The commercial catch of Whalers Sharks was mostly distributed in southern and central Spencer Gulf and Investigator Strait, Gulf St Vincent, and the West Coast (Figure 4-40a). A high proportion of the catch was landed on the West Coast in the 1980s and 1990s, the 2000s and more recently in 2017 (Figure 4-40a, b). Marine Fishing Areas (MFAs) in southern and central Spencer Gulf, supported either a greater or similar proportion of the catch between 2003 and 2012 (Figure 4-390a, b), with a notable peak in Spencer Gulf occurring in 2010. Limited catches were taken in the South-east region in the past decade. Catches mostly occurred between spring and autumn with only sporadic catches during the winter months in three years since 1984 (Figure 4–40c). The MSF licence holders accounted for 99.26% of the catch of Whaler Sharks. Of the remaining catch, only 0.7% and 0.03%, respectively, were landed by NZRLF and SZRLF licence holders in 2019 (Figure 4–40d, e).

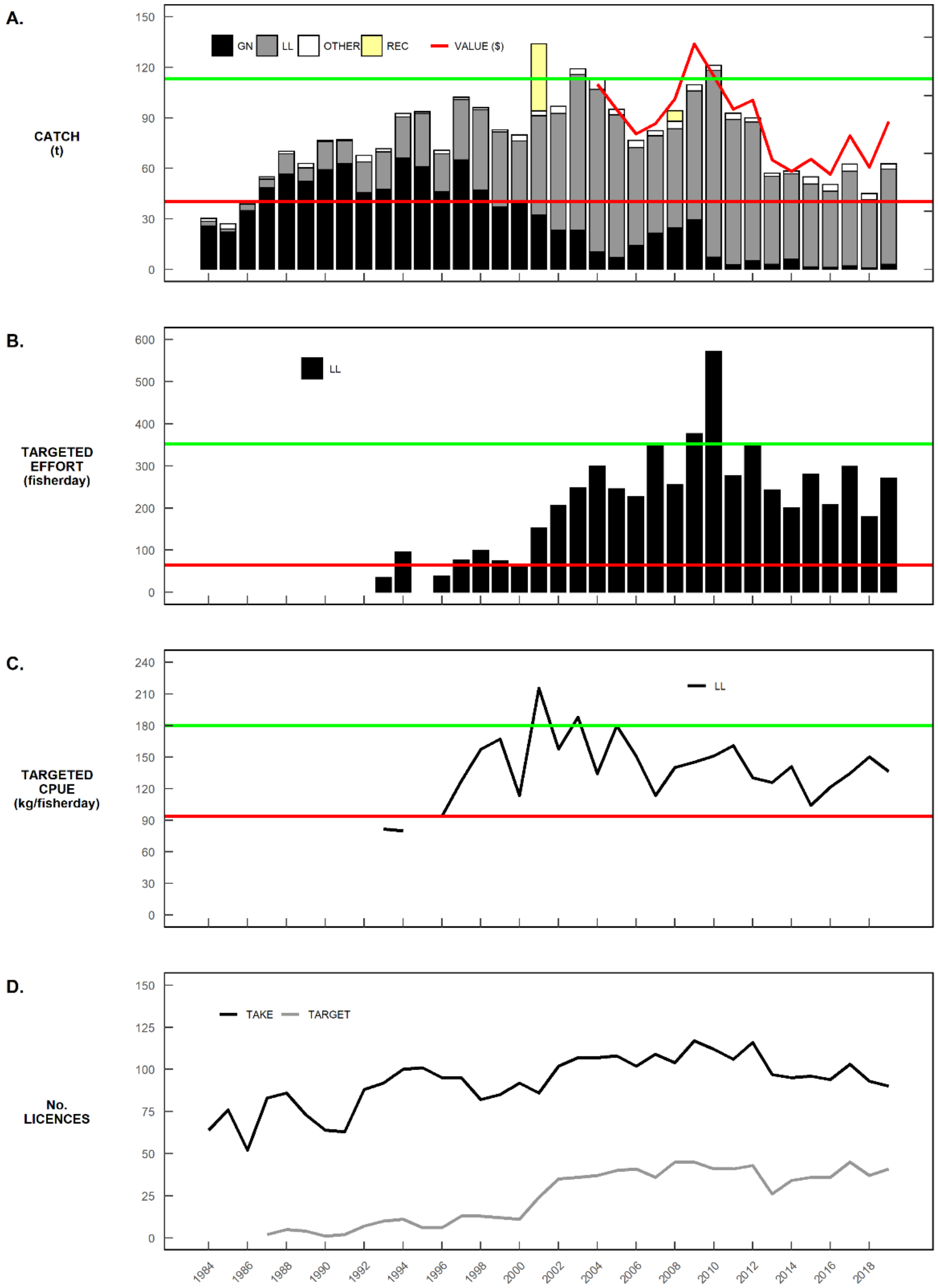

Figure 4-38. Whaler Shark in the MSF. Long-term trends in: (A) total catch of the main gear types (longline and set net), estimates of recreational catch, and gross production value; (B) total effort longline; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-16.

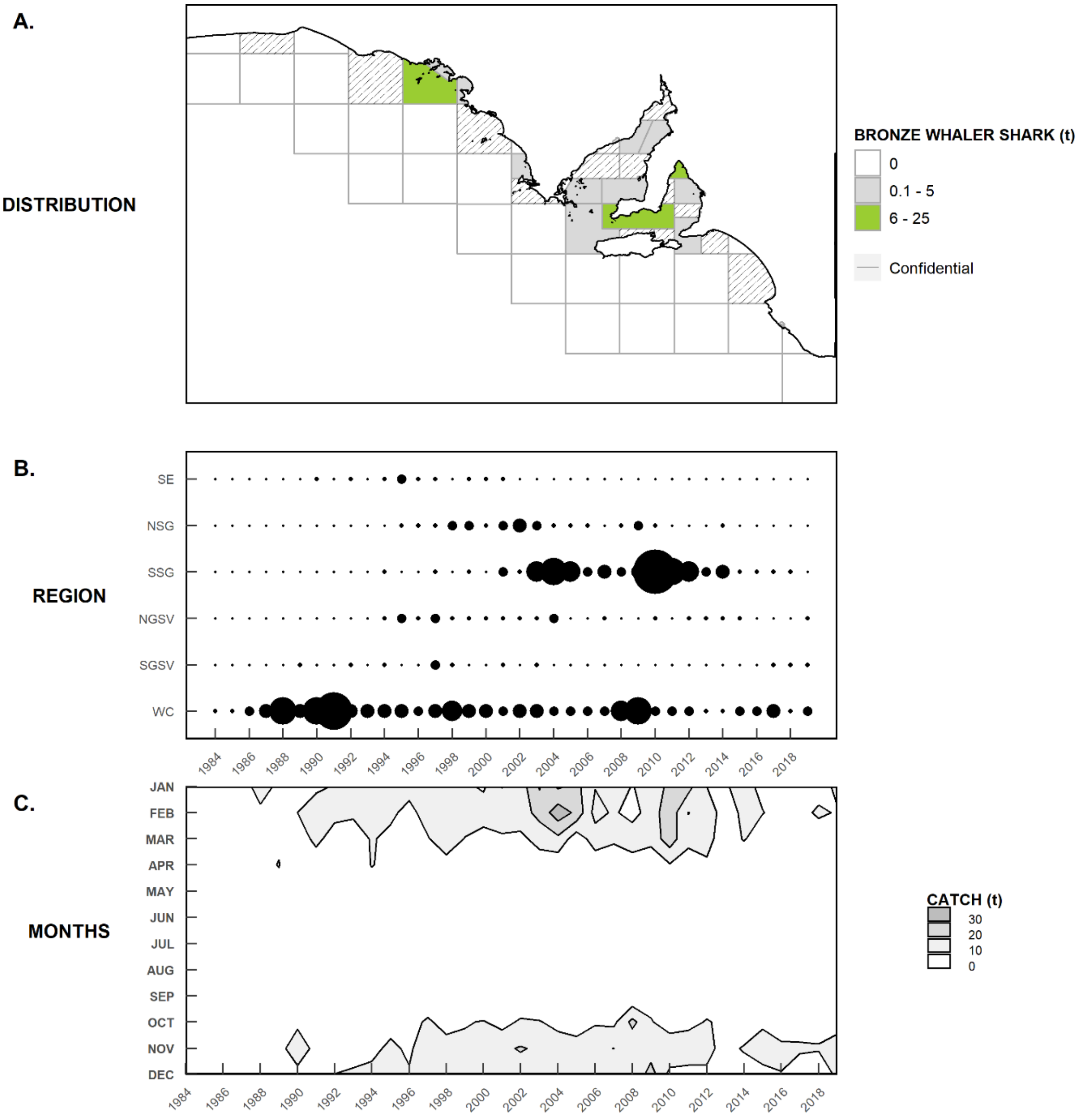

Figure 4-390. Whaler Shark catch in the MSF. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Whaler Shark species combined were assessed for 2019 at the State-wide scale. No trigger reference points were breached (Table 4-16).

Table 4-16. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Whaler Sharks in 2019.

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

There is limited information for determining stock status, and the information available is compounded by a paucity of information on the catch composition (species) of Whaler Sharks harvested. The limited data prevents assessment of current stock size or fishing pressure. Consequently, there is insufficient information available to confidently classify the status of this stock.

On the basis of the evidence provided above, the Southern Australia biological stock is classified as an **undefined** stock.

4.3.13. OCEAN JACKETS

Biology

The Ocean Jacket (*Nelusetta ayraudi*) is the largest species of Leatherjacket of southern Australia and 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 wide depth range from very shallow to >350 m, due to offshore movement associated with ontogenetic development. Juvenile Ocean Jackets occur in shallow, coastal bays whilst the adults are located over flat, sandy bottom in offshore, 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 the capacity of adults for significant long-distance movement (Grove-Jones and Burnell 1991).

The Ocean Jacket is a sexually dichromatic species that is fast-growing and short-lived, as determined from ageing work from rings in vertebrae (Grove-Jones and Burnell 1991). Most fish 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 length-at-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 offshore waters.

Fishery

As adult Ocean Jackets occur in deep, offshore waters, the fishery is essentially commercial only, 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 licence; 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 MSF licences. Currently there are four MSF licences with Ocean Jacket trap endorsements. Each licence holder has access to 20 traps, equating to a total of 80 Ocean Jacket traps that can be used by 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.

Commercial Fishery Statistics

State-wide

The reported catch for Ocean Jackets in 1990 was 930 t (Figure 4-401a). This related to a total fishing effort with fish traps of 2,095 fisher-days by 11 licence holders, and a relatively high fish trap CPUE of 444 kg.fisher-day^{-1}. In the following few years, catch and effort increased to their maxima (Figure 4-41b). Total catch was highest in 1991 at 977 t, whilst effort was highest in the following year at 2,985 fisher-days using fish traps. Total catch and effort declined between 1991 and 2000 before stabilising for several years. Since 2005, catch and effort have further declined to and remained at low levels. There were noticeable increases in catch and effort in both 2016 and 2019. Catch data for the 2018 assessment was confidential. Since 2008, the numbers of fishers who took and targeted Ocean Jackets in each year have generally been less than five (Figure 4-41d). CPUE for fish traps has been variable, shown a number of modes, ranged between 196 and 554 kg.fisher-day^{-1}, but nevertheless showed no long-term trend. There was a considerable increase in fish trap CPUE between 2013 and 2017 from 199 to 554 kg.fisher-day^{-1} (Figure 4-401c). The economic value of the commercial catch of Ocean Jackets in 2019 was approximately $ 1.2 M (*c.f.* $ 315 K in 2018) (Figure 4-41a).

Regional

Most of the catches of Ocean Jackets have been taken in two regions of 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 4-412a). Subsequently, these declined to moderate to low levels. Very high catches were reported from the WC in 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 2016 and 2019. There have only ever been incidental catches of Ocean Jackets reported from the gulf regions and the SE (Figure 4-42b). Throughout the higher catch years of 1989 to 2006, commercial catches of Ocean Jackets were distributed throughout the year, although the highest catches were taken between September and March (Figure 4-42c).

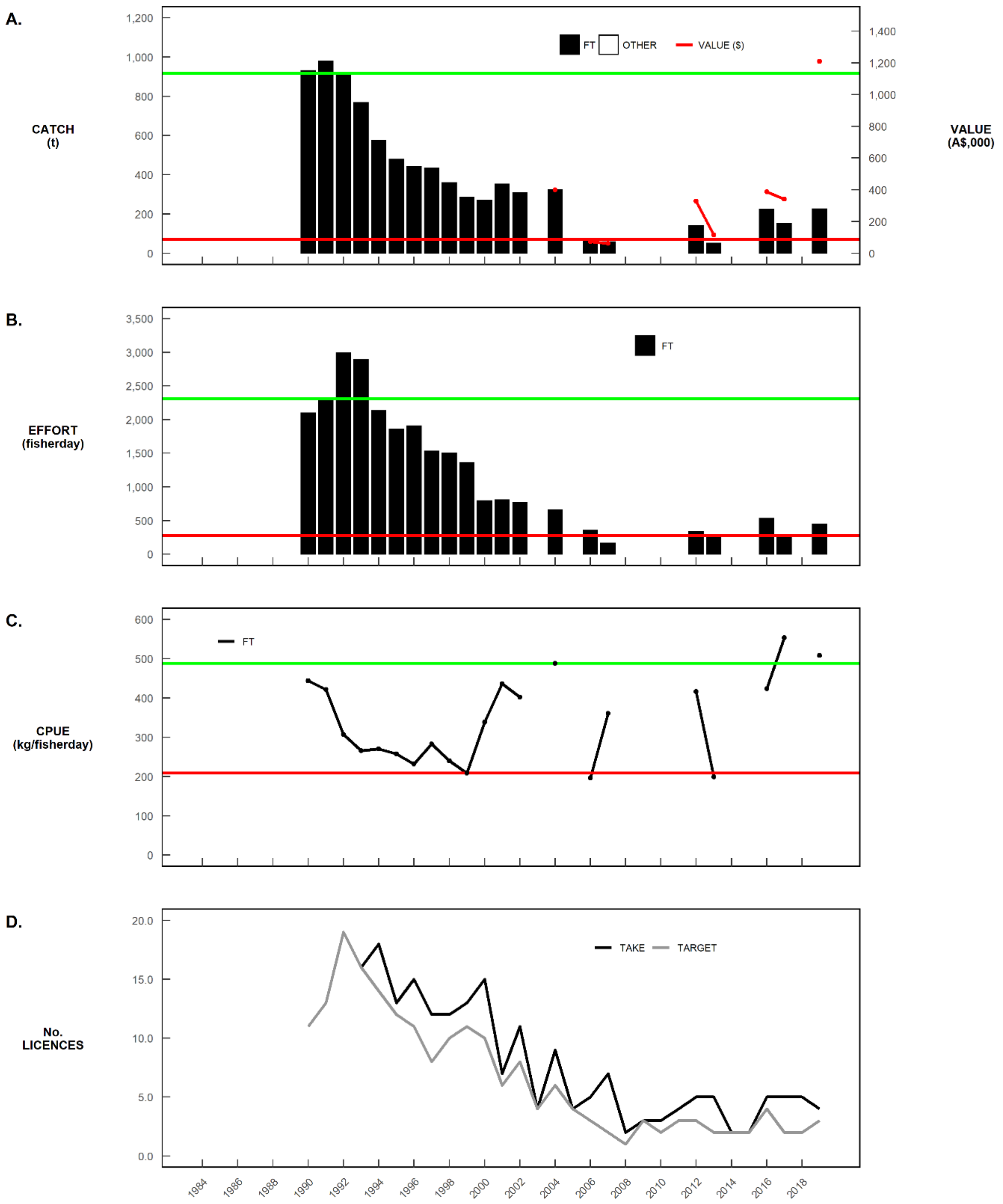

Figure 4-401. Ocean Jacket. Long-term trends in: (A) total catch of the main gear types (fish trap and other), and gross production value; (B) total effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-17.

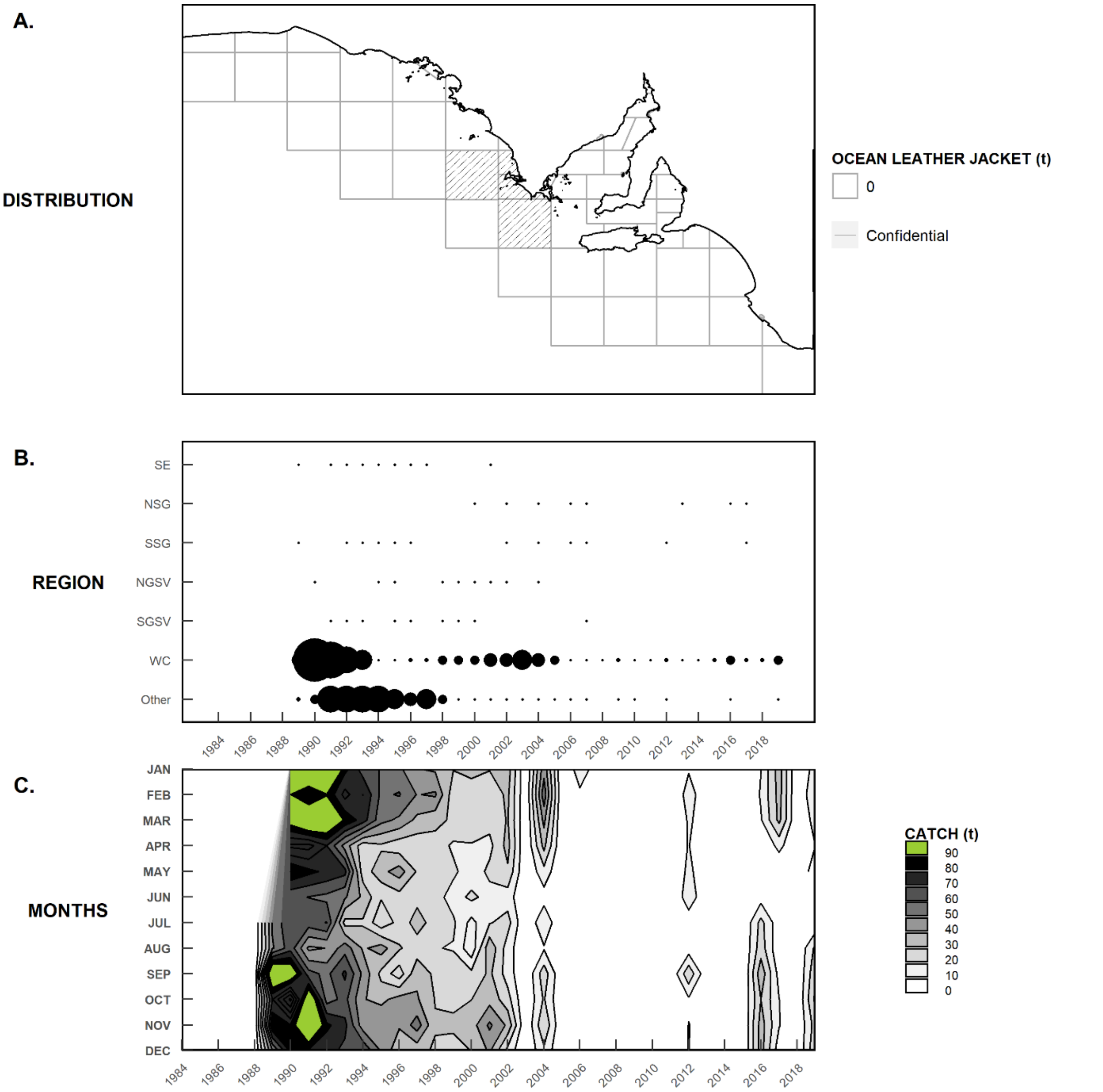

Figure 4-412. Ocean Jacket. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, and (C) months of the year.

Fishery Performance

The general fishery performance indicators for Ocean Jackets were assessed for 2019 at the State-wide scale. One trigger reference points was activated for 2019, with the second highest targeted fish trap CPUE recorded (Table 4-17).

Table 4-17. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Ocean Jacket in 2019.

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	2nd 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 resulting in an exponential increase in total annual catch that reflected both an increase in effort as new entrants came into the fishery and the geographic expansion of the fishery (Grove-Jones and Burnell 1991). The fast rate of fishery development caused concerns about sustainability, which 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 2019, the relatively low fishery catches, low level of targeted fishing effort and the recent high CPUE is unlikely to cause the stock to become recruitment impaired. As such, South Australia's Ocean Jacket fishery is classified as **sustainable**.

4.3.14. BLUETHROAT WRASSE

Biology

There are several temperate Wrasse species (Family Labridae) that occur in South Australian waters (Gomon et al. 2008, Shepherd and Baker 2008). They are associated with shallow, near-shore reef habitats, rendering them vulnerable to line fishing. Only the Bluethroat Wrasse (*Notolabrus tetricus*) is recognised as a legitimate commercial species for the MSF (PIRSA 2013). 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 extends as far west as central South Australia (Gomon et al. 2008, PIRSA 2016). The Bluethroat Wrasse occupies algal beds and reefs through the depth range of 0–50 m. It is a significant predator of 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 transitions into the territorial male within a few weeks. This complex social and reproductive strategy complicates managing the fishery 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

The Bluethroat Wrasse has historically been used as bait to target Southern Rock Lobster, but is also a commercially targeted species in the MSF (PIRSA 2013). Other labrid species are also taken in lower numbers and are reported as Parrotfish in the MSF logbooks. Consequently, it is not possible to differentiate the fishery statistics amongst the wrasse 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). For the commercial sector there is a relatively small targeted fishery for which the captured fish are sold either as fresh or as live product by the Sydney Fish Market. Alternatively, they are captured as by-product when other more valuable species are targeted. As such, there are considerable differences between the numbers of fishers who report taking Bluethroat Wrasse, and those who specifically 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 01 December 2016 there was no size limits or 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 harvest 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, these 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 4-423a). In 1997 it increased considerably after which it remained at >20 $t.yr^{-1}$ until 2004. Since then it has fallen and generally been <20 $t.yr^{-1}$, with considerable decline between 2012 and 2019. The total catch of 7.3 t in 2019 was the lowest since 1996. The economic value of the commercial catch of Bluethroat Wrasse in 2019 was approximately $43 K (c.f. $46 K in 2018) (Figure 4-43a). Up to 2004, the catch was predominantly caught using handlines. Subsequently, the proportion taken on longlines increased considerably, although in 2019 the proportional breakdown has changed back to being dominated by handlines.

Between 1984 and 1991, total line effort was low, before it increased considerably up to 1997. Since then it has been highly variable (Figure 4-423b). From 2005, the proportion of total line effort accounted for by longlines has increased considerably. In 2010, the highest level of effort and the highest proportional contribution from longlines were recorded. Since 2010, effort has declined, as has the proportional contribution from longlines. Between 1984 and 1996, total line CPUE was low, before it increased considerably up to 2000 (Figure 4-43c). Over the following nine years there was a gradual decline in CPUE before it stabilised between 2009 and 2017. In 2018 there was a 37.8% drop in CPUE from 21.7 to 13.5 $kg.fisherday^{-1}$. In 2019, the catch rate declined further to 12.6 $kg.fisherday^{-1}$.

