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Snapper (*Chrysophrys auratus*) Fishery

AJ Fowler, R McGarvey, J Carroll,
JE Feenstra, WB Jackson and MT Lloyd

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SARDI Aquatic Sciences
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October 2016

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Jurisdiction	South Australia		
Stock	SG/WC	GSV	WVS
Stock status	Transitional–depleting	Sustainable	Sustainable
Indicators	Catch, CPUE, age structures, biomass	Catch, CPUE, age structures, biomass	Catch, CPUE, age structures, Recruitment surveys

This is the 11th stock assessment report for the South Australian snapper fishery since 1997 and comes three years after the last assessment that was undertaken in 2013. This assessment follows significant management changes implemented in 2012 and 2013, in response to concerns about fishery sustainability in several regions.

This assessment was done in the context of a recently completed biological study that determined that the six South Australian regional populations involve three stocks. The Spencer Gulf / West Coast Stock (SG/WC) involves Northern and Southern Spencer Gulf (NSG, SSG) and the west coast of Eyre Peninsula (WC). The Gulf St. Vincent Stock (GSV) includes Northern and Southern Gulf St. Vincent (NGSV, SGSV). The South East region (SE) is part of the Western Victorian Stock (WVS). Fishery performance indicators were assessed at the regional population scale, but status was assigned at the scale of stock.

Commercial fishery statistics provided the ‘general’ fishery performance indicators and two specific indicators for snapper, i.e. the proportions of daily catches that exceeded 250 kg for the handline and longline sectors (Prop250kgHL, Prop250kgLL). Also, ‘biological’ performance indicators included population age structures, as well as time-series of estimates of fishable biomass, recruitment, exploitation rate, and egg production that were output from the fishery assessment model SnapEst. For all indicators, the estimate for 2015 or an average of the last three years was assessed against reference points calculated from the historical time series from 1984 to 2015.

For NSG and SSG from 2012 to 2015, total catch, as well as targeted catch, effort and catch per unit effort (CPUE) levels were all low, some at their historical lowest. For the WC, commercial fishery statistics had declined since 2008. These regional declines point to low or declining levels of biomass for the SG/WC Stock. The age structures for NSG and SSG indicated that recruitment through the 2000s had been poor relative to strong year classes in the late 1990s. In contrast, the SnapEst model estimates for both NSG and SSG indicated increasing or relatively high levels of biomass, in response to low exploitation rates and the low and declining levels of commercial fishing effort.

For NGSV, fishery statistics in 2015 remained at near record high levels, consistent with high biomass, relating to a succession of strong year classes having recruited through the 2000s. Model outputs from SnapEst concurred with respect to recruitment and indicated that fishable biomass was at a record level, although also experiencing high exploitation rates reflecting the high fishing effort. For SGSV, the fishery statistics were relatively flat, following marginal declines since 2011. The recent age structures demonstrated a number of strong year classes through the 2000s. These were reflected in model outputs, which indicated an increasing biomass.

For the SE in 2015, record catches in recent years had declined, consistent with the depletion of the recent, episodic high biomass level. The episodic fishery related to strong 2001 and 2004 year classes having recruited to the population.

A total of 10 trigger reference points were breached for the general performance indicators for the six regions. Breaches for NSG, SSG, SGSV, SE and WC related to low estimates of fishery statistics. The one breach for NGSV related to high fishing effort. There were also eight breaches for Prop250kgHL and Prop250kgLL, which showed positive increases in the two Spencer Gulf regions, and a decrease for NGSV.

For the SG/WC Stock, substantial declines in catch, effort and CPUE suggest declining levels of biomass, consistent with poor recruitment throughout the 2000s. Whilst in a poor state, nevertheless with some recent recruitment, low recent fishing effort and with management changes implemented in 2012 and 2013, this stock is classified as **transitional depleting**. NGSV and SGSV had consistent fishery statistics, a consequence of relatively high recruitment through the 2000s, having maintained high biomass. As such, the GSV Stock is classified as **sustainable**. The SE region is part of the WVS that has experienced relatively high recruitment over the past 12 years, and will likely be replenished by emigration in the next few years. This stock is classified as **sustainable**, although the regional population in the SE has produced considerably lower catches than in recent years.

1. INTRODUCTION

1.1 Overview

This report continues the triennial series of stock assessment reports for the South Australian snapper (*Chrysophrys auratus*) fishery that have been done since 1997 (McGlennon and Jones 1997; McGlennon 1999; McGlennon and Jones 1999; Fowler 2000, 2002; Fowler et al. 2003, 2005, 2007, 2010, 2013). The aims of these reports have been: to summarise information about the fishery and biology of the species; and to use this information to determine the current status of the snapper stocks. The previous stock assessment was completed in September 2013 (Fowler et al. 2013), and summarised fishery and biological data up to 31 December 2012. This is the 11th report in the series and incorporates data up to the end of December 2015.

1.2 Description of the fishery

1.2.1 Access

Snapper is an iconic fish species that supports important commercial and recreational fisheries in each of the mainland States of Australia (Kailola et al. 2003). It is unusual for an Australian marine fish species to have such a broad geographic distribution and economic significance, which makes snapper one of Australia's most significant fishery resources. In recent years, South Australia (SA) has been one of the dominant State-based contributors to the national total catches of both fishery sectors (Fowler et al. 2013). The snapper fishery is geographically extensive and encompasses most of the State's coastal marine waters from the far west coast to the south eastern region, although the highest abundances and fishery catches are generally taken from Spencer Gulf or Gulf St. Vincent.

Snapper is a primary target species of commercial and recreational industries of SA. For the commercial industry, license holders from four different commercial fisheries have access to SA's snapper stocks, i.e. the Marine Scalefish Fishery (MSF), the Northern Zone and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) and the Lakes and Coorong Fishery (LCF) (PIRSA 2013). Their main fishing gear types for targeting snapper are handlines and longlines, since the use of hauling nets for taking snapper was prohibited in 1993. Snapper is an icon species for local and inter-state recreational fishers, with many particularly interested in the large trophy fish that can be abundant in the coastal waters of SA. The recreational sector is divided into the general and charter boat sectors. The former target snapper using rods and lines, primarily from boats, although jetty and land-based catches occur. The charter boat sector is a commercial platform for recreational fishing that increases the probability of successful operations, based on the expertise and equipment of licensed operators. Recently, the commercial sector accounted for about 81% of SA's snapper catch (Jones 2009, PIRSA 2013). The 18% of total catch attributable to the recreational sector involved 8% from the general recreational sector and 10% from the charter boat sector (PIRSA 2013).

1.2.2 Management Regulations

Regulations for the commercial sector of South Australia's snapper fishery involve a suite of input and output controls (PIRSA 2013). The four commercial fisheries with access to snapper each have limited-entry, which means that the numbers of fishers who can target snapper have been limited for numerous 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 was prohibited in 1993. From December 2012, the number of hooks on set lines was reduced from 400 to 200 for fishers operating within Spencer Gulf and Gulf St. Vincent, but remains at 400 for other regions. Also, a daily commercial catch limit of 500 kg was introduced for all South Australian waters. There is also a 50 kg bycatch trip limit for the Commonwealth-managed Southern and Eastern Scalefish and Shark Fishery. Commercial handline fishers are limited with respect to the numbers of handlines and hooks per line that can be legitimately used.

For the recreational sector, the minimum legal length of 38 cm TL applies, whilst bag and boat limits vary geographically. In Gulf St. Vincent, Backstairs Passage and Investigator Strait the bag limit is 5 and boat limit 15 fish for the size range of 38 - 60 cm TL, whilst for all other State waters the bag limit is 10 and boat limit 30 fish. For fish >60 cm TL, there is a bag limit of 2 fish and boat limit of 6 fish for all State waters. A recent review of SA's recreational fishery has recommended the removal of the geographic variation in bag and boat limits (PIRSA 2016a), which would mean that the bag limit of 5 fish and boat limit 15 fish for the size range of 38 - 60 cm TL would apply for all State waters. For the Charter Boat sector the bag and boat limits are currently similar to those of the general recreational sector, with a further complication relating to number of passengers on board. When the number exceeds six passengers, the catches are limited to 1 fish per day for those >60 cm TL, and either 3 or 5 for the 38 – 60 cm TL, depending on location.

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

1.3 Biology of snapper

1.3.1 Distribution and stock structure

Snapper (*Chrysophrys auratus*) is a large, long-lived, demersal finfish species that is a member of the family Sparidae (Perciforms: Percoidei). The species is broadly distributed throughout the Indo-Pacific region including Japan, the Philippines, India, Indonesia, New Zealand and Australia (Kailola et al. 1993). It has a broad Australian distribution that includes the coastal waters of the southern two thirds of the continent, extending southwards from the mid-coast of Western Australia, along the southern continental coastline, and up the east coast as far as north Queensland (Kailola et al. 1993, Jackson et al. 2012). Snapper are also found along the north coast of Tasmania and in recent years have extended their range to southern Tasmania (Last et al. 2011). Throughout their broad distribution, snapper occupy a diversity of habitats from shallow, demersal areas to the edge of the continental shelf across a depth range of 1 – 200 m.

Previous genetic studies have indicated that the Australian distribution of snapper is divided into several separate stocks. One division is thought to occur at Wilson's Promontory in Victoria from where the East Coast Stock extends 2000 km up the east coast as far as north Queensland (Sanders 1974). The Western Victorian Stock was suggested to extend westwards from Wilson's Promontory into south eastern South Australia (SA), and to include the important nursery area of Port Phillip Bay (Donnellan and McGlennon 1996). This was based on the analysis of allozymes, mitochondrial DNA and tagging data which indicated a broad stock division between the Western Victorian and the South Australian Stocks in the vicinity of the mouth of the Murray

River. For the South Australian Stock that is distributed across >2000 km of heterogeneous coastline and a diversity of habitats throughout the waters of Gulf St. Vincent (GSV), Investigator Strait (IS), Spencer Gulf (SG), and the Great Australian Bight (GAB), there is no evidence for any finer-scale genetic differentiation (Donnellan and McGlennon 1996).

A recent study provided greater resolution to the understanding of stock structure for snapper in south eastern Australia (Fowler 2016). It indicated, based on demographic characteristics and the physical and chemical characteristics of otoliths, that South Australian snapper involves three different stocks: the Spencer Gulf / West Coast Stock (SG/WC); the Gulf St. Vincent Stock (GSV); and the Western Victorian Stock (Fowler 2016) (Fig.1.1). Each stock depends on a significant primary nursery area and subsequent emigration of sub-adult and adult fish from that region to supplement populations in adjacent regions. The latter stock extends westward from Port Phillip Bay (PPB), Victoria into the south east region of SA, as far west as the Fleurieu Peninsula. This stock depends on recruitment to PPB and subsequent westward emigration of fish from that nursery area. As such, the population dynamics of this episodic fishery are driven by inter-annual variability in recruitment to PPB. The SG/WC Stock involves the regional populations of Northern Spencer Gulf (NSG), Southern Spencer Gulf (SSG) and WC. NSG supports the source population and nursery area from which fish emigrate to ultimately replenish SSG and the WC. Northern Gulf St. Vincent (NGSV) supports the third primary nursery area and a self-sustaining population. The area of SGSV and IS is likely to be a mixing zone for fish from the three stocks.

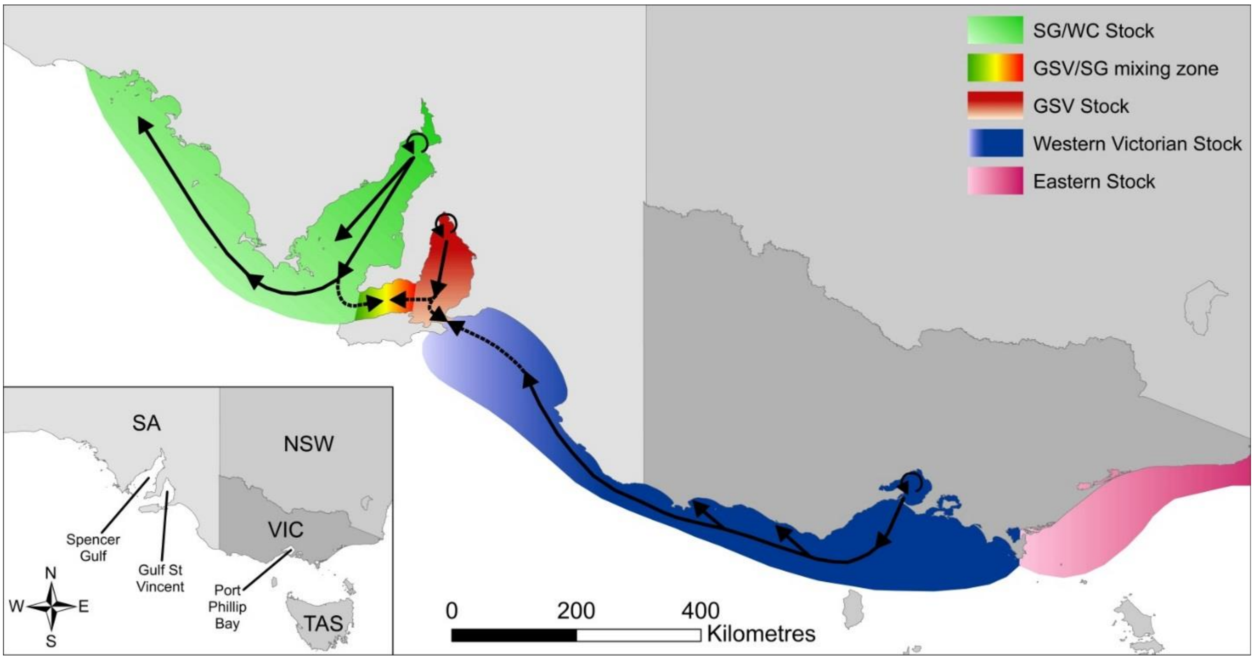

Fig. 1.1 Map of the coast of south eastern Australia, showing the stock structure for snapper based on fish movement (Fowler 2016). The arrows indicate directions and extent of emigration of fish from three primary nursery areas in Northern Spencer Gulf, Northern Gulf St. Vincent and Port Phillip Bay, Victoria. Inset shows the broader geographic region. SG – Spencer Gulf, GSV – Gulf St. Vincent, WC – west coast of Eyre Peninsula.

1.3.2 Growth, Longevity and Age Structures

Transverse sections of the sagittae of adult snapper from SA generally display clear increments of opaque and translucent zones, which form annually and therefore relate to fish age (McGlennon et al. 2000). Such sectioned otoliths have been used to age many thousands of snapper whose otoliths were collected through market measuring in 1991, 1994 and then throughout the 2000s (Fowler and McGlennon 2011; Fowler et al. 2013). Growth conforms to the von Bertalanffy growth equation (McGlennon et al. 2000; SARDI unpublished data). The oldest snapper aged from SA was 36 years, which is four years less than the oldest snapper captured in other Australian waters (Norriss and Crisafulli 2010).

The many market-sampled snapper have been used to develop annual age structures for the regional populations (Fowler et al. 2013). Such age structures display clear strong and weak year classes that reflect the consequences of significant inter-annual variation in recruitment of 0+ fish (McGlennon and Jones 1997; Fowler 2000, 2002; Fowler et al. 2003, 2005, 2007, 2010; Fowler and McGlennon 2011). These age structures indicate that the 1991 year class was particularly strong and largely responsible for the recovery of the snapper fishery throughout all regions of the State, following the poor catches of the 1980s. Further strong year classes recruited in 1997 and 1999 and contributed significantly to all regional fisheries after 2000 (Fowler 2002; Fowler et al. 2003, 2005, 2007, 2010, 2013).

1.3.3 Reproductive Biology

Snapper are multiple batch spawners that have indeterminate fecundity and asynchronous oocyte development (Saunders 2009; Saunders et al. 2012). The individual fish spawn over consecutive days, consistent with findings for Japan and New Zealand (Matsuyama et al. 1988; Scott et al. 1993). Our best understanding for the timing of reproductive activity is for NSG (Saunders 2009; Saunders et al. 2012). In this region gonad development commences in October, spawning starts in late November, peaks throughout December and then declines in January and is finished by early February. The timing of gonad development and spawning appears to vary, to some extent, amongst geographic regions, with reproductive activity persisting for longer in the southern gulfs (SARDI unpublished data). Estimates of batch fecundity in NSG ranged from 12,750 to >1,000,000 and up to 551,000 oocytes in SSG, and varied with fish size, weight and ovary size. There is no evidence in SA that older snapper undergo senescence of reproductive activity and output (SARDI unpublished data).

1.3.4 Early Life-History

Snapper eggs are approximately 0.85 – 1.0 mm in diameter, with unsegmented yolk and a narrow perivitelline space (Crossland 1976). They are pelagic and hatch after approximately 36 hours at 21°C, releasing larvae of 2 mm length, which remain pelagic during development. The larvae take approximately 20 - 30 days to reach 8-12 mm standard length (SL) when they are capable of undergoing settlement and becoming demersal juveniles (Fukuhara 1985; Tanaka 1985; Fowler and Jennings 2003).

The distribution and abundance of 0+ snapper throughout NSG, were documented by an annual recruitment survey from 2000 to 2010 (Fowler and Jennings 2003; Fowler et al. 2005, 2007, 2010). The new recruits were distributed consistently amongst years, being clumped both within and between adjacent stations that were dominated by bare, flat, muddy substratum. This suggests that appropriate habitat for settlement is actively selected by the 0+ fish. In both New Zealand and Japan, the 0+ fish are also strongly associated with fine sediments typical of areas with low current regimes. Recruitment is highly variable and until recently was thought to relate to survivorship of the larvae as influenced by sea surface temperature (Fowler and Jennings 2003; Fowler et al. 2007). However, further research has indicated that the controlling factors are more complex, and relate to inter-annual variation in plankton trophic dynamics (Zeldis et al. 2005, Murphy et al. 2012, 2013). From the estimated spawn dates of the 0+ recruits, as determined from the microstructure of their otoliths, it is apparent that successful recruitment resulted from specific periods through the reproductive season, whose duration and timing varied between years (Fowler et al. 2007).

1.4 Research program

SARDI's research program for snapper involves core-funded monitoring that is augmented by externally-funded projects to address specific issues. The core-funded monitoring provides information on the demographic processes and population dynamics of the regional populations. This is based on market-sampling of commercial catches that are primarily accessed at Adelaide's SAFCOL wholesale fish market. Commercial catches are sampled from the various regions from which individual fish are measured to develop size structures. The otoliths from some fish are removed to determine age. The estimates of size-at-age are informative about growth and used to generate age structures (Fowler and McGlennon 2011), which indicate annual recruitment patterns (Fowler et al. 2013).

The core-funded monitoring work has also been augmented by specific projects to elucidate particular aspects of snapper biology. These have included projects on adult movement and stock structure (McGlennon 2004; Fowler et al. 2005b; Fowler 2016), demographics including small-scale movement (Fowler and McGlennon 2011; Fowler 2016), reproductive biology, early life history and recruitment variability (Fowler and Jennings 2003; Saunders et al. 2012), as well as fishery model development (McGarvey and Feenstra 2004). A current FRDC-funded project is aimed at assessing the applicability of the Daily Egg Production Method for estimating spawning biomass for snapper populations in SA (SARDI unpublished data).

1.5 Information sources for stock assessment

<u>1.5.1 Commercial catch and effort data</u>

Since July 1983, all commercial fishers operating in SA's MSF have been required to submit a monthly catch return that details their fishing activity for the preceding month. The required information includes catch weights by species, targeted fishing effort by gear type, and the Marine Fishing Areas (MFAs) in which the fishing was done. Since July 2003, it has been required that the month's fishing activity be reported on a daily basis. The returns are submitted to SARDI Aquatic Sciences where the data are entered and stored in the Marine Scalefish Fisheries Information System. These catch and effort data constitute the most fundamental dataset available as indicators of fishery status. The data available for this current assessment were from July 1983 to December 2015, i.e. a 32.5 year dataset.

1.5.2 Recreational catch and effort data

Recreational fishery catches must be taken into consideration when determining fish stock status and for resolving resource allocation issues. There have been four State-wide recreational fishing surveys undertaken in SA to quantify recreational catch and effort data. The first was a creel survey that was done through the period of 1994-96 (McGlennon and Kinloch 1997). Subsequently, there have been three telephone/ diary surveys that were done in 2000/01 (Henry and Lyle 2003; Jones and Doonan 2005), 2007/08 (Jones 2009) and 2013/14 (Giri and Hall 2015). The four surveys provide regional, species-specific estimates of recreational catch and targeted fishing effort.

1.5.3 Demographic data

Understanding the demographic processes that operate for the regional populations of snapper has been facilitated by obtaining estimates of size-at-age. From these, size and age structures have been developed and interpreted to provide estimates of recruitment, growth and mortality rates. Since 2000, SARDI's market sampling has provided annual estimates of size-at-age of snapper. The emphasis on sampling snapper has generally been lower during one of every three years, nevertheless at least some snapper have been sampled in each year to 2015. Regional size and age structures, growth curves, and recruitment histories were reported previously from market sampling between 2000 and 2012 (Fowler and McGlennon 2011, Fowler et al. 2013).

1.5.4 'SnapEst' stock assessment model

The computer model 'SnapEst' is a spatial, dynamic fishery model that was specifically developed as a stock assessment tool for SA's snapper fishery (McGarvey and Feenstra 2004). The model provides time-series of biological fishery performance indicators that are interpreted in terms of fishery status. Historically, the model has recognised the three spatial regions of NSG, SSG and GSV that have traditionally accounted for most of SA's snapper catch. The snapper model employs the slice-partition method to describe population numbers by both fish size and age (McGarvey et al. 2007). It integrates all fishery and biological data available on population structure and outputs time series of the parameters: fishable biomass; harvest fraction; egg production; and recruitment. Stock status is determined from recent estimates of these output parameters that are assessed against biological performance indicators and trigger reference points that are identified in the Management Plan for the South Australian Commercial Marine Scalefish Fishery (PIRSA 2013).

1.6 Harvest strategy

1.6.1 Management plan

SA's snapper fishery has experienced considerable change since 2007, particularly with respect to the spatial structure of the fishery. Catches and catch rates in SG (the traditional snapper region) have declined considerably, whilst those in NGSV and the SE have increased to unprecedented levels. These changes resulted in several levels of action: numerous management changes were implemented to limit commercial catches; whilst several FRDC-funded research projects were undertaken to identify the demographic processes responsible for the observed spatial changes (FRDC 2012/020, Fowler 2016), and to develop a fishery independent index of fishable biomass (FRDC 2014/019).

The current harvest strategy for snapper (PIRSA 2013) recognises the changes between 2007 and 2013 and the resulting challenges for fishery management. As such, it does not include explicit decision rules with respect to responses to fishery status. Rather, the proposed approach is to maintain the sustainability of the regional fisheries whilst two FRDC-funded research projects (2012/020, 2014/019) are completed. It proposes that the review of the Management Plan (PIRSA 2013) and harvest strategy that is scheduled for 2018 take into consideration the enhanced understanding from these two projects. The aim is to develop a better harvest strategy with explicit decision rules for management responses to fishery status, based on greater understanding of the biology and fishery, in order to provide greater certainty for sustainable management.

1.6.2 Performance indicators

Determination of stock status for SA's snapper fishery is assisted through assessment of fishery performance indicators that are compared against trigger reference points. There are two sets of fishery performance indicators, 'general' and 'biological' (PIRSA 2013, Table 1.1). The former are based entirely on commercial fishery statistics, whilst the latter are largely based on output from the computer fishery model 'SnapEst', but also include population age structures. In the harvest strategy, the fishery performance indicators are differentiated into primary and secondary. The former are considered key determinants of fishery performance whilst the latter provide supporting information in a weight-of-evidence assessment of fishery performance.

There are two other fishery performance indicators that are specific to snapper and based on commercial fishery statistics, i.e. annual estimates of the proportions of handline and longline fishing trips for which catches reached 250 kg. These parameters are henceforth called ‘Prop250kgTarHL’ and ‘Prop250kgTarLL’, for handlines and longlines, respectively. Their use became necessary due to the imposition of a daily limit on commercial catch imposed in 2012, which reduced the value of CPUE as an indicator of stock status.

1.6.3 Allocation amongst sectors

The *Fisheries Management Act 2007* states that each sector in the fishery is entitled to an allocation of the resource. For MSF species, the shares allocated amongst the different sectors are those to which they had access at the time that the Minister requested the Fisheries Council prepare the Management Plan, based on the most recent information available (PIRSA 2013). At that time, the most recent data were from 2007/08, when a State-wide recreational fishing survey had been done (Jones 2009). For the comparisons, trigger limits are specified in the Commercial and Recreational Management Plans (PIRSA 2013, 2016b). They provide for some variability in the proportional contributions to total catch between years, allowing some flexibility for sectors to exceed allocations without triggering a review. Assessing whether the different sectors have remained within their allocations is based on three trigger limits. Trigger 1 relates to the comparison between commercial fisheries and the recreational sector, and therefore can only be done when new recreational data are available. It asks whether a sector’s contribution to total catch in the assessment year exceeded its allocation by the percentage specified in Table 1.2. Triggers 2 and 3 relate only to the commercial fisheries. Because new commercial fishery data are available each year they can be considered during each stock assessment process. Trigger 2 considers whether a commercial fishery’s contribution to total commercial catch exceeded its allocation by the percentage nominated in Table 1.2 in three consecutive years or in four of the previous five years. Trigger 3 considers whether a commercial fishery’s contribution exceeded its allocation of the total commercial catch by the amount nominated in Table 1.2.

Table 1.1 Fishery performance indicators and trigger reference points used to assess fishery performance as specified in the Management Plan (PIRSA 2013). The type of indicator and whether a primary or secondary one is also indicated. G – general; B – biological; P – primary; S – secondary.

Performance Indicator	Type	P or S	Trigger Reference Point
Total catch	G	S	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Targeted handline effort	G	P	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Targeted longline effort	G	P	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Targeted handline CPUE	G	P	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Targeted longline CPUE	G	S	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Yearly prop. handline trips >250 kg		P	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Yearly prop. longline trips >250 kg		S	3rd lowest/3rd highest
			Greatest interannual change (±)
			Greatest 5-year trend (±)
			Decrease over 5 consecutive years?
Fishable biomass	B	P	3-yr ave is +/- 10% of previous 3-yr ave
Harvest fraction	B	P	above 32% (int. standard)
Egg production	B	S	<20% of pristine pop
Recruitment	B	S	3-yr ave is +/- 10% of historical mean
			3-yr ave is +/- 10% of previous 6-yr ave
Age composition	B	P	prop >10 yrs <20% of fished pop

Table 1.2 Allocation percentages and trigger limits for SA's snapper fishery. Table shows the percentage of total allocation amongst commercial and recreational sectors, and trigger reference point for each sector (Trigger 1). It also shows commercial allocation and trigger reference points for Triggers 2 and 3. Fishing sectors are; MSF = Marine Scalefish, SZRL = Southern Zone Rock Lobster, NZRL = Northern Zone Rock Lobster, LCF = Lakes and Coorong, REC = general recreational, CHTR = charter boat, ABT = aboriginal/ traditional.

	MSF	SZRL	NZRL	LCF	REC	CHTR	ABT
Fishery Allocation (%)	79.0	1.45	0.55	0.03	8.0	10.0	1.0
Trigger 1 (%)	84.0	2.9	1.65	1.0			
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			

1.7 Stock status classification

A national stock status classification system was been developed for assessing Australian fish stocks (Flood et al. 2014). It considers whether fishing pressure is adequately controlled to ensure that stock abundance is not reduced to a point where the production of juveniles is significantly compromised (Table 1.3). 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 either: 'sustainable', 'transitional-recovering', 'transitional-depleting', 'overfished', 'environmentally limited', or 'undefined'. PIRSA has adopted this classification system for assigning status for all South Australian fish stocks. An earlier version of this schema was used in the previous stock assessment for snapper (Fowler et al. 2013).

Table 1.3 Classification scheme used to ascribe fishery stock status. The description of each stock status and its potential implications for fishery management are also shown.

	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. not recruitment overfished) and for which fishing pressure is adequately controlled to avoid the stock becoming recruitment overfished	Appropriate management is in place
↑	Transitional–recovering	Recovering stock—biomass is recruitment overfished, but management measures are in place to promote stock recovery, and recovery is occurring	Appropriate management is in place, and the stock biomass is recovering
↓	Transitional–depleting	Deteriorating stock—biomass is not yet recruitment overfished, but fishing pressure is too high and moving the stock in the direction of becoming recruitment overfished	Management is needed to reduce fishing pressure and ensure that the biomass does not deplete to an overfished state
	Overfished	Spawning stock biomass has been reduced through catch, so that average recruitment levels are significantly reduced (i.e. recruitment overfished). Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect
	Environmentally limited	Spawning stock biomass has been reduced to the point where average recruitment levels are significantly reduced, primarily as a result of substantial environmental changes/impacts, or disease outbreaks (i.e. the stock is not recruitment overfished). Fisheries management has responded appropriately to the environmental change in productivity	Appropriate management is in place
	Undefined	Not enough information exists to determine stock status	Data required to assess stock status are needed

2. METHODS

2.1 Commercial fishery statistics

The catch and effort data for snapper were extracted from the commercial Marine Scalefish Fisheries Information System which includes data from the MSF, NZRLF and SZRLF. Data on snapper catch and effort were also extracted from the Lakes and Coorong Fishery Information system and combined with the former dataset. Then, the data from calendar years of 1984 to 2015, i.e. a 32-year time series were aggregated at both the State-wide and regional spatial scales to provide annual estimates of total and targeted catch, targeted effort for the two primary gear types of handline and longline. Furthermore, the annual estimates of targeted catch and effort for the two gear types were used to calculate catch per unit (CPUE). The time series of CPUE for the two gear types in association with those for catch and effort, were qualitatively interpreted here in terms of the regional trends in fishable biomass. Some regional time-series for CPUE demonstrated long-term increasing trends that were thought to not relate to increasing biomass, but to increasing 'effective' effort due to technological change. A statistical approach was used to remove these long-term trends, as a possible way of allowing for a more equitable comparison of CPUE over time. Each regional time-series of CPUE was detrended by transforming the raw CPUE estimates using the allometric relationship developed by Thorpe (1975):

$\hat{Y}_i = log_{10}Y_i - b(log_{10}X_i - log_{10}\bar{\bar{X}})$, where

$\hat{Y}_i$ = the adjusted estimate of CPUE for the *i*th year

Y_i = the unadjusted measurement of CPUE for the *i*th year

b = within-group regression coefficient of $log_{10}Y$ against $log_{10}X$

X_i = year *i*

$\bar{\bar{X}}$ = overall mean year across the time series.

The data considered at the State-wide scale were 'total catch' and 'targeted effort' (mandays). Untargeted effort is not considered as it is not likely to be meaningful with respect to stock status. The analysis of fishery statistics was considered here for six regional management units (Fig. 2.1), consistent with the spatial scale considered previously (Fowler et al. 2013), and is based on targeted fishing statistics for catch, effort and CPUE for both handlines and longlines.

2.2 Recreational fishery statistics

There have been four State-wide recreational fishery surveys undertaken in South Australia that now provide regional and State-wide estimates of recreational catch and effort. The first was a creel survey done in 1994-96 that used the ‘bus-route’ method for surveying boat ramps (McGlennon and Kinloch 1997). The three subsequent surveys used the telephone/diary methodology and were done in 2000/01 (Henry and Lyle 2003), 2007/08 (Jones 2009) and 2013/14 (Giri and Hall 2015).

2.3 Market sampling

Since 2000, market sampling of commercial catches has been undertaken, augmenting similar work done for NSG in 1991 and 1994. The recent market sampling was concentrated at the SAFCOL fish market although catches were occasionally accessed from elsewhere. Generally, at this market, a team of three researchers processed catches one morning per week prior to the morning auction. Catches of snapper were selected for processing to ensure a broad geographic coverage. A two-stage sampling protocol was used to process catches, where fish from each chosen catch were measured for CFL (mm) and then otoliths were collected from a sub-sample of fish. The latter fish were measured for CFL, weighed, gutted, and their sex and stage of reproductive development were determined. Later, in the laboratory, one otolith from each fish was embedded in resin and sectioned using a diamond saw to produce a thin transverse section. The section was mounted on a glass microscope slide and then examined using low power microscopy to count the opaque zones. This count, the relative size of the most recent increment, and the time of year of capture, were used to estimate the fish’s age (McGlennon et al. 2000). For each region in each year, an age/length key was developed, based on the sizes and ages of fish that were aged during that year, regardless of season or gear type.

Annual estimates of size and age structures were developed for those spatial management units for which sufficient data were available, using the methods of McGlennon et al. (2000). Development of each size structure was based on all fish measured from handline and longline catches from each region, but weighted according to the sizes of catches of the two gear types. The proportional length data were then converted to a biomass distribution using a region-specific, length – weight relationship. An age/length key was generated for each region and year, based on the size and age of all fish aged during that year from each region, regardless of season and gear type. Then, the age/length key was applied to the length frequency distribution to generate an annual, region-specific age structure.

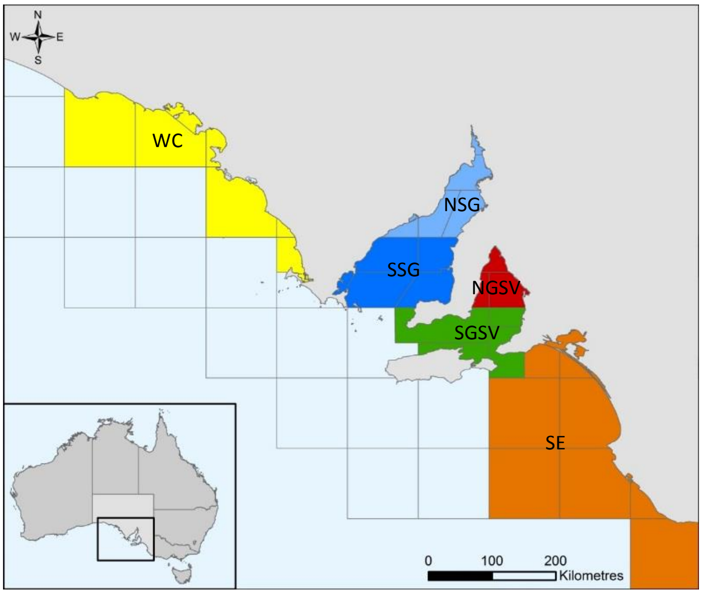

Fig. 2.1 Map of South Australia showing the six regional management units that are considered in the stock assessment processes. Inset shows the location of the geographic region along Australia's southern coastline. NSG – Northern Spencer Gulf, SSG – Southern Spencer Gulf, NGSV – Northern Gulf St. Vincent, SGSV – Southern Gulf St. Vincent, SE – South East, WC – West Coast.

2.4 Stock assessment model – SnapEst

The fishery stock assessment model SnapEst was developed in an FRDC-funded project (McGarvey and Feenstra 2004), as a dynamic, spatial age- and length-structured model. It integrates data collected from October 1983 to September 2015 to estimate biological fishery performance indicators. Five data sets were used as input data to the SnapEst model: commercial catch and effort data; recreational catch and effort data from the telephone and diary surveys done in 2000/01, 2007/08 and 2013/14; charter boat catch and effort data from charter boat logbooks collected since September 2005/06; commercial length-frequency samples; and commercial catch-at-age samples.

SnapEst runs on a half-yearly time step, fitting to data from each summer (Oct-Mar) and winter (Apr-Sep) time step since October 1983. The snapper model employs the slice-partition method to describe fish population numbers by both age and length (McGarvey et al. 2007; McGarvey et al. 2011). The model considers the catches and associated effort divided into six categories (handline, longline, hauling net, all other commercial gears combined, charter boats, and other recreational). Target type is not differentiated, and non-target catches of snapper were, for the most part, low. Full details of the model equations, fishery dynamics and likelihood function, are given in Appendix 6.3.

Spatially, the model is restricted to the two gulfs. Previously, the model recognised only three spatial regions: NSG, SSG and GSV. In this assessment, GSV is divided into NGSV and SGSV based on the recent evidence of different demographic influences in the two regions (Fowler 2016). These model regions are consistent with the spatial management units for which commercial fishery data are also assessed (Section 2.1). The model changes and additional prior analyses of growth (length-at-age) and weight-length for these two new GSV regions are presented in Appendix 6.4. The WC and SE regions are not included in the model because of low historical catches and low sample sizes from market sampling. There is no movement assumed in the model. Thus, the different model regions are considered to be independent of each other.

SnapEst integrates the five input data sets, to carry out maximum likelihood estimation of four annual indicators of fishery performance: recruitment rates, fishable biomass, harvest fraction, and egg production. Recruitment and egg production are computed once per model year while annual indicators for biomass and harvest fraction are computed from the two half-yearly model estimates. Yearly recruit numbers (i.e. numbers reaching 2 years of age at the start of the model half year that commences in October) are dated by year class from the summer when spawned. Annual fishable biomass is the average of the two half-yearly estimates, which start in October and April of each model year. Harvest fraction is the sum of model-predicted half-yearly catches divided by the annual fishable biomass. The proportion of pristine egg production is the estimated annual egg production (assuming a 50:50 sex ratio, and fecundity and maturity ogives divided by a single equilibrium estimate of 'pristine', i.e. pre-fishery, egg production obtained by running the model as a projection with fishing effort set equal to zero for all years.

2.5 Assessment of fishery performance

2.5.1 Fishery Performance Indicators

The fishery performance indicators for snapper (Table 1.1) were assessed at the spatial scale of regional spatial management unit (Fig. 2.1). The general fishery performance indicators considered for each region were; total catch, targeted handline effort, targeted longline effort, targeted handline CPUE and targeted longline CPUE. For each region the time series of data from 1984 to 2015 for each indicator was calculated. Then, the value for 2015, was compared using the trigger reference points calculated for the ‘reference period’, i.e. the historical data time series back to 1984 (Appendix 4, PIRSA 2013). This comparison was done by addressing four questions:

- was the value of the indicator in 2015 among either the top three or bottom three values over the reference period of 1984 to 2015?
- was the change in the indicator between 2014 and 2015, i.e. the two most recent years, the greatest inter-annual increase or decrease over the reference period?
- was the slope of the linear trend over the last five years to 2015, the greatest rate of increase or decrease over five-year periods throughout the reference period?
- and did the indicator decrease over the last five consecutive years?

A ‘results’ table was prepared that showed the outcomes of these comparisons for the six regions, indicating whether or not the target reference points had been breached.

Furthermore, the proportions of handline and longline fishing trips for which catches reached 250 kg were also considered fishery performance indicators, i.e. ‘Prop250kgTarHL’ and ‘Prop250kgTarLL’ . The calculation of these performance indicators was based on daily catch data from the commercial sector. The requirement to report such data on a daily rather than monthly basis only became mandatory in July 2003. As such, the calculation of these two performance indicators was restricted to the calendar years of 2004 to 2015. Furthermore, the targeted catch data from November to January in each summer were excluded from these calculations in order to remove the influence of the seasonal closure on the data (PIRSA 2013). The regional estimates of Prop250kgTarHL and Prop250kgTarLL for 2015 were compared against those from 2004 to 2014, using the same trigger reference points that are used for the general performance indicators.

There are five biological performance indicators: fishable biomass; egg production; harvest fraction; recruitment; and age structure (Table 1.1; PIRSA 2013). The first four are time-series of output parameters from ‘SnapEst’, whilst the age structures are catch proportions by age from market sampling. The estimates of output parameters were considered for the four model regions considered in SnapEst, i.e. NSG, SSG, NGSV and SGSV. The trigger reference points are indicated in Table 1.1. For the recruitment indicator, only model estimates up to and including the 2011 year class are included in this assessment, as it takes several years for a year class to fully recruit to the fishery. For the recruitment performance indicator, the most recent 3-year average covering

2009-2011 was compared with the average over the previous 6 year classes, 2003-2008, and with the historical mean taken over 1983-2008.

2.5.2 Comparison with allocations for fishery sectors

For this assessment, new recreational fishery data from the survey undertaken in 2013/14 (Giri and Hall 2015), allowed contributions of the four commercial fisheries and the recreational sector to be assessed against their allocations and trigger limits (Trigger 1 – Table 1.2). The reported catches and allocations for the commercial sector from 2013/14 that were compared against the data from the recreational survey period of December 2013 to November 2014. For the assessment of allocation amongst only the commercial fisheries, Triggers 2 and 3 (Table 1.2) were used. The data considered here were from the calendar year of 2015.

3. RESULTS

3.1 Commercial fishery

3.1.1 State-wide fishery statistics

Estimates of total State-wide commercial catch of snapper show cyclical variation, with the cycles typically increasing and decreasing over several years (Fig. 3.1a). Since 2003, i.e. the year that produced the minimum catch at the start of the most recent cycle, State-wide catch increased to a record level of 1,035 t in 2010, before declining by more than 50% to 512 t in 2015. Handlines were historically the most significant gear type, largely accounting for cyclical variation in total catch until 2008 (Fig. 3.1a). Longline catch increased marginally between 2005 and 2008 before increasing considerably until 2010, when it became the dominant gear type. Both longline and handline catches declined between 2010 and 2013, but were relatively consistent between 2013 and 2015. The commercial catch has historically been dominated by the MSF which has generally contributed >95% of the reported catch (Fig. 3.1a). The NZRLF has generally contributed <3% of the total, but has been as high as 7%. That for the SZRLF has generally been <1% of total catch, but ranged from 2 to 4% between 2008 and 2013. The annual catch of the LCF has always been very low and never exceeded 0.4% of total catch.

There was a long-term declining trend of targeted commercial fishing effort between the mid-1980s and 2008 (Fig. 3.1b). This was followed by a period of elevated fishing effort between 2009 and 2012 that was associated with the increase in longline effort.

However, since 2011, longline effort has declined exponentially, complementing the on-going, long-term declining trend for handline effort. As such, in 2015, targeted fishing effort was the lowest since 1984. The MSF has generally accounted for >94% of targeted effort. Estimates from the NZRLF and SZRLF have accounted for up to 6% and that of the LCF has generally been <0.5% of targeted effort.

The number of fishers from across all four commercial sectors who reported taking snapper, declined consistently from 401 in 1984 to 244 in 2000. It then stabilised for a period before once again declining from 2010 onwards. Between 2010 and 2015, it fell from 266 to 186 fishers. The number of commercial fishers who targeted snapper varied similarly and fell to the lowest number of 150 in 2015.

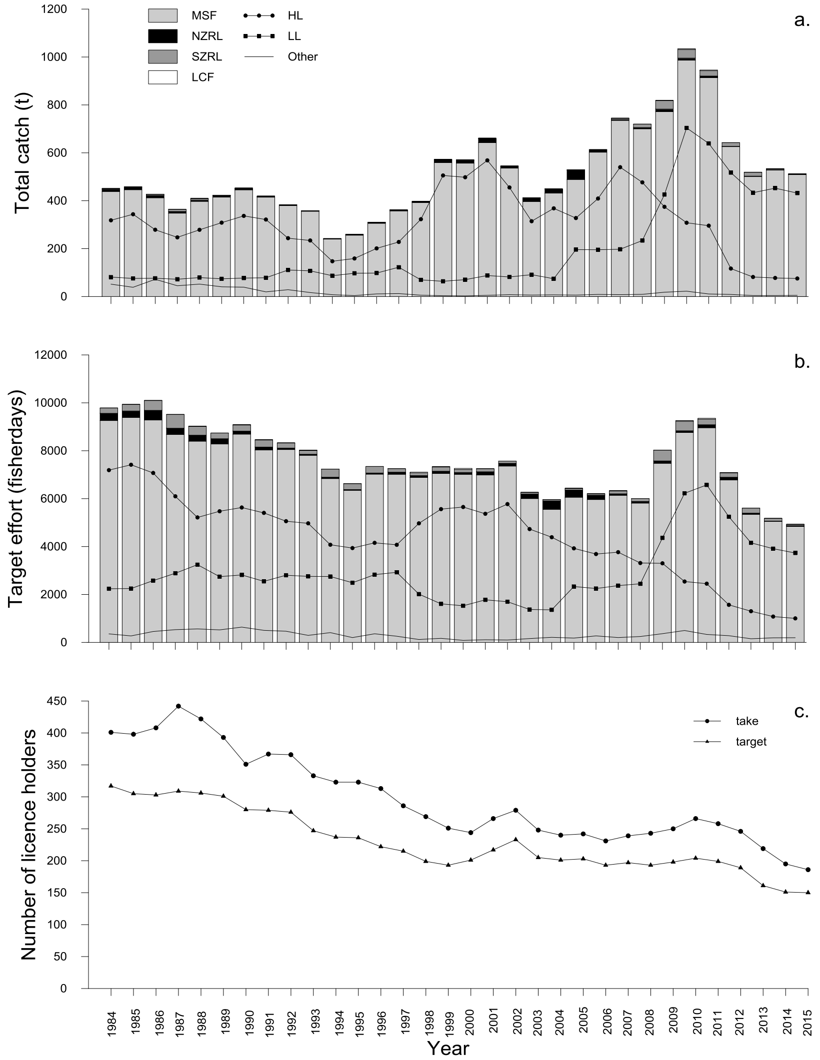

Fig. 3.1 State-wide annual commercial fishery statistics by calendar year from 1984 to 2015. a. catches of snapper by commercial fishery and gear type. b. estimates of targeted fishing effort by fishery and gear type. c. numbers of license holders who reported taking and targeting snapper in each year.

3.1.2 Regional Analysis of Catch and Effort Statistics (1984 – 2012)

The division of the State-wide, annual estimates of total catch into their regional components produced temporal trends that differed amongst regions and indicated a significant change in the spatial structure of the fishery over time (Fig. 3.2). NSG supported the highest regional catches from 1984 to 2004, which subsequently declined and fell to their lowest levels between 2012 and 2015. SSG was the dominant regional contributor to annual State-wide catch between 2005 and 2009, after which regional catches declined rapidly. Catches in NGSV were very low until around 2004, increased gradually for a few years before this accelerated between 2007 and 2010. This region has remained the dominant contributor to total catch up to 2015. The catches in the SE also increased dramatically between 2007 and 2010 before declining consistently to a relatively low level in 2015. The annual catches from SGSV and the WC have generally been relatively minor. SGSV experienced a marginal increase from 2009 to 2011. The highest catches for the WC were taken in 2008 and 2009 and have since fallen considerably.

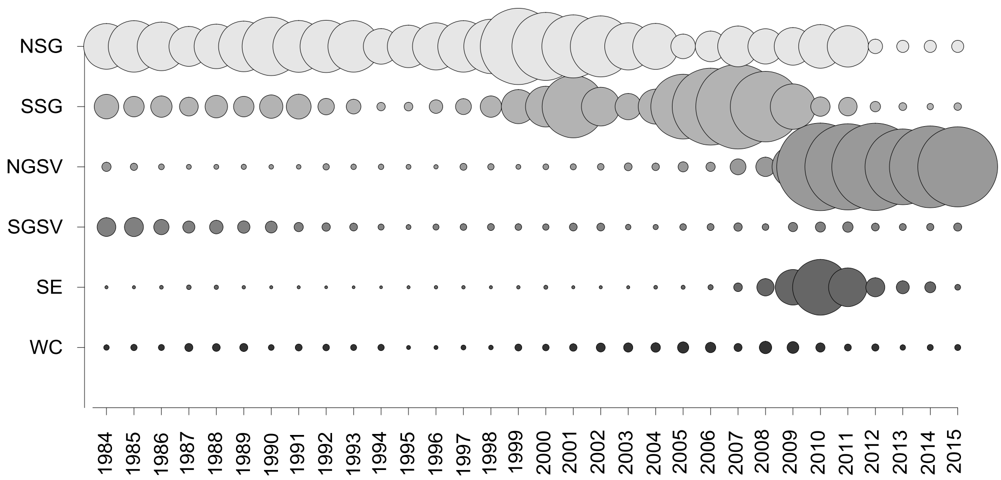

Fig. 3.2 Relative estimates of total annual commercial catch of snapper by region, indicated by sizes of circles.

Northern Spencer Gulf

Total catch from NSG has varied cyclically with peaks in 1990, 1999 and 2010, and low catches recorded in 1987, 1994 and 2005 (Fig. 3.3a). The highest catch of 360 t was recorded in 1999, after which there has been a general decline, particularly in 2012. Low catches persisted until 2015 when it was 47 t. Targeted handline catch was highest between 1998 and 2002 with the highest of 319 t taken in 1999, which fell to only 40 t in 2015 (Fig. 3.3b). Targeted handline fishing effort has also decreased since 2002, with particular drops in 2005 and 2012 (Fig. 3.3c). Between 2002 and 2015, it fell from 3,405 to 494 fisherdays, a decline of 85.5%. From 1984 to 2011, targeted CPUE showed a long-term increasing trend, although varying cyclically in association with targeted catch (Fig. 3.3d). Then in 2012, it declined by 51.4% from 140.6 to 68.4 kg.fisherday^{-1}. It declined further in 2013, before increasing marginally in 2014 and then to 79.9 kg.fisherday^{-1} in 2015. The detrended estimates of CPUE varied cyclically through the 32-year time-series, with the value for 2013 the lowest ever, whilst those for 2014 and 2015 remained amongst the lowest. The number of license holders who targeted snapper has also shown a long-term decline from the highest number of 88 in 1992 to 28 in 2015, with the lowest of 24 in 2014 (Fig. 3.3e). The estimates of Prop250kgTarHL were variable, and relatively high in 2014 and 2015 (Fig. 3.3f).

Targeted longline catch peaked at 84 t in 1997 (Fig. 3.3g). It decreased regularly after that and in 2015 was at only three tonnes, the lowest yet recorded. Longline fishing effort declined from 2,353 fisherdays in 1997 to only 49 fisherdays in 2015, i.e. a reduction of 97.9% in 18 years (Fig. 3.3h). Targeted longline CPUE was relatively consistent until 2002 (Fig. 3.3i). Subsequently, it was highly variable, varying between 87.3 kg.fisherday^{-1} in 2007 and 24.3 kg.fisherday^{-1} in 2013. It increased to 50.5 kg.fisherday^{-1} in 2015, although the catch and effort levels from which the values were calculated in 2012 to 2015 were very low. The detrended estimates of CPUE in 2013 and 2014 were the lowest ever, but did increase in 2015. The number of longline fishers who targeted snapper declined consistently from 1993, and in 2015 was only 5 fishers (Fig. 3.3j). Prop250kgTarLL was low from 2010 to 2015, but increased in 2015, although the number of catches was very low (Fig. 3.3k).