Since 1984, there has been a disparity between the high numbers of fishers who reported taking Bluethroat Wrasse and those who targeted it (Figure 4-423d). The former increased up to 2013, but since then has declined from 74 to 38 fishers in 2019. The numbers who targeted this species have declined since 2015 dropping from 21 to 6 fishers in 2019.

Regional

Since 1997, the WC has provided the highest catches of Bluethroat Wrasse with SSG as the next most significant region. Only incidental catches have been reported from the other four regions (Figure 4-434a). Catches have not been concentrated in any season but have been distributed throughout the year (Figure 4-434c).

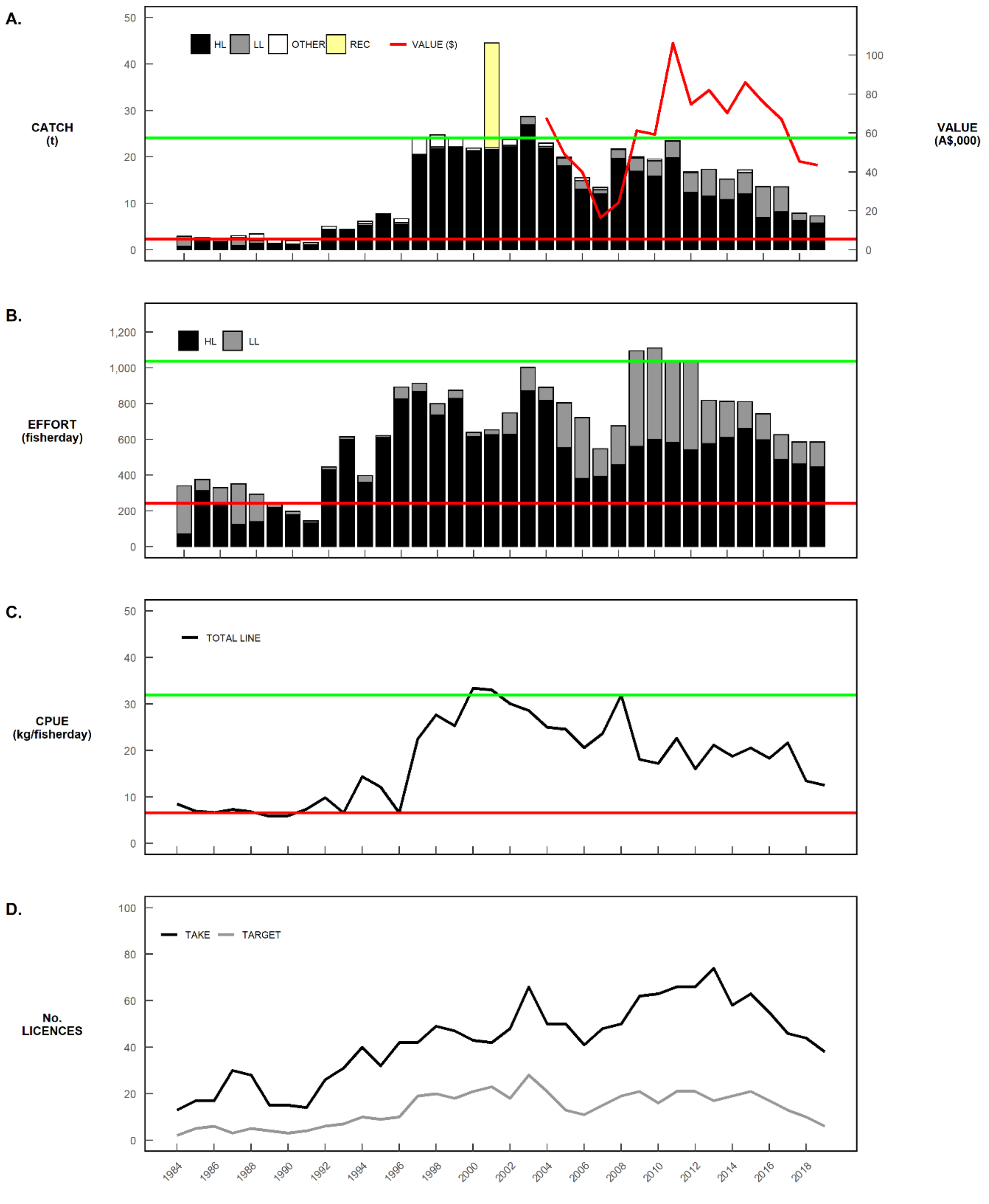

Figure 4-423. Bluethroat Wrasse. Long-term trends in: (A) total catch of the main gear types (handline and longline), estimate of recreational catch, and gross production value; (B) total line effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-18.

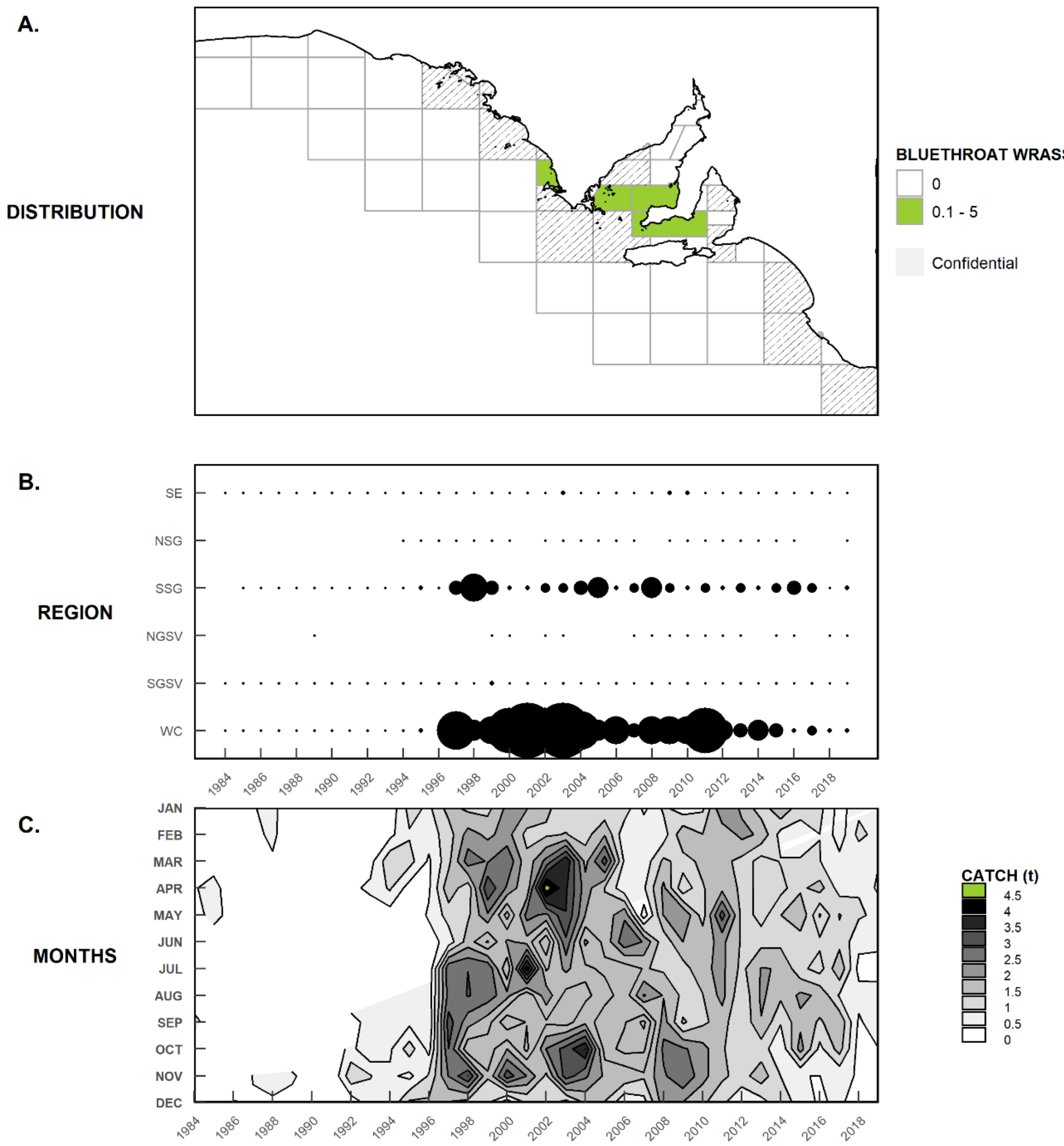

Figure 4-434. Bluethroat Wrasse. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Bluethroat Wrasse were assessed for 2019 at the State-wide scale. Total line effort combined across handline and longline fishing methods consistently declined over five consecutive years, breaching the associated trigger reference point (Table 4-18).

Table 4-18. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide spatial scale for Bluethroat Wrasse in 2019.

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 LINE EFFORT	G	3rd Lowest / 3rd Highest	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	✓
TOTAL 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 total annual 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 2011, corresponding with a general decline in longline effort. The latter decline is evident as the single trigger reference point that was activated. From 2011 to 2017, annual CPUE was relatively stable around a medium level. However, in 2018, there were notable declines in both total catch and CPUE, which continued into 2019. As such, the recent estimates of catch and catch rate are considerably lower than the high values recorded through the peak period of the early 2000s, but nevertheless remain higher than the low levels of the 1980s and 1990s. The declines in commercial catch and catch rate in 2018 which were maintained in 2019 are not yet sufficient to indicate that a change in stock status is warranted. As a result, the Bluethroat Wrasse stock is classified as **sustainable**.

4.3.15. SILVER TREVALLY

Biology

The Silver Trevally (*Pseudocaranx georgianus*) is distributed from Coffs Harbour in New South Wales (NSW) across southern Australia to Perth in Western Australia (Stewart 2015). It forms schools over sandy bottom in estuaries, as well as gulf, nearshore coastal and shelf waters, where it feeds on small fish, benthic and pelagic invertebrates.

The population biology of Silver Trevally in South Australian waters is poorly understood. They are slow-growing and live up to 25 years in NSW waters (Stewart 2015), and 33 years in New Zealand waters (Langley 2004). Spawning occurs 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 Marine Scalefish Fishery (MSF). In South Australia, the commercial catches have been dominated by MSF fishers, with only incidental catches reported by the Northern Zone Rock Lobster Fishery (NZRLF). Handline catches account for the majority of commercial catches, with smaller contributions taken using net gear types.

The recreational catch is taken using rods and lines and is substantial relative to the commercial catch. The State-wide recreational survey in 2013/14 estimated that 73,924 Silver Trevally were captured by the recreational sector, of which 57,140 were harvested. The estimated total recreational harvest weight was 14.6 t (Giri and Hall 2015).

Management Regulations

Silver Trevally is considered a tertiary species of the commercial MSF, being of low-medium value and making a minor contribution to the total production value of the fishery (PIRSA 2013). For the commercial sector, regulations are in place that manage fishing effort and limit the take of this species. These include temporal and spatial netting closures, restrictions to net lengths and mesh sizes, and a minimum legal size of 240 mm TL (PIRSA 2016).

For the recreational sector, there are multiple management regulations in place for Silver Trevally. Input and output controls ensure that the total catch is maintained within sustainable limits and that access is distributed equitably among fishers. These include a daily bag limit of 20 fish and boat limit of 60 fish, as well as gear restrictions. The minimum size limit of 240 mm TL also applies to the recreational sector.

Commercial Fishery Statistics

State-wide

Total annual commercial catch of Silver Trevally has been highly variable, ranging from 2.1 t in 1985 to 21 t in 2000 (Figure 4-445a). From 1984 to 1991, catches were low and rarely exceeded 4.5 $t.yr^{-1}$. Since then, they have ranged from 5–15 $t.yr^{-1}$, except for the peak catch of 21 t taken in 2000. The total catch of 6.9 t in 2019 was a considerable drop from the 10.5 t taken in 2017. The economic value of the commercial catch of Silver Trevally in 2019 was approximately $ 50.5 K (*c.f.* $ 31 K in 2018) (Figure 4-45a).

Since 1992, handline catches have contributed most to annual catches, with the remainder taken using various net types. Handline fishing effort that produced catches of Silver Trevally has varied cyclically since the mid-1980s (Figure 4-445b). It was 129–395 $fisher\text{-}days.yr^{-1}$ during the 1980s, increased to a peak of 1167 fisher-days in 1993, and declined to 261 fisher-days in 2001. It increased to a further peak of 802 fisher-days in 2015, has been variable since, and was 786 fisher-days in 2019. Handline CPUE has increased slowly over the long-term. The high catch in 2000 was associated with uncharacteristically high CPUE which declined in the following year. It then increased to 16.7 kg.fisher-day-1 in 2006, but has shown a long-term decline to 8.13 kg.fisher-day-1 in 2019 (Figure 4-45c). Historically, there has been a considerable difference between the numbers of licence holders who take Silver Trevally compared with those who target this species. The former has often been >50 $fishers.yr^{-1}$, whilst the latter have generally been <10 $fishers.yr^{-1}$ (Figure 4-445d). This suggests that for many fishers, Silver Trevally has been taken as by-product when they fished for more valuable species.

Regional

Catches of Silver Trevally have been reported from each of the six regions in most years since 1984 (Figure 4-456a). Since 2000, the majority of catches have been taken from Southern Spencer Gulf during May, June and July (Figure 4-456c). In 2019, MSF fishers took 99.8% of the commercial catch with the NZRL fishers taking the remaining 0.2%.

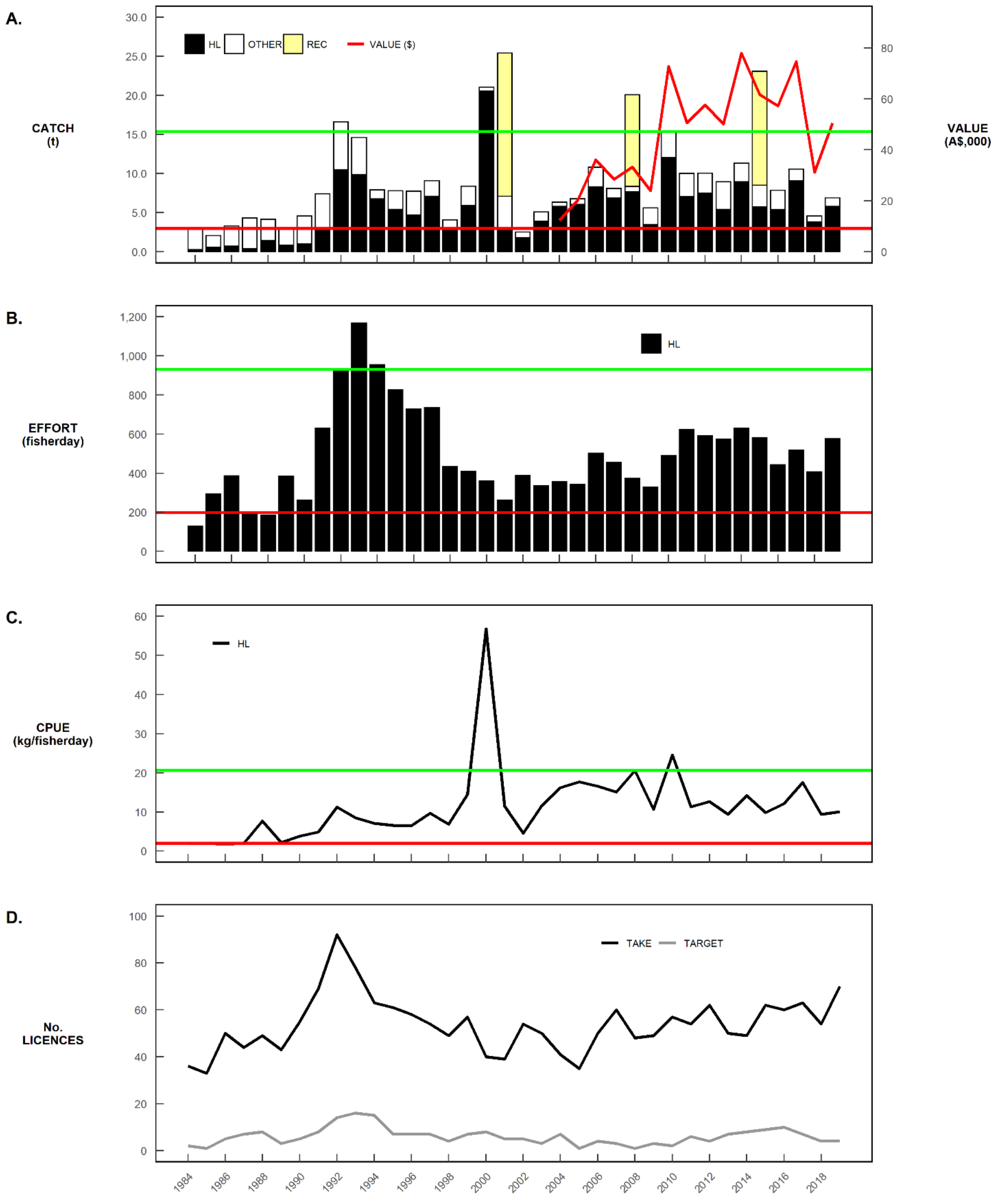

Figure 4-445. Silver Trevally. Long-term trends in: (A) total catch of the main gear types (handline and other), estimates of recreational catch, and gross production value; (B) total handline effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-19.

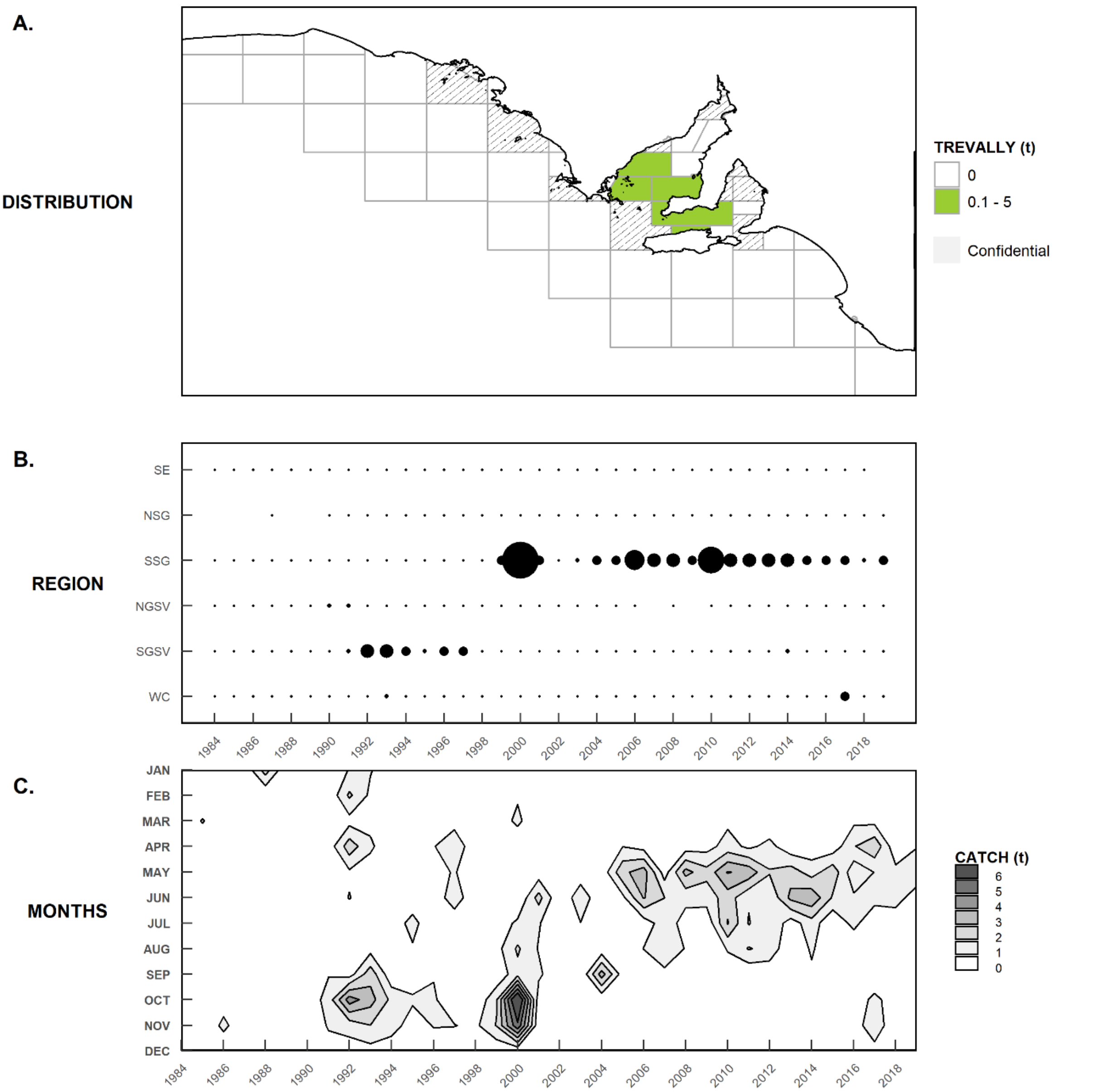

Figure 4-456. Silver Trevally catch in the MSF. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Silver Trevally were assessed for 2019 at the State-wide scale. No trigger reference points were breached (Table 4-19).

Table 4-19. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State-wide spatial scale for Silver Trevally in 2019.

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 sector of the MSF. Relatively few fishers actively 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. Over the decade prior to 2018, estimates of total catch, handline effort and handline CPUE for Silver Trevally were stable at moderate levels. In 2018, each of these performance indicators showed a downturn, but no trigger reference points were breached. In 2019, there has been some recovery in catch and effort, but CPUE has remained flat, whilst again no trigger reference points have been breached. The recent trends in fishery performance indicators suggest that it is unlikely that the Silver Trevally population in South Australia will become recruitment limited. On this basis, it is classified here as a **sustainable** stock.

4.3.16. LEATHERJACKETS

Biology

Of 19 species of Leatherjackets (Monacanthidae) that occur in the waters of southern Australia, at least six species inhabit coastal reef habitats in South Australia. Leatherjacket species are characterised by having a compressed, deep body, prominent dorsal spine above the eyes and leathery skin (Gomon et al. 2008). Most are sexually dimorphic in body shape and colouration. They are omnivores that feed on small invertebrates, algal turfs and seagrass (Shepherd and Baker 2008). The Ocean Jacket (*Nelusetta ayraudi*) is the predominant species of Leatherjacket caught in the MSF by a large margin. Therefore, this species is assessed independently. The current chapter assesses the remaining species of Leatherjackets caught in the MSF as a species complex.

For South Australia's MSF, anecdotal evidence suggests that the Horseshoe Leatherjacket (*Meuschenia hippocrepis*) and the Sixspine Leatherjacket (*M. freycineti*) are the dominant species taken, following Ocean Jackets. Nevertheless, mixed species catches are reported collectively 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.

Fishery

In South Australia, Leatherjacket species are taken in the commercial and recreational sectors of the MSF. For the commercial sector, Leatherjackets are predominantly taken as by-product when more valuable species are targeted; however, a small number of fishers also target these species. Leatherjackets are mostly caught using hauling nets or handlines, but are also susceptible to fish traps.

Leatherjacket species are taken with rod and line by recreational fishers. In 2013/14, an estimated 121,962 Leatherjackets were captured by this sector of which 75,787 fish were released, and 46,175 fish retained (Giri and Hall 2015). No estimate of total State-wide harvest weight is available for Leatherjacket spp. taken for the recreational sector.