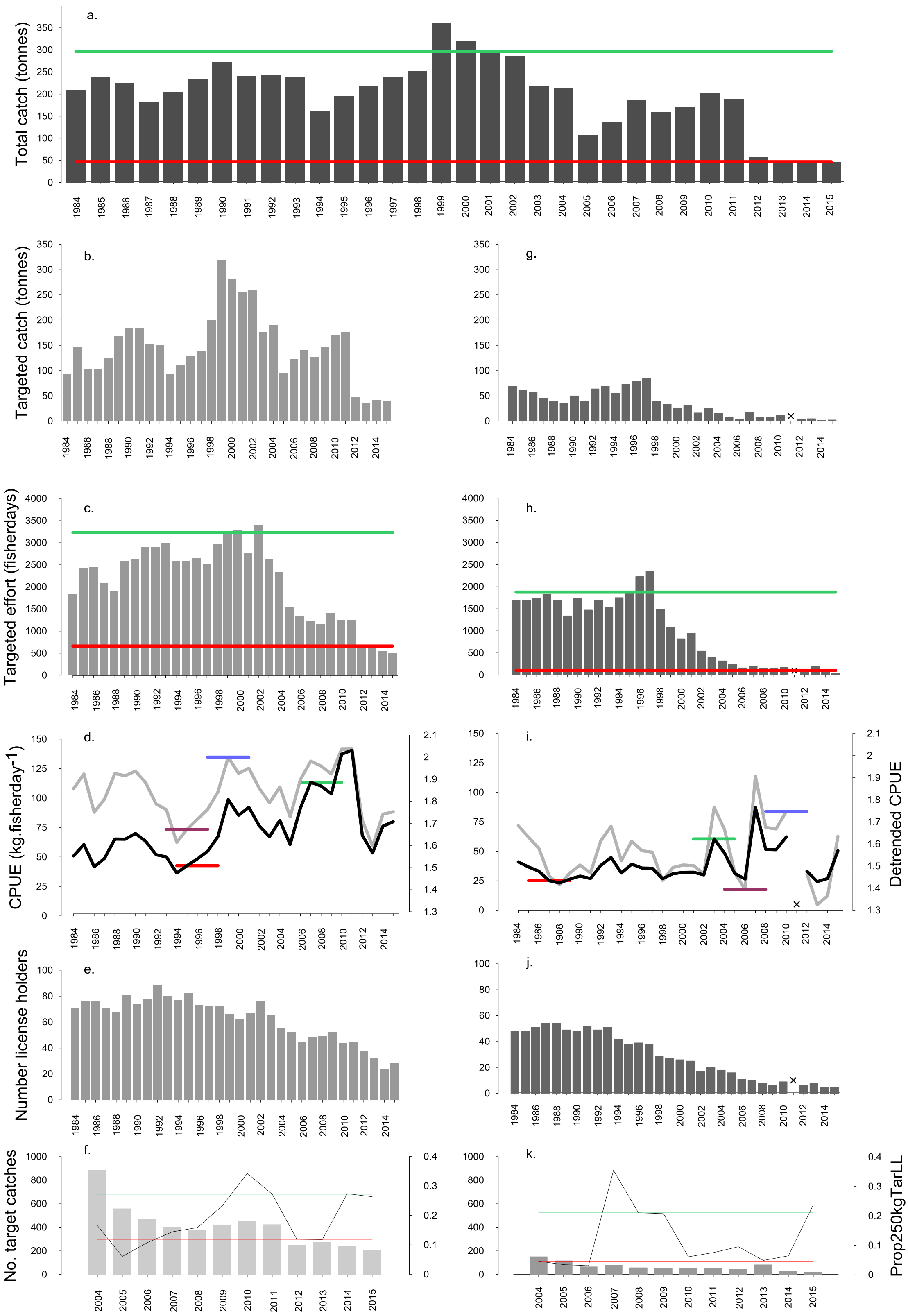

Fig. 3.3 Northern Spencer Gulf. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

Southern Spencer Gulf

After low catches taken in SSG during the mid-1990s, total catch demonstrated two modes during the 2000s, the first peaked in 2001 at 294 t, whilst the second had a maximum of 402 t in 2007 (Fig. 3.4a). Total catch has subsequently declined regularly, falling to the lowest ever reported level in 2014 and 2015. Targeted handline catch has been highly variable since the low catch of 1994 (Fig. 3.4b). It peaked at 251 t in 2001 and again at 236 t in 2007. Since then it fell to 14 t in 2012, and further to only 6 t in 2015, the lowest recorded level. Targeted handline fishing effort has also varied cyclically, increasing from 559 fisherdays in 1994 to a peak of 1,631 fisherdays in 2001 (Fig. 3.4c). It has subsequently declined to the lowest level of only 106 fisherdays in 2015. Targeted CPUE peaked at 154 $kg.fisherday^{-1}$ in 2001, and then at the record level of 182.6 $kg.fisherday^{-1}$ in 2007 (Fig. 3.4d). However, from then until 2015, it declined by 68.8% to 56.9 $kg.fisherday^{-1}$. The detrended estimates of CPUE in 2013, 2014 and 2015 were comparable to the low values in 1994 and 1995. The numbers of fishers targeting snapper have been highly variable (Fig. 3.4e). They were particularly low through the mid-1990s, increased to their highest number of 86 in 2002, but then decreased consistently to the lowest number of 21 in 2015. Prop250kgTarHL increased in 2014 and again in 2015 (Fig. 3.4f).

Targeted longline catch in SSG was very low until 2004, then increased rapidly in 2005 and peaked at 127.0 t in 2006 (Fig. 3.4g). It then declined substantially to only 10.3 t in 2015. The increase in catch between 2005 and 2009 was associated with a substantial increase in targeted fishing effort from 274 fisherdays in 2004 to 985 fisherdays in 2007, i.e. an increase of 259.5% (Fig. 3.4h). Nevertheless, since then, targeted effort has declined and in 2014 and 2015 was at the lowest level since the late 1990s. Targeted CPUE increased gradually through the late 1990s and early 2000s to around 70 $kg.fisherday^{-1}$ (Fig. 3.4i). In 2005, it increased sharply to >120 $kg.fisherday^{-1}$, and remained at this high level until 2008. It has subsequently fallen considerably to the low value of 52.0 $kg.fisherday^{-1}$ in 2014. The detrended estimates of longline CPUE in 2014 and 2015 were the lowest ever, even compared to the low values of the mid-1990s (Fig. 3.4i). The number of longline fishers that operated in SSG was highest at 31 in 2007, when record catches and catch rates were taken and effort levels were highest (Fig. 3.4j). They have since decreased consistently to 16 fishers in 2015. Prop250kgTarLL has declined since 2008 and was low in both 2014 and 2015 (Fig. 3.4k).

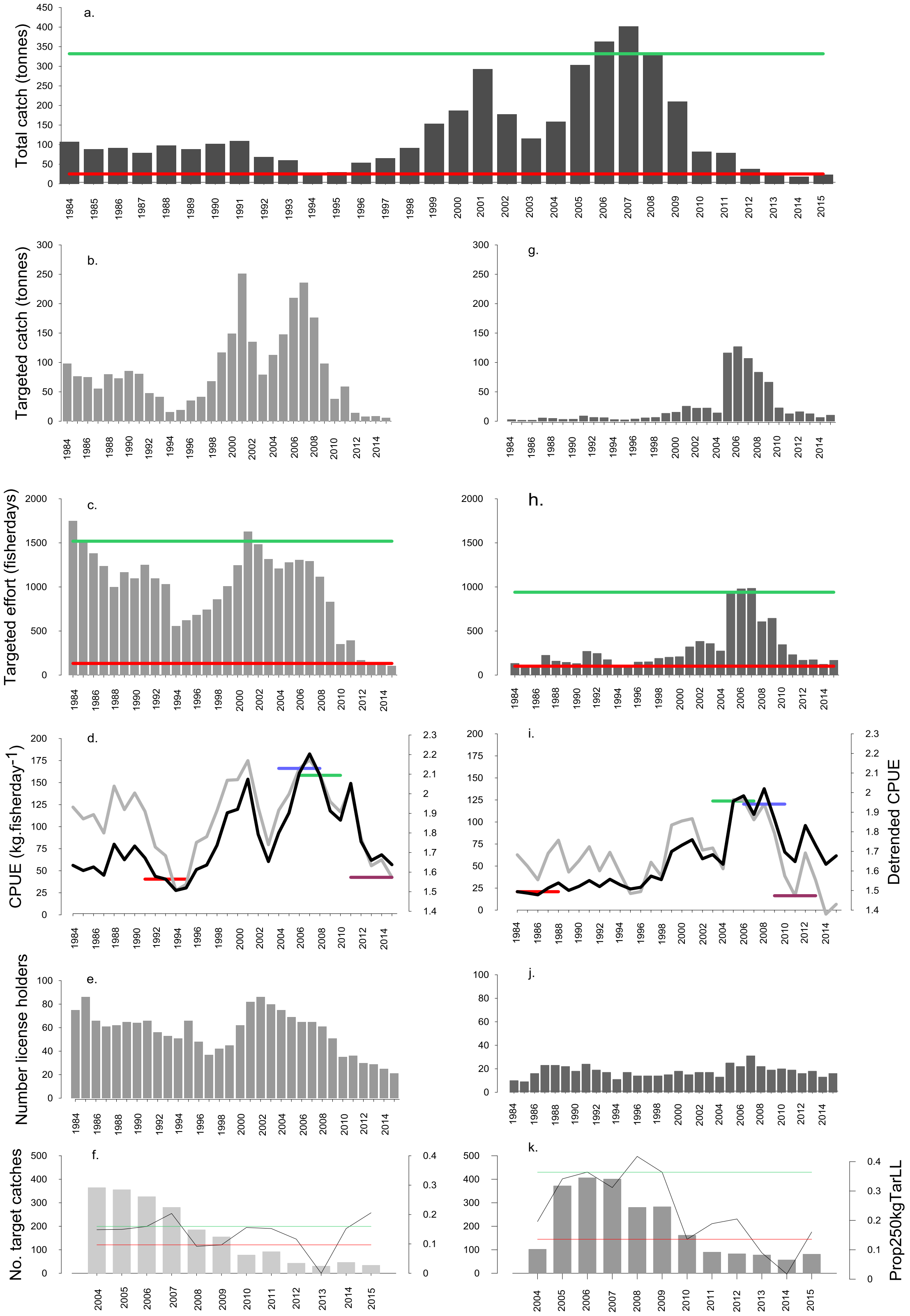

Fig. 3.4 Southern Spencer Gulf. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

Northern Gulf St. Vincent

Historically, NGSV produced only very low catches from the 1980s to early 2000s (Fig. 3.5a). However, from 2007 to 2010, total catch increased exponentially, culminating in the record catch of 417 t in 2010. This has subsequently declined marginally to 380 t in 2015. Targeted handline catch in this region was generally low at <15 $t.yr^{-1}$ up to 2006 and peaked at 46.5 $t.yr^{-1}$ in 2010 (Fig. 3.5b). It has subsequently declined consistently to 7.5 $t.yr^{-1}$ in 2015. The higher catches to 2010 were associated with an increase in targeted handline effort from 2004 to 2010 (Fig. 3.5c). This has subsequently declined to 147 fisherdays in 2015. Targeted handline CPUE was relatively stable until 1996, after which it was variable, but nevertheless showed a long-term increase to 2012 (Fig. 3.5d). Since then it has declined by 49.0% to 50.9 $kg.fisherday^{-1}$ in 2015. Detrended CPUE declined steeply from 2012 to its lowest level in 2015 (Fig. 3.5d). The number of handline fishers that operated in NGSV increased in 2004 and remained high until 2012, before declining to less than half in 2015 (Fig. 3.5e). Estimates of Prop250kgTarHL increased from 2004 to 2013 before declining in 2014 and 2015 (Fig. 3.5f).

The longline fishery in NGSV has largely accounted for the recent rapid increase in total catch. Between 2008 and 2012, targeted longline catch increased by 873.5% from 37.0 to 360.2 t, and continued to increase to 370.6 t in 2015 (Fig. 3.5g). This increase was associated with a 542.1% increase in longline fishing effort from 390 to 2,504 $fisherdays.yr^{-1}$ in 2015 (Fig. 3.5h). Longline CPUE demonstrated a long-term increase primarily between 2000 and 2010, when it peaked at 161 $kg.fisherday^{-1}$ (Fig. 3.5i). It has marginally declined to 148 $kg.fisherday^{-1}$ in 2015. This recent decline was accentuated in the detrended estimates of CPUE, which suggest a considerable recent fall in catch rate (Fig. 3.5i). The number of fishers who used longlines to target snapper in NGSV increased from 11 in 2007 to 50 in 2011 and 2012, but has declined to 36 in 2015 (Fig. 3.5j). Prop250kgTarLL increased considerably from 2004 to 2010 and was highest in 2014 and 2015 (Fig. 3.5k).

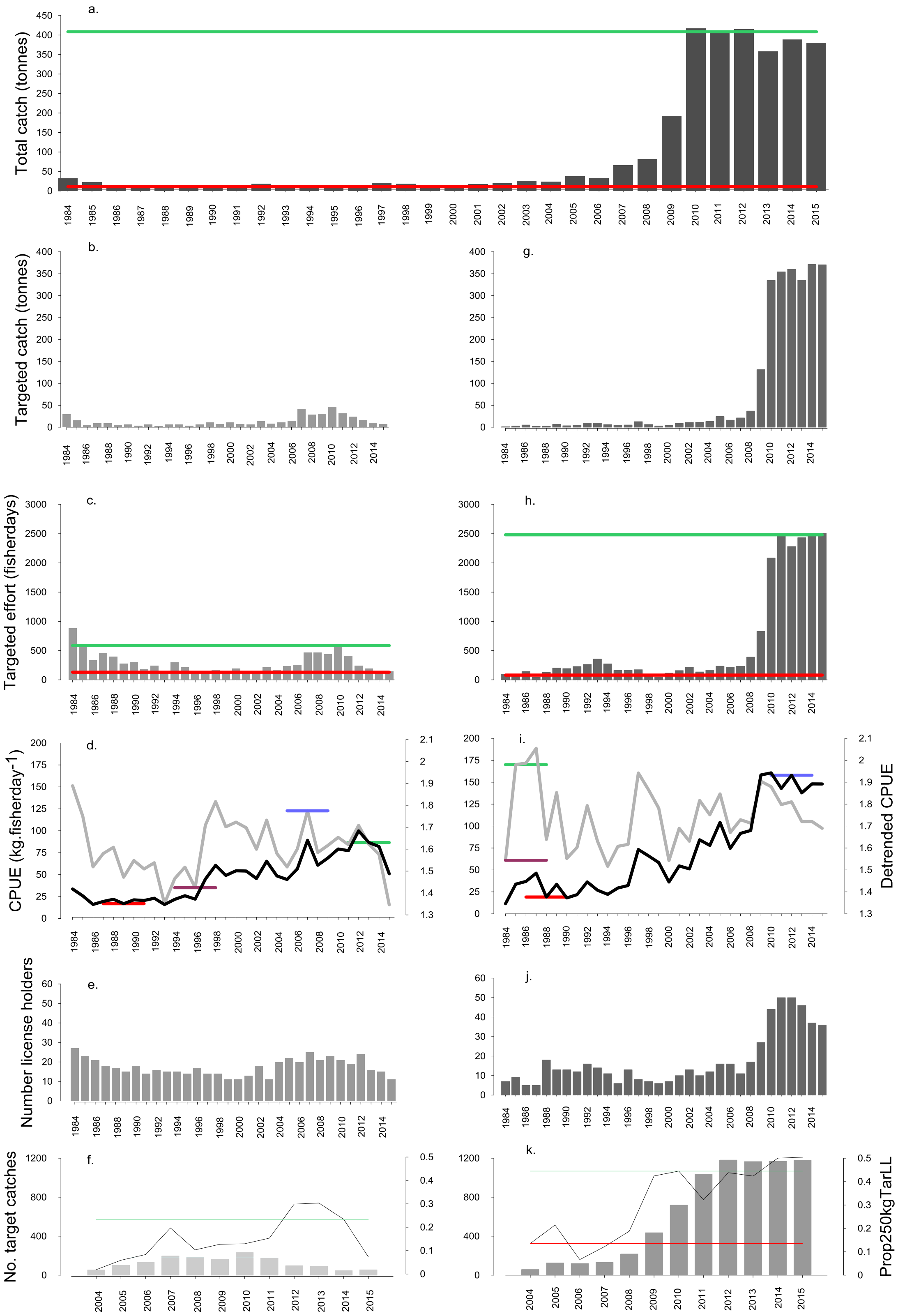

Fig. 3.5 Northern Gulf St. Vincent. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

Southern Gulf St. Vincent

This regional fishery in SGSV is characterised by relatively low catches (Figs. 3.2, 3.6a). The highest catches of around 80 t were taken through the 1980s, but have subsequently ranged from 20 – 40 t. Such catches are approximately one tenth of those of the more productive regions. In the period of 2009 to 2011, relatively high annual catches of around 38 t were taken, but they have subsequently declined to 27 t in 2015. The targeted handline fishery in SGSV produced its highest catches in the 1980s and early 1990s, before dropping to a low of only 4.7 t in 1995 (Fig. 3.6b). Since then there has been some cyclical variation but nevertheless it has remained low at <20 $t.yr^{-1}$, particularly between 2008 and 2015. Targeted handline effort also declined between 1984 and 1995, and has subsequently remained low, particularly 2008 and 2015 (Fig. 3.6c). Targeted CPUE was variable but increased consistently between 1995 and 2007, reaching a peak of 48.2 $kg.fisherday^{-1}$ (Fig. 3.6d). It declined significantly to 19.1 $kg.fisherday^{-1}$ in 2012 before increasing again to 33.4 $kg.fisherday^{-1}$ in 2015. Detrended CPUE showed two periods of low CPUE, i.e. through the mid to late-1990s and from 2010 to 2012 (Fig. 3.6d). It was considerably higher in 2014 and 2015. The number of handline fishers who targeted snapper declined from 70 in 1985 to 17 in 2000, and has remained low until 2015 (Fig. 3.6e). Prop250kgTarHL has always been low, and since 2012 was at zero (Fig. 3.6f).

Targeted longline catch remained at <10 $t.yr^{-1}$ until 2009 when it increased to 18.4 t and then again to 27.5 and 28.6 t in the following two years (Fig. 3.6g). From 2012 to 2015, it has been lower at 13 – 17 $t.yr^{-1}$. Effort was relatively stable at <250 $fisherdays.yr^{-1}$ between 1997 and 2004, but increased to 549 fisherdays in 2011 (Fig. 3.6h), corresponding to the period of expansion of longline fishing in NGSV. Nevertheless, it has subsequently declined to 344 fisherdays in 2015. Targeted longline CPUE demonstrated a general increasing trend between 1996 and 2010 from 15.2 $kg.fisherday^{-1}$ to a record level of 68.5 $kg.fisherday^{-1}$ (Fig. 3.6i). It subsequently declined to 31.5 $kg.fisherday^{-1}$ in 2012 before increasing to 50.6 $kg.fisherday^{-1}$ in 2015. Detrended CPUE shows the recent estimates to be at a moderate level. The number of longline fishers was as high as 25 between 2010 and 2012, but has subsequently declined to 19 in 2015 (Fig. 3.6j). Prop250kgTarLL has been variable with peaks on 2010 and 2014, and remained relatively high in 2015 (Fig. 3.6k).

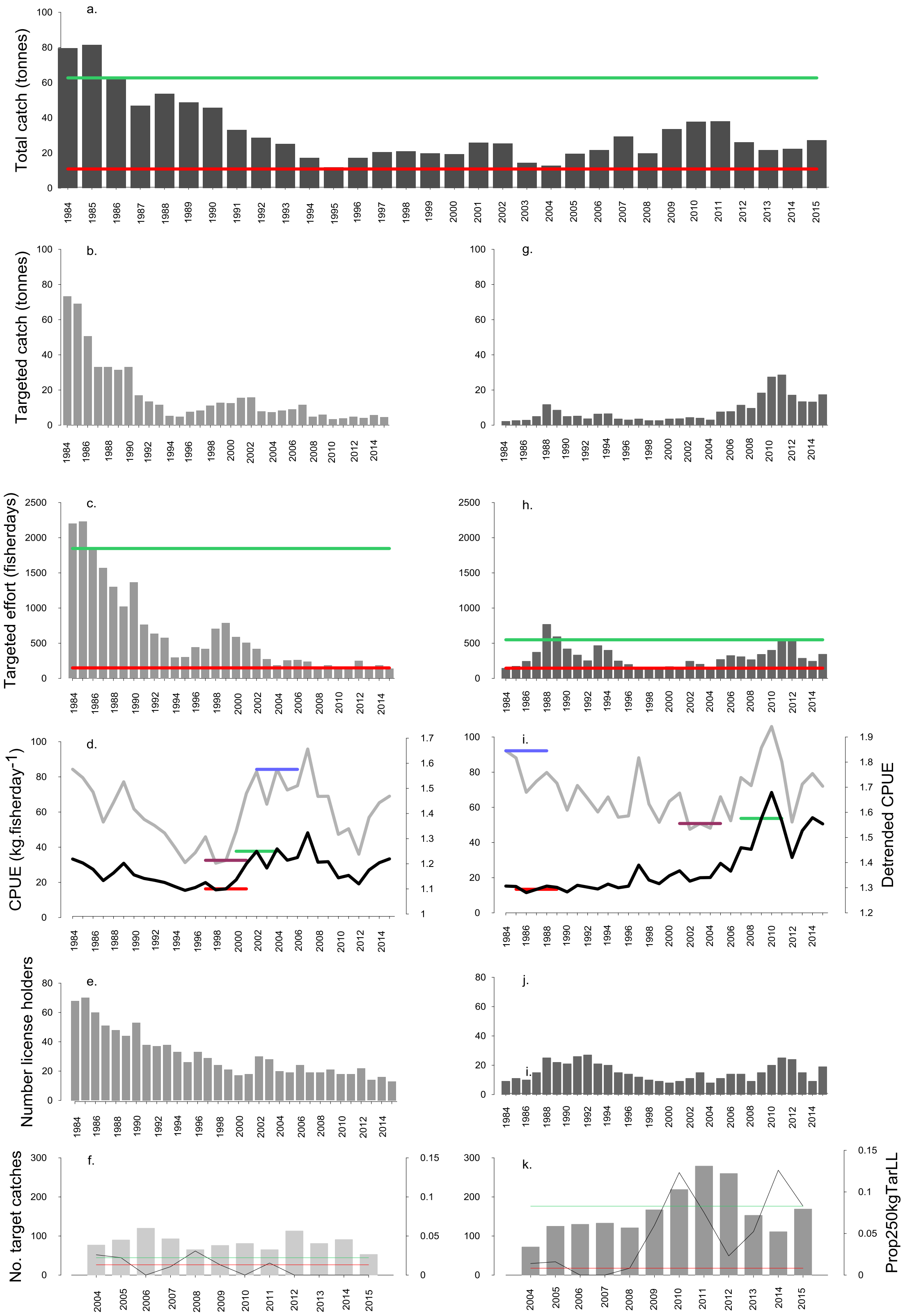

Fig. 3.6 Southern Gulf St. Vincent. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

South East

Historically, the SE region produced only marginal catches of snapper (Fig. 3.7a). However from 2006 to 2010 there was an exponential increase that culminated in the record catch of 271 t in 2010. Since then, it has declined regularly back to 16 t in 2015. Targeted handline catch in the SE has always been low (Fig. 3.7b). There was a minor increase from 2006 to 2009, which has subsequently declined to <1 t in 2015. Such catches reflect low but variable fishing effort, which declined from 287 fisherdays in 2007 to 28 in 2015 (Fig. 3.7c). CPUE has generally been less than 20 kg.fisherday^{-1}, but increased from 2003 and was highest from 2006 to 2009. By 2012, it had declined to a minimum level (Fig. 3.7d). The detrended levels of CPUE were highest between 2006 and 2009 (Fig. 3.7d). The number of fishers who targeted snapper was variable up to 2009, although generally <10 before declining to only two fishers in 2015 (Fig. 3.7e). Prop250kgTarHL was highest from 2006 to 2009, and has subsequently been at very low levels (Fig. 3.7f).

Targeted longline catches were always less than several tonnes.yr^{-1} up to 2007 (Fig. 3.7g). From then, there was a rapid increase to the maximum level of 239 t in 2010, which has subsequently declined to 15 t in 2015. There was a considerable increase in targeted longline effort, which peaked in 2010 at 2,614 fisherdays, but which has subsequently declined to 291 fisherdays (Fig. 3.7h). Targeted CPUE also increased dramatically from 2007 to 2010, peaking at 91.5 kg.fisherday^{-1} before declining to 51.8 kg.fisherday^{-1} in 2015 (Fig. 3.7i). The detrended estimates of longline CPUE also indicate a considerable decrease between 2010 and 2015 (Fig. 3.7i). The number of longline fishers who targeted snapper increased dramatically from 2005 and peaked at 25 in 2010 before declining gradually to 11 fishers in 2015 (Fig. 3.7j). Prop250kgTarLL was relatively high from 2007 to 2014, before declining in 2015 (Fig. 3.7k).