Management Regulations

All species of Leatherjackets are permitted in the commercial sector of the MSF (PIRSA 2014). They are classified as tertiary taxa in the commercial MSF Management Plan as they have 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 catches for Leatherjackets were highest during the early 1990s when they varied between 50–70 t. Total catch declined regularly over the long-term to the lowest recorded level of 10.5 t in 2014 (Figure 4-467a). Since 2014, catches peaked at 34.1 t in 2016, and have decreased to 16.9 t in 2019. The economic value of the commercial catch of Leatherjackets in 2019 was approximately $ 68.9 K (*c.f.* $103.6 K in 2018) (Figure 4-47a).

Since 1990, generally >50% of the annual catches were taken with hauling nets. The second major gear type that contributed to catches of Leatherjackets was handlines, for which the annual catches peaked at 5.5 t in 1997. Annual estimates of total fishing effort that produced catches of Leatherjackets have always been dominated by hauling nets. Hauling net effort has consistently declined from its peak of 4,860 fisher-days in 1992 to 676 fisher-days in 2014 before increasing in recent years, attaining 891 fisher-days in 2019 (Figure 4-467b).

Between 1990 and 2001, hauling net CPUE was relatively consistent until it declined in 2002 to its lowest recorded level of 6 kg.fisher-day^{-1} (Figure 4-47c). Nevertheless, it increased to 18.1 kg.fisher-day^{-1} in 2004 and since then has remained relatively high, i.e. between 12–19 kg.fisher-day^{-1}. Hauling net CPUE peaked at 22.3 kg.fisher-day^{-1} in 2018 and has marginally declined to 16.8 kg.fisher-day^{-1} in 2019.

The number of fishers who reported taking Leatherjackets has declined from 141 in 1990 to 75 fishers in 2014, and has remained at 77 fishers in 2019. An average of 12 fishers.yr^{-1} reported that they actively targeted these species since 1984, with eight fishers targeting Leatherjackets in 2019. The higher numbers of fishers who took Leatherjackets compared to those who targeted it suggests that this taxon has largely been a by-product when more valuable species were targeted (Figure 4-467d).

Regional

Between 1990 and 2018, NSG and NGSV provided the highest catches of Leatherjackets. Incidental catches were taken from the other four regions (Figure 4-4848a). Historically, catches have been highest between March and October (Figure 4-4848c). In 2019, the MSF fishers accounted for 99.43% of the commercial catch, whilst the Northern and Southern Zone Rock Lobster fishers accounted for the remainder.

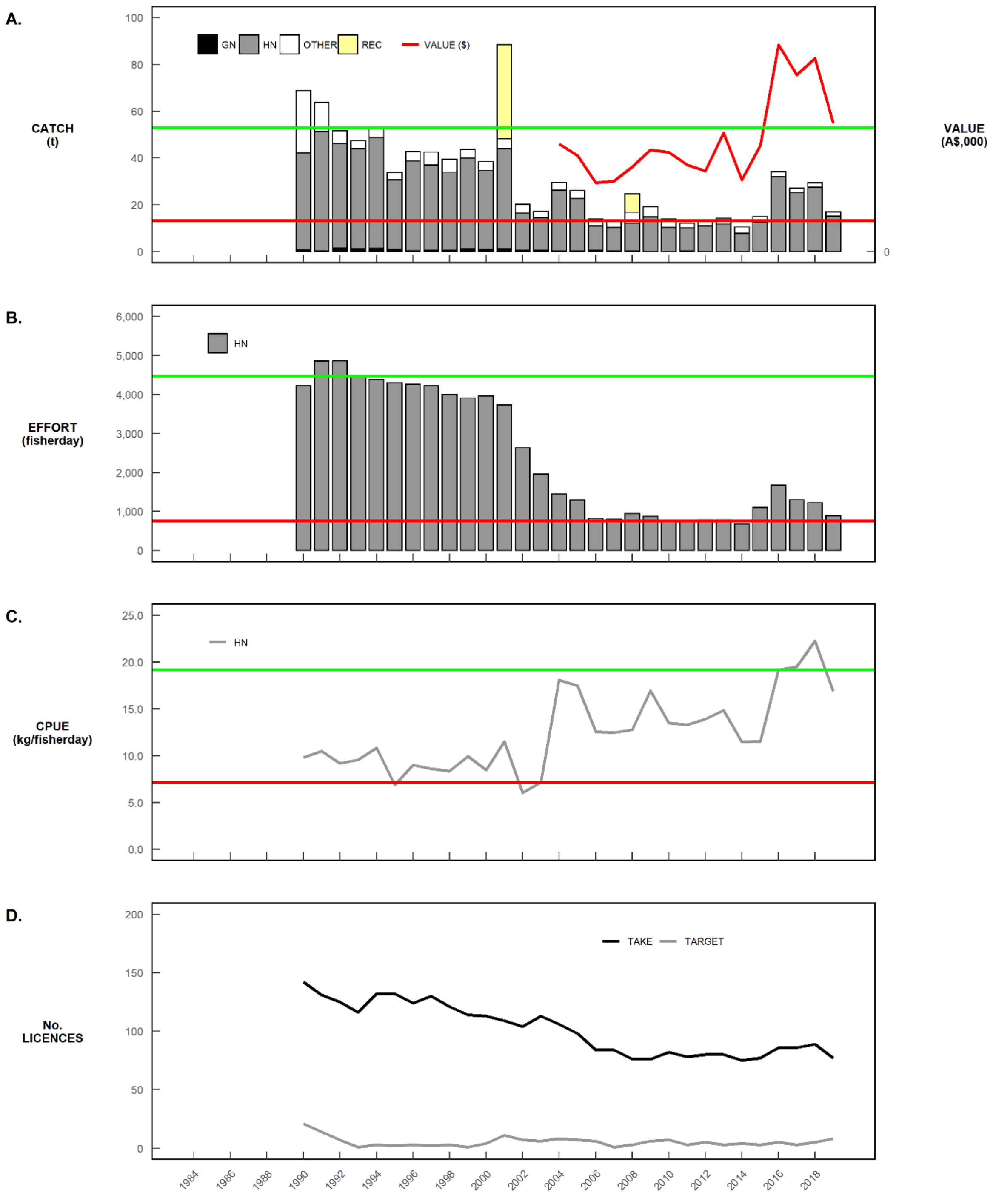

Figure 4-467. Leatherjackets. Long-term trends in: (A) total catch of the main gear types (hauling net and gillnets), estimates of recreational catch, and gross production value; (B) total hauling net effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-20.

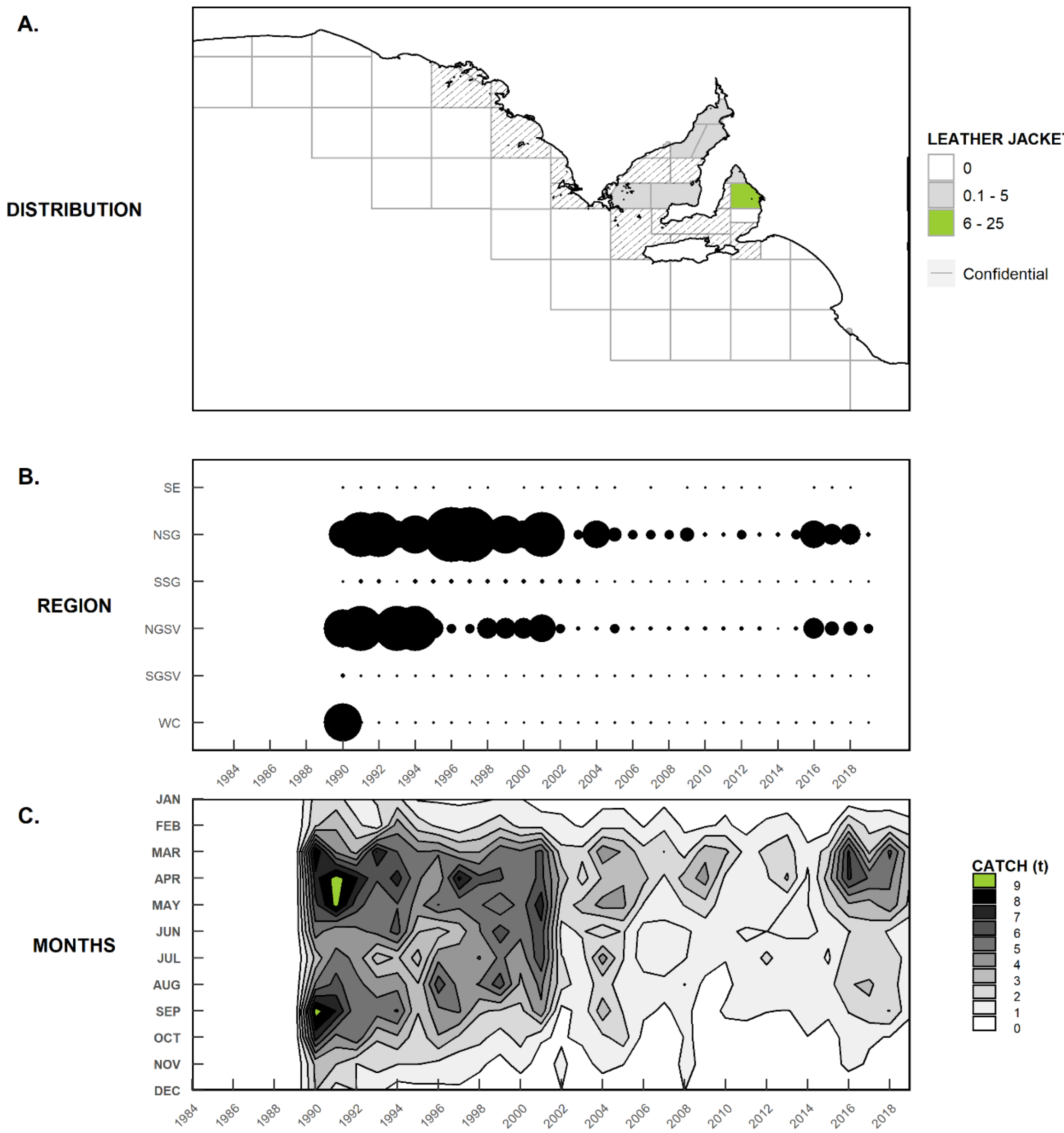

Figure 4-48. Leatherjacket catch in the MSF. (A) Catch distribution for 2019. Long-term trends in: (B) the annual distribution of catch among regions, (C) months of the year (t).

Fishery Performance

The general fishery performance indicators for Leatherjackets were assessed for 2019 at the State-wide scale, using the reference period of 1990 to 2019. No trigger reference points were breached for 2019 (Table 4-20).

Table 4-20. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Leatherjacket in 2019.

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	×
	G	Greatest % interannual change (+/-)	×
	G	Greatest 3 year trend	×
	G	Decrease over 5 consecutive years	×

Stock Status

There is limited information for determining stock status, and the information available is compounded by a paucity of information on the catch composition (species) of Leatherjackets harvested. The limited data prevents assessment of current stock size or fishing pressure. Consequently, there is insufficient information available to confidently classify the status of this stock.

On the basis of the evidence provided above, the Southern Australia Leatherjacket stock is classified as an undefined stock.

4.3.17. RAYS AND SKATES

Biology

Rays and Skates that are common in South Australian waters belong to several Families, including the Myliobatiae (e.g. Southern Eagle Ray), Dasyatidae (e.g. Smooth Stingray) and Rajidae (e.g. Bight Skate). The catch of Rays and Skates in the MSF is not differentiated by species in the fishery log-books. Products from Southern Eagle Rays (*Myliobatis tenuicaudatus*) are regularly identified during market sampling, and hence, it is likely this species comprises a prominent proportion of the Ray and Skate landings in the MSF.

The Southern Eagle Ray is distributed from Jurien Bay in Western Australia to Moreton Bay in Queensland. The species is also found in South Australia, Victoria, Tasmania and New Zealand (Last and Stevens 2009). Southern Eagle Rays reach a maximum size of up to 1.6 m disc width (>3.0 m TL) (Last and Stevens 2009). Age and growth studies suggest the species reaches a maximum age of >15 years for males and >26 years for females in New Zealand (Hartill 1989).

Fishery

Rays and Skates are mostly taken as bycatch in the MSF when fishers use large-mesh hauling nets and longlines to target higher value species (Fowler et al. 2009). The most recent recreational fishing survey estimated that 9,489 Southern Eagle Rays were captured by recreational fishers in South Australia, and all were released (Giri and Hall 2015).

Management Regulations

Rays and Skates of all species are permitted to be taken by the MSF (PIRSA 2014). No commercial harvest strategy has been developed for this species group (PIRSA 2013). There is currently no size, daily bag or boat limits for Ray and Skate species taken in the commercial or recreational fishing sectors in South Australian State-managed waters.

Commercial Fishery Statistics

State-wide

The total state-wide catch of Rays and Skates was 11.8 t in 2019 (*c.f.* 10.2 t in 2018). Total annual catches were relatively stable between 2014 and 2019 and averaged 12.6 t per year (Figure 4-49a). The economic value of the commercial catch of Rays and Skates in 2019 was approximately $ 24 K (*c.f.* $ 20 K in 2018) (Figure 4-49a).

Rays and Skates were predominantly taken using longlines (68%), hauling nets (30%), and handlines (2%). The total annual catches using longlines, hauling nets and handlines were 8.00 t, 3.56 t and 0.26 t, respectively during 2019. Annual trends in longline effort in the MSF related to Skates and Rays showed a steady decline from 1,306 to 282 fisher-days between 1992 and 2019. Longline effort increased moderately from 183 fisher-days in 2016, and averaged 248 fisher-days per annum in the past 5 years. (Figure 4-49b). Annual trends in hauling net effort when Rays and Skates were retained ranged between 185 and 301 fisher days between 2014 and 2019. Longline CPUE when Rays and Skates were taken has ranged between 20–36 kg.fisher-day^{-1} in the past 6 years, and was 28.46 kg.fisher-day^{-1} in 2019 (Figure 4-49). Hauling net CPUE for Rays and Skates ranged between 14–20 kg.fisher-day^{-1} in the past 5 years, and was 15 kg.fisher-day^{-1} in 2019 (Figure 4-49c). The number of licences taking (~55) and targeting (~6) Rays and Skates has been stable over the past decade.

Regional

The largest annual catches of Rays and Skates occurred off the West Coast between 1988 and 2005. Southern GSV was the second most significant region until 2003, with NSG and the SE also supporting significant annual catches in some years (Figure 4-470a). In the past five years, catches have been homogeneously distributed, albeit at low levels, with fishers from the WC and NSG maintaining the highest catches (Figure 4-470b). Catches of Rays and Skates are generally more frequent between spring through autumn (Figure 4-470c).

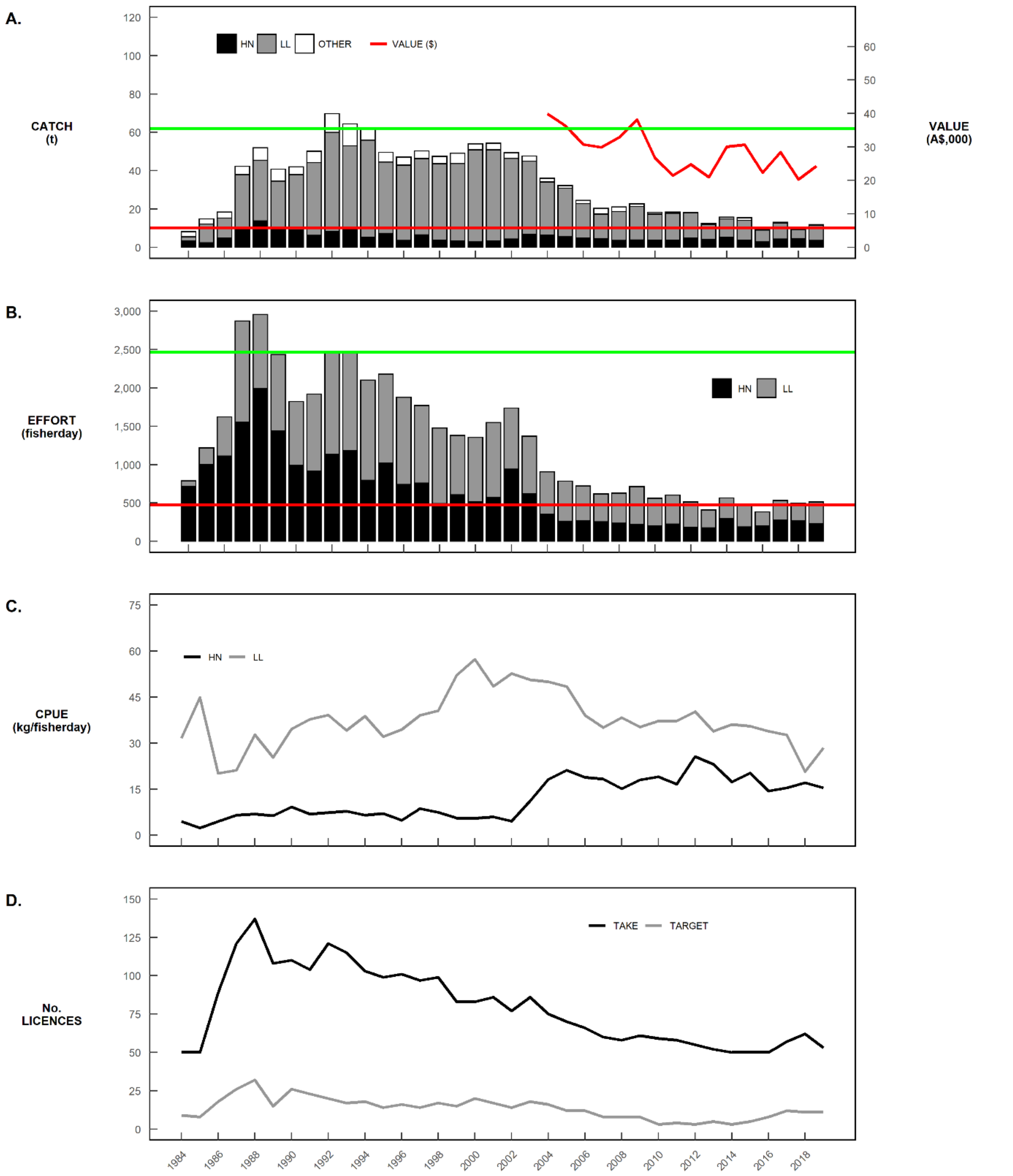

Figure 4-49. Rays and Skates. Long-term trends in: (A) total catch of the main gear types (longline and hauling net), and gross production value; (B) total effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-21.

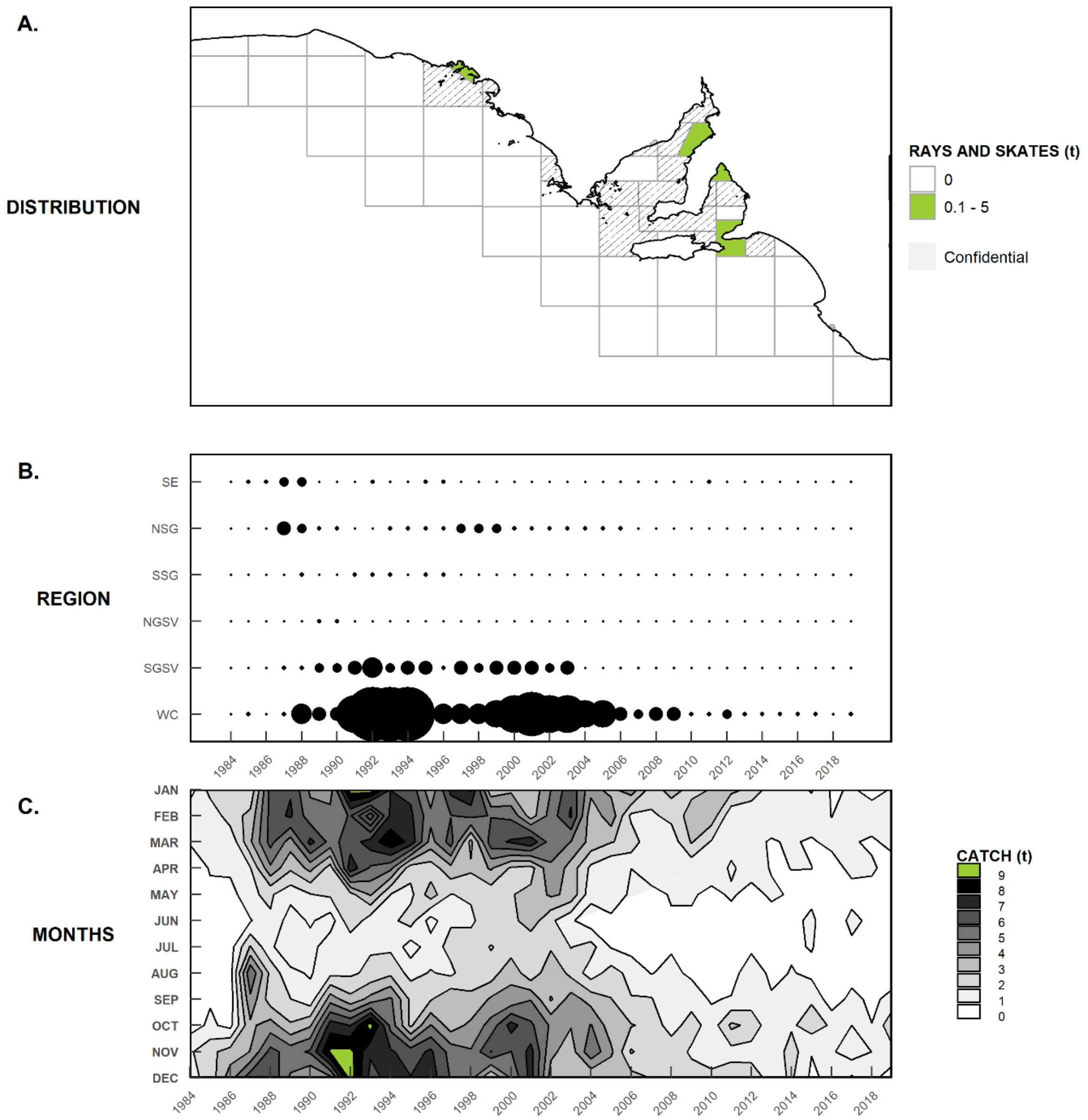

Figure 4-470. Rays and Skates. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Rays and Skates were assessed for 2019 at the State-wide scale. No trigger reference points were breached in 2019 (Table 4-21).

Table 4-21. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Rays and Skates in 2019.

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	×
	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

There is limited information for determining stock status, and the information available is compounded by a paucity of information on the catch composition (species) of Rays and Skates harvested. The limited data prevents assessment of current stock size or fishing pressure. Consequently, there is insufficient information available to confidently classify the status of this stock.

On the basis of the evidence provided above, the Southern Australia Rays and Skates stock is classified as an undefined stock.

4.3.18. CUTTLEFISH

Biology

Giant Australian Cuttlefish (*Sepia apama*) and Nova's Cuttlefish (*S. novaehollandiae*), are commercially harvested in the MSF. The 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).

Two populations of Giant Australian Cuttlefish have been identified in South Australia, (Gillanders et al. 2016). While the Cuttlefish stock in southern Spencer Gulf extends into Gulf St. Vincent, the northern stock is restricted to northern Spencer Gulf (NSG) with individuals returning to the site of hatching to breed at either one or two years of age. The NSG population forms a breeding aggregation at Point Lowly (Steer et al. 2013, Steer 2015, Gillanders et al. 2016) during late autumn and early winter each year. The species is semelparous, dying soon after spawning (Hall and Fowler 2003).

Fishery

Cuttlefish species are taken in the commercial and recreational sectors of the Marine Scalefish Fishery. Handlines and jigs are used in the commercial sector where they are either targeted or taken as by-product whilst fishing for Southern Calamari. Historically, Cuttlefish were retained by commercial fishers as bait for Snapper.

Recreational fishers mostly take Cuttlefish using jigs when they are targeting Southern Calamari. In 2013/14, the State-wide recreational survey estimated that 2,648 Cuttlefish were captured, of which 1,217 were released, leaving 1,431 retained (Giri and Hall 2015). This provided a total estimated recreational catch of 0.34 t, which was considerably lower than the estimated commercial catch of 2 t during the survey period.

Management Regulations

Cuttlefish species are permitted to be taken by the commercial sector of 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. A cephalopod fishing closure, that aimed to protect the 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 to prohibit the targeting and retention of Giant Australian Cuttlefish to the north of Wallaroo, Spencer Gulf. In 2020, the northern Spencer Gulf Cuttlefish closure was revised and some previously closed areas were reopened to commercial cephalopod fishing.

Commercial Fishery Statistics

State-wide

Between 1994 and 1997, the reported commercial catch of Cuttlefish increased from 12.3 t.yr^{-1} to a peak at 262 t.yr^{-1} (Figure 4-481a) corresponding with an increase in both targeted and untargeted effort. Total catch declined but remained high in 1998 at 150 t, and then averaged ~19.6 t over the four-year period between 1999 and 2002. Between 2003 and 2016 the total catches of Cuttlefish decreased further and ranged from 10.5 t in 2007 to 1.3 t in 2016. The total catch of 0.9 t in 2017 was the lowest since 1987 and had only increased marginally to 1.1 t in 2019. The economic value of the commercial catch of Cuttlefish in 2019 was approximately $ 10 K (*c.f.* $ 10 K in 2018) (Figure 4-51a).

Until 1994, total jig effort was <350 fisher-days.year^{-1}, before peaking at 1,477 fisher-days in 1997 (Figure 4-481b). Since then, it has fluctuated between 600 and 900 fisher-days.yr^{-1} before dropping to 326 fisher-days in 2019 (*c.f.* 374 fisher-days in 2018). Jig CPUE followed a similar trend and increased from >50 kg.fisher-day^{-1} to 173 kg.fisher-day^{-1} in 1997, subsequently declining to <5 kg.fisher-day^{-1}.year^{-1} since 2014. The short-term expansion of the fishery between 1994 and 1997 reflects the fleet's concentration of fishing effort on the spawning aggregation in north-western Spencer Gulf. The fishery's take of Cuttlefish was reduced considerably by the False Bay spawning closure, which accounted for >90% of the State-wide catch.

During the late 1990s and early 2000s up to 56% of the fishers catching Cuttlefish were actively targeting them. The number of fishers actively targeting Cuttlefish has rarely exceeded 20% since 2010, indicating that the majority of Cuttlefish landed are incidentally caught (Figure 4-481c, d).

Regional

Between 1994 and 2002, NSG has provided the highest catches of Cuttlefish with only incidental catches from the other regions (Figure 4-492a). During these years, the seasonality of catches aligned with the timing of the spawning aggregation between April and August. In 2019, the MSF fishers accounted for 100% of the commercial catch, and the majority of this was landed in the south eastern corner of Spencer Gulf (Figure 4-492a).

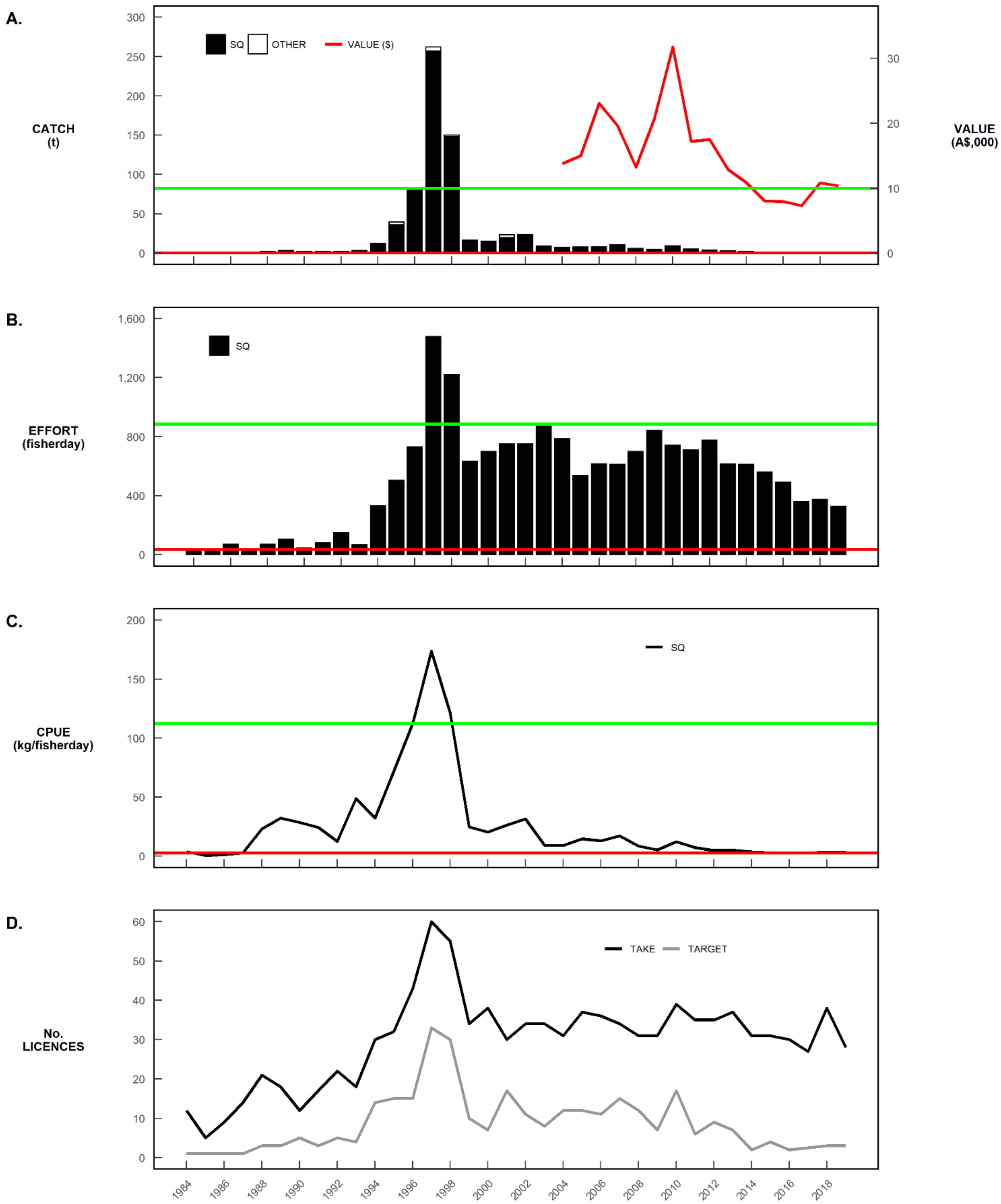

Figure 4-481. Cuttlefish. Long-term trends in: (A) total catch of the main gear types (squid jig and other), and gross production value; (B) total effort; (C) catch per unit effort (CPUE); and (D) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-22.

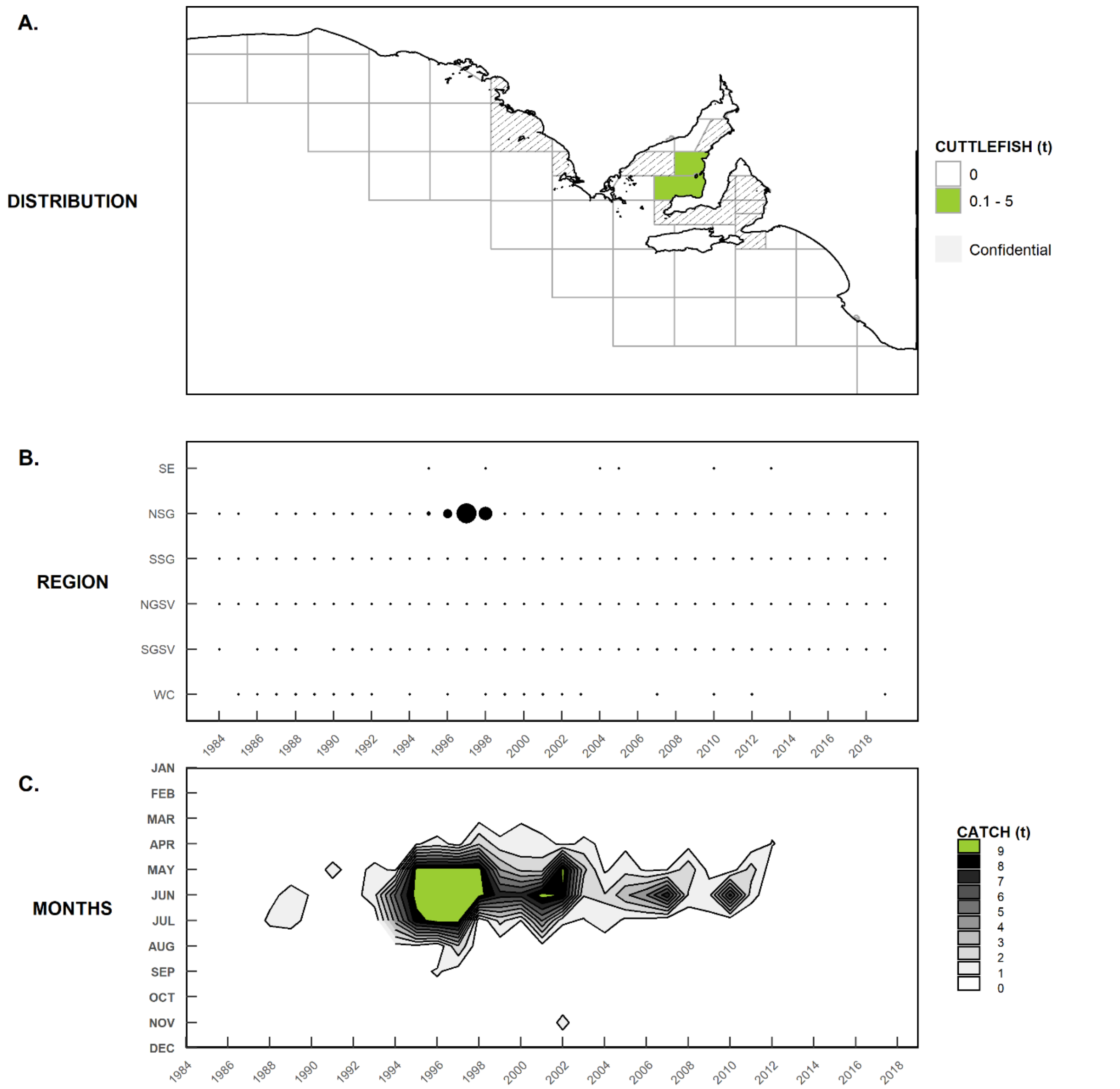

Figure 4-492. Cuttlefish catch in the MSF. (A) Catch distribution for 2019. Long term trends in: (B) the annual distribution of catch among regions, (C) months of the year.

Fishery Performance

The general fishery performance indicators for Cuttlefish were assessed for 2019 at the State-wide scale. One trigger reference point was activated in 2019 (Table 4-22). Total jig effort has declined over 5 consecutive years.

Table 4-22. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Cuttlefish in 2019.

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	×
	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 were a large number of fishers who 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 (Steer 2015). Since 2014, total jigging CPUE has been at historically low levels (<4 kg.fisher-day^{-1}) compared to the peak levels through the mid to late 1990s. There was one trigger reference point breached in 2019, reflecting the declining total jigging effort 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 2019 (Steer, unpublished data). This, in addition to the low recent catches and decrease in effort, suggests that the fishery is unlikely to become recruitment impaired at the current level of fishing pressure. On this basis, South Australia's Cuttlefish fishery is currently classified as **sustainable**.

4.3.19. BLACK BREAM

Biology

Black Bream (*Acanthopagrus butcheri*) occurs in estuaries and nearshore coastal waters across southern Australia from the Murchison River in Western Australia, to Myall Lake in New South Wales, including Tasmania (Norriss et al. 2002; Gomon et al. 2008). It is a medium-bodied, slow-growing species that can reach 600 mm TL and live to 32 years of age. In South Australia, Black Bream mature at 289–340 mm TL (Ye et al. 2015).

Unlike most Sparids, the Black Bream is an estuarine-dependent species, completing much of its life-cycle within a single estuary (Chaplin et al. 1998). Tagging studies in estuaries in South Australia (Hall 1984), Western Australia (Norriss et al. 2002) and Victoria (Butcher and Ling 1962; Hindell et al. 2008) found limited or no evidence of migration among estuaries. Spawning is usually confined to estuaries and occurs from August to December each year.

Fishery

Black Bream are taken by the commercial and recreational sectors of the MSF. In the commercial sector, the species is targeted and taken as by-product using hauling nets and set nets. However, in most years during the past decade around 70% of annual State-wide commercial catches have been taken by the Lakes and Coorong Fishery, which is not considered in this report (Earl and Bailleul 2021).

Recreational fishers target the species using rod and line in coastal waters and estuaries (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 (Giri and Hall 2015). A total of 16,979 fish were retained and contributed to an estimated harvest weight of 4.97 t.

Management Regulations

Black Bream is a tertiary species of the commercial MSF, being of low-medium value and making a minor contribution to the total production value of the fishery (PIRSA 2013). For the commercial sector, regulations are in place to manage fishing effort and limit the take of Black Bream. These include temporal and spatial netting closures, restrictions to net lengths and mesh sizes, and a minimum legal size of 300 mm TL (PIRSA 2016).

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. These include gear restrictions and a daily bag limit of 10 fish and boat limit of 30 fish. The minimum size limit of 300 mm TL also applies to the recreational sector. A spatial and temporal closure prohibits the take of Black

Bream from 1 September to 30 November in the area upstream of the Main South Road Bridge in the Onkaparinga River at Noarlunga.

Commercial Fishery Statistics

State-wide

Total annual commercial catches of Black Bream have averaged <1 t per year since 1984 (Figure 4-53a). Total catch peaked at 3.9 t in 2007 and 3.8 t in 2018, total catch then decreased by 90% to 0.38 t in 2019. The economic value of the commercial catch of Black Bream in the MSF during 2019 was approximately $ 7 K (*c.f.* $71 K in 2018) (Figure 4-53a). Catch and effort data for Black Bream in the MSF were confidential for several years (2011, 2013–15 and 2017) during the last decade, hence, substantially reducing the timeframe of this assessment (Figure 4-53b).

Estimates of total annual fishing effort Black Bream have been highly variable since 1984. Effort declined to 8 fisher-days.yr^{-1} in 1996, before increasing to an historic peak of 253 fisher-days in 2003 (Figure 4-53c). From then until 2010, effort was highly variable ranging from 11 to 82 days per year, with additional peaks of 84 days per year in 2016 and 101 days per year in 2018. Total effort reduced by 73% in 2019 to 27 fisher-days.yr^{-1}. Total CPUE fluctuated between 3–21 kg.fisher-day^{-1} until 2007 when it increased to a peak of 47 kg.fisher-day^{-1} (Figure 4-53c). In the past decade, for the reportable years the CPUE has ranged between 13.8 and 38.1 kg.fisher-day^{-1} and was 14.26 kg.fisher-day^{-1} for 2019. The numbers of fishers who reported taking and targeting Black Bream were variable over time, suggesting the catch is largely by-product when other species are targeted (Figure 4-53d).

Regional

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

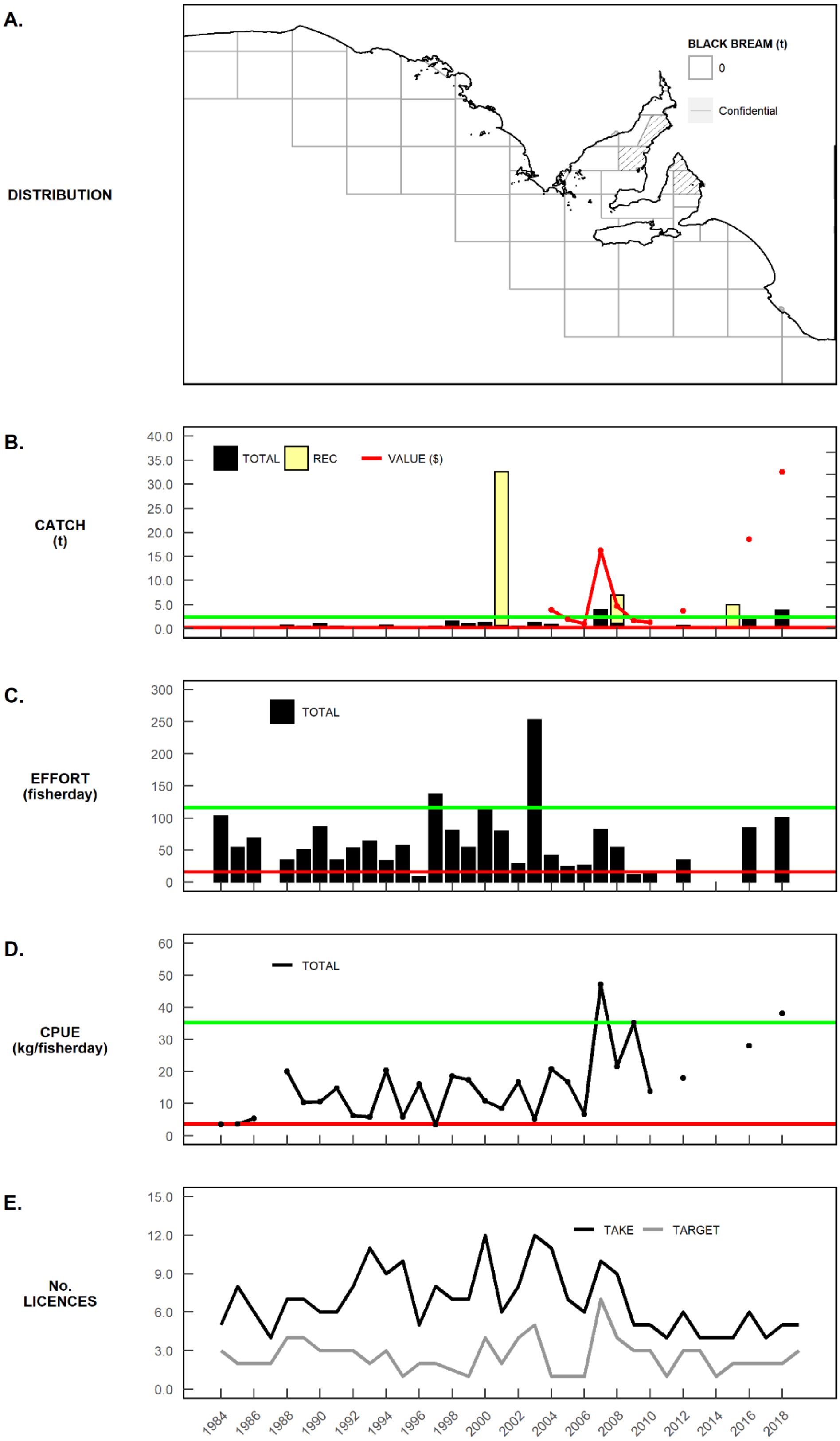

Figure 4-503. Black Bream in the Marine Scalefish Fishery: (A) MSF Catch distribution for 2019. Long-term trends in (B) total catch, and estimates of recreational catch; (C) MSF total effort; (D) MSF catch per unit effort (CPUE); and (E) the number of active licence holders taking or targeting the species. Green and red lines represent the upper and lower reference points identified in Table 4-23.

Fishery Performance

Confidentiality constraints prevented the assessment of 2019 catch and effort data against some of the performance indicators (Table 4-23).

Table 4-23. Results of the assessment of the general (G) fishery performance indicators against their trigger reference points at the State spatial scale for Black Bream in 2019.

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

Stock Status

Black Bream is a tertiary species for the commercial sector of the MSF (PIRSA 2013). This reflects low annual catches and its minor contribution to the total production value of the sector. Catches and targeted effort for Black Bream was low from 1984 to 2006, which resulted in low CPUE. Between 2014 and 2018, catches increased slightly and estimates of CPUE were > 80% higher than the long-term average catch rate. In 2019, catches reduced by ~90% compared to the previous year.

In South Australia, Black Bream is currently assessed at the management unit level where it is has been classified as 'depleted' for the Lakes and Coorong Fishery since 2014/15 (Earl 2016b; Earl and Bailleul 2021). There is currently no evidence of population linkage between Black Bream taken by the MSF to those taken in Lakes and Coorong Fishery. Therefore, the two fisheries are assessed independently. The recent reduction in MSF total catch and effort and a long-term trend of minor total catches indicates that the biomass of this stock is unlikely to be depleted and that recruitment is unlikely to be impaired. On this basis, for the MSF at the state scale, the Black Bream stock is classified as **sustainable**.

5. DISCUSSION

This report assessed the fishery performance of 20 species/taxonomic groups taken in the MSF based on data available until the end of 2019. Collectively, these taxa were considered across 30 management units, at a resolution that aligned with either the biological stock, State-wide or regional level. Of these, 23 (77%) stocks were classified as sustainable, three (10%) were classified as depleted, one (3%) was classified as recovering, and the remaining three (10%) were classified as undefined as there was insufficient information to assign a stock status.

The four primary species, including King George Whiting, Snapper, Southern Garfish, and Southern Calamari have consistently accounted for more than half of the State-wide total commercial catch in the MSF over the last decade, which emphasises their collective importance to the regions and the State's economy. Previous stock assessments for King George Whiting (Steer et al. 2018a), Southern Garfish (Steer et al. 2018b) and Snapper (Fowler et al. 2020a) have identified different levels of concern regarding stock sustainability. All three King George Whiting stocks remain sustainable. The statuses of the Southern Garfish stocks remain unchanged from the previous assessment (Steer et al. 2018b), with two stocks of concern, the NSG stock classified as recovering and NGSV as depleted. These stocks will be reassessed in the upcoming stock assessment in 2021. For Snapper, the SG/WC Stock and the Gulf St Vincent Stock were both determined to be depleted in the most recent stock assessment (Fowler et al. 2020a). This reflects a significant reduction in the spawning biomass, as well as declining catches and CPUE, and recent poor recruitment in both gulf Stocks (Fowler et al. 2020a). In each case, the stock status classifications have supported the development and implementation of specific management arrangements to recover each stock.