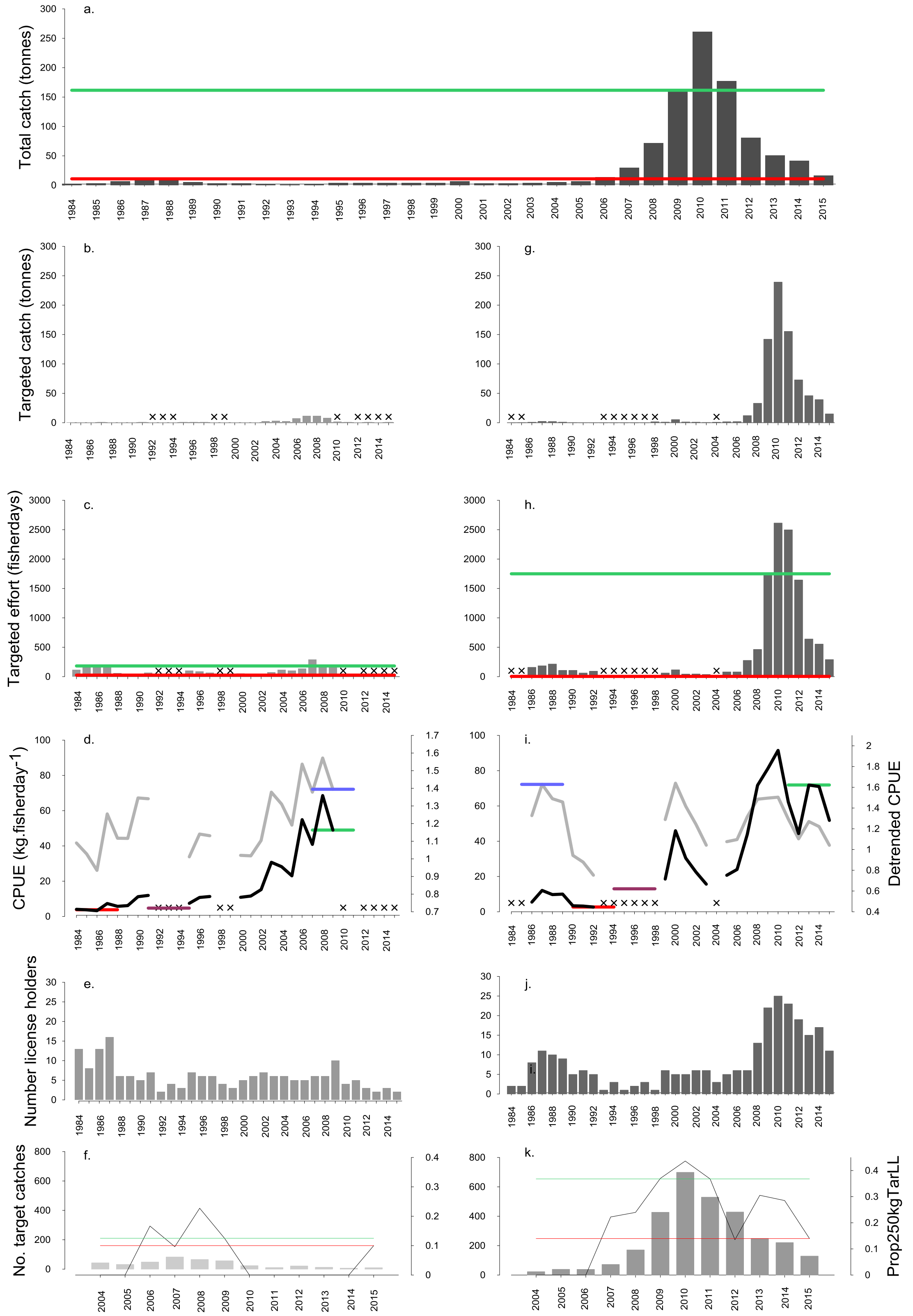

Fig. 3.7 South East. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

West Coast

The WC region has historically produced relatively low catches of snapper, nevertheless with some modes in production (Fig. 3.8a). The first peaked in the 1980s and then declined to low levels in the mid-1990s. The latter peaked in 2008 at 48 t. Since then, total catch has declined to 18 t in 2015. Targeted handline catch from the WC has generally been <12 $t.yr^{-1}$ (Fig. 3.8b). It peaked in 2008 at 18.5 $t.yr^{-1}$ and has subsequently fallen to only 3.0 $t.yr^{-1}$ in 2015. Targeted handline effort has also been quite variable, but since 2005 has declined from 338 to 90 fisherdays (Fig. 3.8c). Targeted CPUE increased from 1995, peaking in 2008 and 2009 (Fig. 3.8d). It has subsequently fallen to 32.9 $kg.fisherday^{-1}$ in 2015. The recent estimates of detrended CPUE are historically low, with only those from the mid-1990s being lower. The number of fishers who targeted snapper with handlines has shown two longterm cycles (Fig. 3.8e). There was a high period during the 1980s, when the number reached 32, which declined back to below 20 during the 1990s. They increased again in the late 1990s and early 2000s, peaking at 34 in 2001. Since then there has been a gradual long-term decline back to below 20 fishers. Prop250kgTarHL was generally low, particularly from 2010 to 2015 (Fig. 3.8f).

Targeted longline catch was relatively low until the early 2000s when it increased to peak at 25.7 $t.yr^{-1}$ in 2007 (Fig. 3.8g). Targeted effort displayed similar variation, increasing to a maximum of 605 fisherdays in 2009, before declining to 340 fisherdays in 2015 (Fig. 3.8h). Targeted CPUE increased after 1998 reaching a maximum of 93.5 $kg.fisherday^{-1}$ in 2003 (Fig. 3.8i). It has decreased systematically since then to 31.7 $kg.fisherday^{-1}$ in 2015. Detrended CPUE showed a similar decline between 2003 and 2015 (Fig. 3.8i). The number of longline fishers varied considerably between 1984 and 2015 (Fig. 3.8j). However, the number was highest between 2006 and 2015, peaking in 2008 at 29 fishers, and has subsequently declined to 23 fishers in 2015. Prop250kgTarLL has always been low for this region (Fig. 3.8k).

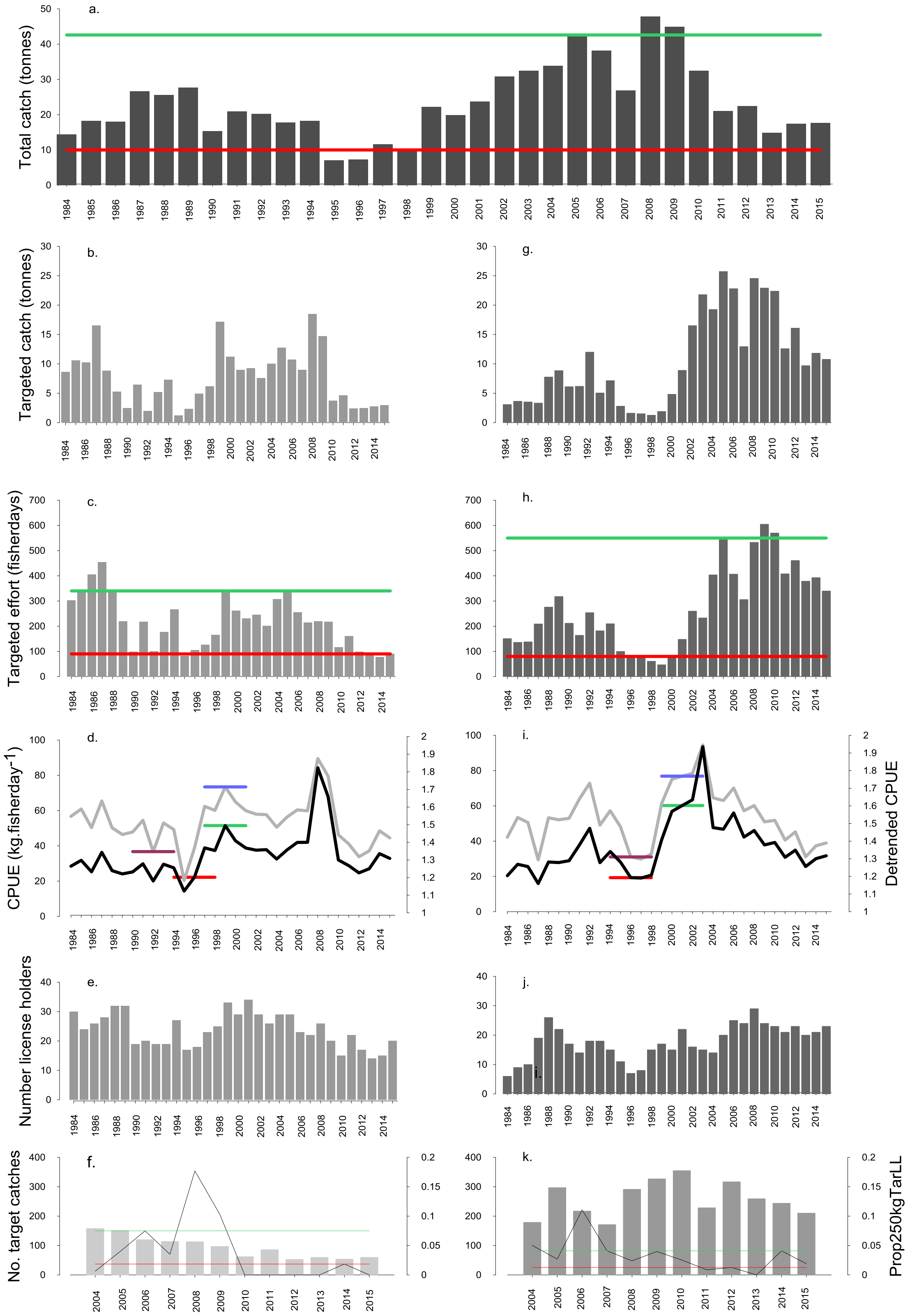

Fig. 3.8 West Coast. a. Time series of total catch. Left hand graphs – time series for targeted handline sector. b. catch. c. effort. d. raw (black line) and detrended (grey line) CPUE. e. number of license holders. f. Prop250kgTarHL (line graph) and number of catches (bar chart). Right hand graphs – time series for targeted longline sector. g. catch. h. effort. i. raw (black line) and detrended (grey line) CPUE. j. number of license holders. k. Prop250kgTarLL (line graph) and number of catches (bar chart). Crosses indicate confidential data, i.e. < 5 fishers. Third highest (green, blue lines) and third lowest (red, brown lines) values are shown for fishery performance indicators (Table 1.1).

3.2 Recreational fishery

The results from the three recreational telephone /diary surveys that were undertaken in 2000/01, 2007/08 and 2013/14 were compared (Henry and Lyle 2003, Jones 2009, Giri and Hall 2015). The estimated number of snapper harvested by the recreational sector in 2013/14 was 207,809 individuals, which was the highest amongst the three surveys (Fig. 3.14a). The numbers were dominated by catches from Gulf St. Vincent (Fig. 3.14b), which differs from the 2000/01 survey, when catches from SG gave the highest numbers. The average estimated weight per individual fish in 2013/14 was 1.6 kg, which is considerably lower than for the previous surveys (Fowler et al. 2010). In 2013/14, the total estimated weight of snapper captured by the recreational sector was 332.5 t, which was intermediate between those of the two earlier surveys (Fig. 3.14c). This included charter boat catch based on fishers surveys, but not from charter boat logbooks. The distribution of catch amongst regions was dominated by that from GSV, with relatively low amounts captured from NSG, SSG, SE and WC (Fig. 3.14d). The proportion of total catch accounted for by the recreational sector varied between the three surveys. In 2013/14, 38.4% of total catch was attributable to the recreational sector, which is intermediate relative to the estimates of 42.6% in 2001/01 and only 19.6% in 2007/08 (Fig. 3.14e). There was considerable regional variation evident for each survey in the contribution to total catch by the recreational sector (Fig. 3.14f).

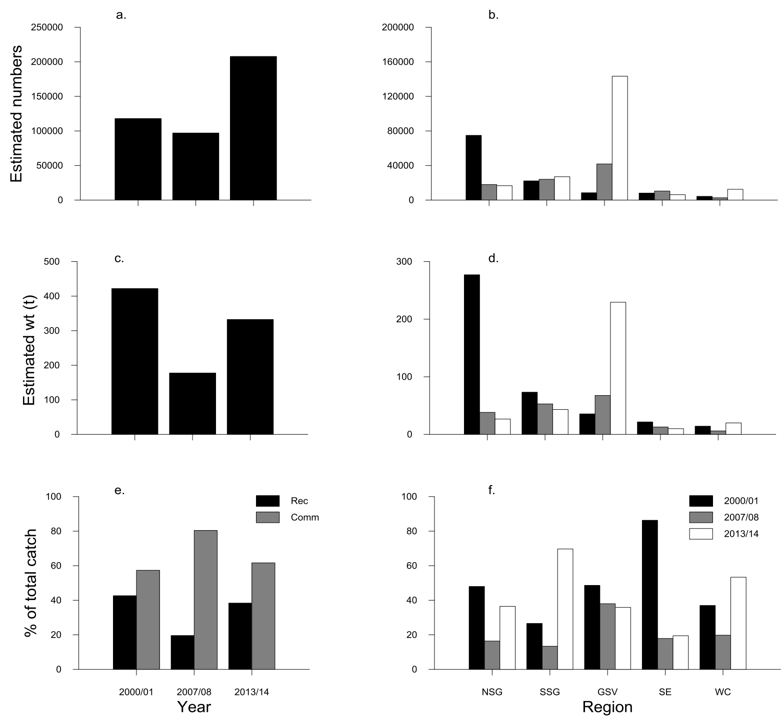

Fig. 3.9 Recreational fishery statistics from three State-wide telephone diary surveys.

3.3 Stock assessment model - SnapEst

The yearly estimates of SnapEst biological performance indicators for the four modelled regions are shown in Figures 3.10 to 3.13. With 95% confidence interval error bars, model outputs are shown for fishable biomass, recruitment numbers, yearly harvest fraction, and egg production, the latter expressed as a percentage of an unfished ('pristine') stock.

Declining levels of harvest fraction in the two Spencer Gulf regions (Figs. 3.10, 3.11) principally reflected reductions in targeted fishing effort. Relatively high estimates of biomass in NSG and SSG reflect these lower exploitation rates, along with model-inferred better recruitment in NSG in the last three year classes shown of 2009-2011.

Model estimates of much higher biomass and higher exploitation levels in NGSV reflect similar conclusions from catch and effort data in that region of all-time high snapper catches and catch rates. The majority of South Australian snapper fishing is now focused in this high-catch region. Biomass estimates in SGSV may be optimistic.

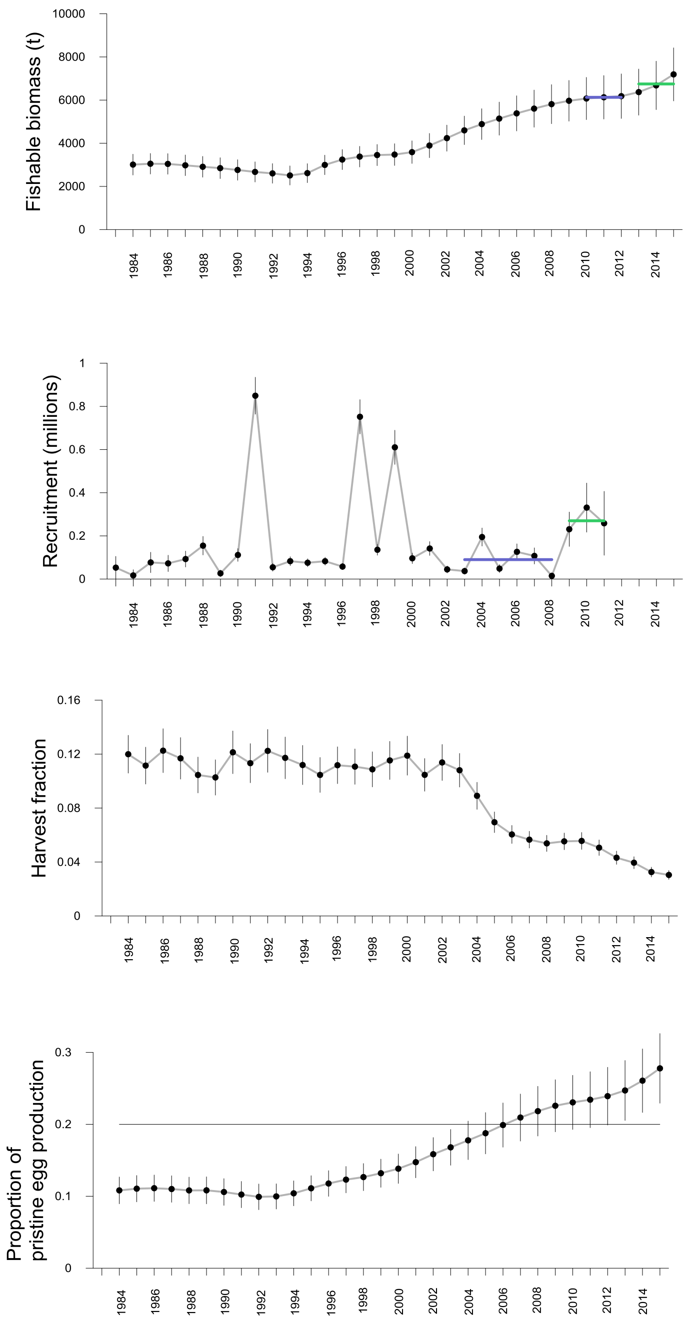

Fig. 3.10 Time series of the four annual biological performance indicators from the SnapEst fishery assessment model for Northern Spencer Gulf. Green lines show averages over the last three years, compared with blue lines giving averages over the three preceding years for biomass and six preceding years for recruitment, as in the trigger reference points for these indicators in Table 3.2.

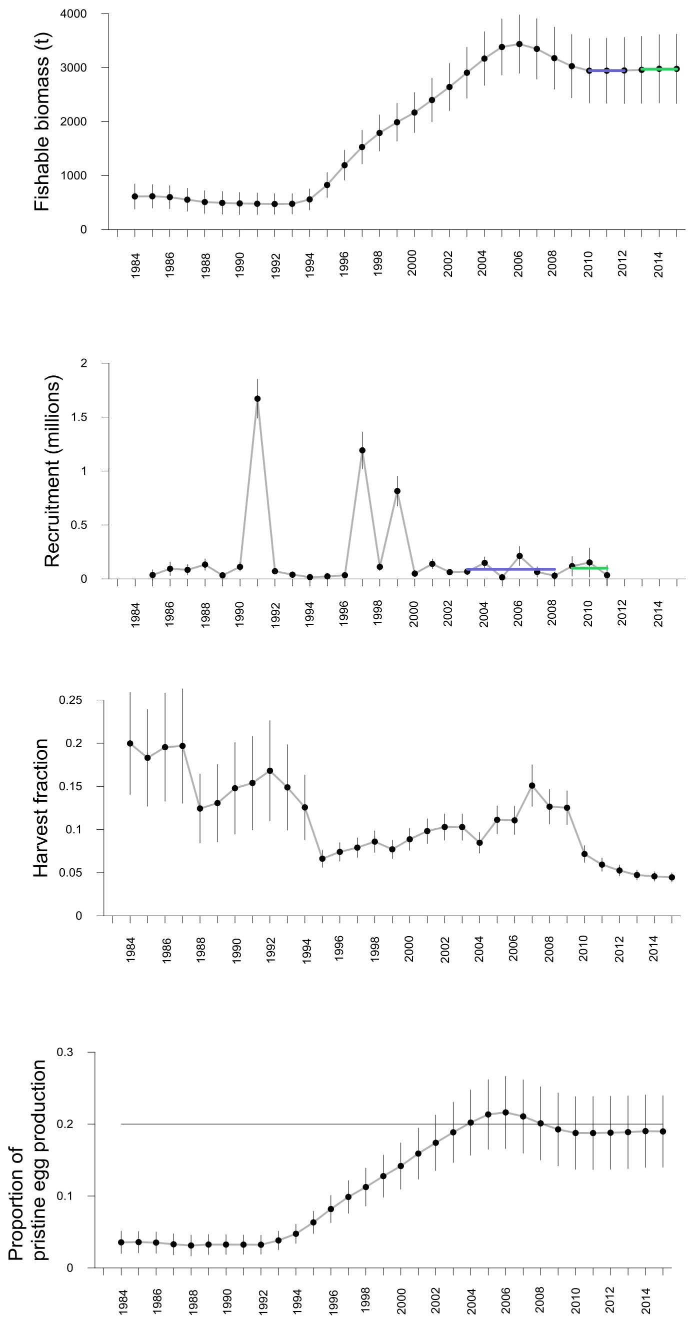

Fig. 3.11 Time series of the four annual snapper biological performance indicators from the SnapEst model for Southern Spencer Gulf.

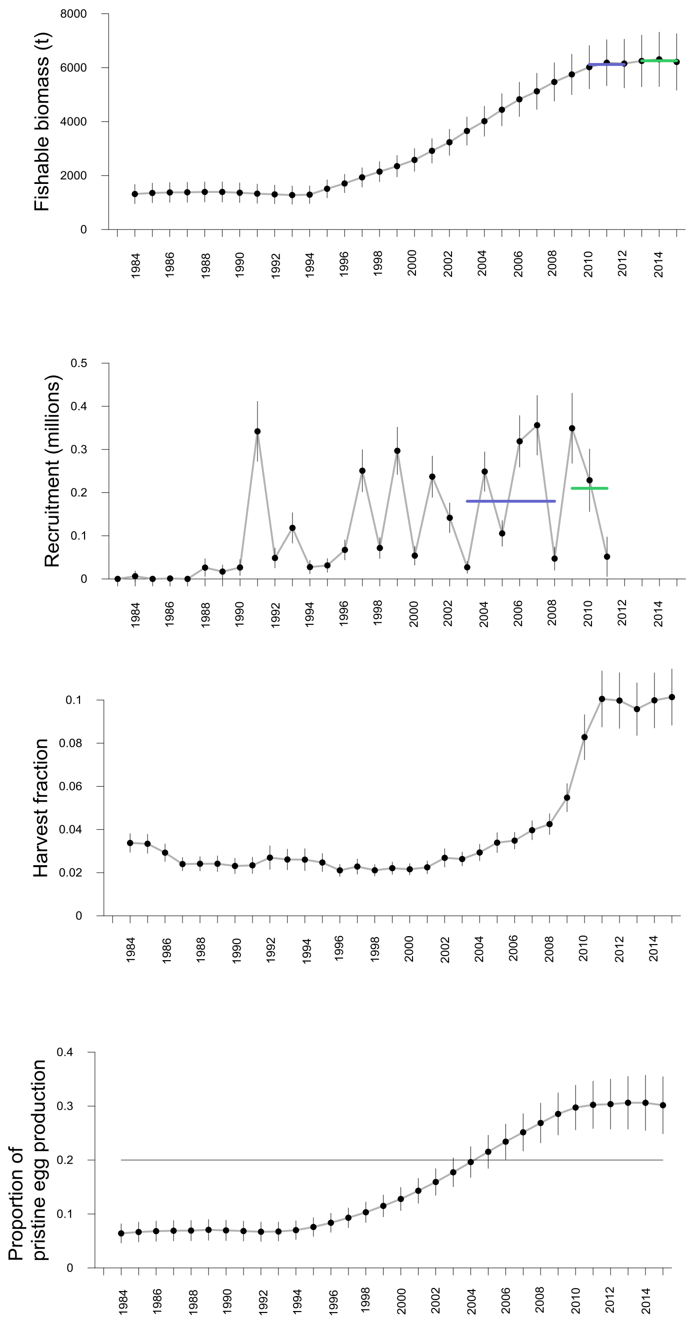

Fig. 3.12 Time series of the four annual snapper biological performance indicators from the SnapEst model for Northern Gulf St. Vincent.

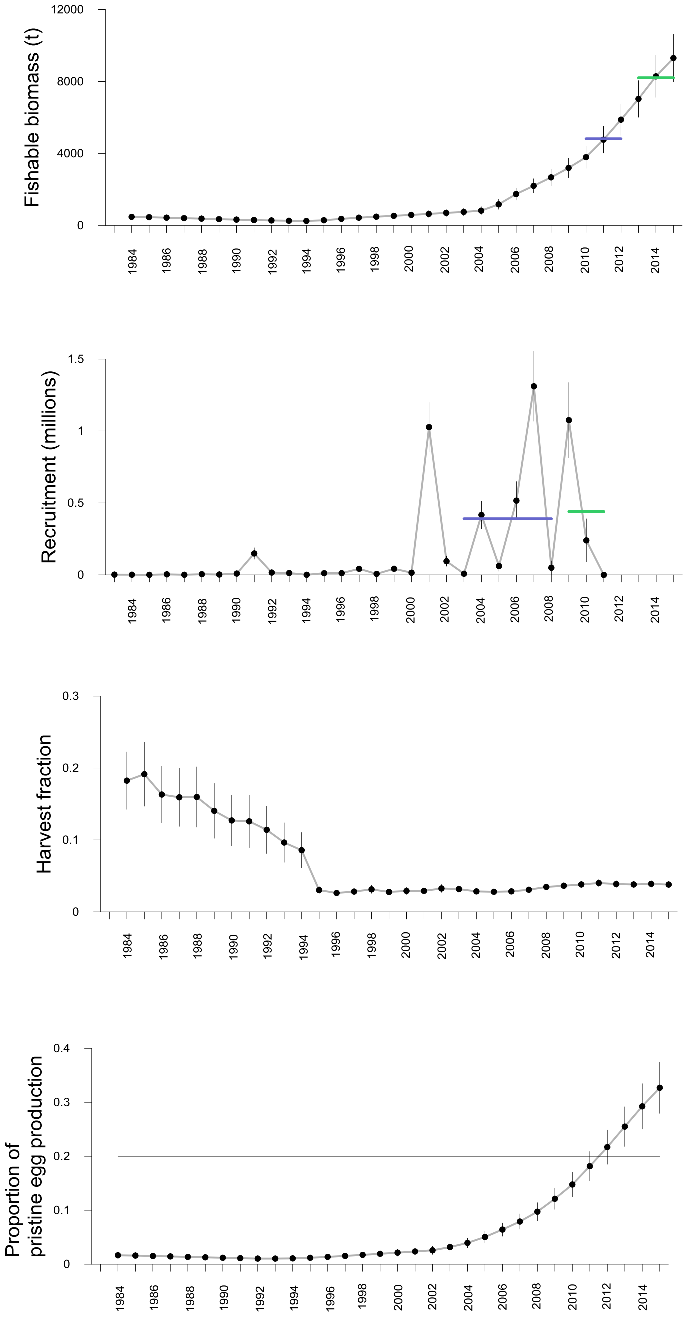

Fig. 3.13 Time series of the four annual snapper biological performance indicators from the SnapEst model for Southern Gulf St. Vincent.

3.4 Year class contributions to fishery catches

The relative contributions to fishery catches of year classes from different time periods were considered for the six regional populations, based on the age structures presented in the Appendix (Figs. 6.2, 6.4, 6.6, 6.8, 6.10). For NSG, up to 2011, year classes from the 1990s contributed >40% of the numbers of fish taken in the fishery, which fell to 20% in 2015. For SSG, >50% of fish captured in each year through the 2000s came from year classes from the 1990s. In comparison, for NGSV, by 2011 <20% of the fish captured were from year classes from the 1990s. As such, most of the large catches taken from 2010 to 2015 had recruited as 0+ fish throughout the 2000s. For both SGSV and the SE from 2010 onwards, the catches involved no fish from any year classes prior to the 2000.

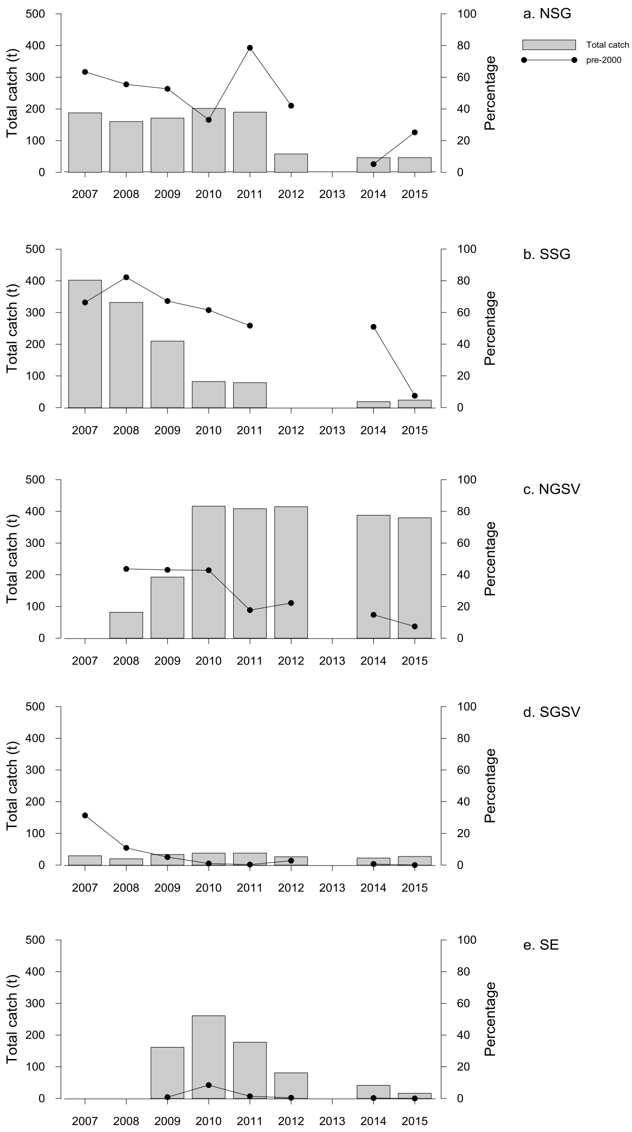

Fig. 3.14 Estimates of annual total catches for each region and percentage of population that recruited prior to 2000, determined from annual age structures.

3.5 Fishery performance

3.5.1 Assessment against allocations

The availability of new recreational fishery data from the survey undertaken in 2013/14 (Giri and Hall 2015), made it possible to assess the contributions of the four commercial fisheries and the recreational sector against the allocations and trigger limits that are specified in Table 1.2. The four commercial fisheries each took less than their allocations (Table 3.1). Alternatively, the percentage of total catch taken by the recreational sector exceeded its allocation and trigger limit.

The assessment of the commercial catches in 2015 against Triggers 2 and 3 indicated that no allocations were exceeded.

Table 3.1 Comparisons of percentages of total catch of snapper taken by the different fishery sectors with their allocations and trigger limits specified in the Management Plan (PIRSA 2013). Trigger 1 relates to commercial and recreational sectors. Triggers 2 & 3 relate only to commercial fishery data. MSF – Marine Scalefish, SZRL – Southern Zone Rock Lobster, NZRL – Northern Zone Rock Lobster, LCF – Lakes and Coorong. Green colour – allocation not exceeded, red colour – allocation trigger activated.

	MSF	SZRL	NZRL	LCF	REC	CHTR	ABT
Fishery Allocation (%)	*79.0*	*1.45*	*0.55*	*0.03*	*8.0*	*10.0*	*1.0*
Trigger 1 (%)	*84.0*	*2.9*	*1.65*	*1.0*	*27.0*		
% total 2014	61.0	1.06	0.08	0.15	37.7		
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 2011	96.6	2.3	0.7	0.3			
% total 2012	97.3	2.3	0.3	0.1			
% total 2013	96.5	3.1	0.4	0.1			
% total 2014	98.9	0.7	0.1	0.3			
% total 2015	99.4	0.5	0.2	0			

3.5.2 General Performance Indicators

The general fishery performance indicators, and also ‘Prop250kgTarHL’ and ‘Prop250kgTarLL’, were assessed at the regional spatial scale. There were 18 breaches of trigger reference points across the six regions. For NSG, three triggers were breached that related to low estimates of total catch and targeted handline and longline effort (Table 3.2, Fig. 3.3). For SSG in 2015, the lowest handline effort was recorded (Fig. 3.4), and also the highest estimate of ‘Prop250kgTarHL’ (Table 3.2, Fig.

3.4). The latter related to a very low number of catches being taken from SSG in this year.
For NGSV in 2015, there were five trigger reference points that were breached (Table 3.2). The second highest longline effort was recorded (Fig. 3.5). Also, there were contrasting results for 'Prop250kgTarHL' and 'Prop250kgTarLL'. The former was low having decreased considerably compared to 2014 (Fig. 3.5), whilst, the latter was the highest ever recorded. For SGSV in 2015, there were several breaches of trigger reference points (Table 3.2). The lowest handline effort was recorded (Fig. 3.6). There were no fishing trips that produced handline catches that exceeded 250 kg. Alternatively, the longline sector produced its third highest value of 'Prop250kgTarLL' (Fig. 3.6).

For the SE, there were two breaches of trigger reference points for fishery data from 2015 (Table 3.2). Both total catch and targeted longline effort decreased over five consecutive years between 2010 and 2015 (Fig. 3.7). For the WC, there were also two breaches of trigger reference points in 2015 (Table 3.2). Targeted handline effort was the third lowest, whilst 'Prop250kgTarHL' was zero (Fig. 3.8).

3.5.3 Biological Performance Indicators (BPIs)

The time series of plotted model-estimated BPIs (Figs. 3.10 to 3.13) show generally stable or rising trends in abundance. Accordingly, model-based BPIs yielded predominantly positive directions when they triggered. Quite high recruitment variation of South Australian snapper stocks gives rise to wide variation in the performance indicators, which was evident for the past three years of this assessment. For this reason, averages over the past three years were compared with averages over the preceding 3 years (biomass) or the preceding 6 years and the historical average (recruitment). Model biomass levels may be biased on the high side in Spencer Gulf and SGSV, meaning exploitation rates are higher than shown.

Because of the high variability in snapper recruitment, recruitment indicators triggered in all four model regions, being more than 10% higher or lower than the previous 3 years, or the historic averages.

Table 3.2 Fishery performance indicators and trigger reference points used to assess fishery performance as identified in the Management Plan (PIRSA 2013). The type of indicator and whether a primary or secondary one is also indicated. G – general; B – biological; P – primary; S – secondary.

Performance Indicator	Type	P or S	Trigger Reference Point	NSG	SSG	NGSV	SGSV	SE	WC
Total catch	G	S	3rd lowest/3rd highest	3rd lowest	2nd lowest	n	n	n	n
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	Y	n
Targeted handline effort	G	P	3rd lowest/3rd highest	Lowest	Lowest	n	Lowest	n	3rd lowest
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	n	n
Targeted longline effort	G	P	3rd lowest/3rd highest	Lowest	n	2nd high	n	n	n
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	Y	n
Targeted handline CPUE	G	P	3rd lowest/3rd highest	n	n	n	n	n	n
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	n	n
Targeted longline CPUE	G	S	3rd lowest/3rd highest	n	n	n	n	n	n
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	n	n
Yearly prop. handline trips >250 kg		P	3rd lowest/3rd highest	n	Highest	3rd lowest	Y-zero	n	Y-zero
			Greatest interannual change (±)	n	n	Highest ↓	n	n	n
			Greatest 5-year trend (±)	n	n	Highest ↓	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	n	n
Yearly prop. longline trips >250 kg		S	3rd lowest/3rd highest	n	n	Highest	3rd high	n	n
			Greatest interannual change (±)	n	n	n	n	n	n
			Greatest 5-year trend (±)	n	n	n	n	n	n
			Decrease over 5 consecutive years?	n	n	n	n	n	n
Fishable biomass	B	P	3-yr ave is +/- 10% of previous 3-yr ave	+10%	+1%	+2%	+71%		
Harvest fraction	B	P	above 32% (int. standard)	3%	4%	10%	4%		
Egg production	B	S	<20% of pristine pop	28%	20%	30%	33%		
Recruitment	B	S	3-yr ave is +/- 10% of historical mean	+73%	-50%	+90%	+198%		
			3-yr ave is +/- 10% of previous 6-yr ave	+211%	+13%	+14%	+11%		
Age composition	B	P	prop >10 yrs <20% of fished pop	32.3%	22.0%	19.7%	10.4%	14.2%	na

4. DISCUSSION

4.1 Information for stock assessment

This assessment has considered the results from several long-term monitoring programs to determine the current status of the stocks of snapper in South Australia. The datasets were: commercial catch and effort data from 1984 to 2015; and data on population size and age structures that were collected throughout the 2000s up to 2015. They were augmented by results from three telephone/diary recreational surveys. All data were integrated in the SnapEst computer fishery model. Time series for a suite of general and biological fishery performance indicators were generated and the data for 2015 were compared against trigger reference points calculated from the historical time series from 1984 to 2015, in a weight-of-evidence approach. The outcome of the process is presented using the classification system of Flood et al. (2014) (Table 1.3).

In this report, the spatial scale for classifying stock status differed from earlier reports (Fowler et al. 2013), based on findings of the recently-completed, FRDC-funded project into the stock structure of SA's snapper population (Fowler 2016). That project considered large-scale movement patterns and stock structure in the context of significant, unprecedented changes in the spatial structure of this fishery and uncertainty about the underlying demographic processes. It concluded that South Australian snapper involved three stocks; the Spencer Gulf / West Coast Stock (SG/WC), the Gulf St. Vincent Stock (GSV), and the cross-jurisdictional Western Victorian Stock (WVS). Each stock involves a number of regional populations, one of which includes a significant nursery area that is the primary source of recruitment for the whole stock. These nursery areas are located in NSG, NGSV and Port Phillip Bay (PPB), Victoria. The populations in these natal regions are self-replenishing, whilst adjacent populations depend on immigration from these natal regions. Such movement may occur over distances of up to hundreds of km. The rates of emigration vary amongst years as determined by inter-annual variation in recruitment of 0+ fish to the nursery areas. The natal regions experience higher recruitment than do the distant regions, as the latter depend on overflow from the former. This is likely to be a density-dependent process that occurs at a greater rate following strong recruitment year classes. Therefore, the demographic processes that drive population dynamics differ amongst regions. Consequently, in this report, the trends in fishery performance indicators were considered at the regional scale to elucidate the recent demographic processes. Then, based on this refined understanding, the results from component regions were assessed together to assign stock status at the scale of biological stock.

4.2 Status of snapper stocks

4.2.1 Spencer Gulf / West Coast Stock

Northern Spencer Gulf

NSG supports a self-replenishing population based around a significant nursery area (Fowler 2016). During the 1990s, this was the most productive region in South Australia's snapper fishery that consistently contributed greater than 60% of the State's commercial catch. However, total catches declined through the 2000s and then in 2012 dropped to approximately 30% of that of 2011. From 2013 to 2015, total catches remained low, producing the four lowest consecutive annual catches for the region. Understanding this downturn in regional productivity has been challenging because of conflicting signals from different fishery performance indicators. This is further complicated by significant management changes that were implemented in 2012 and 2013, in response to emerging indications of a risk to sustainability (Fowler et al. 2013, PIRSA 2013).

Targeted handline and longline effort declined in this region throughout the 2000s, with particular drops in 2012. Declining effort is significant as fishing effort is recognised as a primary performance indicator for snapper, thought to relate to fishable biomass (PIRSA 2013). This is because snapper is a premium species that returns a high value per unit weight to fishers, and so should attract high levels of targeted effort as long as sufficient biomass is available. Furthermore, the considerable drops that occurred in targeted catch and effort in 2012, were associated with a significant decline in handline CPUE from 141 to 68 $kg.fisherday^{-1}$. Whilst management changes implemented in late 2012, i.e. daily trip limits, gear restrictions and extension of the seasonal closure, may have contributed, to some extent, to these declines in primary and secondary performance indicators, they cannot fully account for the declines. Rather, the declines in targeted catch, effort and CPUE are likely to represent a considerable decrease in fishable biomass throughout the 2000s, but particularly from 2012. The elevated levels of CPUE prior to 2012 have previously been attributed to hyperstability, consistent with the hypothesis of declining biomass through the 2000s (Fowler and McGlennon 2011, Fowler et al. 2013). In 2014 and 2015, catch and effort remained low, but handline CPUE, as well as Prop250kgTarHL and Prop250kgTarLL increased to some extent, suggesting some recent recovery in biomass.

It was hypothesised above that the empirical data and fishery performance indicators for snapper in NSG in the late 2000s were consistent with declining levels of fishable biomass. The population age structures provide a possible explanation for this trend that relates to inter-annual variation in recruitment rates (Fig. 6.2). From 2000 onwards, the successive age structures show the diminishing significance of the strong 1991 year class and emergence of the 1997 and 1999 year classes that were both significant contributors to fishery catches until 2015. However, no year classes that recruited throughout the 2000s contributed to fishery catches as regularly or to the same extent as those from 1997 and 1999. As such, year classes that had recruited to the population through the 1990s accounted for relatively high proportions of fishery catches during the 2000s. Consequently, the declining biomass through the 2000s, particularly from 2012 to 2015, reflects the relatively weak recruitment year classes throughout the 2000s.

In contrast to the interpretation of empirical data, the model-estimated biomass for NSG demonstrated an increasing trend from 1994, which accelerated in 2014 and 2015. As such, there was a discrepancy between the interpretation of the empirical data and the outputs of the model. This reflects different emphasis being placed on the fishery statistics and population age structures. The interpretation of the empirical data considered that the relatively weak year classes from 2000 onwards indicated poor recruitment. Conversely, the SnapEst model focussed on the persistence of 10 – 20 year old fish in the population, reflective of low rates of mortality further compounded by recent low and declining levels of fishing effort that depressed model-estimated mortality and exploitation rates. Such low exploitation of the stock was interpreted by the model as "adult fish being left in the water, providing opportunity for the population to increase through reproduction and recruitment". This discrepancy is considered further in Section 4.5, Future research needs.

Southern Spencer Gulf

Through the 2000s, this region supported a highly productive snapper fishery which had two peak periods in production. The more significant peak was between 2005 and 2009, when SSG produced the highest annual regional catches for the State, surpassing those of NSG. This reflected a strong handline fishery that was augmented by development of the longline sector, associated with the uptake by fishers of new longline fishing technology. Nevertheless, after the peak productivity of the fishery in 2007 when this region contributed 54.0% of the State-wide catch, targeted handline and longline catches, effort and CPUE all declined markedly to 2015, some to their lowest levels. In 2014 and 2015, the region contributed only 3.5% and 4.7%, respectively of the State's total catches. In 2015, the low estimates of fishery catch, effort and CPUE culminated in two negative breaches of general performance indicators (i.e. for total catch and targeted handline effort). As these declining trends had commenced prior to late 2012, they are unlikely to have been solely attributable to changes in fishery management. Rather, they are consistent with a decline in biomass between 2007 and 2015.

The annual age structures for SSG through the 2000s were typically dominated by either one or two strong year classes. This reflects the dependence of this region on emigration from NSG, from where only the strongest year classes are likely to have provided significant numbers of immigrants to SSG. The age structures for SSG up to 2014 were dominated by the 1991, 1997 and 1999 year classes. The former year class largely accounted for the peak in catch around 2001, whilst the latter two contributed to the larger peak around 2007. In comparison, recruitment throughout the 2000s was poor. From 2007, the declining catches in SSG reflected the lack of strong year classes subsequent to the 1999 year class, whilst the older year classes were gradually depleted through fishing and natural mortality.

As with NSG, for this region there was a discrepancy in biomass between the interpretation of the empirical data and the estimates from the model. SnapEst estimates support the hypothesis of low recruitment into SSG subsequent to the 1997 and 1999 year classes, which resulted in a decline in biomass after 2006. Nevertheless, due to lower mortality rates inferred from the declining commercial fishing effort and model-estimated harvest fractions, the extent of the decline in model-estimated biomass was modest.

West Coast

This region is considered part of the SG/WC Stock based on evidence of connectivity from an early otolith chemistry study (Fowler et al. 2005b). It is considered that when strong year classes recruited to NSG, some fish emigrated from SG to the WC (Fowler 2016). There are no recent age structures for this region because of the difficulty in accessing fishery catches to obtain biological samples. As such, the only fishery performance indicators that can be considered are commercial fishery statistics. The region has historically produced small catches relative to the gulfs. In 2008 and 2009, relatively high levels of targeted handline and longline catch and effort culminated in record catches and catch rates. Since then, total catch has decreased reflecting declining levels of targeted catch, effort and CPUE. This region produced 7% of the State's catch in 2008, which was halved by 2012 and has since remained low. Such declines culminated in activation of two trigger reference points in 2015, including the 3rd lowest handline effort yet recorded. As declining trends in fishery statistics had commenced prior to the management changes in late 2012, they suggest a declining level of biomass. This is consistent with minimal emigration from NSG, reflecting the lack of strong recruitment year classes to the nursery area through the 2000s.

Assignment of Stock Status

The assignment of stock status for the SG/WC Stock has been challenging because of conflicting signals from different fishery performance indicators, particularly with respect to recent trends in fishable biomass. The empirical data were interpreted as reflecting declining levels of biomass as a consequence of poor recruitment to NSG through the 2000s. Alternatively, the time-series of fishable biomass from the SnapEst model increased in both NSG and SSG. Nevertheless, there was some consistency in the two interpretations as both indicated poor recruitment through the 2000s, relative to the 1990s. Anecdotal reports from the fishing industry suggest that the stock in SG is in a poor state, relative to periods of record productivity during the early and mid-2000s. As such, the model estimates of biomass for both regions appear to be positively biased. Nevertheless, the model outputs have usefully drawn attention to the low exploitation rates and low levels of fishing effort. The model output also indicated that recruitment in NSG increased in 2014 and 2015, reflecting the recent upturn in handline CPUE.

Whilst the biomass of the SG/WC has declined and recruitment was below average through the 2000s, there is some evidence of recent recruitment. Low fishing effort in the three regions indicates that exploitation rates have fallen to low levels. Furthermore, significant management changes were implemented in 2012 and 2013 that were focussed on reducing commercial catch and maximising reproductive output and recruitment. On the basis of the evidence provided above, the SG/WC Stock is classified as **transitional depleting**.

4.2.2 Gulf St. Vincent Stock

Northern Gulf St. Vincent

The region of NGSV includes one of the primary nursery areas for snapper in south eastern Australia, and is a self-replenishing population (Fowler 2016). Historically, it supported only very low catches through the 1980s, 1990s and early 2000s. However, from 2007 to 2010, total catch increased to not only a regional peak but this region became the dominant contributor to the State-wide catch, whose contributions increased from 9% in 2007 to 74% in 2015. High longline catches related to an exponential increase in longline effort and a substantial increase in longline catch rate. The increase in effort was, in part, due to a substantial influx of longline fishers to the region. Contemporaneously, there were marginal increases in targeted handline effort, catch and CPUE. Whilst the large increases for this region are likely to have partly been related to the greater efficiency of the new longline fishing gear, the data are also consistent with a substantial increase in fishable biomass through the 2000s, relative to earlier years.

The recent population age structures are informative about the recruitment history to the region. They demonstrate that several year classes through the 2000s (i.e. 2001, 2004, 2006, 2007 and 2009), each made significant contributions to catch and were persistent in time. Consequently, the high catches from 2010 onwards involved a high proportion of fish that had recruited to the population through the 2000s. In this sense it contrasts considerably with SG for which the 1997 and 1999 year classes remained significant contributors to the regional populations.

For NGSV, the trends in model-estimated biomass increased considerably up to 2010, relating to strong, model-estimated year classes throughout the 2000s. As such, the model outputs are consistent with the interpretation of fishery statistics presented above. Furthermore, the estimated exploitation rates increased substantially over time, reflecting the substantial increase in effort that occurred.

Southern Gulf St. Vincent

SGSV is the most demographically complex of the six South Australian regional populations (Fowler 2016). It is located at the boundary of, and in the mixing zone between the three stocks, and likely to receive some supplementation from each. Nevertheless, such supplementation appears to be low, as this region has never produced the substantial catches that the other gulf regions have at different times. In every year since 1994, SGSV has produced <6% of the State's total catch. From 2009 to 2011, longline catches and catch rates increased marginally, resulting in higher total catches than taken during the early 2000s. These increases were concomitant with those in NGSV and the SE, but nevertheless on a smaller scale. In 2011, when this region produced its highest catch since 1990, it accounted for only 4.0% of the State's total catch. This peak was associated with expansion of the longline sector, which occurred contemporaneously with those in NGSV and the SE. Since then, total catch has declined, reflecting decreases in longline catch, effort, CPUE and number of fishers. In 2015, one general trigger reference point was breached along with one each for Prop250kgTarHL and Prop250kgTarLL.

Overall, the fishery statistics suggest that this region supports a relatively low biomass of snapper, which has experienced marginal decline since 2011. In the age structures, some year classes were stronger than others including those in 1991, 1997, 2001, 2004, 2006, 2007 and 2009. Recent catches were dominated by year classes that recruited after 2000. The complex age structures reflect the influence of immigration from different sources. The 2001 fish had originated in PPB and were part of the WVS, whilst the 1991, 1997 and 2004 year classes had originated in the northern gulfs (Fowler 2016). The origins of the 2006, 2007 and 2009 year classes remain undetermined.

The model output for this region indicated an increasing biomass reflecting four strong recruitment year classes through the 2000s, as well as low exploitation rates. The comparison of model and data Z (total mortality) for SGSV show a clear difference. The model estimates were lower, implying that the model has under-estimated mortality rate for this region compared to that estimated from raw age samples, suggesting that the model has over-estimated biomass. The demographic complexity of this population and likely migration into it in recent years pose challenges to the underlying assumptions of the SnapEst model.

Assignment of Stock Status

Since the mid-2000s, the bulk of the biomass for the GSV Stock has been located in the northern part of the gulf. There was considerable consistency in the general and biological fishery performance indicators for this region that reflected a substantial increase in biomass relating to a succession of strong year classes. In 2015, there were marginal declines in total catch and CPUE that may have related to management changes in 2012 and 2013, or to the marginal declines in biomass due to the long-term high effort. Nevertheless, there were no indications that the biomass was moving in the direction of being overfished. For SGSV, the model is likely to have provided overly-optimistic estimates of biological performance indicators. Nevertheless, the recent trends in general fishery performance indicators were relatively stable.

The above evidence indicates that the biomass of this stock is unlikely to be recruitment overfished and that the current level of fishing mortality is unlikely to cause the biomass to become recruitment overfished. On this basis the GSV Stock is classified as **sustainable.** However, based on the extent and speed of the decline of fishery status in SG that was, to some extent, hidden through the maintenance of high catch rates through hyperstability, it is possible that similar processes could occur in NGSV.

4.2.3 Western Victorian Stock

South East

The recent analysis of adult movement patterns and stock structure (Fowler 2016), determined that the SE regional population is part of the WVS. This stock depends on recruitment into the primary nursery area of PPB, Victoria. From there, young fish emigrate and subsequently move and replenish the populations along the west coast of Victoria (Hamer et al. 2005, 2006, 2011), and south eastern South Australia (Fowler 2016).

Historically, the snapper fishery in the SE was largely incidental, producing low catches, associated with low effort and catch rates. However, it experienced a dramatic, exponential increase in total catch from 2005, which peaked at 261 t in 2010. In that year, this region contributed 25% of the State's total commercial catch. Nevertheless, since then, the regional catch has fallen back towards low historic levels. The unprecedented increase in catch was primarily driven by significant increases in targeted catch, effort, CPUE and number of fishers in the longline sector. This period was contemporaneous with the developing longline sector in NGSV, and is probably partly attributable to the adoption of similar new fishing practices. However, the expansion also suggests a significant, unprecedented, episodic increase in biomass of snapper, which has subsequently declined. Population age structures indicate that the episodic increase related to recruitment of strong 2001 and 2004 year classes into the population. These were the two strongest year classes to recruit to PPB in the 24 years from 1993 to 2016 (Hamer and Conron 2016). As such, the population has been dominated by fish that recruited since 2000.