The improvement in the status of the GSV/KI stock of King George Whiting in 2017 appears to be unrelated to the changes in management arrangements that were implemented in December 2016, as the recovery occurred within a year of their implementation. The changes included: a spatial closure to protect spawning grounds; and an increase in the legal minimum length. Nevertheless, the spatial spawning closures that were implemented during May 2017 and 2018 may have provided additional benefit particularly since the recent advancement of fishing technologies. Increased vessel power and engine reliability, affordable electronic fish-finding equipment, improved fishing gear and communication has increased the fleet's capacity to extend their fishing effort into offshore areas that have been difficult to access in the past. A recent FRDC project (FRDC 2016/003 – King George Whiting (*Sillaginodes punctatus*) spawning dynamics in South Australia's southern gulfs), investigating the key spawning areas in the southern gulfs and Investigator Strait, identified that the critical areas for spawning KGW is predominately in south and south-western Spencer Gulf and western Investigator Strait. These key spawning areas were comprehensively covered in the larger 2017 spatial closure, while the reduced sized closure in 2018 omitted a critical area of self-seeding breeding stock in south-western Spencer Gulf (Drew et al. 2020). It is likely that the implementation of a spatial closure in these key spawning areas would ultimately benefit both gulf populations, however the impact and success of these is still unclear as the fish spawned in these years are yet to enter the commercial fishery. Bio-physical modelling highlighted that it is a combination of optimal oceanographic conditions and successful spawning events that are required for larvae to advect to appropriate nursery areas (Drew et al. 2020).

The short lifespan and rapid generation turnover of Southern Garfish increases the capacity of the population to respond to effective management arrangements. This was apparent for the NSG Southern Garfish stock, which was classified as recovering in 2017, based on promising signs of improvement in biomass, exploitation rates, egg production, and population age structure (Steer et al. 2018b). Targeted CPUE in the hauling net sector for NGSV has increased and the harvest fraction has trended downwards; however, fishable biomass, egg production and recruitment have remained relatively stable. This indicates that current fishing mortality is constrained by management to a level that should allow the stock to recover from its recruitment-impaired state. Nevertheless, measurable improvements in stock biomass are yet to be detected. Although adequate management may now be in place to recover this stock, more time is required to determine the relative effects of the 2017 and 2018 management arrangements, which included an extended closure and increased hauling net mesh sizes. The next full stock assessment for Southern Garfish is scheduled for 2021. Furthermore, a dedicated research project (FRDC Project 2015/018) was completed in 2018, which provided important insights into the population biology and ecology of Southern Garfish throughout Gulf St. Vincent (Fowler 2018). The project demonstrated that there were complex spatial patterns in the dispersion of Southern Garfish at different life history stages, with the abundances and biomass of adult fish being highest in the northern gulf and declining southward down the eastern and western sides of the gulf. These findings are useful in the interpretation of spatially-limited, fishery-dependent data in terms of stock status.

The recent performances of the SG/WC and GSV Snapper stocks have deteriorated despite considerable management interventions aimed at reducing exploitation rates and enhancing reproductive output and recruitment (Fowler et al. 2013, 2016, Steer et al. 2018b, Fowler et al. 2020a). Despite these changes, commercial fishery statistics for the SG/WC stock up to 2019 show no improvements, with estimates of catch and gear-specific effort and CPUE, remaining at historically low levels, and daily egg production method-based (DEPM) spawning biomass estimates indicating successive years of significant declines (Fowler et al. 2020a). Furthermore, commercial statistics for the GSV stock have declined considerably since 2015, and SnapEst derived estimates of fishable biomass have declined by 90% between 2011 and 2020 to current record low levels (Fowler et al. 2020a). The population age structures derived from commercial catch sampling also provided no evidence of recruitment for both gulf stocks, with NSG having a severely truncated age structure (Fowler et al. 2020a). Considerable changes to management arrangements have occurred in the past decade, and further restrictions have been implemented to address the concerning statuses of these two Snapper stocks. These arrangements include an extensive, almost state-wide, Snapper fishing closure from 1 November 2019.The exception is the South East region which has been opened to restricted fishing from 1 February to 31 October.

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 driven by economics where it has become more cost-effective to target the latter species based on their relative abundance, catchability, low set-up and vessel running costs and high market value. Targeted jig effort for Southern Calamari has remained high in 2019, for NSG, SSG, and NGSV. This trend reaffirms Southern Calamari as an established opportunistic target species for commercial fishers. Furthermore, it has now surpassed Snapper and King George Whiting as the most valuable commercial MSF species in SA, in terms of gross production value. Although the resource is considered sustainable at the biological stock level, targeted CPUE has declined in specific regions, i.e. SSG and NSG, suggesting that increased fishing pressure in these regions may have contributed to localised depletion. The seven years of continual decline in targeted jig effort in SSG raises concern for regional depletion of this component of the stock even though CPUE is well within the trigger reference limits. These concerns regarding regional declines in productivity have also been raised by industry, who have anecdotally reported that Southern Calamari have become 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, Southern Calamari's high-paced life history, dynamic spawning behaviour and movement potential favours population replenishment at the broader biological stock level (Pecl et al. 2006). Given the economic importance of Southern Calamari to the fishery (Econsearch 2020), future assessments will need to become more sophisticated and move beyond reporting only on fishery dynamics.

The long-term decline in fishing effort through reduction in numbers of licence holders is a distinct feature of the MSF. Since 1984, the number of licences was been reduced from more than 600 to 207 following the recent MSF reform.

Furthermore, the fishery underwent a structural reform in 2021 to enhance its long-term sustainability and economic viability. There were three pillars of the reform: 1) Regionalisation, where four management zones will enable the MSF to be assessed and managed at local levels, rather than at the State level, 2) Unitisation, where Tier 1 stocks will be managed using output controls to increase fishery sustainability and maximise production, and 3) Rationalisation, where a voluntary licence surrender program reduced the number of operators in the fishery, with the aim of increasing the economic returns of those who remain. The reform was informed by work undertaken as part of a current research project (FRDC 2017/014) that aims to disentangle the complexity of this multi-sector, multi-species and multi-gear fishery.

The multi-species nature of the MSF can be considered a strength of this 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 and there has been a resurgence in catches of Ocean Jackets and Salmon over the past five years. For some species, increases in effort have 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 'lesser-known' (or '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 recent study of 'lesser-known' species (FRDC 2017/023) identified 13 taxa currently within the MSF that could support increased exploitation, the scale of increased harvest is dependent on the individual species life history and varied on scales of hundreds to tens of tons (Fowler et al. 2020b).

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. These species share similar commercial catch and effort trends for which fishing effort within the hauling net sector has declined due a reduction in net endorsements 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 and Southern Calamari). Nominal CPUE for the by-product species has trended upwards, suggesting that they are relatively abundant and being harvested at sustainable levels.

The MSF continues to demonstrate its capacity to respond to productivity levels and market demands. The rapid growth of Southern Calamari, coupled with its high market value, has effectively counteracted the decline in Snapper productivity. Similar opportunities exist for some lesser-known species, such as Western Australian Salmon, Ocean Jackets and Snook, which may contribute to distributing fishing pressure more widely throughout the fishery and to reducing target effort on key species.

5.1. Challenges and Uncertainties in the Assessment

Determining stock status through the weight-of-evidence approach for the MSF stocks considered in this report has relied heavily on 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 for which fewer data are available and there are limited resources for developing more sophisticated fishery-independent assessment programs. But for such species considered in this report, the primary measure of fishable biomass is CPUE from the dominant gear type and reliance solely on these data can be problematic. For these species, CPUE is assumed to be proportional to abundance and is therefore used as relative index of abundance. However, the CPUE likely also reflects changes in the relative efficiency of the fleet in recent years. In addition, for several species, especially those that are taken in low quantities and for which most of the recent annual catches have been taken as by-product, CPUE is considered a poor indicator of relative abundance. Catch per unit effort standardisation may help improve the usefulness of CPUE as a relative index of abundance, including by accounting for differences in the relative contributions of targeted and non-targeted catches to the total catch. Improving the reliability of CPUE as an indicator of biomass would improve the confidence in assessments of stock status.

One significant gap in our knowledge for assessing the status of the stocks that support the MSF is determining the relative contribution of the State-wide catch of the recreational fishing sector. This sector's total harvest has traditionally been determined through infrequent 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 key implications for the assessments of King George Whiting, for which recreational contribution to overall State-wide catch has been significant. Improving the precision of the estimates of the recreational catches, either through more frequent surveys or increased participation rates, will improve assessments of stock status. The 2021/22 Recreational Fishing Survey commenced in February 2021 and will continue until 28 February 2022. The survey involves a traditional telephone/diary survey and State-wide onsite sampling. To increase participation rates, a smartphone application has been made available for all recreational fishers to contribute information on where they fished and their catch.

In recent years, it has become increasingly evident that the fishing behaviour 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 reduced the reliability of CPUE as a suitable index of stock biomass and performance, and led to the development and evaluation of an alternate fishery-independent indicator (Steer et al. 2017, Fowler et al. 2019). Similarly, the issue of advancing fishing technologies and improved efficiency was identified as a key concern for offshore stocks of King George Whiting.

Another challenge is the complication of having a multi-species complex in three of the stocks assessed in this report. Currently, there are uncertainties and limited data around the proportion of species in the Whaler shark, Rays and Skates, and Leatherjackets catch. As a result of these uncertainties and limited data, these stocks have been assessed as undefined. A greater level of detail in species identification is required to be able to untangle the relative stock composition, this will be potentially resolved as the MSF catch reporting moves onto an electronic reporting system. Currently, the stocks which have been assessed as undefined as a result of the unknown species composition are predominately one main species in each stock (i.e. Southern Eagle Ray in Rays and Skates). Improving species identification in catch reporting will allow us to potentially remove these species from the multi-species complex and assess them individually or appropriately weight the fishery statistics to the known contribution of each species in a stock.

5.2. Research Priorities

The poor status of Snapper stocks in SA and the significant response of the government has directed considerable research focus towards this species. Considerable funding has been directed towards research to support the monitoring and recovery of the SG/WC and GSV Snapper stocks. These include: undertaking stock assessments for Snapper during the closure period, including DEPM-based surveys of spawning biomass; developing a cost-effective method for monitoring the numbers of juvenile Snapper to provide an early indication of recruitment strength (FRDC 2019/046 – Cost-effective, non-destructive solutions to developing a pre-recruit index for Snapper), quantifying post-release mortality rates across all sectors of the Snapper fishery (FRDC 2019/044 – Quantifying post-release survival and movement of Snapper: informing strategies to engage the fishing community in practices to enhance the sustainability of an important multi-sector fishery) and stock enhancement of both gulfs through the release of Snapper fingerlings.

Assessing new technologies and techniques that could improve the cost-effectiveness and robustness of recreational fishing surveys was the central focus of an FRDC-funded (Project 2017/198 – Assess new technologies that could improve the cost-effectiveness and robustness of recreational fishing surveys) national recreational fisheries science workshop hosted by SARDI (Aquatic Sciences) in July 2018 (Beckmann et al. 2019). The outcomes of this workshop have been integrated into a current recreational fishing survey in South Australia which is applying a traditional phone/diary survey supplemented by beach/boat ramp surveys. This project is also aiming to develop a recreational fishing mobile phone App which may increase survey extension, accuracy and time between surveys (FRDC 2020-056 Evaluation of a smart-phone application to collect recreational fishing catch estimates, including an assessment against an independent probability-based survey, using South Australia as a case study). This project was developed in a cross-jurisdictional research collaboration that aims to unify and improve our understanding of Australia's recreational fishing dynamics.

For the primary finfish species, for which there are dedicated quantitative stock assessment models, there is a need to explore the relative effects of nominal increases in effective effort, and to determine whether greater influence should be placed on biological metrics, or if commercial fishery-independent data streams (such as spawning biomass estimates, pre-recruit information, or recreational fishing data) are required to 'ground-truth' model-derived estimates of biomass, as has been the case for Snapper. A greater understanding of unfished stock biomass (B_0) is also required given that many species have been fished since before the MSF logbook program commenced in 1983. 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 a standardised CPUE. New statistical and modelling methods are emerging for 'data-limited' fisheries, and their application to SA is being considered to increase the robustness of fishery assessments for the data-limited species. The MSF is currently undergoing considerable transition through the structural reform, development of new harvest strategies and pending review of the Management Plan. An FRDC project that will provide statistical support to this structural reform is currently underway to review fishery assessment methods and consider the implementation of data-limited approaches to optimise sustainable utilisation of the resource.

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7. APPENDICES

7.1. Appendix 1. Annual commercial catches (t) of 21 species and species groups taken in the Marine Scalefish Fishery between 1984 and 2019.

Crosses indicate confidential data (<5 fishers) and dashes indicate no data.

	Garfish	KGW	Snapper	Calamari	YFW	A. Salmon	A. Herring	Vongole	Snook	B. Crab	S. Crab	Y.eye Mullet	Mulloway	W. Sharks	Ocean Jacket	Wrasse spp.	S. Trevally	L.Jackets.	Rays & Skates	Cuttlefish	Bream
1984	441.9	636.0	451.1	183.9	104.5	400.2	364.2	0.2	110.9	114.7	22.8	96.0	14.8	30.1		2.9	3.0	x	8.2	0.3	0.4
1985	438.4	597.0	457.9	196.2	61.4	659.6	231.2	0.3	75.6	126.1	30.4	100.5	14.7	27.0		2.6	2.1	x	14.9	0.1	0.2
1986	449.1	693.2	426.9	201.7	41.7	541.7	409.2	15.2	72.5	170.1	25.0	129.4	9.8	40.2		2.3	3.3	x	18.4	0.3	0.4
1987	382.4	602.1	364.3	168.2	23.8	650.6	493.8	37.0	70.8	165.6	28.0	147.0	14.2	54.8		3.0	4.3	x	42.3	0.2	x
1988	391.0	586.6	409.7	281.3	14.5	524.9	427.7	43.9	85.5	209.4	40.5	126.3	8.1	70.0		3.4	4.2	x	51.9	2.3	0.7
1989	513.7	638.0	423.3	231.6	26.9	573.3	396.2	28.6	116.4	323.6	136.5	133.3	9.0	62.8	429.4	2.5	3.0	c	40.8	3.5	0.5
1990	527.7	683.8	453.1	212.1	40.8	313.6	296.0	23.4	94.8	390.5	151.9	174.7	13.4	76.6	930.0	1.9	4.6	68.9	42.0	2.0	0.9
1991	422.5	678.0	419.5	348.5	39.9	486.5	342.8	24.4	102.3	434.6	135.2	154.8	7.6	76.9	977.3	1.6	7.4	63.7	50.1	2.1	0.5
1992	492.8	776.3	383.1	268.3	44.4	607.2	362.1	36.2	114.7	429.1	81.6	131.8	11.6	67.7	916.8	5.0	16.6	51.6	69.6	2.1	0.3
1993	531.5	668.8	358.2	312.9	107.4	658.7	321.2	25.5	120.5	566.3	65.9	128.6	10.9	71.6	766.3	4.4	14.6	47.3	64.4	3.3	0.4
1994	469.0	635.0	242.1	352.5	73.3	500.1	299.9	15.1	132.6	484.3	40.1	102.5	17.9	92.4	575.3	6.1	7.9	52.9	61.8	12.3	0.7
1995	401.9	565.0	260.2	355.2	110.3	638.0	231.5	34.9	147.3	692.9	53.0	102.1	24.2	93.6	477.0	7.8	7.8	33.9	49.5	39.8	0.3
1996	503.9	579.1	310.2	374.5	95.4	500.9	212.9	73.1	131.8	559.6	66.5	66.0	12.7	70.7	441.7	6.7	7.8	42.8	46.9	82.5	0.1
1997	546.4	570.6	362.4	390.7	107.0	653.5	219.1	83.1	110.1	320.9	125.9	107.3	11.4	102.2	433.0	23.9	9.1	42.5	50.3	262.0	0.5
1998	447.2	562.3	396.7	433.2	51.2	572.7	353.1	151.8	108.3	74.3	119.5	92.2	6.5	96.1	359.6	24.7	4.1	39.4	47.4	150.1	1.5
1999	452.2	602.1	572.0	400.4	113.7	584.7	298.3	142.4	105.4	123.9	132.1	67.8	6.6	82.8	284.1	24.1	8.4	43.7	49.0	16.3	0.9
2000	517.4	440.7	570.0	419.3	109.3	542.1	250.7	159.2	94.9	78.5	175.7	71.3	7.1	79.7	269.2	21.9	21.0	38.4	54.0	15.0	1.3
2001	522.8	449.1	661.4	455.6	178.9	576.4	250.9	179.7	113.9	92.9	131.7	71.6	6.2	93.9	352.1	21.9	7.1	48.1	54.2	23.3	0.7
2002	419.9	370.7	545.0	323.3	152.9	279.7	252.9	240.7	108.4	66.7	104.7	50.8	2.7	96.9	308.0	23.7	2.5	20.2	49.4	23.8	0.5
2003	295.7	381.8	412.0	314.5	167.7	496.3	149.4	261.0	90.4	66.2	104.9	47.7	7.8	119.1	391.5	28.8	5.1	17.1	47.6	8.9	1.3
2004	327.3	345.7	449.8	468.8	162.9	213.8	178.8	296.7	85.6	51.9	84.9	43.4	2.6	113.2	322.7	22.9	6.3	29.5	36.1	7.1	0.9
2005	390.8	348.0	529.2	357.9	120.5	173.5	165.5	389.5	69.0	47.8	177.0	48.5	6.1	94.8	299.5	19.9	6.8	26.1	32.2	7.9	0.4
2006	350.0	347.9	613.5	299.3	126.1	262.5	93.2	309.1	58.1	47.6	105.5	41.6	5.9	76.5	69.2	15.5	10.8	14.0	24.5	8.0	0.2
2007	264.5	350.3	743.8	295.9	78.8	126.3	112.6	311.5	82.0	41.8	70.2	30.5	7.2	82.4	57.7	13.4	8.1	13.3	20.3	10.5	3.9
2008	277.1	313.3	719.7	279.1	85.7	126.7	130.0	233.6	72.1	51.0	98.5	30.5	3.3	87.9	x	21.7	8.4	16.8	21.0	6.0	1.2
2009	316.7	358.5	818.5	331.0	114.7	136.1	176.7	154.5	64.3	60.4	72.7	25.6	3.7	109.5	x	20.0	5.6	19.2	22.7	4.5	0.4
2010	254.9	326.7	1031.5	347.9	114.4	163.5	147.1	86.6	64.9	54.2	65.7	23.4	2.0	121.1	x	19.5	15.3	14.0	18.3	9.1	0.2
2011	291.7	328.2	941.9	415.4	87.5	204.0	86.4	78.5	46.8	53.6	93.2	31.8	3.3	92.6	x	23.5	10.0	12.1	18.3	5.2	x
2012	238.9	310.9	642.2	429.4	119.0	98.0	109.7	64.1	49.2	56.6	79.0	27.9	4.5	90.0	138.6	16.7	10.1	13.2	18.3	3.8	0.6
2013	250.4	292.5	518.8	399.0	152.0	59.4	172.1	70.7	41.9	62.5	65.0	18.9	2.8	57.2	50.2	17.3	9.0	14.2	12.4	3.1	x
2014	264.0	280.6	533.0	402.5	96.2	220.1	114.5	73.6	40.3	60.9	46.9	16.0	1.3	58.3	x	15.2	11.3	10.5	15.7	2.2	x
2015	163.3	288.5	512.4	370.3	101.0	349.5	104.3	61.3	46.7	45.0	63.2	16.1	1.3	54.8	x	17.2	8.5	15.0	15.4	1.5	x
2016	155.2	287.3	386.8	398.8	114.6	370.1	93.5	72.5	53.5	31.2	48.4	12.5	1.1	50.4	224.2	13.6	7.9	34.1	9.6	1.3	2.4
2017	183.5	244.8	339.7	412.9	141.6	374.1	61.2	61.7	38.9	51.7	44.7	22.1	5.6	62.5	151.2	13.6	10.6	27.0	13.1	0.9	x
2018	176.2	250.2	281.3	371.1	140.2	156.3	104.5	68.6	43.2	35.6	44.2	19.7	9.0	45.1	94.8	7.9	4.6	29.5	10.2	1.3	3.8
2019	190.2	226.7	251.8	327.0	140.2	228.7	99.8	61.2	40.5	53.4	58.8	13.9	5.2	62.7	x	7.3	6.9	16.9	11.8	1.1	0.4

7.2. Appendix 2. Annual commercial catches (t) of remaining permitted species and species groups taken in the Marine Scalefish Fishery between 1984 and 2019

These species were not considered in detail in this report. Crosses indicate confidential data (<5 fishers).