As the SE regional population is part of the WVS, its stock status largely depends on that of the main reproductive population in and around PPB, Victoria. A stock assessment was recently completed in Victoria for the WVS (Hamer and Conron 2016). The stock was assigned the status of 'sustainable', largely based on results of the 0+ recruitment survey, which showed above-average recruitment levels for six of the past 12 years. As such, the SE regional population is classified as **sustainable.** Supplementation of the SE region is already apparent with several new year-classes apparent in recent age structures.

4.3 Conclusions

This stock assessment was the beneficiary of the project on adult snapper movement and stock structure (Fowler 2016), which informed about the obligate connectivity between different regions through fish movement and the consequences for regional population dynamics. The fishable biomass in both SSG and the WC depend on emigration from NSG. That in the SE depends on movement over hundreds of km from PPB. For the source regions that contain the primary nursery areas in the gulfs (i.e. NSG and NGSV), the population dynamics are driven by inter-annual variability in recruitment. For the destination regions of SSG, SGSV, SE and WC, the population dynamics are driven by emigration from the source regions.

In this assessment, the fishery statistics, population age structures and model outputs were considered at the regional scale, and subsequently interpreted at the scale of biological stock (Fowler 2016). The SG/WC Stock is classified as **transitional depleting**, reflecting the declining levels of regional biomass as a consequence of relatively poor recruitment into NSG through the 2000s. As no strong year classes have recruited to this region since 1999, there has been minimal emigration of fish to SSG and WC. In contrast, the SE region was the beneficiary of two strong year classes that recruited to PPB, and subsequent emigration. Those year classes have now been depleted and the biomass has declined to a lower level. Nevertheless, as there has been above-average recruitment into PPB for six of the past 12 years (Hamer and Conron 2016), emigration to the SE is expected to continue. As such, this stock is classified as **sustainable**. The GSV Stock experienced an unprecedented increase in biomass through the 2000s based on numerous strong recruitment year classes to NGSV. Consequently, this stock is considered **sustainable** despite recent small declines for some indicators. The poor status of the SG/WC Stock provides a warning about NGSV with respect to the impact of sustained high fishing effort.

4.4 Uncertainties in the assessment

Our primary uncertainty about this assessment relates to the discrepancy between trends in biomass of snapper from the empirical data and output from the fishery model SnapEst. This eventuated from the emphasis placed on different datasets. Declining trends in fishery catch, effort and CPUE and recent low year class strength were interpreted in terms of declining biomass for the SG/WC Stock. Alternatively, the SnapEst model interpreted broad age structures and low levels of fishing effort in terms of low exploitation rates, leading to increasing fishable biomass. This conflict reflects that the fishery performance indicators, such as CPUE and fishing effort, used in this fishery are not necessarily closely related to fishable biomass. Furthermore, because of the multi-species nature of this fishery, such parameters are not only influenced by changes in fishable biomass, but by other factors such as fisher behaviour, as fishers can move between regions or species to pursue better financial gain.

There are several further concerns about using commercial fishery statistics as indicators of stock biomass. Since 1984, when the collection of detailed data commenced for the commercial sector in SA, there has been considerable technological creep in this industry. This includes: the use of electronic equipment for finding fish and navigation; the increase in power and range of vessels; and improvements to fishing technology, such as with the adoption in SA of new monofilament longline gear during the mid-2000s. The influences of these developments on ‘effective’ effort are unknown. In this assessment, a statistical approach was used to de-trend the time-series of CPUE, i.e. to remove long-term trends that could relate to increasing 'effective' effort. Such de-trending is useful if biomass has not increased over time, but is less useful when there has been a considerable change in biomass, as occurred for NGSV during the 2000s. This means that differentiating between time-series of CPUE and their de-trended versions is complex and requires subjective interpretation. This situation is not yet resolved for snapper in SA.

The second concern regarding the use of commercial fishery statistics as indicators of biomass relates to the management arrangements that were introduced in 2012 and 2013, which included a daily catch limit of 500 kg and reduction in number of longline hooks. Besides limiting catches and thereby impacting on estimates of regional catch and CPUE, these changes are also likely to have impacted on the usefulness of CPUE as an indicator of biomass. This was the reason for developing the two new fishery performance indicators of 'Prop250kgTarHL' and 'Prop250kgTarLL' (PIRSA 2013), i.e. the proportions of catches taken per gear type per year (excluding November to January) that reach 250 kg. They were developed to replace CPUE as a measure of relative abundance. Nevertheless, between 2004 and 2015, both parameters were highly variable from year-to-year, making questionable their relationship with biomass and value as indicators.

A further key uncertainty for South Australia's snapper fishery remains the poor understanding of recreational catch and effort. Uncertainties about recreational catch and effort remain considerable, whilst the spatial and temporal resolution of the data is poor. The results from the three State-wide telephone / diary surveys that were undertaken throughout the 2000s, have consistently indicated that the recreational sector accounts for considerable proportions of total catch, but the estimates have varied considerably. Such variability provides challenges for fishery modelling, stock assessments and fishery management.

4.5 Future research needs

The discrepancy in interpretation of fishery performance indicators for snapper, particularly for NSG, has highlighted the current dependence on fishery-related data. Currently, there is no fishery performance indicator that directly relates to fishable biomass or recruitment, as is the case for Victoria (Hamer and Conron 2016). Consequently, different performance indicators can provide ambiguous outcomes with respect to stock status. Awareness of this issue several years ago highlighted the need for a fishery-independent estimate of biomass for snapper. FRDC Project 2014/019 has assessed the Daily Egg Production Method for estimating the biomass of snapper in SA. This project is currently nearing completion, and the outcomes should provide an important new source of data that will be a useful empirical anchor point for the SnapEst model. Also, a review of the Management Plan that is scheduled for 2018 will provide an opportunity for assessing the usefulness of the current suite of performance indicators, including Prop250kgTarHL and Prop250kgTarLL.

Part of the confusion in interpreting fishery performance indicators in this assessment related to the inconsistency between some populations reputedly having low levels of biomass, but at the same time still including 10 – 20 year old fish. It would be expected that if fishing mortality was high enough to reduce biomass, then the population would have experienced age truncation and old fish would not remain in the population. It is unknown whether through their behaviour some fish gain access to a refuge from fishing. As such, our understanding of snapper behaviour remains incomplete, despite recent advancements in this area (Fowler 2016). This issue relates to habitat use and movement at the local scale and would be appropriately addressed using acoustic telemetry.

5. REFERENCE LIST

Crossland J (1976). Snapper tagging in north-east New Zealand, 1974: analysis of methods, return rates and movements. New Zealand Journal of Marine and Freshwater Research 10: 675-686.

Donnellan SC, McGlennon D (1996). Stock identification and discrimination in snapper (*Pagrus auratus*) in southern Australia. Final Report to the Fisheries Research and Development Corporation, 31 pp.

Dunn, A, Francis RICC, Doonan IJ (2002). Comparison of the Chapman–Robson and regression estimators of *Z* from catch-curve data when non-sampling stochastic error is present. Fisheries Research 59: 149-159.

Flood M, Stobutzki I, Andrews J, Ashby C, Begg G, Fletcher R, Gardner C, Georgeson L, Hansen S, Hartmann K, Hone P, Horvat P, Maloney L, McDonald B, Moore A, Roelofs A, Sainsbury K, Saunders T, Smith T, Stewardson C, Stewart J, Wise B (eds) (2014). Status of key Australian fish stocks reports 2014, Fisheries Research and Development Corporation, Canberra.

Fowler AJ (2000). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 2000/13. 55 pp.

Fowler AJ (2002). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 2001/13. 64 pp.

Fowler (2016). The influence of fish movement on regional fishery production and stock structure for South Australia's snapper (*Chrysophrys auratus*) fishery. Final Report to FRDC (Project No. 2012/020). 181 pp.

Fowler AJ, Jennings PR (2003). Dynamics in 0+ recruitment and early life history for snapper (*Pagrus auratus*, Sparidae) in South Australia. Marine and Freshwater Research 54: 941-956.

Fowler AJ, McGlennon D (2011). Variation in productivity of a key snapper, *Chrysophrys auratus*, fishery related to recruitment and fleet dynamics. Fisheries Management and Ecology 18: 411-423.

Fowler AJ, McGarvey R, Feenstra JE, Jackson WB, and Jennings PR (2003). Snapper (*Pagrus auratus*) Fishery. Fishery Assessment Report to PIRSA for the Marine Scalefish Management Committee. 70 pp.

Fowler AJ, Gillanders BM, Hall KC (2005b). Relationship between elemental concentration and age from otoliths of adult snapper (*Pagrus auratus*, Sparidae): implications for movement and stock structure. Marine and Freshwater Research 56: 661-676.

Fowler AJ, McGarvey R, Feenstra JE, Jackson WB, and Jennings PR (2005a). Snapper (*Pagrus auratus*) Fishery. Fishery Assessment Report to PIRSA for the Marine Scalefish Management Committee. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, RD03/0068-2. 99 pp.

Fowler AJ, McGarvey R, Feenstra JE and Jackson WB (2007). Snapper (*Pagrus auratus*) Fishery. Fishery Assessment Report to PIRSA Fisheries. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, F2007/000523-1, SARDI Research Report Series No. 224. Pp 90.

Fowler AJ, McGarvey R, Burch P, Feenstra JE and Jackson WB (2010). Snapper (*Chrysophrys auratus*) Fishery. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, F2007/000523-2, SARDI Research Report Series No. 473. Pp 109.

Fowler AJ, McGarvey R, Burch P, Feenstra JE, Jackson WB, Lloyd MT (2013). Snapper (*Chrysophrys auratus*) Fishery. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide, F2007/000523-3, SARDI Research Report Series No. 713. Pp 103.

Fukuhara O (1985). Functional morphology and behaviour of early life stages of red sea bream. Bulletin of the Japanese Society of Scientific Fisheries 51: 731-743.

Gilbert DJ, Davies NM, McKenzie JR (2006) Development of an age–length structured model of the Hauraki Gulf–Bay of Plenty snapper (*Pagrus auratus*) population. *Marine and Freshwater Research* 57: 553–568.

Giri K, Hall K (2015) South Australian Recreational Fishing Survey. Fisheries Victoria Internal Report Series No. 62.

Hamer P, Conron S (2016). Snapper Stock Assessment 2016. Fisheries Victoria Science Report Series No. 10, Fisheries Victoria, Queenscliff.

Hamer PA, Acevedo S, Jenkins GP, Newman A. (2011). Connectivity of a large embayment and coastal fishery: spawning aggregations in one bay source local and broad-scale fishery replenishment. Journal of Fish Biology 78: 1090-1109.

Hamer PA, Jenkins GP, Coutin P (2006). Barium variation in *Pagrus auratus* (Sparidae) otoliths: a potential indicator of migration between an embayment and ocean waters in south-eastern Australia. Estuarine, Coastal and Shelf Science 68: 686-702.

Hamer PA, Jenkins GP, Gillanders BM (2005). Chemical tags in otoliths indicate the importance of local and distant settlement areas to populations of a temperate sparid, *Pagrus auratus*. Canadian Journal of Fisheries and Aquatic Sciences 62: 623-630.

Henry GW, Lyle JM (2003). The National Recreational and Indigenous Fishing Survey. Final Report to FRDC (Project No. 1999/158). NSW Fisheries Final Report Series no. 48. 188 pp.

Jackson G, Fowler A, Holmes B, Kemp J, Stewart J (2012). Snapper *Pagrus auratus* in M Flood, I Stobutzki, J Andrews, G Begg, W Fletcher, C Gardner, J Kemp, A Moore, A O'Brien, R Quinn, J Roach, K Rowling, K Sainsbury, T Saunders, T Ward & M Winning (eds), Status of key Australian fish stocks reports 2012, Fisheries Research and Development Corporation, Canberra, 344-354.

Jones GK (2009). South Australian Recreational Fishing Survey. PIRSA Fisheries, Adelaide, 84 pp. South Australian Fisheries Management Series Paper No. 54.

Jones GK, Doonan A (2005). 2000-01 National Recreational and Indigenous Fishing Survey – SA Regional information. South Australian Fisheries Management Series Paper no. 46. 99 pp.

Kailola PJ, Williams MJ, Stewart PC, Reichelt RE, McNee A, Grieve C (1993). Australian Fisheries Resources. Bureau of Resource Sciences and the Fisheries Research and Development Corporation Canberra Australia. Imprint Limited, Brisbane.

Last PR, White WT, Gledhill DC, Hobday AJ, Brown R, Edgar GJ, Pecl G (2011). Long-term shifts in abundance and distribution of a temperate fish fauna: a response to climate change and fishery practises. Global ecology and Biogeography 20: 58-72.

Matsuyama M, Adachi S, Nagahama Y, Matsuura S (1988). Diurnal rhythm of oocyte development and plasma steroid hormone levels in the female Red Sea Bream, *Pagrus major*, during the spawning season. Aquaculture 73: 357-372.

McGarvey R (2004). Model comparison of seasonal closure and maximum size for management of the South Australian snapper fishery. Ecological Management & Restoration 5: 139-141.

McGarvey R, Jones GK (2000). Biological requirements and yield- and egg-per-recruit estimates for management of the South Australian snapper (*Pagrus auratus*) fishery. Report to the Marine Scalefish Fishery Management Committee.

McGarvey R, Feenstra JE (2004). Stock assessment models with graphical user interfaces for key South Australian marine finfish stocks. Final Report to FRDC (Project No. 1999/145). South Australian Research and Development Institute (Aquatic Sciences), Adelaide. 176 pp.

McGarvey R, Feenstra JE, Ye Q (2007). Modeling fish numbers dynamically by age and length: partitioning cohorts into 'slices'. Canadian Journal of Fisheries and Aquatic Sciences 64: 1157-1173.

McGarvey R, Fowler AJ (2002). Seasonal growth of King George whiting (*Sillaginodes punctata*) from length-at-age samples truncated by legal minimum size. Fishery Bulletin 100: 545-558.

McGarvey R, Burch P, Feenstra JE (2010). Management Strategy Evaluation for South Australian Snapper. SARDI Aquatic Sciences Publication No. F2010/00026-1. SARDI Research Report Series No. 441. April 2010. 32 pp.

McGarvey R., Burch P, Feenstra JE (2011). Use of management strategy comparison scatterplots to identify clusters of high performing strategies. Fisheries Management and Ecology 18: 349–359.

McGlennon D (1999). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 98/7.

McGlennon D (2004). The fisheries biology and population dynamics of snapper *Pagrus auratus* in northern Spencer Gulf, South Australia. PhD thesis, University of Adelaide. 212 pp.

McGlennon D, Jones GK (1997). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 97/07. 59 pp.

McGlennon D, Jones GK (1999). Snapper (*Pagrus auratus*). South Australian Fisheries Assessment Series 99/13. 23 pp.

McGlennon D, Jones GK, Baker J, Jackson WB, Kinloch MA (2000). Ageing, catch-at-age and relative year-class strength for snapper (*Pagrus auratus*) in Northern Spencer Gulf, South Australia. Marine and Freshwater Research 51: 669-677.

McGlennon D, Kinloch MA (1997). Resource allocation in the South Australian marine scalefish fishery. FRDC project 93/249, Final Report. 105 pp.

Moran M, Burton C, Caputi N (1998). Sexual and local variation in head morphology of snapper, *Pagrus auratus*, Sparidae, in the Shark Bay region of Western Australia. Marine and Freshwater Research 50: 27-34.

Moran M, Burton C, Jenke J (2003). Long-term movement patterns of continental shelf and inner gulf snapper (*Pagrus auratus*, Sparidae) from tagging in the Shark Bay region of Western Australia. Marine and Freshwater Research 54: 913-922.

Murphy HM, Jenkins GP, Hamer PA, Swearer S (2012). Interannual variation in larval survival of snapper (*Chrysophrys auratus*, Sparidae) is linked to diet breadth and prey availability. Canadian Journal of Fisheries and Aquatic Sciences 69: 1340-1351.

Murphy HM, Jenkins GP, Hamer PA, Swearer S (2013). Interannual variation in larval abundance and growth in snapper, *Chrysophrys auratus*, Sparidae, related to prey availability and temperature. Marine Ecology progress Series 487: 151-162.

Norriss JV, Crisafulli B (2010). Longevity in Australian snapper *Pagrus auratus* (Sparidae). Journal of the Royal Society of Western Australia 93: 129-132.

Paul LJ (1967). An evaluation of tagging experiments on the New Zealand snapper, *Chrysophrys auratus* (Forster), during the period of 1952 to 1963. New Zealand Journal of Marine and Freshwater Research 1: 455-463.

PIRSA (2013). Management Plan for the South Australian Commercial Marine Scalefish Fishery. PIRSA Fisheries and Aquaculture, Adelaide, 143 pp. The South Australian Fishery Management Series, Paper No. 59.

PIRSA (2016a). Review of size, bag and boat limits in South Australia's recreational fishing sector, marine and freshwater. Support document for the management plan for recreational fishing in South Australia. January 2016.

PIRSA (2016b). Draft Management Plan for Recreational Fishing in South Australia. Public Consultation Document. January 2016.

Sanders MJ (1974). Tagging indicates at least two stocks of snapper *Chrysophrys auratus* in south-east Australian waters. New Zealand Journal of Marine and Freshwater Research 8: 371-374.

Saunders RJ (2009). The reproductive biology and recruitment dynamics of snapper, *Chrysophrys auratus*. PhD thesis, University of Adelaide. 154 pp.

Saunders RJ, Fowler AJ, Gillanders BM (2012). The spawning dynamics of snapper (*Chrysophrys auratus*) in northern Spencer Gulf, South Australia. New Zealand Journal of Marine and Freshwater Research 46: 491-510.

Scott SG, Zeldis JR, Pankhurst NW (1993). Evidence of daily spawning in natural populations of the New Zealand snapper *Pagrus auratus* (Sparidae). Environmental Biology of Fishes 36: 149-156.

Steer, M.A., McGarvey, R., Carroll, J., Jackson, W. B., Lloyd, M. T. and Feenstra, J. E. (2016). Southern Garfish (*Hyporhamphus melanochir*) Fishery. Fishery Assessment Report to PIRSA Fisheries and Aquaculture. South Australian Research and Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. F2007/000720-4. SARDI Research Report Series No. 891. 75pp.

Tanaka M (1985). Factors affecting the inshore migration of pelagic larval and demersal juvenile red sea bream *Pagrus major* to a nursery ground. Transactions of the American Society 114: 471-477.

Thorpe RS (1975). Quantitative handling of characters useful in snake systematics with particular reference to intraspecific variation in the ringed snake *Natrix natrix* (L.), Biological Journal of the Linnean Society 7: 27-43.

Zeldis JR, Oldman J, Ballara S, Richards LA (2005). Physical fluxes, pelagic ecosystem structure, and larval fish survival in Hauraki Gulf, New Zealand. Canadian Journal of Fisheries and Aquatic Sciences 62: 593-610.

6. APPENDICES

6.1 Annual size and age structures

This section presents the annual estimates of population size and age structures determined from SARDI's market sampling program that has focussed on Adelaide's SAFCOL fish market. The data available in the different years varied amongst regions, based on the availability of captured fish from the commercial sector, as determined by variation in regional productivity.

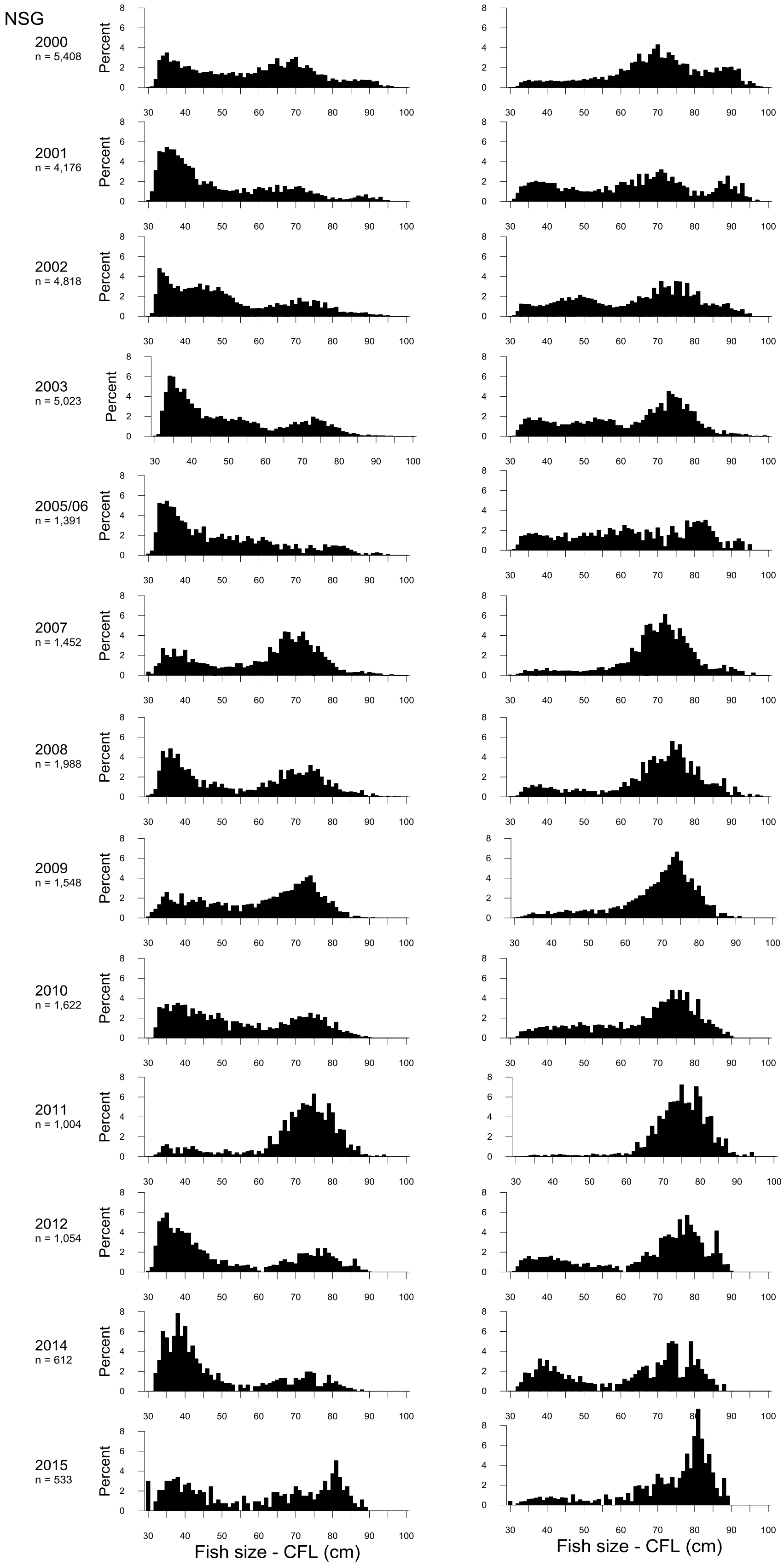

Fig. 6.1 Size and biomass distributions for snapper caught in NSG in each of 13 years. Left hand graphs show the size structures. Right hand graphs show the percentage of biomass accounted for by each size class.

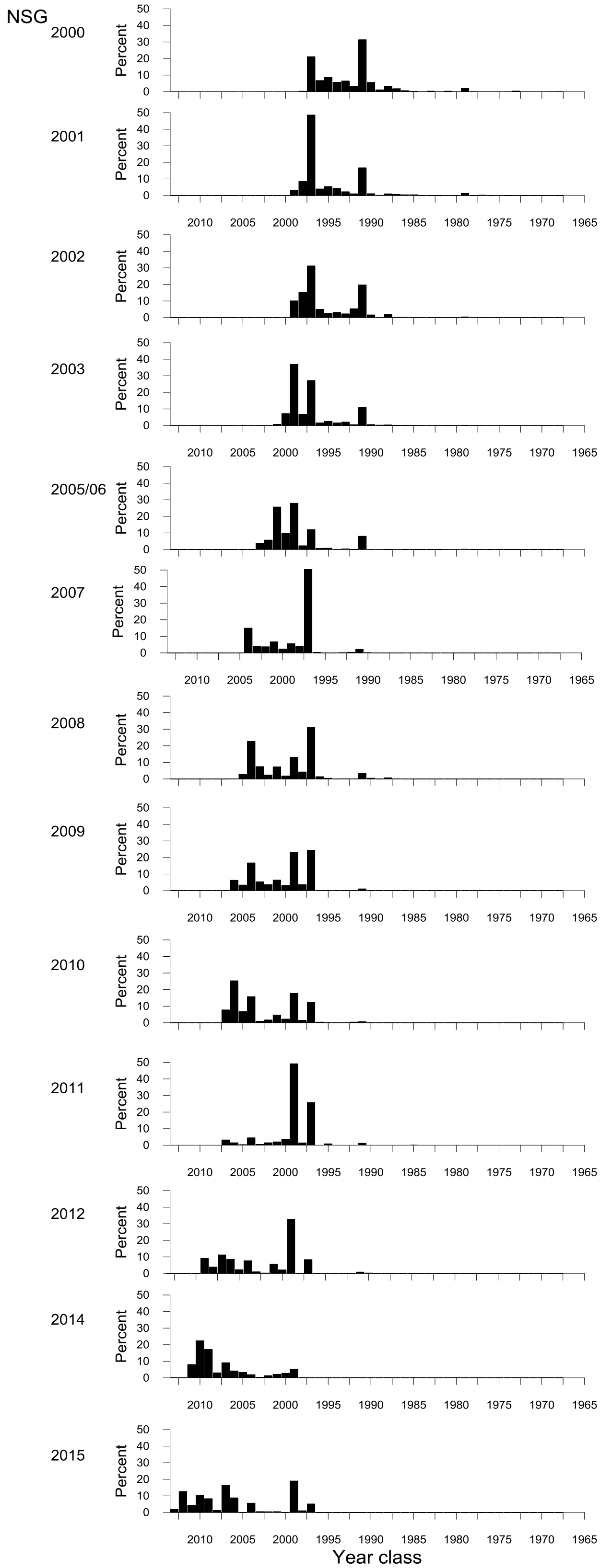

Fig. 6.2 Estimated age structures of fish caught in NSG in each of 13 years. For each year, data are presented as the relative percentage of total catch accounted for by each year class, i.e. the years in which they were spawned.

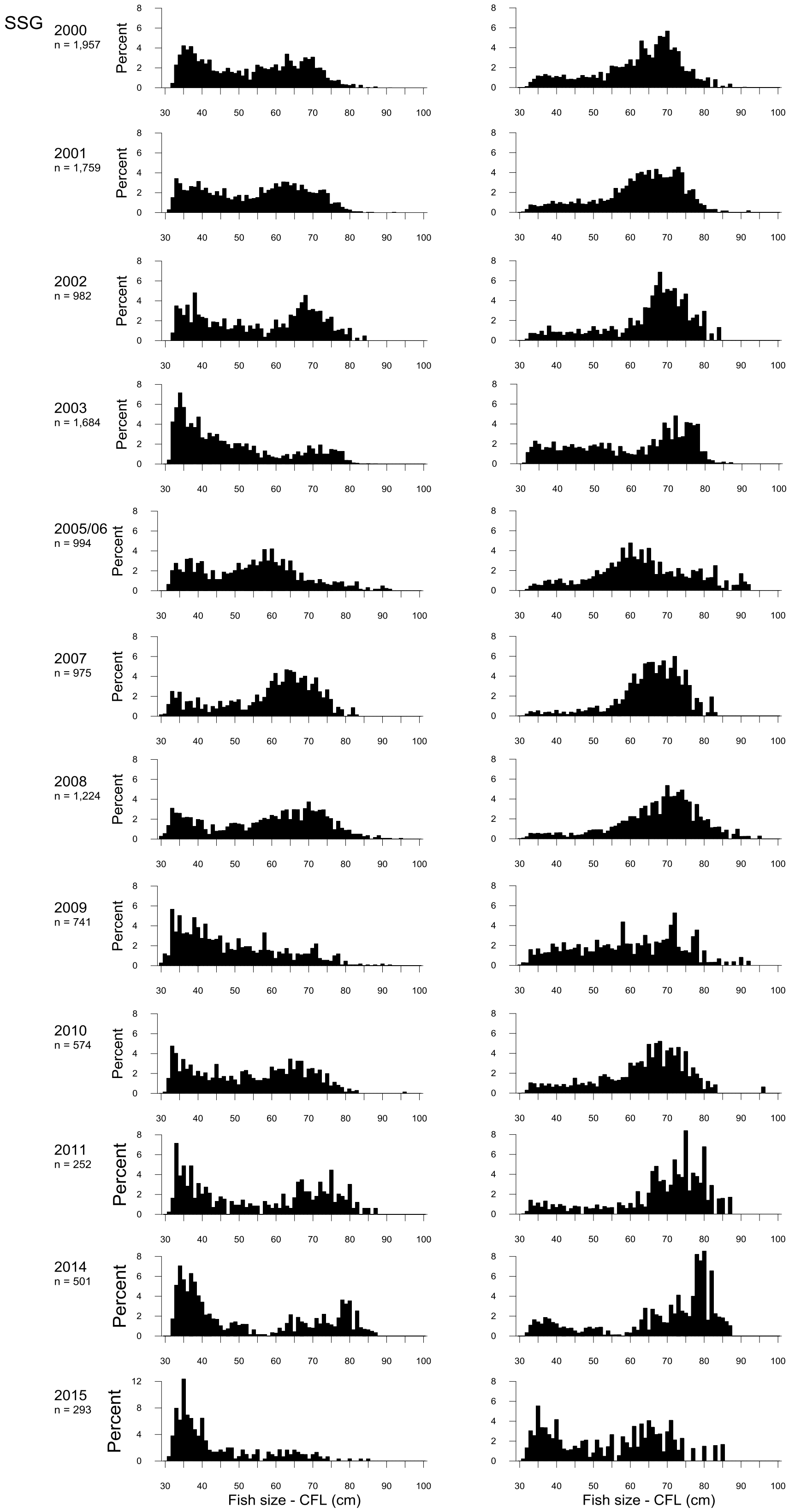

Fig. 6.3 Size and biomass distributions for snapper caught in SSG in each of 12 years. Left hand graphs show the size structures. Right hand graphs show the percentage of biomass accounted for by each size class.

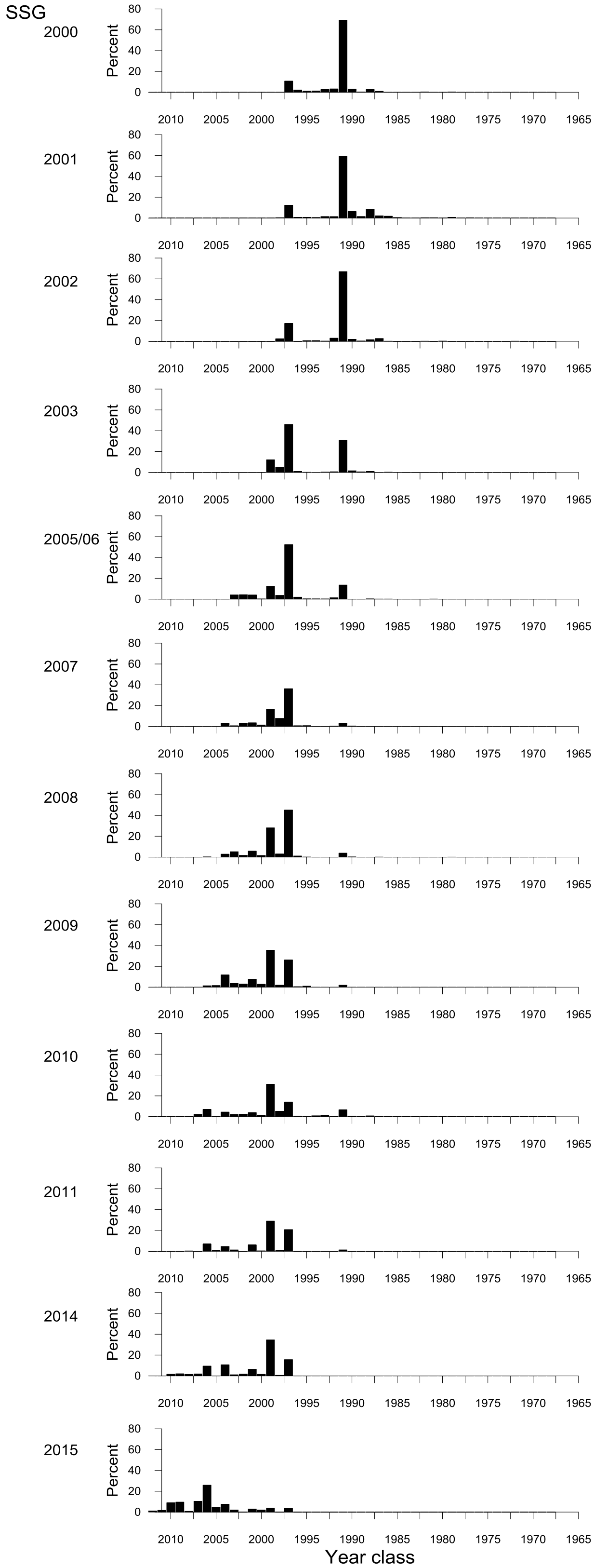

Fig. 6.4 Estimated age structures of fish caught in SSG in each of 12 years. For each year, data are presented as the relative percentage of total catch accounted for by each year class, i.e. the years in which they were spawned.

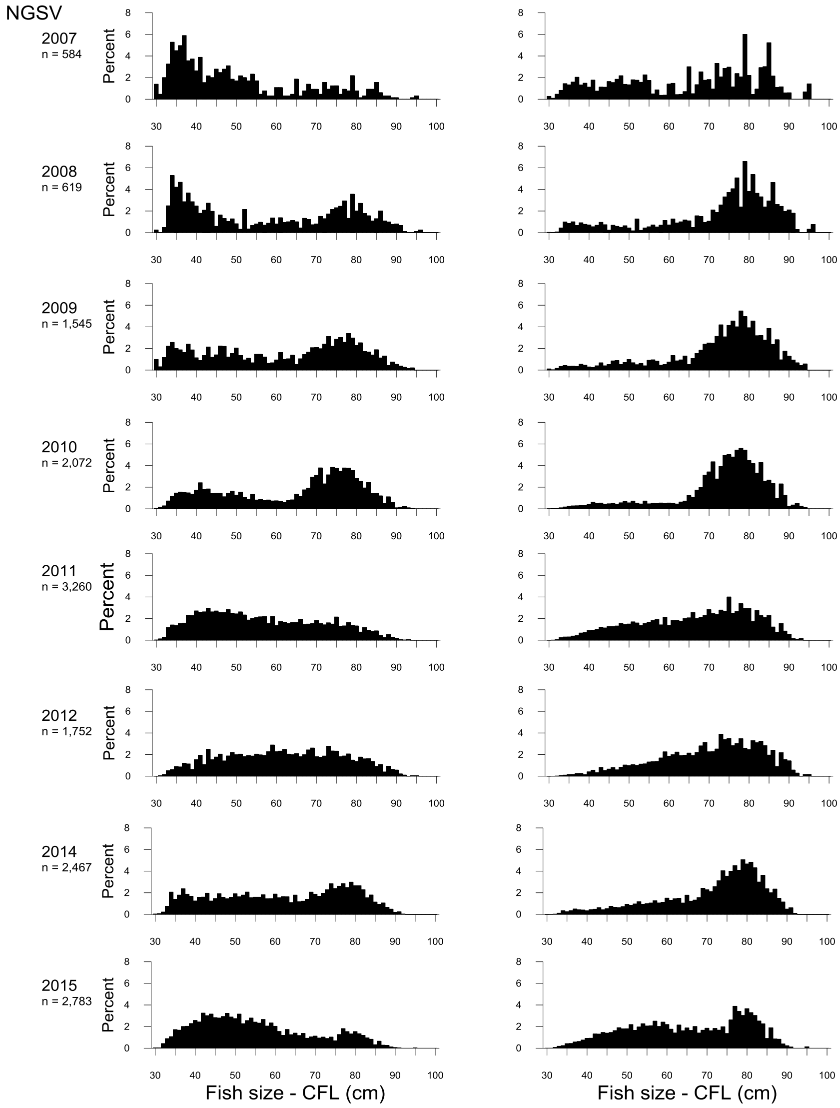

Fig. 6.5 Size and biomass distributions for snapper caught in NGSV in each of eight years. Left hand graphs show the size structures. Right hand graphs show the percentage of biomass accounted for by each size class.

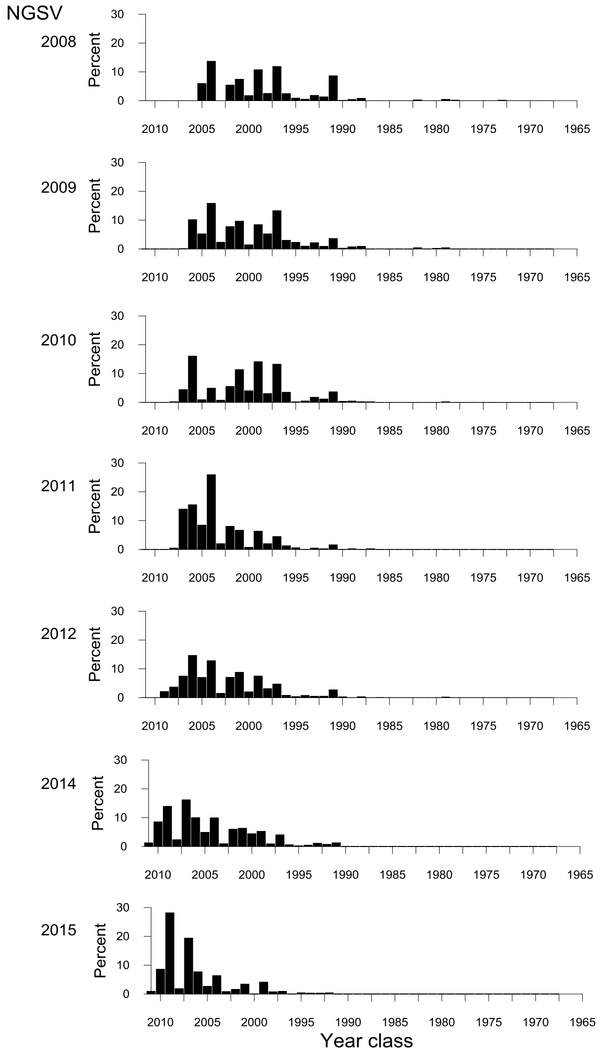

Fig. 6.6 Estimated age structures of fish caught in NGSV in each of seven years. For each year, data are presented as the relative percentage of total catch accounted for by each year class, i.e. the years in which they were spawned.

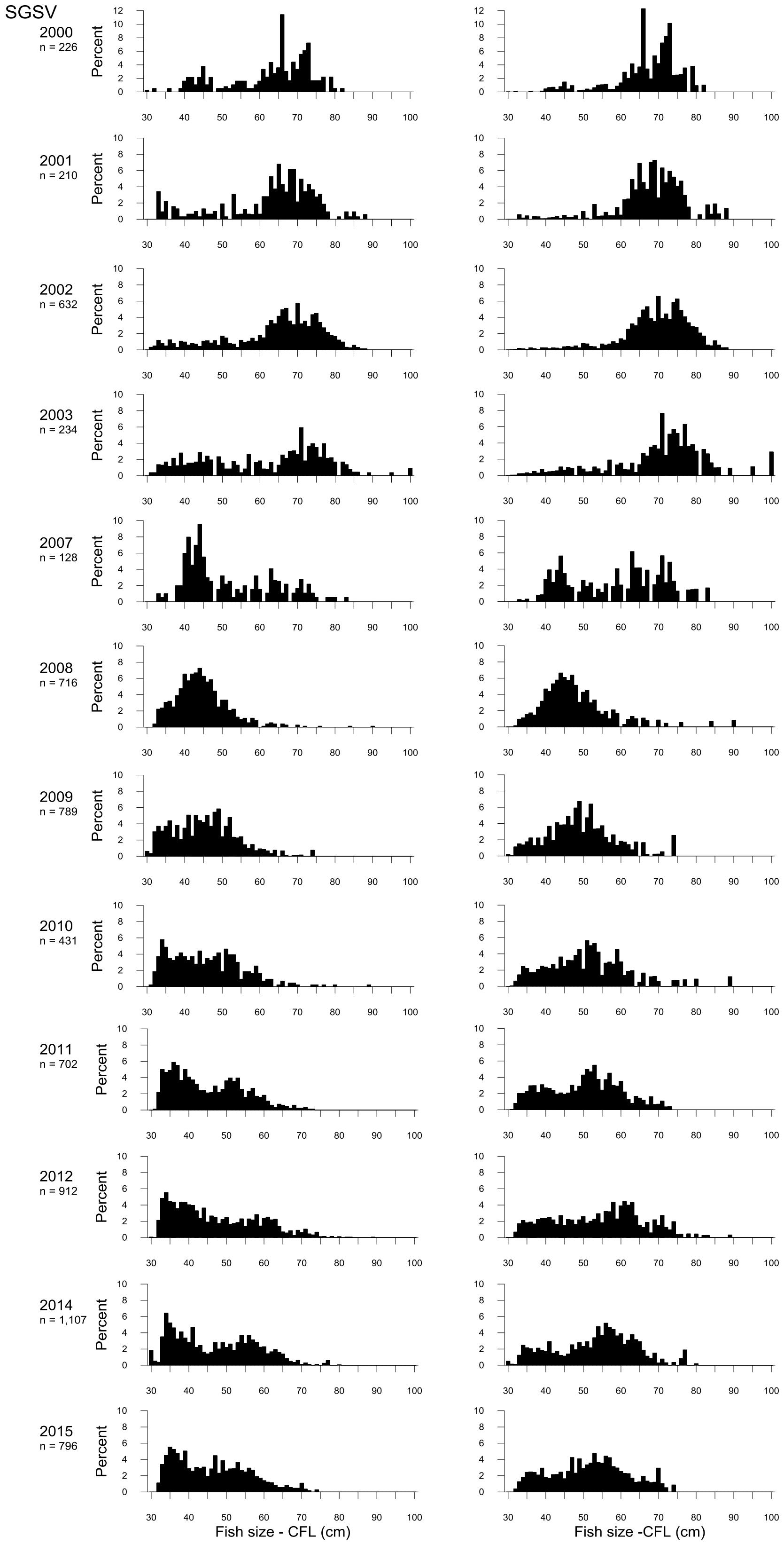

Fig. 6.7 Size and biomass distributions for snapper caught in SGSV in each of 12 years. Left hand graphs show the size structures. Right hand graphs show the percentage of biomass accounted for by each size class.

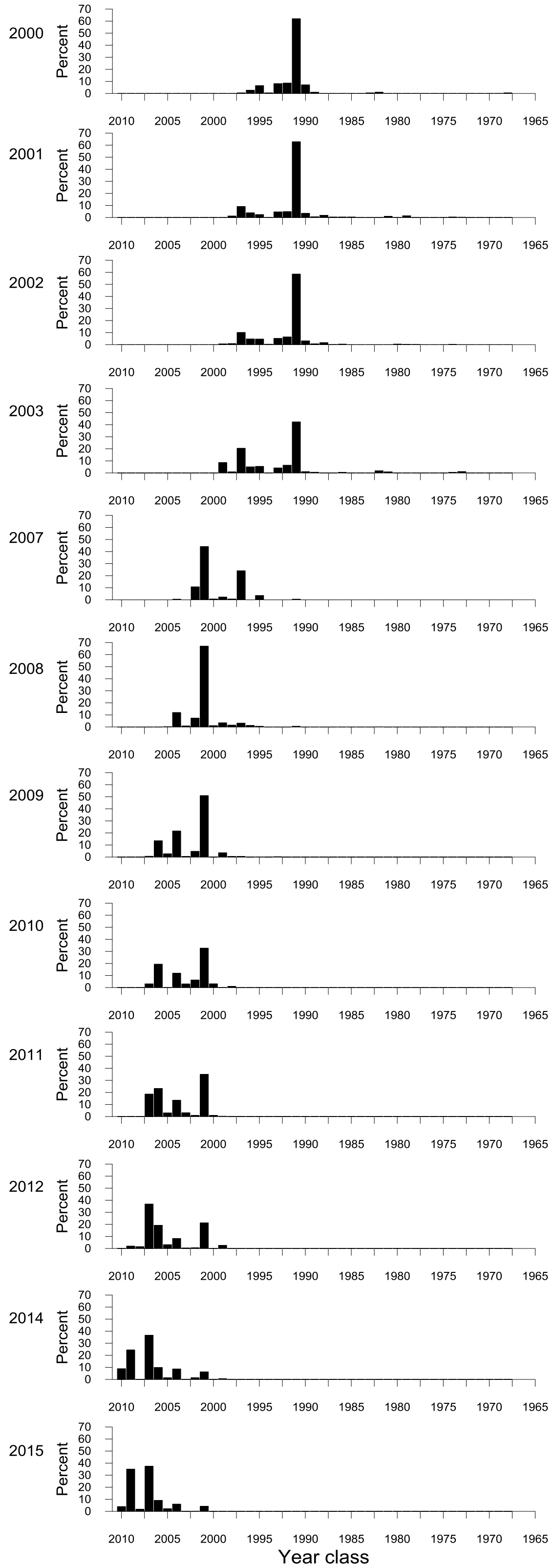

Fig. 6.8 Estimated age structures of fish caught in SGSV in each of seven years. For each year, data are presented as the relative percentage of total catch accounted for by each year class, i.e. the years in which they were spawned.

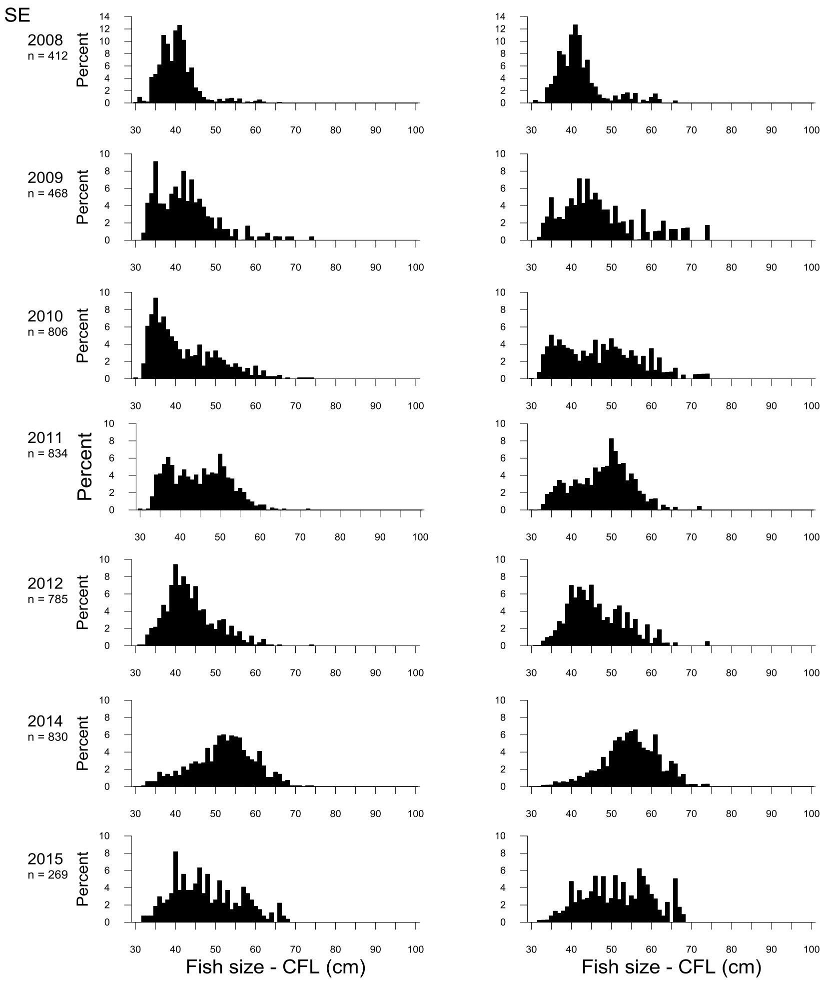

Fig. 6.9 Size and biomass distributions for snapper caught in SE in each of seven years. Left hand graphs show the size structures. Right hand graphs show the percentage of biomass accounted for by each size class.

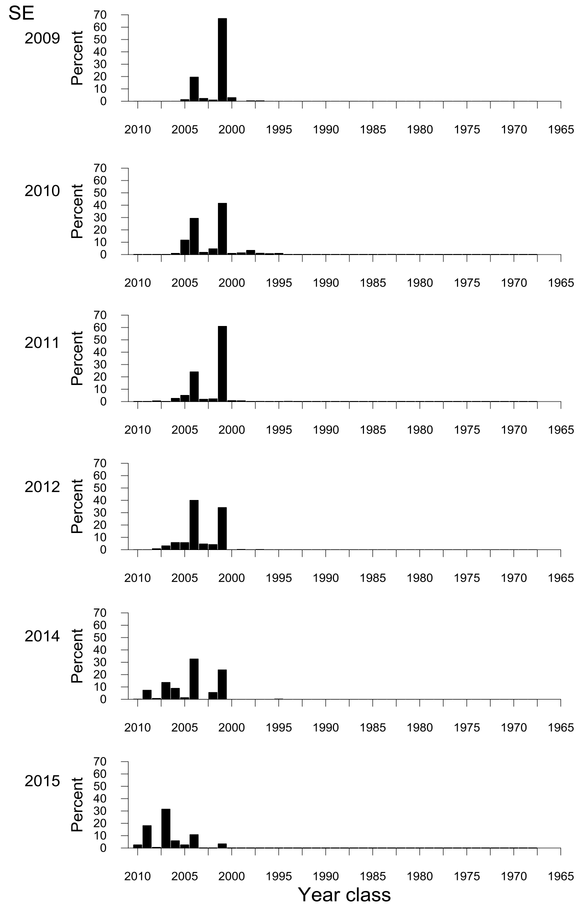

Fig. 6.10 Estimated age structures of fish caught in SE in each of six years. For each year, data are presented as the relative percentage of total catch accounted for by each year class, i.e. the years in which they were spawned.

6.2 Snapper stock assessment model

In this section we summarise the following components of the stock assessment model: (1) growth, (2) recruitment, (3) the population array including length slices, (4) mortality, and (5) the likelihood function relating model to data. The slice-partition method, with detailed pseudo-code, is described in Appendix C of the 2015 Garfish stock assessment report (Steer et al. 2016).