	Annelids	Goolwa Cockle	Mussel	Octopus	Oyster	Scallop	Gould's squid	Anchovy	Barracouta	Cod	Dories	Flathead	Flounder	Goatfish	Yellowtail Kingfish	Pink Ling	Blue Mackerel	Jack Mackerel	Morwong	Other Mullet	Bight Redfish	Sweep	Swallowtail	Blueeye Trevalla	School Whiting	Other Shark
1984	13.9	x	x	x	x	x	x	x	76.1	0.4	x	4.6	0.3	2.5	0.7	x	x	2.1	10.5	x	5.1	3.5	x	3.2	x	5.4
1985	14.6	x	x	0.2	x	x	x	x	24.0	x	x	3.2	1.0	2.6	x	x	x	x	13.0	x	8.9	3.1	x	3.6	x	8.8
1986	15.2	x	x	x	x	x	x	x	7.6	x	x	3.4	1.2	3.7	x	0.1	x	3.0	19.3	x	16.3	1.7	x	24.6	x	17.3
1987	11.1	x	x	1.4	x	x	x	x	5.8	x	x	3.3	0.5	3.3	x	1.1	3.7	x	23.6	x	13.8	1.8	x	153.4	x	36.2
1988	11.2	x	x	3.1	x	x	x	x	12.2	0.4	x	5.1	0.3	4.0	x	0.4	0.8	37.4	21.2	x	14.7	2.7	x	81.8	x	46.2
1989	13.5	x	x	2.6	x	x	x	x	9.1	0.2	x	4.0	0.3	4.7	x	0.2	1.3	x	26.4	x	22.0	9.6	0.2	54.9	x	41.7
1990	15.7	x	x	3.9	x	x	x	x	12.9	x	x	5.6	x	6.3	x	0.2	0.6	x	26.8	x	15.6	10.5	0.3	84.3	0.1	45.3
1991	15.6	x	x	6.2	x	x	x	x	5.2	x	x	6.9	0.2	3.9	0.4	0.1	1.4	0.3	20.1	x	9.4	7.0	0.4	70.6	x	68.6
1992	16.8	366.1	x	9.7	x	x	x	x	2.5	x	x	5.9	0.2	4.8	2.5	0.4	0.7	0.4	16.1	x	10.4	3.2	0.3	49.0	x	64.5
1993	13.7	x	x	6.5	x	x	x	x	2.0	x	x	4.5	0.1	4.6	1.7	2.1	0.5	0.4	13.5	x	13.5	4.8	0.4	54.5	0.1	42.6
1994	13.7	x	x	5.3	x	x	x	x	0.5	x	x	3.9	0.1	4.9	0.7	0.7	6.7	0.0	20.1	x	13.7	8.9	0.5	35.8	0.1	45.3
1995	13.7	x	x	6.8	x	x	x	x	x	x	x	2.8	0.5	4.1	0.5	0.6	5.0	0.3	25.8	x	18.2	5.8	0.1	17.9	0.0	61.2
1996	14.0	436.1	x	11.4	x	x	x	x	0.9	x	x	2.3	0.2	4.9	x	1.3	5.7	x	29.6	x	11.9	5.9	0.4	6.6	0.1	103.8
1997	11.5	362.6	x	5.9	x	x	x	x	x	x	x	2.2	0.1	3.5	x	1.6	4.0	x	14.1	x	9.3	8.7	0.1	4.5	x	62.4
1998	11.2	x	x	x	x	x	x	x	0.3	x	x	2.5	x	4.6	x	x	4.6	x	8.6	x	4.6	5.9	0.1	x	x	58.6
1999	11.5	340.7	x	7.4	x	x	x	x	x	x	x	2.8	0.2	4.7	x	x	2.4	x	3.7	x	5.5	2.6	x	x	x	50.2
2000	14.3	332.0	x	7.5	x	x	x	x	x	x	x	2.1	0.0	3.7	x	x	3.6	x	1.6	x	3.0	1.4	x	x	x	53.8
2001	10.8	338.7	x	x	x	x	x	x	x	x	x	2.1	x	4.8	x	x	0.5	x	0.5	x	1.6	1.8	x	x	x	58.1
2002	8.2	273.5	x	5.5	x	x	x	x	2.0	x	x	2.1	x	3.6	0.2	x	5.2	x	1.5	x	3.6	2.0	x	x	x	43.8
2003	7.0	x	x	5.1	x	x	x	x	2.4	0.0	x	2.2	x	3.4	0.4	x	1.5	x	2.5	x	3.4	2.0	x	x	0.1	29.9
2004	7.2	x	x	x	x	x	x	x	5.5	x	x	2.1	x	3.8	0.1	0.1	3.6	x	3.0	x	4.7	1.7	x	x	x	26.9
2005	7.5	34.3	x	x	x	x	x	x	4.3	x	x	2.2	x	3.7	0.4	x	0.8	x	3.8	0.2	7.5	1.4	x	x	x	21.1
2006	7.5	2.2	x	8.1	x	x	x	x	0.9	x	x	1.7	x	4.6	x	x	2.6	x	2.0	x	3.9	1.4	0.0	x	x	22.8
2007	6.6	x	x	18.9	x	x	x	x	x	x	x	2.1	x	5.7	x	x	3.7	x	2.3	x	4.6	0.8	0.1	x	x	14.8
2008	7.6	x	x	23.3	x	x	x	x	x	x	x	2.4	x	4.5	0.5	x	4.1	x	1.8	x	3.3	1.2	0.1	x	0.1	3.8
2009	6.1	x	x	x	x	x	x	x	2.2	0.4	x	3.3	x	4.9	0.1	x	2.2	x	2.6	2.4	6.8	2.5	0.4	x	x	7.4
2010	5.8	x	x	x	x	x	x	x	x	x	x	4.2	x	4.3	0.3	x	2.6	x	3.4	0.2	8.9	2.2	0.5	x	x	7.3
2011	5.9	x	x	14.6	x	x	x	x	x	x	x	5.7	x	3.3	x	x	1.5	x	2.9	x	14.2	3.1	0.2	x	x	10.0
2012	6.5	x	x	x	x	x	x	x	x	x	x	2.6	x	2.9	0.2	x	1.8	x	1.2	x	10.7	3.1	0.3	x	x	4.9
2013	5.4	x	x	7.6	x	x	x	x	x	x	x	1.6	x	5.2	x	x	1.6	x	1.0	x	10.0	2.4	0.2	x	0.0	4.6
2014	5.0	x	x	11.4	x	x	x	x	x	x	x	2.0	x	4.3	2.8	x	2.4	x	0.6	x	8.3	2.0	0.1	x	0.2	2.5
2015	5.2	x	x	10.6	x	x	x	x	x	x	x	2.0	x	3.5	1.3	x	2.6	x	0.9	x	12.6	1.1	0.1	x	x	1.8
2016	4.3	x	x	x	x	x	x	x	x	x	x	0.8	x	3.5	2.0	x	2.8	x	0.9	x	12.2	0.9	0.1	x	x	1.1
2017	4.7	x	x	14.4	x	x	x	x	x	x	x	1.1	x	3.3	2.1	x	4.4	x	1.2	x	19.8	0.7	0.2	x	x	1.9
2018	3.8	x	x	x	x	x	x	x	x	x	x	1.1	x	4.0	1.9	x	3.8	x	1.1	3.1	20.7	1.6	0.2	x	x	0.7
2019	2.9	x	x	x	x	x	x	x	x	x	x	1.0	x	3.4	4.2	x	3.7	x	1.3	x	19.2	0.9	0.2	x	x	2.9

7.3. Appendix 3. Recreational catch data in 'WhitEst'

The recreational sector constitutes 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 by 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, specifically for how recreational catch data are allocated among months of the year. This method for pre-processing the recreational survey data was first applied for the 2017 assessment (Steer et al. 2018b).

The most recent recreational fishing survey covering 2013/14 (Giri and Hall 2015) did not provide the estimated King George Whiting catch number broken down by month, as the two previous surveys had done, and included no species-specific effort estimates. As WhitEst uses a monthly time step, we introduced several additional steps of data pre-processing to obtain the required data inputs of recreational catch by model spatial cell 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. Recreational surveys measure catches in numbers rather than weight, so the model accordingly fits to recreational catch number by month and spatial cell. In the third subsection we plot model-estimated recreational catches of King George Whiting in weight landed for comparison with commercial catches which are nearly 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 recreational 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 $\left\{N_{cell};\ cell=1,n_{cell}\right\}$, where the subscript *r* is an index over the n_{cell} = 5 model spatial cells (Figure A4.1). The estimated total 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 reported yearly totals $\left\{N_{cell};\ cell=1,n_{cell}\right\}$ by spatial cell, 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(*cell*) + factor(*cell*):factor(*month*),

using a gaussian GLM with an identity link, to the data of King George Whiting catches by *month* and WhitEst model *cell* 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 $\left\{x_{month,cell};\ cell=1,n_{cell}\right\}$, for each combination of *cell* and *month* (red line in Figure A3.1) computed as GLM[factor(*cell*)] + GLM[factor(*cell*):factor(*month*)].

To convert the GLM-estimated but still unscaled $\left\{x_{month,cell};\ cell=1,n_{cell}\right\}$ inferred from the two previous surveys into monthly catch estimates for 2013/14, for each cell we rescaled these estimated monthly relative catches. Denoting the rescaling factor to be derived for each cell as f_{cell}, we require that the sum of the 12 monthly catches equals the yearly 2013/14 survey harvest number (N_{cell}):

$$\sum_{month=1}^{12}\left(x_{month,cell}\cdot f_{cell}\right)=N_{cell}\ .$$

Solving for f_{cell} we obtain

$$f_{cell}=\frac{N_{cell}}{\sum_{month=1}^{12}x_{month,cell}}\ .$$

The final constructed King George Whiting harvest number totals by spatial cell and month for 2013/14 become

$$C_{month,cell}^{rec,1314}=x_{month,cell}\cdot f_{cell}=x_{month,cell}\cdot\frac{N_{cell}}{\sum_{month=1}^{12}x_{month,cell}}\ .$$

The $C_{month,cell}^{rec,1314}$ estimates are plotted as the "Rescaled GLM" line in Figure A3.1.

Figure A3.1. 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 A3.2. The summer holiday month of January is the highest recreational catch month in all spatial cells. Other seasonal peaks (around March or April, and October) also appear to coincide with yearly times of school holiday.

The yearly recreational catch numbers, showing the breakdown between charter and non-charter sub-sectors, are shown in Figure A3.3.

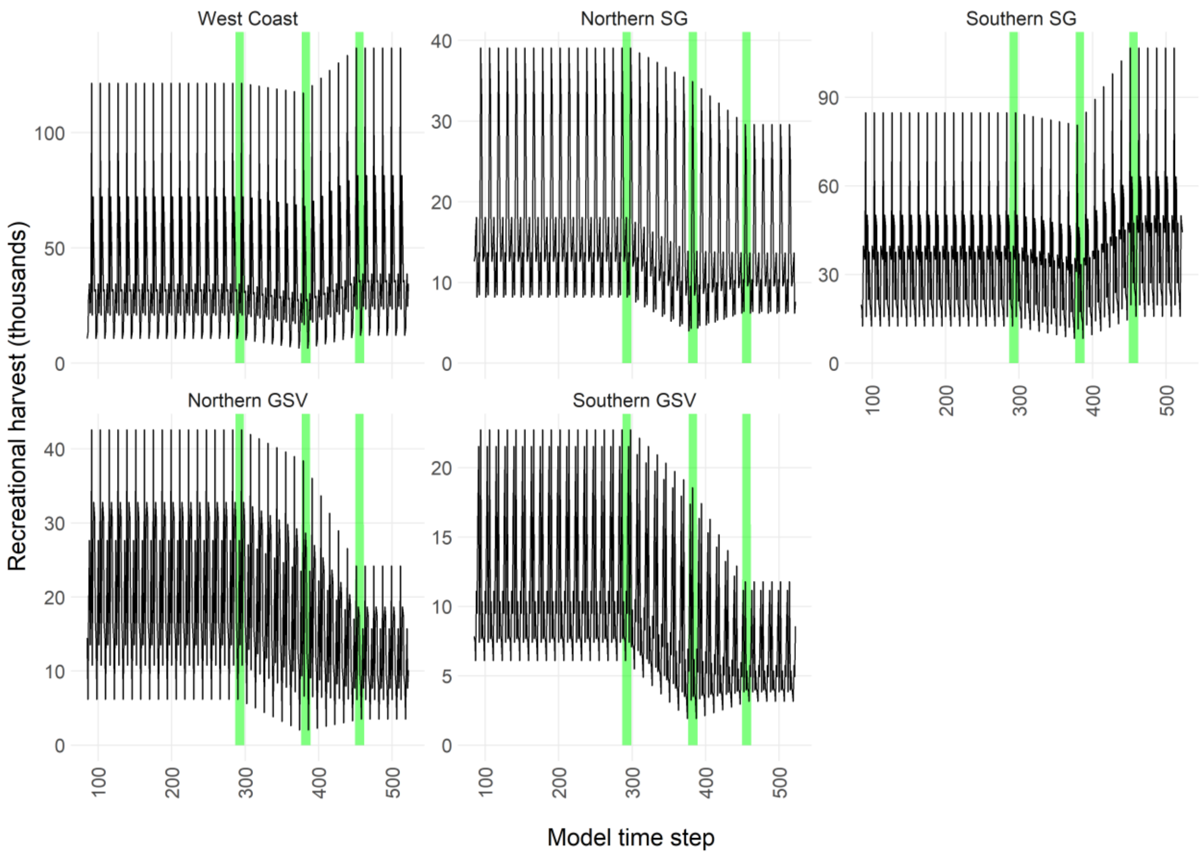


Figure A3.2. Monthly catches of King George Whiting by the recreational sector used as data input by the WhitEst model. From November 2007 onward, charter boat catches have been reported in logbooks by that sub-sector, and these were subtracted from the survey estimates which included both charter and non-charter recreational catch. The charter boat catches are fitted separately in WhitEst from the time when charter logbooks commenced in November 2007. Green bands indicate the years of the three recreational surveys.

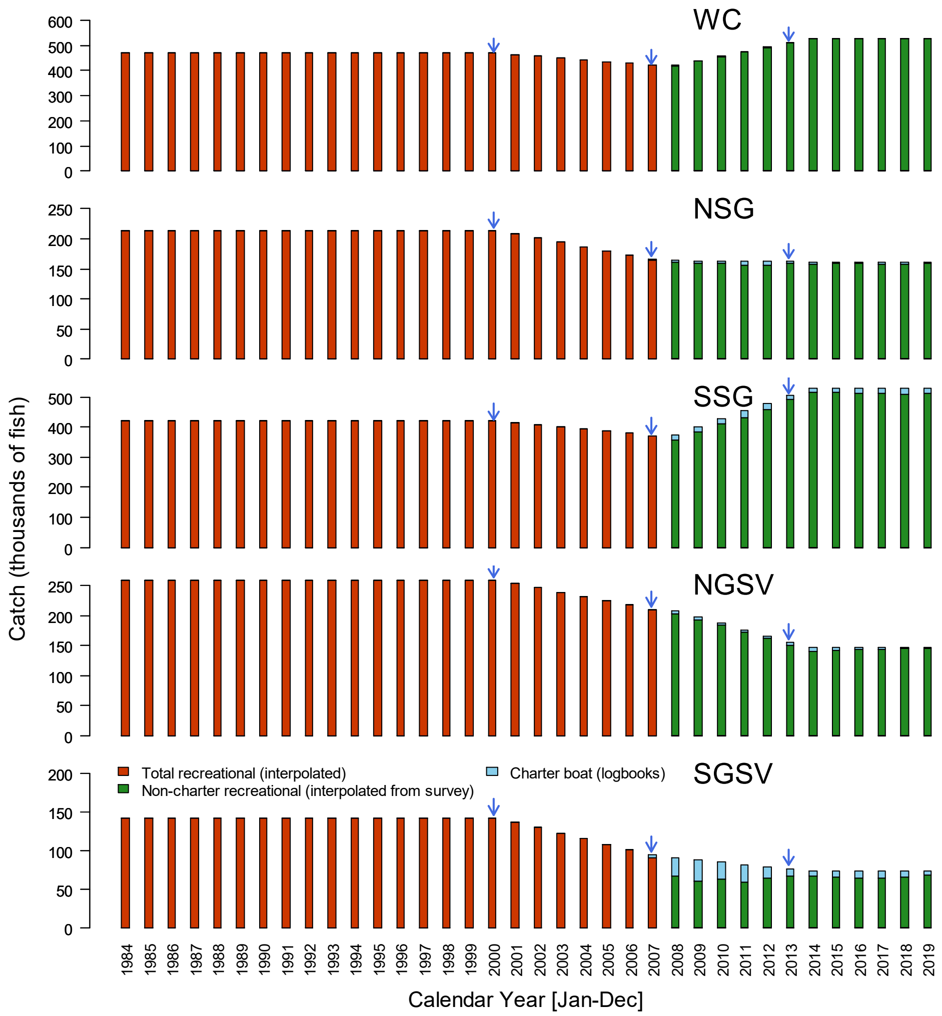


Figure A3.3. Yearly catches of King George Whiting by the recreational sector. The blue arrows indicate the three years when telephone and diary recreational harvest surveys were undertaken. Between those survey years (see also Figure A3.2), catches were obtained by interpolation. Recreational catches for all years preceding the first 2000/01 survey assumed the 2000/01 estimates. 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), the WhitEst fitting procedure to recreational catches was modified. For all other effort types, the model assumes a linear relationship between fishing mortality (*F*) and logbook-reported fishing effort (broken down by monthly model time step, spatial cell, and effort type). This relationship is incorporated into the corresponding Baranov relationships used to model catches and population survival in each time step (Equations A4.1-A4.4). The principal modifications to account for the absence of recreational effort data in the most recent Giri and Hall (2015) survey were 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 4, Equation A4.2b). With effort set to 1, these catchabilities effectively equal fishing mortality *F* for this recreational effort type, thereby obviating the need for recreational effort data. The final step (3) was to substantially reduce the weighting assigned to fitting recreational catches by cell and model time step so that they have little effect on model-estimated trends in stock biomass but still accurately account for recreational catch in number.

Model computed catches of King George Whiting in weight

As a natural outcome of WhitEst modelling, estimates of recreational catch in weight harvested (Figure A3.4) are outputted as a consequence of the fit to reported catch in numbers. This uses the tracking of catches by length bin (i.e. by model 'slice') of each cohort as it passes through the fishery. These tonnages landed do not include release mortality. For comparison, both commercial and total recreational King George Whiting harvest are plotted by year in Figure A3.4. The trend of increasing proportions taken by the recreational sector is evident, driven mainly by greatly reduced commercial fishing effort in the two gulfs since the late 1990's (Figure 3-5, 3-6)

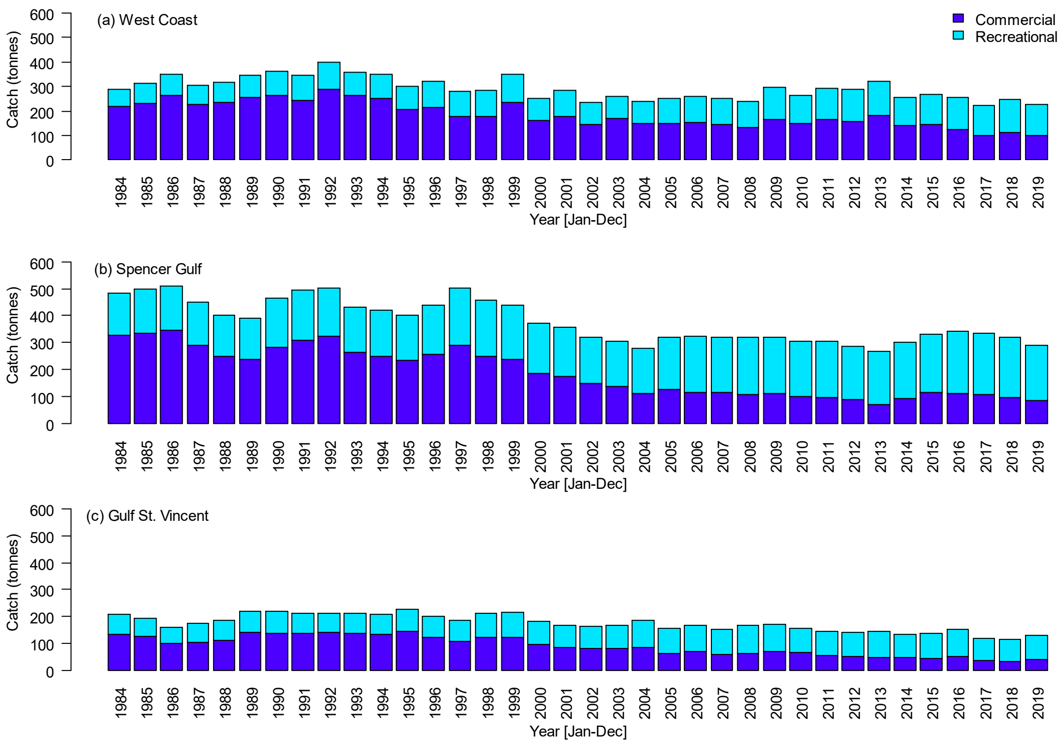


Figure A3.4. Yearly recreational (light blue) and commercial (dark blue) harvests of King George Whiting for the three South Australian stocks, given in tonnes landed.

7.4. Appendix 4: 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 WhitEst 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 neighbouring slices, to grow with the cohort. The slice partition points (i.e. fish lengths separating neighbouring 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 A4.1). 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.

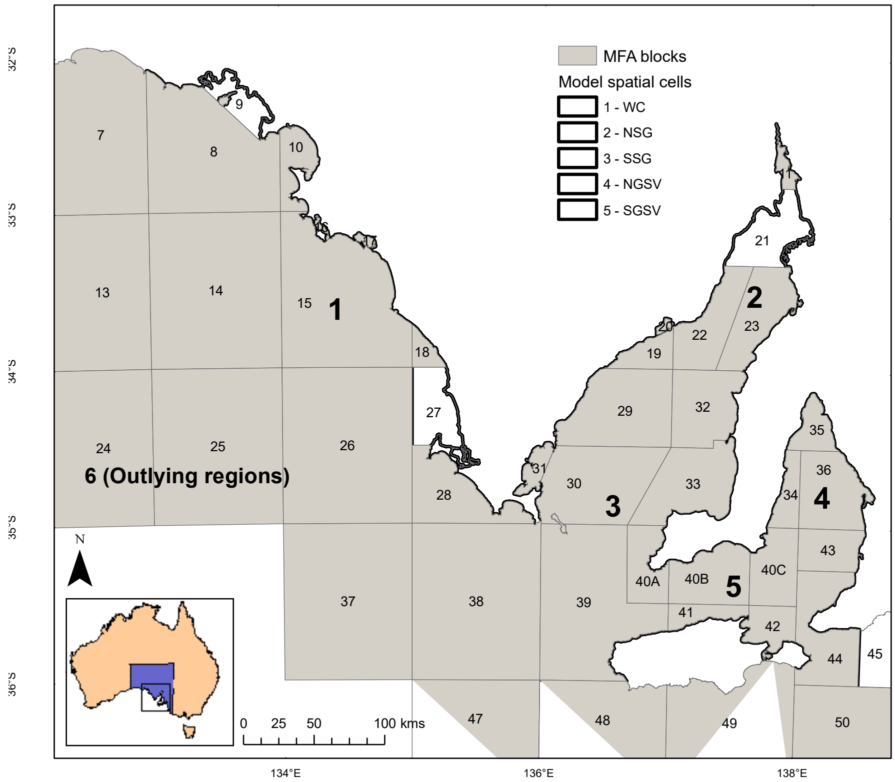


Figure A4.1. Map of South Australia showing the Marine Fishing Areas in which commercial catch and effort are reported, and the 6 spatial cells used in WhitEst. The three regions containing the three separate King George Whiting stocks are West Coast (cell 1 and its offshore areas), Spencer Gulf (cells 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 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 CPUE 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 1994-2019, (3) three separate years of recreational catch (numbers) and effort obtained from three national telephone and diary surveys (Appendix 3), 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 earlier 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 3), permitting the creation of a 14th effort type; thus, non-charter recreational catch, modelled still as the last effort type, is indexed as effort type 14, while charter catch is effort type 13.

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 16,931 were sampled over 2004-2019. 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 2004-2019 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 A4.1), 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 5). 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 A4.1), 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 achieved by estimation of a parameter that models the proportion splitting the recruit number between upper and lower cells in each gulf. In the West Coast, recruitment is all initially assigned to the inshore cell 1. Subsequent to cohort creation at age 1 year, cohort number is reduced only by natural mortality until reaching legal size. Faster growing fish (the upper tail of the pdf) reach and grow beyond legal minimum length sooner. In each model time step, legal slices are created, 'sliced' off of the still sub-legal fish with proportions computed from growth parameters (e.g. Table A4.1), and become subject to harvesting.

The slice-creation algorithm assumes the existence of a 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-at-age pdf having length ≥ 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-partition form of length-based modelling inside a stock assessment model are threefold: (1) the proportions transferred from the sublegal component of each cohort to each newly created slice, in the age when each slice reaches legal size (Table A4.1), (2) the slice length partition points (Table A4.2) (from which are derived the slice midpoints), and (3) the mean weight of each slice (Table A4.3). The derivation of these slice-partition inputs to WhitEst is given in Appendix 5. These three slice quantities were computed in Mathematica (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 four regulated levels of legal minimum length in this fish stock (28 cm, 30 cm, 31 cm, and 32 cm). Each fishery change in LML regulation requires 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 bin 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 (e.g. Table A4.3; see also Appendix 5) is multiplied by catch numbers by age and slice to yield model catch in weight in fits to catch totals from logbooks which are 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-partition inputs, based on the growth submodel, varied only with age for each region and sex. To reduce WhitEst computation time, once each cohort had fully recruited to legal size, we re-aggregated the population numbers by slice into a single number of fish by age (creating 'post-legal cohorts'). 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:

$$F[t,\ cell,\ sex,\ cohort,\ slice,\ Etype] = q[cell,\ month,\ sex,\ Etype, a] \cdot \tilde{E}[t, cell, Etype]\,. \tag{A4.1}$$

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

$$q[cell,\ month,\ sex,\ Etype, a] = q_{CE}[region,\ Etype] \cdot s_m[cell, month] \cdot s_X[sex] \cdot s_3[a]\,. \tag{A4.2a}$$

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 from the 2017 assessment onwards, 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 recreational effort as a meaningful input. See Appendix 3 for details.

$$q_{rec}[cell,\ month,\ sex, a] = q_{rec}[cell,\ month] \cdot s_X[sex] \cdot s_3[a] \tag{A4.2b}$$

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

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:

$$F[t, cell, sex, cohort, slice] = \sum_{Etype=1}^{nEtype} F[t,\ cell,\ sex,\ cohort,\ slice,\ Etype] \qquad \text{(A4.3)}$$

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. Fishing mortality 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:

$$\begin{aligned} &N[t+1, cell, sex, cohort, slice] = \\ &\quad N[t, cell, sex, cohort, slice] \cdot \exp\left[-\left(M + F[t, cell, sex, cohort, slice]\right) \cdot p_{yr}[t]\right] \end{aligned} \qquad \text{(A4.4)}$$

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 yr^{-1}, was taken from a prior-estimated constant.

Movement

Yearly summer migration was modelled 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 A4.1) to upper gulf cells, and thus P_{ii} = 1 for spawning cells (*i* = 1, 3, 5) where fish are assumed to remain once they migrate in. For age 4 King George

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 four general categories: (1) yearly recruit numbers for each region, and proportions allocated among cells within each region, (2) catchabilities, (3) relative selectivities, (4) movement rate parameters 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:

$$\hat{C}^{w}\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right] = N\left[t,\ cell,\ sex,\ cohort,\ slice\right] \cdot w[slice \mid sex, region, a] \cdot \frac{F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]}{M + F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]} \cdot \left\{1 - \exp\left[-\left(M + F\left[t,\ cell,\ sex,\ cohort,\ slice, Etype\right]\right) \cdot p_{yr}[t]\right]\right\} \quad \text{(A4.5)}$$

where derivation of weights by age and slice $w[slice \mid sex, region, a]$ are given in Appendix 5.

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

$$L_{Cw} = \prod_{t=1}^{nt} \prod_{Etype=1}^{nEtype-2} \prod_{cell=1}^{ncell} \frac{\exp\left[-\frac{1}{2}\left(\frac{\hat{C}^{w}[t,cell,Etype] - \tilde{C}^{w}[t,cell,Etype]}{\sigma^{C}[region,gear]}\right)^{2}\right]}{\sqrt{2\pi}\cdot\sigma^{C}[region,gear]} \quad \text{(A4.6)}$$

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 gulf regions to 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 6.

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, $\tilde{n}[a,sex\,|\,i_{AX}]$. The multinomial likelihood was written:

$$L_{AX} = \prod_{i_{AX}=1}^{n_{AX}} \prod_{a=1}^{12+} \prod_{sex=0}^{1} \hat{p}[a, sex \mid i_{AX}]^{\tilde{n}[a, sex \mid i_{AX}]} \qquad \text{(A4.7)}$$

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 262 free parameters, convergence takes about five minutes, and hessian calculations half an hour (laptop, Intel Core i7, RAM 32 GB).

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 5), 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 A4.2). 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 WhitEst model implements a Statewide increase in the LML at the end of August 1995 from 28 cm to 30 cm, and in the two gulfs only from 30 to 31 cm at end of September 2004 and from 31 to 32 cm at end of November 2016, each new LML requiring an additional set of slice-partition inputs.

Mean weights (kg) of each slice (e.g. Table A4.3) were used to calculate model-predicted catch by weight. The quantity $P_{sublegslice}(a)$ (derived in Appendix 5, Equation A5.3) 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 A4.1). 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 5), denoted $P_{slice}(a)$ (Table A4.1).

The explicit representation of population numbers by length in each cohort altered the (1) shape of the length distribution (Figure A4.2), 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 A4.2), the mean legal-size length of modelled 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 2019.
- *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 old fish the year following spawning in May, at age 13 months. Over the period modelled this ranges from 1983 to 2017.
- *month* = calendar month, January to December, of any given year.
- *cell* = spatial model cell. There are 6 spatial cells (Figure A4.1), plus a hypothetical 7th cell to which West Coast fish migrate. The "outlying regions" (cell 6, Figure A4.1), 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 all commercial combinations of four gear types and three target types (targeting King George Whiting, targeting some other species, or not declaring any target type), plus charter boats and recreational. *Etype* ranges from 1 to *nEtype* = 14.

Tables

Table A4.1. 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

Table A4.2. Left-hand length boundaries for each slice length subinterval: Gulf St. Vincent females, LML = 28 cm. Similar slice model inputs are produced for all other combinations of male or female, stock (i.e. region), and LML's of 28, 30, 31 and 32 cm.

		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 A4.3. 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

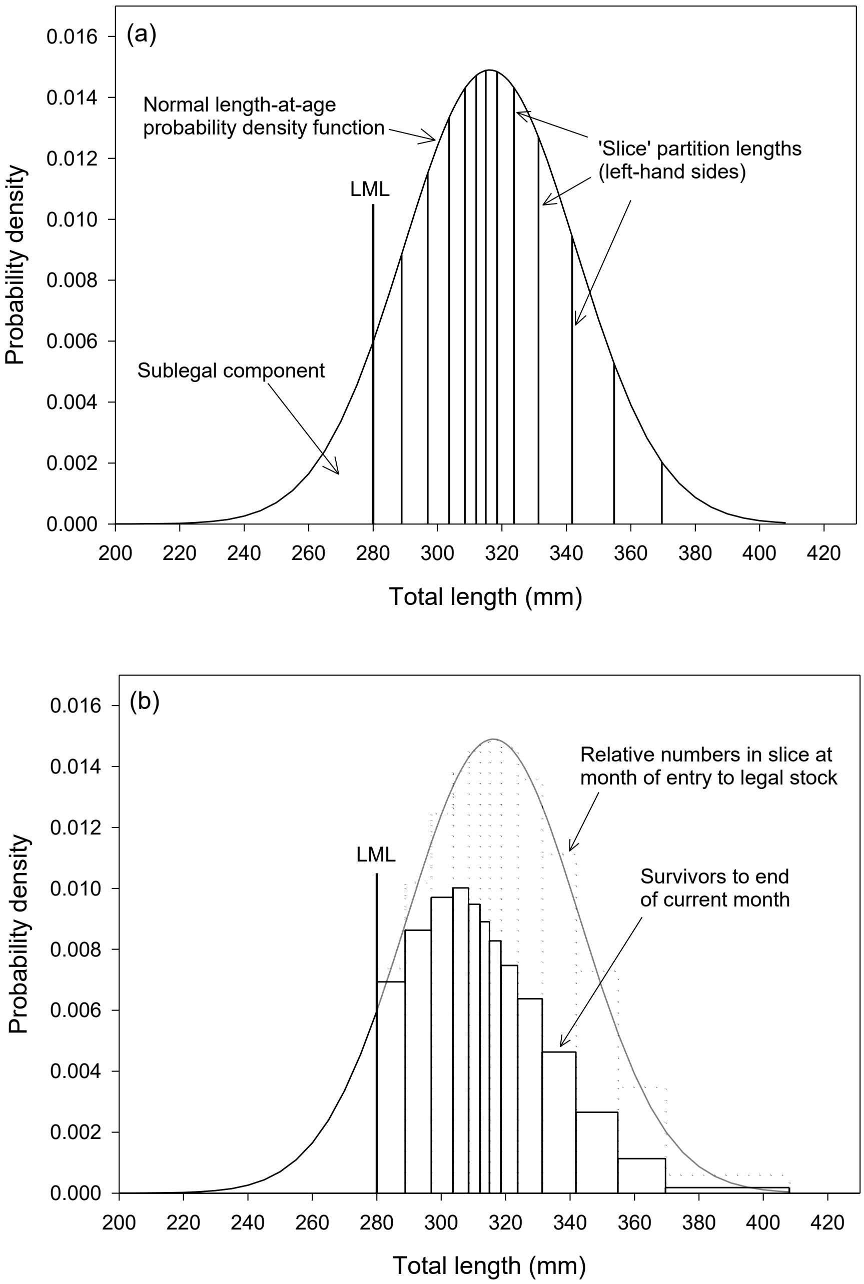


Figure A4.2. Length partition of a Gulf St. Vincent female model cohort, here having been of legal size for 13 monthly time steps. Fish are transferred from the sublegal component to each newly created slice (dotted bars). Thinner slices are created during slow-growth months. The normal length-at-age 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.

7.5. Appendix 5: 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 v. 12 (Wolfram 2019).

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 (≥ LML) in monthly age *a* is $P_{leg}(a)$:

$$P_{leg}(a) = \begin{cases} 0, & at\ age\ a\ if \int_{LML}^{\infty} P(l \mid \theta; a)\, dl < 0.02 \\ 1, & at\ age\ a\ if \int_{LML}^{\infty} P(l \mid \theta; a)\, dl > 0.98 \\ \int_{LML}^{\infty} P(l \mid \theta; a)\, dl & otherwise. \end{cases} \qquad \text{(A5.1)}$$

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. $P_{leg}(1) = 0$:

$$P_{slice}(a) = P_{leg}(a) - P_{leg}(a-1),\ a = 2, \ldots, \max(a). \qquad \text{(A5.2)}$$

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:

$$P_{sublegslice}(a) = \frac{P_{slice}(a)}{1 - P_{leg}(a-1)}, \quad a = a_{1c}, \ldots, a_{fc}. \tag{A5.3}$$

Note that the intuitively expected outcomes for the two critical ages, a_{1c} and a_{fc}, were obtained (Table A4.1), 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:

$$n_s(a) = a - a_{1c} + 1, \quad a = a_{1c}, \ldots, a_{fc}. \tag{A5.4}$$

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 A5.2. 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

$$P_{slice}(a_{1c} - 1 + slice) = \int_{Llhs[a,\ slice]}^{Llhs[a,\ slice-1]} P(l \mid \theta;\ a)\ dl \qquad \text{(A5.5)}$$

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:

$$w[a,\ islice] = \int_{Lhs[a,\ islice]}^{Lhs[a,\ islice-1]} \alpha\, l^{\beta}\ P(l \mid \theta; a)\ dl \qquad \text{(A5.6)}$$

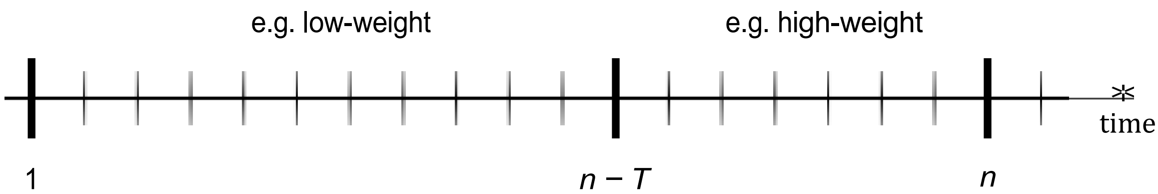
where $\alpha\, l^{\beta}$ or other function gives mean fish weight as a function of length using prior-estimated parameters.

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.

7.6. Appendix 6. 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. The reduced weighting is applied to all time steps up to 1994, denoted 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 present assessment, *n* = 438, covering all months from July 1983 to December 2019. 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

$$p_i = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x_i-\mu_i)^2}{2\sigma^2}} \tag{A6.1}$$

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 (A6.1) 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,

$$L(x;\mu,\sigma)=\prod_{i=1}^{n} p_i. \quad \text{(A6.2)}$$

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

$$L(x;\mu,\sigma)=\left(\prod_{i=1}^{n-T} p_i\right)^{Y}\left(\prod_{i=n-T+1}^{n} p_i\right). \quad \text{(A6.3)}$$

And hence

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

(A6.4)

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

$$\partial NLL/\partial\sigma=(Y(n-T)+T)\sigma^{-1}-\sigma^{-3}\left(\sum_{i=1}^{n-T}Y\left(x_i-\mu_i\right)^2+\sum_{i=n-T+1}^{n}\left(x_i-\mu_i\right)^2\right) \quad \text{(A6.5)}$$

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

$$\sigma^2 = \frac{S}{Y(n-T)+T} = \frac{S}{F}. \tag{A6.6}$$

Inserting the square root of Eq (A6.6) into the NLL — Eq (A6.4) — provides the expression to be minimized (ignoring some additive constants) for parameter estimation

$$\begin{aligned} NLL &= Y\sum_{i=1}^{n-T}\ln(\sigma) + \sum_{i=n-T+1}^{n}\ln(\sigma) + \frac{1}{2\sigma^2}S \\ &= F\ln(\sigma) + \frac{1}{2}F \cdot \end{aligned} \tag{A6.7}$$

7.7. Appendix 7: 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 A7.1), to catch age composition samples for the 24 most recent fitted combinations of region, month and sex (Figure A7.2), and to sex ratios for the 24 most recent fitted combinations of region and month (Figure A7.3). 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, August 2014 to October 2016, and April 2017 to November 2019.

It is visually evident that the fits to the catch totals by the effort-conditioned WhitEst model (Figure A7.1) are quite close for most months and regions.

The fits to the catch-at-age proportions (Figure A7.2) and the sex ratios (Figure A7.3) show greater variability, for example the two samples for inshore West Coast (spatial cell 1, “Mc1”) taken in November 2019. These show high proportions of whiting for ages 4 and up. These do not appear in West Coast samples from previous years, and West Coast historical sampling has not previously observed King George Whiting above age 4, and age 4 fish appear rarely. This November 2019 sample is anomalous, and represents fish taken in deeper waters outside the bays where West Coast King George Whiting are more commonly taken.

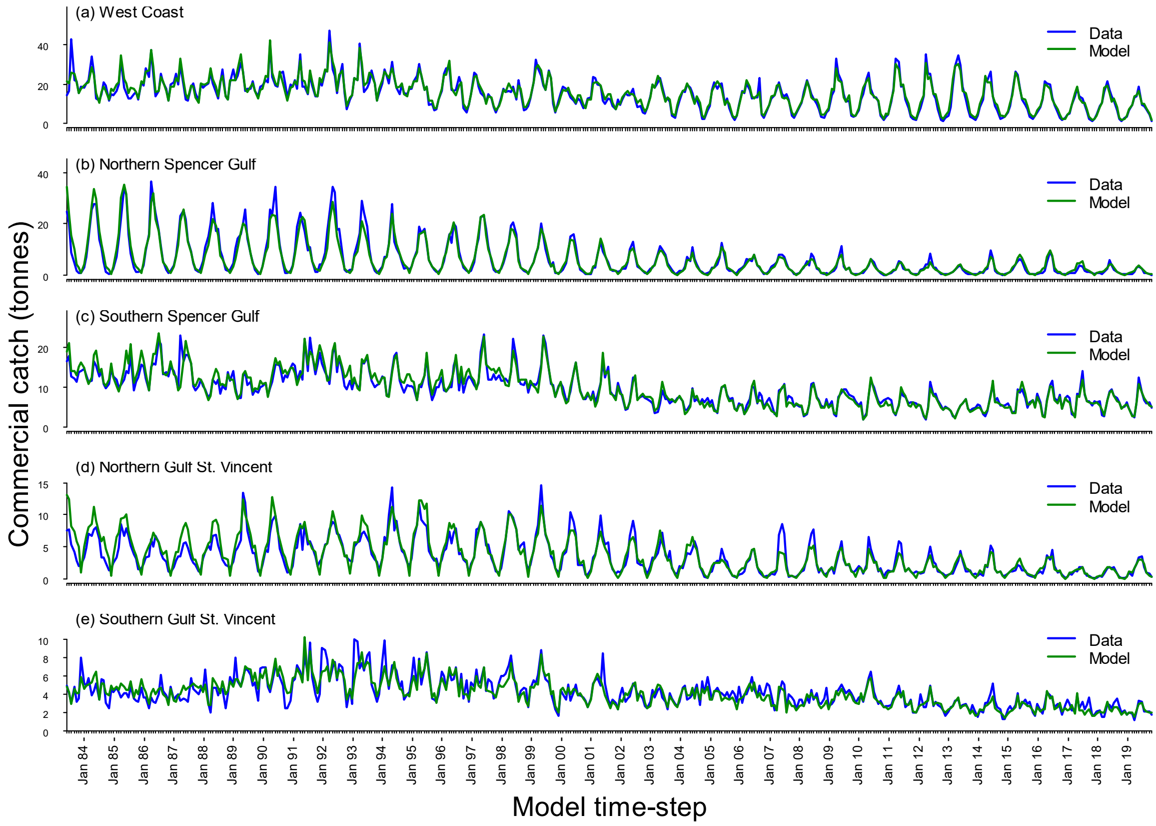


Figure A7.1. Fits of model to data monthly commercial catch totals (all gears and target types combined), for the 5 principal King George Whiting regions of South Australia.

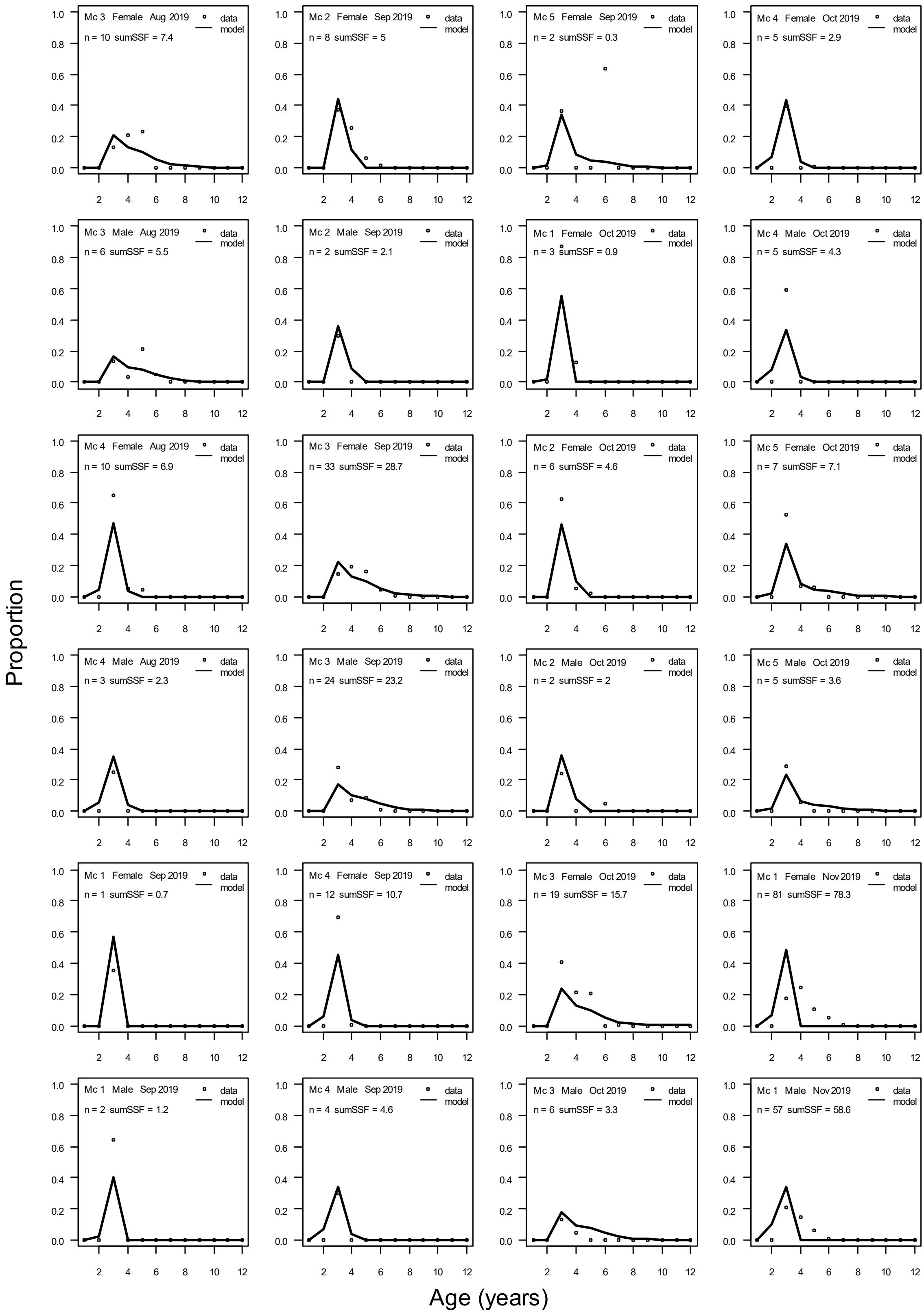


Figure A7.2. Fits of model to market sample data catch-at-age proportions (all gears and target types combined), in the regions (denoted Mc1-Mc5), sex, and months shown.

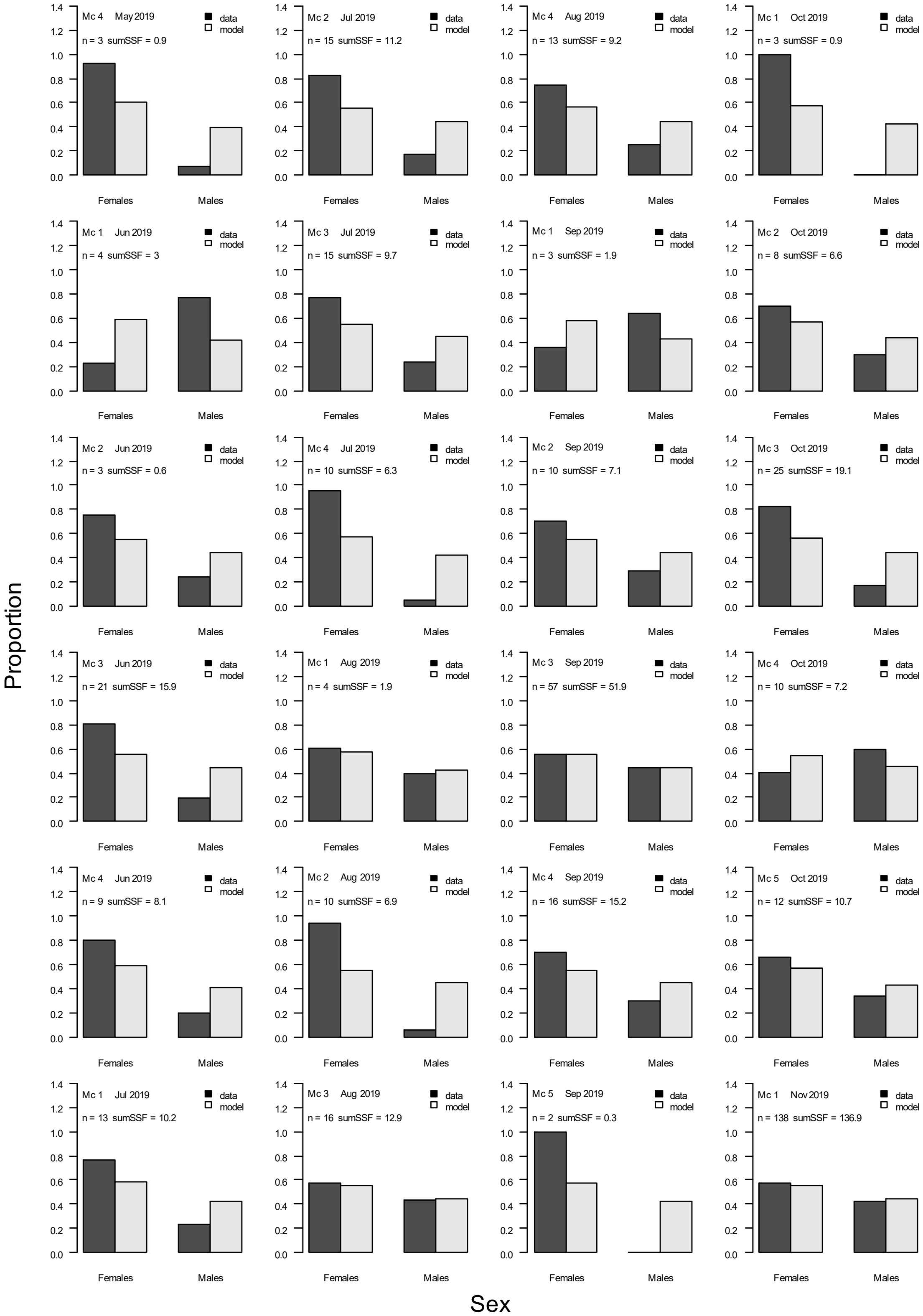


Figure A7.3. Fits of model to SAFCOL market sample catch-by-sex proportions (all gears and target types combined), in the regions (denoted Mc1-Mc5) and months shown.