6.2.1 Growth

The starting point and basis of the slice method for partitioning fish cohorts by length is the length-at-age growth submodel. A statistical growth submodel is needed which fully specifies the probability density function (pdf) of fish lengths for each model age. This represents the (normal) distribution of fish by length in each cohort age that would be observed in the absence of length-asymmetric mortality, because length-selective capture mortality will subsequently be imposed on these model cohorts, after they are partitioned into slices. To model mean fish length $\bar{l}$, the mean of the normal length-at-age pdf, for any half-yearly cohort age, a, we employed a 4-parameter exponent-generalized von Bertalanffy mean length-at-age curve: $\bar{l}(a) = L_\infty \left\{1 - \exp\left[-K\left(\frac{a-t_0}{2}\right)\right]\right\}^r$ (McGarvey and Fowler 2002). Using two additional parameters, the dependence of the length-at-age standard deviation $\sigma(a)$ is modelled as an allometric function of mean length: $\sigma(a) = \sigma_0 \cdot \left(\bar{l}(a)\right)^{\sigma_1}$.

The growth parameters can be estimated by fitting to length-at-age samples (1) previous to, or (2) by integrating growth estimation into, the stock assessment likelihood. We undertook both in that order. First we fitted the growth submodel directly to catch lengths-at-age to obtain approximate growth parameter estimates. A likelihood probability of observation truncated at LML was assumed to make explicit the absence of sublegal snapper in these catch samples (McGarvey and Fowler 2002). A second growth estimation was integrated into the stock assessment likelihood, re-estimating the two parameters that most directly determine the mean rate of growth and spread of lengths at each age, von Bertalanffy K and the normal length-at-age standard deviation coefficient σ_0.

Starting from this growth submodel, an algorithm (described in Appendix C of Steer et al. 2016) was devised to effectively 'slice off' the length subintervals of fish which have grown past legal minimum length (LML) in each model time step. Once this population number is assigned to each newly created slice bin by transferring these fish from the sublegal component, there is no subsequent further exchange of fish between length bins. Fish within slices incur only mortality. The simplification of neglecting growth diffusion among length bins affords the slice approach large reductions in computation time compared with, for example, a length-transition approach, which requires $(n_L)^2$ growth-transition multiplications in each model time step and for each cohort, where n_L is the number of length bins. In a slice partition model, growth is quantified as the increasing length range with age of each slice subinterval, and no computation is needed to shift fish among bins.

6.2.2 Recruitment

Recruitment is defined as the creation of the (normal) length-at-age cohort at age a_b = 5 half-years (at age 2 years) when the fastest growing fish first reach legal size. The number of fish in each cohort at the birth age, a_b, is the model estimate of yearly recruitment. Each yearly recruit number is a freely estimated model parameter. The numbers of snapper above legal minimum length at age a_b (in the upper tail of the length at age pdf) are computed (Appendix C of Steer et al. 2016) and defined as the first newly created slice. In subsequent model time steps, new slices are created as the calculated proportion of sublegal fish in each cohort that have grown into legal size since the previous time step, thereby modelling the gradual recruitment of each cohort to fishable sizes over the number of model time steps required, as determined by the growth submodel (Appendix C of Steer et al. 2016).

6.2.3 Model population array

The model snapper population array $N(t,r,c,s)$ is 4-dimensional, fish numbers broken down by (1) half-yearly model time step (1 = summer 1983 to 64 = winter 2015) "t", (2) spatial region (1 = SSG, 2 = NSG, 3 = SGSV, 4 = NGSV) "r",(3) cohort (i.e. year-class, given by year of spawning) "c", and (4) slice "s".

Variable subscripts for winter or summer half-year (t_{season}), and cohort age in half-years (a), were calculated as functions of model time step, t, and cohort year, c. Ages ran from a_b to 48+ half-years, the oldest age being a 'plus' group. Snapper catch and effort, for data and model, were divided into six effort types, i_E : (i) handline (all target types), (ii) longline (all target types) , (iii) hauling nets and minor gears (all target types), (iv) all other commercial gears combined , (v) charter boat, and (vi) recreational. The three commercial gears, g , are handline, longline, and hauling net, with handline having age selectivity modelled by a decreasing logistic function and longline having length selectivity modelled by an increasing logistic function. Data quantities, such as reported effort $\tilde{E}$, are denoted by a tilde.

6.2.4 Mortality

Mortality is differentiated for legal and sublegal fish. Legal-size fish, partitioned into length slices, are subject to both fishing and natural mortality. Length-dependent gear selectivity, and any other length-dependent mortality processes, are applied to the length-partitioned fish numbers, specifically in the legal size range. In addition to the knife-edge cut-off below legal minimum length, gear-specific length selectivity is modelled for legal size snapper. Sublegal population numbers (fish below the legal size limit) incur only natural mortality.

The catch equations were effort conditioned. Thus, fishing mortality was written as a linear proportion of reported fishing effort for each component of catch:

(B.1) $$F(t,r,c,s,i_E) = q(r,\ t_{season},\ i_E)\ \cdot \tilde{E}(t,r,i_E)\ \cdot s_{len}(r,g(i_E),s) \cdot s_{age}(r,g(i_E),ageHY)\ .$$

The catchability, q , was assumed to vary with region, season, and effort type. Length selectivity, s_{len} , by region for longline only, followed a logistic function of fish length, the latter specified by the midpoint of each slice

(B.2) $$s_{len}(r,g(i_E),s) = fl_{sel}\left(r,g(i_E)\right) + 1 \Big/ \left\{ \begin{array}{l} 1+\exp\left[-r_{sel}\left(r,g(i_E)\right)\cdot\left(\bar{l}(s) - l_{50}\left(r,g(i_E)\right)\right)\right] \\ +fl_{sel}\left(r,g(i_E)\right)/(1-fl_{sel}\left(r,g(i_E)\right)) \end{array} \right\}$$

where $r_{sel}\left(r,g(i_E)\right)$ is the logistic slope parameter, $l_{50}\left(r,g(i_E)\right)$ is the logistic 50% level parameter, and $fl_{sel}\left(r,g(i_E)\right)$ is a parameter to raise the level of the function over the whole range of lengths.

A decreasing logistic selectivity function of fish age was applied for handline only, by region, as

(B.3) $$s_{age}(r,g(i_E),ageHY) = 1 - 1 \Big/ \left\{ \begin{array}{l} 1+\exp\left[-r_{agesel}\left(r,g(i_E)\right)\cdot\left(ageHY - l_{50agesel}\left(r,g(i_E)\right)\right)\right] \\ +fl_{agesel}\left(r,g(i_E)\right)/(1-fl_{agesel}\left(r,g(i_E)\right)) \end{array} \right\}$$

where the three parameters are analogous to those for the length selectivity function above.

For commercial effort, the catchability was written:

(B.4) $$q(r,t_{season},i_E) = q_{CSE}(r,i_E)\cdot\ s_S(r,i_E,t_{season})$$

with $q_{CSE}(r,i_E)$ being the absolute catchability given by region and effort type, a relative selectivity coefficient $s_S(r,i_E,t_{season})$ by region and effort type describing the seasonality of catchability. Charter boat and recreational fisheries involve non-regional absolute catchability and relative seasonal catchability parameters. For some regions and commercial effort types $q_{CSE}(r,i_E)$ was replaced for limited time periods with an alternative catchability parameter (separate and specific to each time period).

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:

(B.5) $$F(t,r,c,s) = \sum_{i_E=1}^{n_E} F(t,r,c,s,i_E)\,.$$

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

(B.6) $$N(t+1,r,c,s) = N(t,r,c,s)\cdot \exp\left[-\left(M + F(t,r,c,s)\right)\cdot p_{yr}(t)\right]$$

where $p_{yr}(t)$ quantifies the proportion of a year spanned by the days in each half-yearly time step. Instantaneous natural mortality rate was taken as constant, M = 0.05 yr^{-1} (Gilbert *et al.* 2006; Gilbert, pers. comm.).

6.2.5 Estimation: Parameters and model likelihood

The model likelihood (Fournier and Archibald 1982) was fitted to (1) half-yearly catch totals by weight (commercial fishery), (2) market sample catch proportions by age, and (3) market sample catch moment properties of fish length for each age.

Parameters

Estimated parameters for the model fall into six categories: (1) yearly recruit numbers by region, (2) catchabilities by region (for commercial effort type) and effort type, (3) relative seasonal selectivities by region (for commercial effort type) and effort type, (4) logistic length and age selectivity, (5) growth, and (6) likelihood standard deviations of fits to half-yearly catch totals.

Likelihood for catch totals by weight

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

(B.7) $$\begin{aligned}\hat{C}(t,r,c,s,i_E) &= N(t,r,c,s)\cdot w(a(t,c),s)\cdot \\ &\frac{F(t,r,c,s,i_E)}{M + F(t,r,c,s)}\cdot\left\{1-\exp\left[-\left(M+F(t,r,c,s)\right)\cdot p_{yr}(t)\right]\right\}\end{aligned}$$

where the weights by age and slice $w(a(t,c),s)$ are derived in Appendix C of Steer et al. (2016).

The likelihood factor for each combination of region, *r*, and commercial effort type (i_E up to $n_E - 2$), was written:

(B.8)

$$L_C = \prod_{t=1}^{n_t} \prod_{i_E=1}^{n_E-2} \prod_{r=1}^{n_r} \frac{1}{\sqrt{2\pi} \cdot \sigma_C(t_{season}, r, i_E) \cdot \tilde{C}(t,r,i_E)} \exp\left[-\frac{1}{2} \left(\frac{\ln\left(\hat{C}(t,r,i_E)\right) - \ln\left(\tilde{C}(t,r,i_E)\right)}{\sigma_C(t_{season}, r, i_E)} \right)^2 \right]$$

where

$\sigma_C(t_{season}, r, i_E)$ = an estimated catch-likelihood standard deviation parameter, one per effort type, season, and region;

$\tilde{C}(t,r,i_E)$ = reported catch by weight for each time step, *t*, region, *r*, and effort type, i_E;

$\hat{C}(t,r,i_E)$ = model-predicted catch by weight for each *t*, *r*, and i_E.

A weighted sum-of-squares was used to fit to charter boat ($i_E = n_E - 1$) catches in number since summer 2007, and similarly for recreational ($i_E = n_E$) catches in number are fit to for three telephone and diary surveys run in 2001/02, 2007/08 and 2013/14. Recreational effort data between the survey years were assumed to vary linearly (by region and season) between the survey-estimated values and retained the values of 2001/02 prior to that first survey except for a human population scaling factor, and the values of 2013/14 were retained post 2013/14. Only catch number data for the full year by region were available from the 2013/14 survey recently completed, for which we assumed (1) survey catches by year were broken down into two half-years using proportions taken in winter, and (2) effort varied relative to 2007/08 values with the same slopes by gulf and season observed for catches.

Likelihood for catch samples by age

A multinomial likelihood was used to fit to catch-sample proportions by age. The source data, from the samples per principal gears handline and longline in the half-yearly time steps and four regions where catch was monitored, consists of the observed counts of sampled fish falling into each half-yearly age, $\tilde{n}(a;\ i_A)$. But the data fitted consists of the observed counts multiplied by a factor that depends on the relative discrepancy ratio of each age sampled length value compared to that length in the full market samples of lengths (including fish not aged), the latter samples taken as being more length-representative of the population than the aged samples (see the FRDC report, McGarvey and Feenstra (2004)). Finally, each such corrected count at age-length was multiplied by a scaling factor so that the total raw sample size is preserved at the level of region, time step, and gear. The multinomial likelihood factor is written

(B.9)
$$L_A = \prod_{i_A=1}^{n_A} \prod_{a=a_b}^{48+} \hat{p}(a;\, i_A)^{\tilde{n}_{cor}(a;\, i_A)}$$

where

i_A = index over the set of n_A catch samples of fish ages over half-year, region, and gear;

$\hat{p}(a;\, i_A)$ = an array of model-predicted fish proportions captured by age for each sample indexed by i_A;

$\tilde{n}_{cor}(a;\, i_A)$ = scaled and corrected observed fish numbers for each age in the catch-at-age sample i_A.

Likelihood for catch samples by length

A normal likelihood was applied to fit the model to data moment 'properties', mean length, standard deviation of length, skewness, and kurtosis. Fournier and Doonan (1987) first proposed fitting to length moments and also fitted a normal likelihood, but to the central moments rather than moment properties. The likelihood for the length moments fit was written:

(B.10)
$$L_{mp} = \prod_{i_A=1}^{n_A(i_{mp})} \prod_{i_{mp}=1}^{4} \prod_{a=a_b}^{48+} \left\{ \frac{\exp\left[-\frac{1}{2} \left(\frac{\left\{ \tilde{b}(i_{mp}, a; i_A) - \hat{b}(i_{mp}, a; i_A) \right\}}{\sigma_{mp}} \right)^2 \right]}{\sqrt{2\pi} \cdot \sigma_{mp}} \right\}^{\tilde{n}(a;\, i_A)} .$$

where

σ_{mp} = is the estimated moment-likelihood standard deviation parameter, separately per season, region, and gear.

$\tilde{b}(i_{mp}, a; i_A)$ = observed moment, indexed by i_{mp}, per sample and half-yearly age.

$\hat{b}(i_{mp}, a; i_A)$ = model-predicted counterpart to $\tilde{b}(i_{mp}, a; i_A)$.

The observed moments were not calculated using the raw counts of fish per age and length category, but instead were based on length counts from the aged fish that were corrected for representative length sampling as noted further above (see the FRDC report, McGarvey and Feenstra (2004)). We weighted each factor in the log-likelihood by the uncorrected sample size ($\tilde{n}(a;\ i_A)$), that is by the actual number of aged fish. Higher moment properties require more data to be informative. We therefore set criteria for exclusion of smaller catch sample data sets, i_A, from the L_{mp} likelihood, depending on the moment property fitted. Thus the number of qualifying data sets, $n_A(i_{mp})$, decreased with increasing moment property i_{mp}. We required at least 8 aged fish for kurtosis, 4 for skewness, 2 for standard deviation, and 1 for fitting to mean length. Similarly we required 4 model slices for kurtosis, 3 for skewness, 2 for standard deviation, and 1 for fitting mean length.

6.2.6 Model performance indicators

Yearly recruitment numbers

Each yearly recruitment number, by region, is a freely estimated model parameter, as described in Section 6.2.2.

Annual fishable biomass

The annual biomass indicator is the average of the two half-yearly estimates, which for each region r and year y commencing in October (1983 to 2014) is computed as follows

(B.11) $$B(y,r) = \frac{1}{2} \sum_{t=t_{season}(1,y)}^{t_{season}(2,y)} B(t,r).$$

The fishable biomass at start of each half-yearly time step t in year y ($t_{season}(1,y)$ = October-March, $t_{season}(2,y)$ = April-September) is given by

(B.12)
$$B(t,r)=\sum_{c=cohort1}^{cohort23plus}\sum_{s=1}^{nlegs}N(t,r,c,s)\cdot w(a(t,c),s)$$

where, for each time step t ranging from 1 (October 1983 to March 1984) to 64 (April to September 2014), the biomass sum is over cohorts (c ranging from $cohort1$ of 2 years olds of half-yearly age a_b, to $cohort23plus$ of 23 year olds, i.e. the plus group) and over slice (the slice index s ranging from 1 to *nlegs* which is the number of length slices of legal size). The weights by age and slice $w(a(t,c),s)$ are derived in Appendix C of Steer et al. (2016).

Annual harvest fraction

A yearly harvest fraction is defined as the sum of the model-predicted half-yearly catches divided by the annual average fishable biomass (defined above), as follows

(B.13)
$$H(y,r)=\frac{\sum_{i_E=1}^{n_E}\sum_{t=t_{season}(1,y)}^{t_{season}(2,y)}\hat{C}(t,r,i_E)}{B(y,r)}$$

where i_E is the index for effort type ranging from 1 (handline) to n_E (recreational).

Annual egg production

The annual egg production indicator is computed as a proportion of pristine, i.e. as a proportion of an unfished stock. The estimated total annual egg production (1) assumes a 50:50 sex ratio, (2) includes both legal size and undersize females, and (3) employs a combined fecundity-maturity-at-length relation of $0.00072012\cdot\left[\bar{l}(s)\right]^3$. The measure of pristine egg production is obtained by running the model without estimation (as a projection) with all effort set to zero. Specifically a single equilibrium projected value of egg production is computed as the average over the last 10 years of a 134 year model period, where annual recruitment is set to be fixed at the average over historical estimates from 1982-2009. The estimated annual egg production for the summer half-year of each year y is given by

(B.14)

$$Eggs(y,r)=$$
$$\sum_{c=cohort1}^{cohort23plus}\sum_{s=0}^{nlegs}\frac{N(t_{season}(1,y),r,c,s)}{2}\cdot\exp\left[-0.5\cdot\left(M+F(t_{season}(1,y),r,c,s)\right)\cdot p_{yr}(t_{season}(1,y))\right]\cdot fm(\bar{l}(s))$$

where $fm(\bar{l}(s))$ is the fecundity-maturity function applied to mid-slice length $\bar{l}(s)$.

6.3. Estimating length-at-age and weight-length for the two newly implemented Gulf St. Vincent regions

Because the spatial resolution of the model was modified, with Gulf St. Vincent partitioned into northern and southern regions (NGSV and SGSV), prior estimates of parameters quantifying two basic body size relationships, length-at-age, and weight-at-length, were re-estimated with data from each region separately.

Growth, as mean and standard deviation of observed body lengths for every age of a cohort was estimated from market sampled catch lengths-at-age. A normal distribution of each cohort's lengths-at-age prior to reaching legal size is assumed. In addition, the knife-edge cut-off in sampled lengths below the legal minimum length (LML) of 38 cm was explicitly accounted for by fitting lengths at age to a likelihood pdf that is truncated at 38 cm, meaning that the probability of observing a sampled fish below that size is set to zero. Sampled snapper less than 38 cm were removed from this analysis. This truncation length-at-age estimation method (adapted from that presented in McGarvey and Fowler 2002 for King George whiting) avoids bias arising from truncation of catch samples from a fishery with a strict minimum legal size.

A normal likelihood, prior to imposing truncation at LML, was fitted to model the distribution of lengths at each age

$$L = \frac{1}{\sqrt{2\pi}\,\sigma(a_i)} \exp\left[-\frac{1}{2}\left\{\frac{l_i - \bar{l}(a_i)}{\sigma(a_i)}\right\}^2\right] \tag{1}$$

where l_i = length of fish sample i , and a_i = age of fish sample i , given in half years obtained from count of its otolith annuli and an assumed birthdate in January of each (year class) summer spawning.

The mean length-at-age

$$\bar{l}(a_i) = L_\infty \left\{1 - \exp\left[-K\left(\frac{a_i - t_0}{2}\right)\right]\right\}^r \tag{2}$$

was modeled by a von Bertalanffy growth formula, generalized by the inclusion of an exponent, *r*. Seasonality in growth was not made explicit due to the small number (2) of yearly time steps.

The likelihood standard deviation (σ) quantifying the spread of normal lengths-at-age for each half-yearly age was modeled as an allometric function of mean length:

$$\sigma(a_i) = s_0 \cdot \left(\bar{l}\,(a_i)\right)^{s_1}. \tag{3}$$

This power function for standard deviation in terms of mean length has the desired property that once growth stops, the standard deviation in lengths-at-age also ceases to change.

The left-truncated normal likelihood, which applies to samples from commercial or recreational fishers,

$$L_i = \begin{cases} \dfrac{1}{\sigma(a_i)} \exp\left[-\dfrac{1}{2}\left\{\dfrac{l_i - \bar{l}\,(a_i)}{\sigma(a_i)}\right\}^2\right] \Big/ \left\{\displaystyle\int_{LML}^{+\infty} \dfrac{1}{\sigma(a_i)} \exp\left[-\dfrac{1}{2}\left\{\dfrac{l - \bar{l}\,(a_i)}{\sigma(a_i)}\right\}^2\right] dl \right\}, & if\ l_i \geq LML \\ 0, \ if\ l_i < LML & \end{cases}$$

(4)

(4)

postulates a probability cut-off to zero for landed samples less than LML and a renormalized probability, integrating to 1, for the range of legal lengths.

Parameters were estimated by minimising the negative sum of log-likelihoods using the ADMB estimation software:

$$O = -\sum_{i=1}^{n} \ln(L_i). \tag{5}$$

The length-at-age curves with associated 95% confidence intervals obtained from Eq. 3 (their fits to data shown in Figures 6.11a and 6.11b) were taken as inputs into SnapEst. Subsequently, two key growth parameters (K and s_0) were further re-estimated in SnapEst, integrated with the overall stock assessment estimation. Because of the slice-partition age and length population breakdown in SnapEst, this re-estimation allows for further correction of growth bias, notably accounting for the asymmetric nature of fishing mortality which removes faster growing fish from the population at younger ages, namely at ages when they reach the legal harvestable size range sooner than slower growing fish (McGarvey and Feenstra 2007).

Parameters for the two Gulf St. Vincent weight-at-length relationships were also re-estimated for this assessment. Mean weight versus total length was modeled by an allometric relationship:

$$\bar{w}(l_i) = \alpha\, l_i^{\beta}\,. \tag{6}$$

A normal likelihood was again used. The standard deviation $\sigma_w(l_i)$ of the likelihood (i.e. of the fitted spread of observed weights about the mean $\bar{w}(l_i)$) was assumed to vary in a power relationship with model predicted weight at each given fitted total fish length applying an analogous error structure to that assumed for length-at-age in Eq. 3:

$$\sigma_w(l_i) \;=\; \sigma_{w0}\left(\bar{w}(l_i)\right)^{\sigma_{w1}}. \tag{7}$$

The resulting weight-length curves (Figures 6.11c and 6.11d) were obtained by minimizing the negative log-likelihood function (Eq. 5).

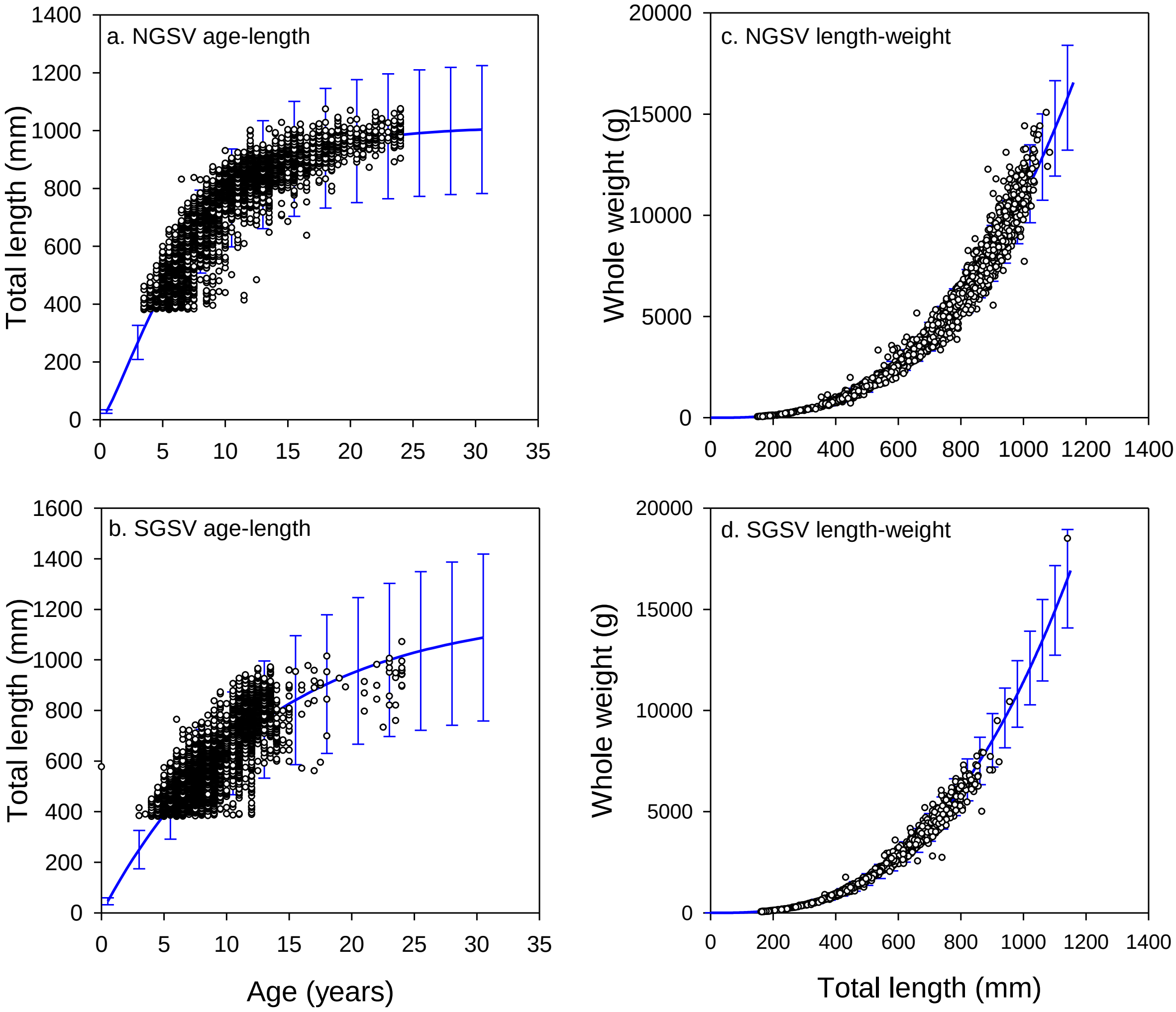

Fig. 6.11 Fitted ogives of growth as length-at-age (graphs a and b, for Northern Gulf St. Vincent and Southern Gulf St. Vincent regions respectively) and weight-at-length (c and d). See text for details. Solid blue lines plot the fitted means (Eq. 2 for a and b, Eq. 6 for c and d). Blue error bars show estimated 95% confidence intervals (1.96 times estimated $\sigma(a_i)$ for a and b, and 1.96 times $\sigma_w(l_i)$ for c and d) surrounding all fitted data points shown.