7.8. Appendix 8. WhitEst Model Sensitivity Analysis.

Introduction

In this Appendix, we present WhitEst model sensitivity testing under (1) alternative weightings for the two principal data sources in the model likelihood, age-sex proportions sampled from the commercial catch and catch log totals, and (2) different assumed levels of natural mortality rate.

Method

Sensitivity to data source weighting

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 catch sampling was undertaken. For catch-log data, the model fits to the monthly catch totals for each of 14 effort types, in each of the five spatial cells, conditioned on the corresponding reported effort.

We adjust only the weighting on the age-sex data component, leaving the likelihood weightings for the other data sources, catch and movement tag-recoveries, unaltered. The value of this age-sex weighting for the baseline (i.e. the current WhitEst model, as reported in this assessment) 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.

Sensitivity to M

The choice of instantaneous natural mortality rate (M) is made prior to estimation in most or nearly all fishery assessment models because the information in fishery data describes the fates only of fish that are captured. To test for sensitivity of WhitEst model biomass estimates to the choice of M, we have run several alternatives to the WhitEst baseline value of $M = 0.45$, namely $M = 0.55$, $M = 0.35$, and $M = 0.25$.

Results

Sensitivity to data source weighting

The biomass estimates for the West Coast were quite insensitive to increasing the relative weighting of age-sex data (Figure A8.1a). This is consistent with a region where the two principal data sources are in close agreement as interpreted by the model.

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 19% for age-sex weighting = 8 (Figure A8.1b). But while the absolute biomass levels were reduced, the time trend was not much altered. Considering NSG and SSG separately (Figure A8.2, a and b), we find that they are about equally sensitive, each showing similar biomass reduction. Relative to the 4-fold weighting, an 8-fold weighting produced only marginally lower biomass levels for all years.

The biomass results for Gulf St. Vincent overall were more sensitive to the weighting of the age-sex data source, mainly in the years 2012 to 2017 (Figure A8.1). Biomass estimates were higher in these years for age-sex weighting = 4, and more so for age-sex weighting = 8. Such high sensitivity implies some inconsistency between data sets in those years. Considering NGSV and SGSV separately (Figure A8.2, c and d), we find that most of this sensitivity for GSV to age-sex weighting is associated with SGSV, which comprises most of the region's King George Whiting biomass.

In summary, the sensitivity analysis under higher age-sex data weighting, for the West Coast showed no effect, and for Spencer Gulf showed a relatively modest and consistent effect of decreasing biomass by spatial cell and year. However for SGSV the effect was more variable, with 2012-2017 exhibiting a strong increase and the other time periods much less so. In NGSV the reverse was observed, namely a strong decrease for all years except for 2012-2017. This implies inconsistency of age-sex sample data with the other two data sources, and greater uncertainty for model outputs in that GSV stock.

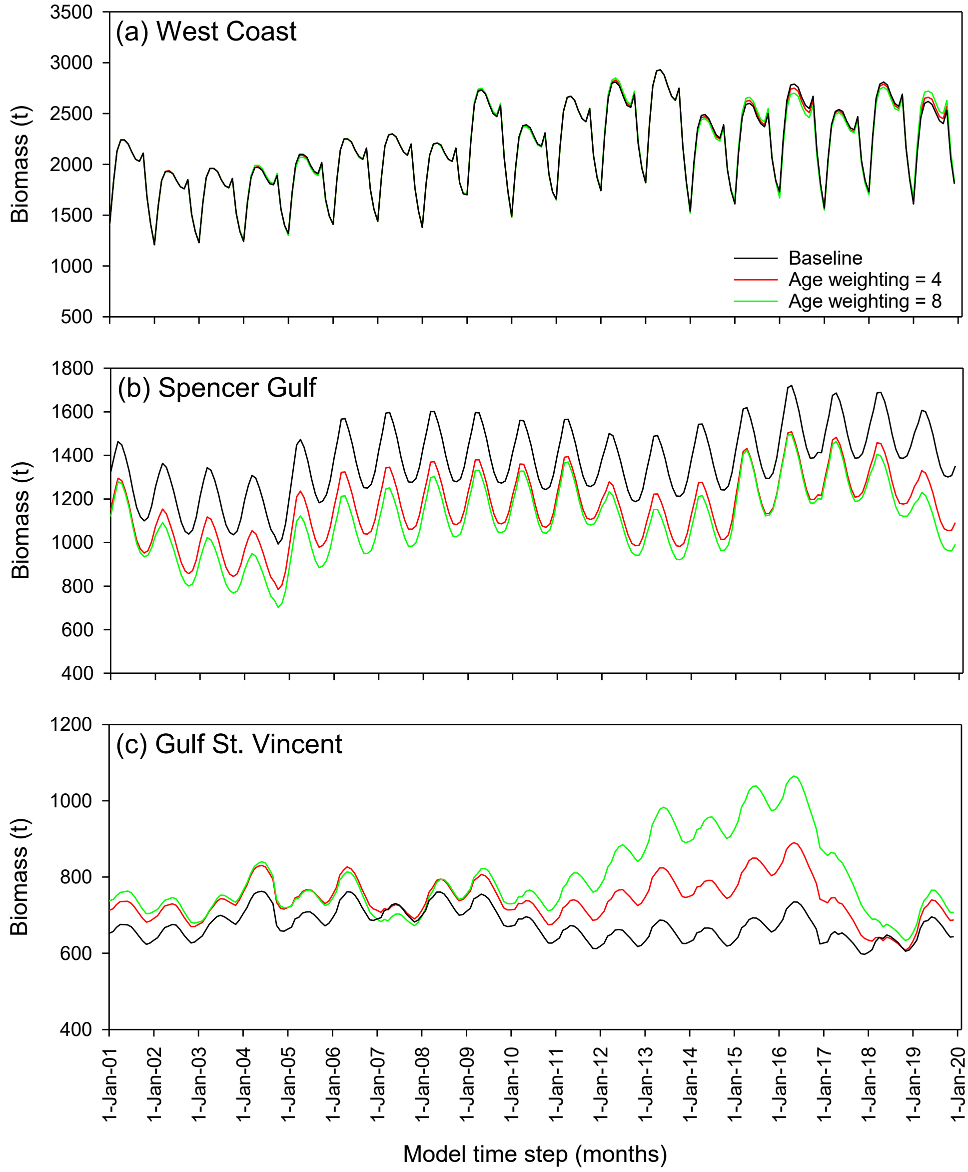


Figure A8.1. Plot of biomass by region from three runs of WhitEst: the baseline (with age-sex weighting = 1), and two alternatives: age-sex weighting = 4 and age-sex weighting = 8.

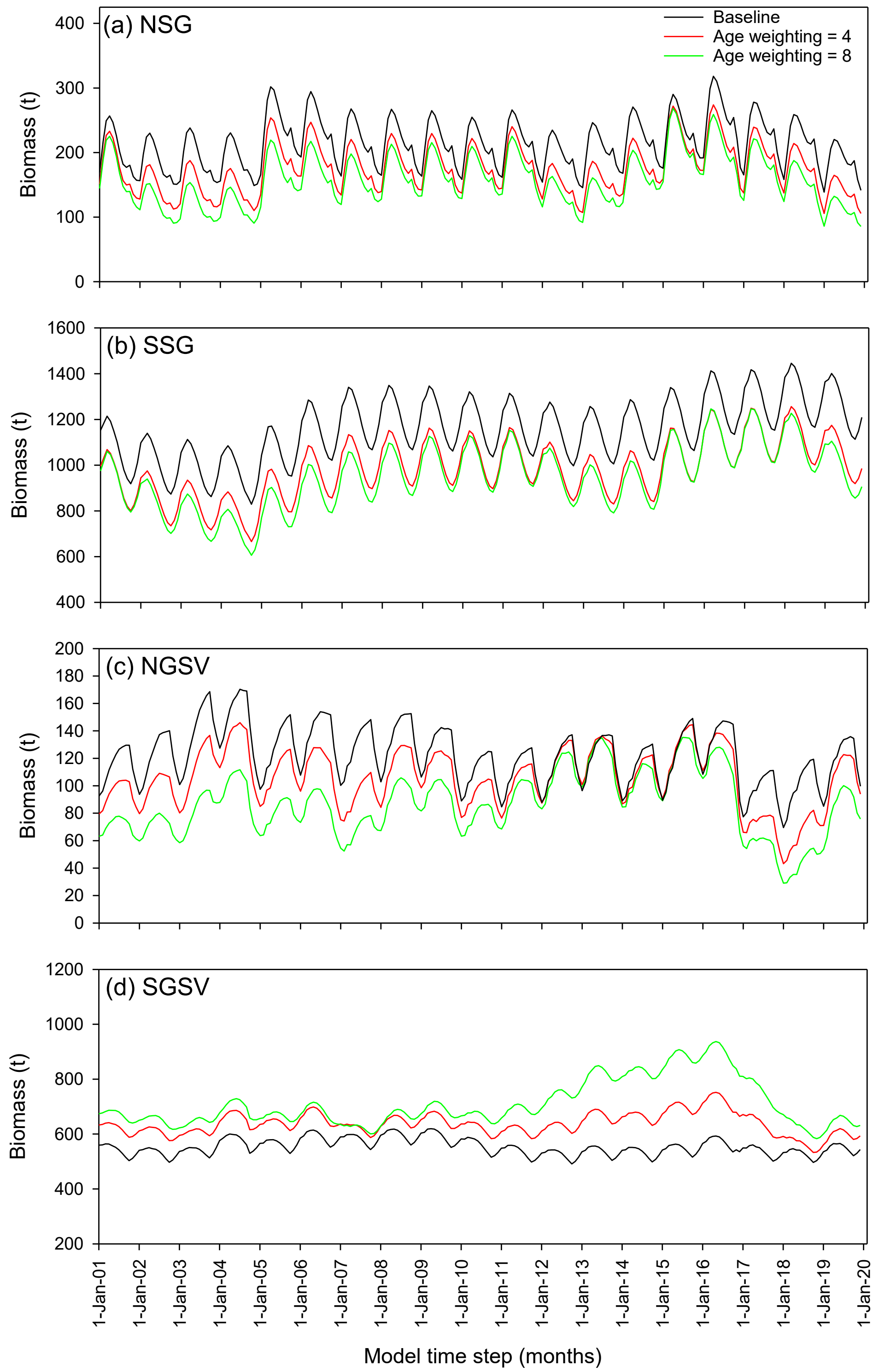


Figure A8.2. Plot of biomass by gulf subregion from three runs of WhitEst: the baseline (with age-sex weighting = 1), and two alternatives: age-sex weighting = 4 and age-sex weighting = 8.

Sensitivity to M

The impact of lowering *M* is expected to be a reduction in model estimates of biomass. This was confirmed for one region, GSV, in the sensitivity results for WhitEst (Fig. A8.3). However, the results were qualitatively different for SG and WC. In SG, all 4 biomass time series are relatively similar—the SG submodel is relatively insensitive to M. In the WC, the absolute biomass levels diverge from baseline in the opposite direction observed for GSV, with lower assumed *M* inducing higher biomass levels.

The values of the negative log likelihood (-lnL) would suggest that the higher value of *M* = 0.55 is the best fitting of the 4 choices of *M* tested. These -lnL differences are 80 units better fit for *M* = 0.55 than baseline *M* = 0.45, 432 units better fit for baseline *M* = 0.45 than *M* = 0.35, and 734 units better fit for *M* = 0.35 than *M* = 0.25, respectively. These are very highly statistically significant differences favouring higher *M*.

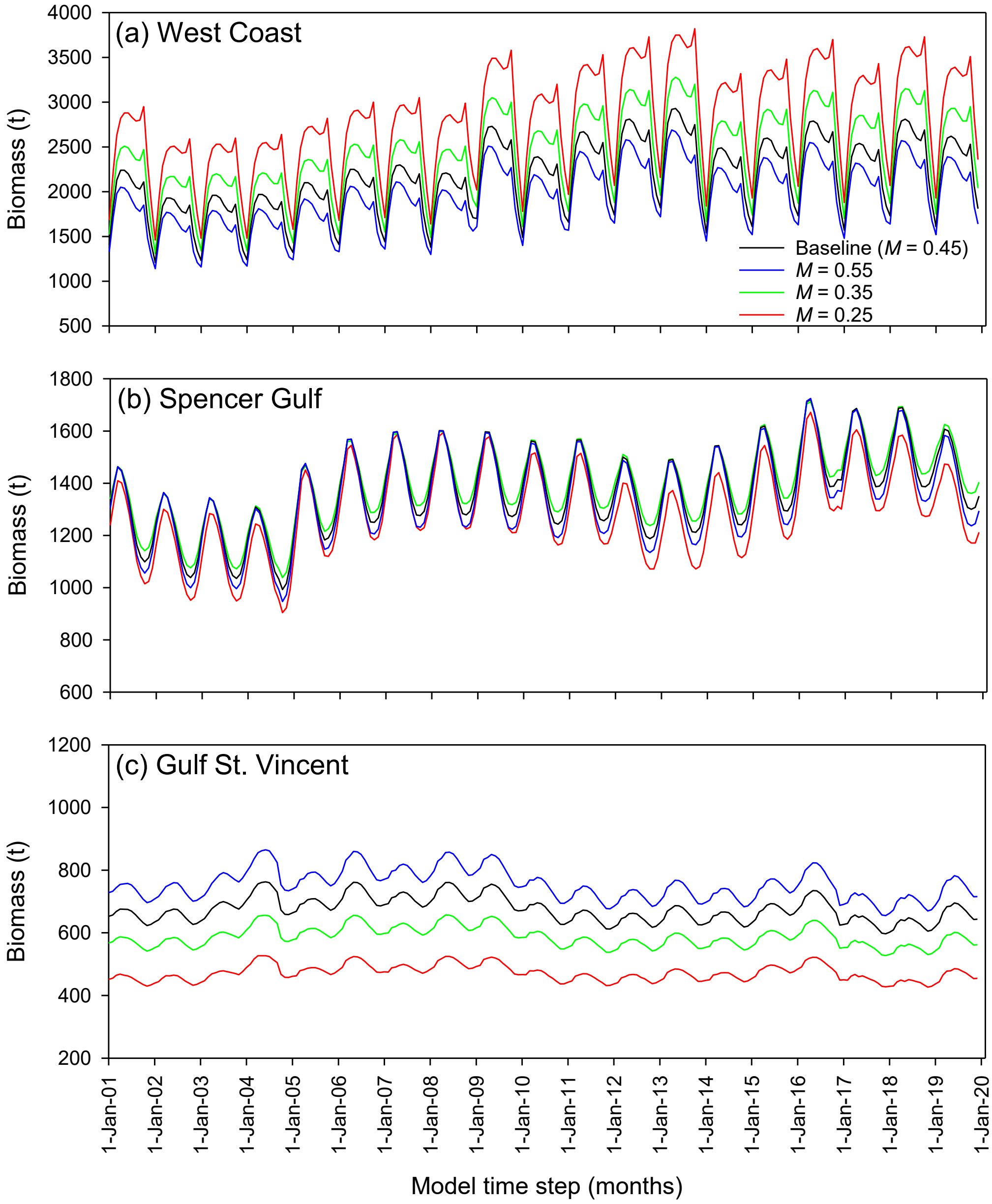


Figure A8.3. Plot of biomass by region from four runs of WhitEst: the baseline (with *M* = 0.45), and three alternatives of *M* = 0.55, *M* = 0.35, and *M* = 0.25.

Discussion

Sensitivity to data source weighting

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 (spatial cell 5) show a greatly extended tail of older fish in the later years (bottom right of (Figure 3-5).

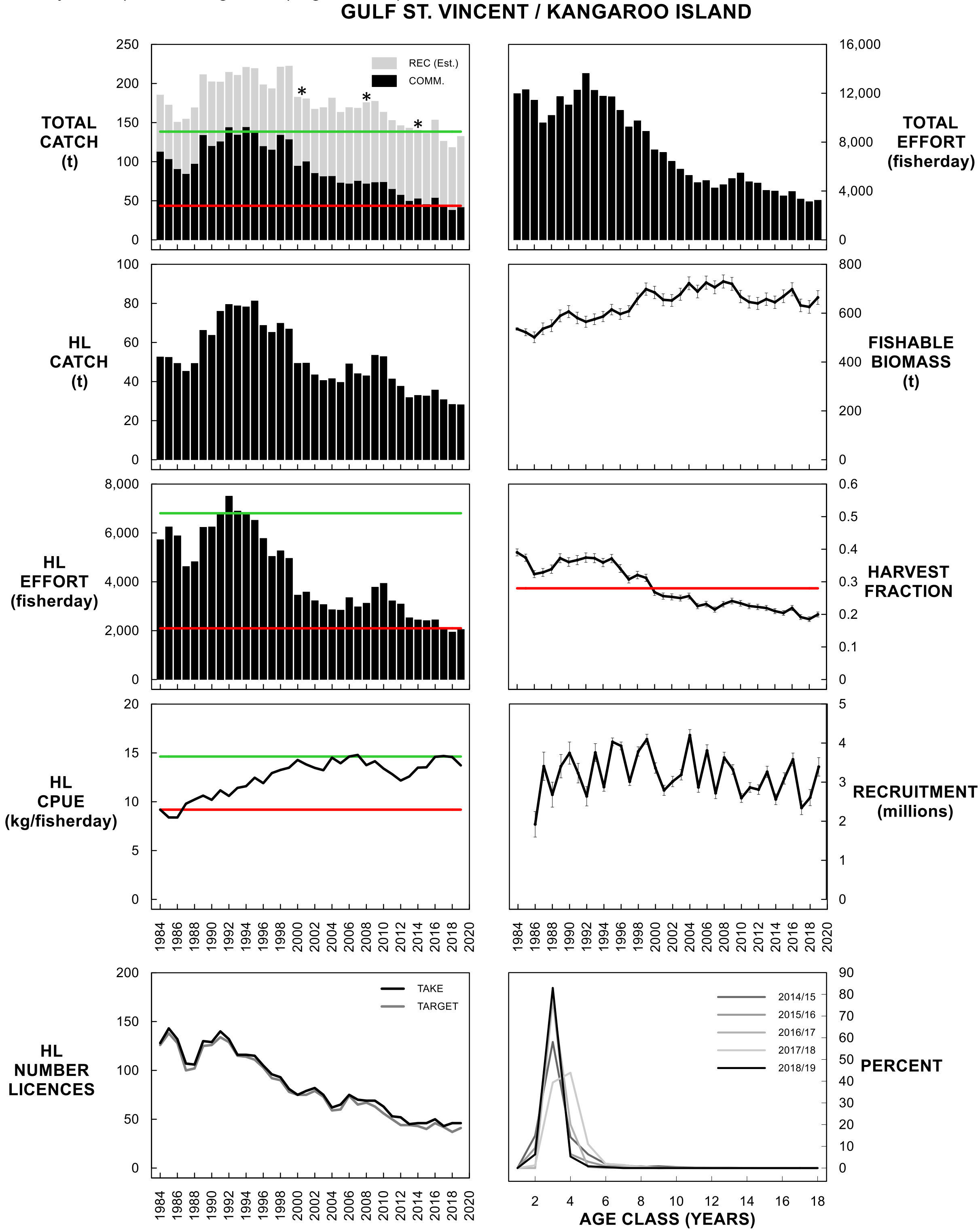


Figure 3-5 Unlike SG and WC, where nearly all fish in age samples are 2 or 3 years old, King George Whiting in southern GSV contain many fish of ages 4-6. Second, GSV biomass tracks

target HL CPUE fairly closely, except in the last few years (Figure 3-5) when the differences among sensitivity runs are largely resolved, suggesting this is not the source of sensitivity divergence. In both gulfs, biomass is much higher in the southern spatial cells, which therefore dominate in the model fits to catch.

The principal source of uncertainty in the SGSV model outputs, and very probably the cause of the differing response in level and trend for GSV and SG model biomass, is inconsistency between age composition and catch log (including CPUE) data. This is likely to be associated with the qualitatively important presence of older King George Whiting in the SGSV market samples. In the time period of 2012-2017, for which the largest response by biomass was observed in the sensitivity runs, the sampling ratio between north and south in GSV was 0.37 and for SG was 0.87, compared with ratios that are closer to 0.5 for the other periods in both regions. In addition, the total numbers sampled is much lower in the past 4 years, which can create an imbalance over time, with years when higher numbers of King George Whiting were sampled have correspondingly greater influence on overall parameter estimates.

Thus, while a definitive conclusion about the specific data discrepancies implied by variation among sensitivity runs is not proposed, there is indication that it may result from variations over time in the balances of age sampling between north and south, with for example GSV over 2012-2017 having more age sampling in the south than in the north. And the variation in age sampling over time, notably less sampling in recent years, may also play a role.

Sensitivity to M

The biomass outcomes for GSV of lower M giving lower absolute biomass level estimates were anticipated. However. the relative biomass results for SG and WC were not anticipated. The modest impact on biomass levels for SG, and the reverse of anticipated for WC remain unexplained.

Likewise, very large improvements in the measure of model fit (the negative log likelihood) for successively higher M is counter-intuitive, based on general assumed levels of M applied in other fish stocks worldwide. Values greater than our baseline value of M = 0.45 are high by international fishery standards.

The other dynamic process that WhitEst requires due to King George Whiting’s life history, is movement, from inshore to offshore at ages 3 and 4. This process interacts and sometimes confounds estimation of mortality, and so brings a second level of interaction that can alter the impact of varying the assumed value of M.

One overall conclusion that might be drawn is that the data inputted to WhitEst are insufficient to estimate *M* to even a rough degree of reliability. This is consistent with the model assessment practice worldwide wherein *M* is usually not estimated. Age data, in combination with catch totals and CPUE, contain no information about the death of fish that are never captured.