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Southern Garfish (*Hyporhamphus melanochir*) Fishery

MA Steer, R McGarvey, J Carroll, WB Jackson, MT Lloyd and JE Feenstra

SARDI Publication No. F2007/000720-4
SARDI Research Report Series No. 891

SARDI Aquatics Sciences
PO Box 120 Henley Beach SA 5022

March 2016

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

SOUTH AUSTRALIA

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This publication may be cited as:
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.

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Printed in Adelaide: March 2016

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Date:	24 March 2016
Distribution:	PIRSA Fisheries & Aquaculture. SAASC Library, University of Adelaide Library, Parliamentary Library, State Library and National Library
Circulation:	Public Domain

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ACKNOWLEDGEMENTS

Funds for this research were provided by PIRSA Fisheries and Aquaculture, obtained through commercial licence fees. The commercial catch and effort data were provided by Angelo Tsolos of the Information Systems and Database Support Program of SARDI (Aquatic Sciences). We are grateful for the numerous SARDI staff and volunteers who assisted in the collection of biological samples as part of the on-going market sampling program. We are also extremely appreciative of the staff at the SAFCOL fish markets, who always warmly accommodate SARDI's research needs. Thanks to Damian Matthews for generating figure 1.1. This report was reviewed by Dr Stephen Mayfield, A/Prof Tim Ward, Michelle Besley (PIRSA) and Dr Tony Smith (CSIRO) and formally released by Dr Stephen Mayfield Science Leader, Fisheries, SARDI Aquatic Sciences.

EXECUTIVE SUMMARY

STOCK	Northern Spencer Gulf	Northern Gulf St. Vincent	Southern Spencer Gulf	Southern Gulf St. Vincent	West Coast	South East
Status	↑ Transitional - Recovering	Overfished	Sustainable	Sustainable	Undefined	Undefined
Indicators	Harvest Fraction Biomass Egg Production Recruitment Age Structure *Biomass (20%)*	Harvest Fraction Biomass Egg Production Recruitment Age Structure *Biomass (20%)*	Trends in Catch & Effort	Trends in Catch & Effort	Limited Data	Limited Data

Stock assessments for the South Australian Southern Garfish Fishery have been produced since 1997; this is the sixth report in that 18-year period. The current status of South Australia's Garfish resource was determined through the analysis of several long-term monitoring programs, including: the commercial catch and effort data from 1984 to 2014; recreational fisheries statistics obtained from three State-wide telephone/diary surveys carried out over the last 20 years; and data on the population size and age structures collected since 2005. Data from these three sources were integrated into the 'GarEst' fishery assessment model to produce a time series of estimated biological performance indicators. The current status of the stock was determined through the assessment of the fishery against the general and biological limit reference points outlined in the Management Plan for the Marine Scalefish Fishery (PIRSA 2013).

Assessment of South Australia's Garfish fishery relies heavily on data obtained from the hauling net sector which accounts for approximately 90% of the State-wide commercial catch. Similarly, the assessment places considerable emphasis on catch and effort trends in the northern gulfs where most commercial hauling net fishing is undertaken.

Historically, Northern Spencer Gulf (NSG) has been the most productive region in South Australia and in 2014 contributed 55% of the State-wide catch. The assessment shows that long-term management changes have resulted in a reduction in the exploitation rate below the operational target of 60%; sustained increases in egg production and fishable biomass; and improved recruitment. Management measures (i.e. further increases in mesh size and legal minimum length (LML)) are also in place to promote stock recovery. On this basis the current status of the NSG Garfish stock is classified as **transitional-recovering**.

Northern Gulf St. Vincent (NGSV) accounted for 35% of the State-wide catch in 2014. The assessment shows that the management regime that has been established in NGSV appears to have been insufficient to recover the stock as evidenced by negative breaches in fishable biomass

and recruitment against the trigger reference points (TRPs); persisting low rates of egg production; relatively high exploitation rates coupled with increased effort and declining catch rates. On this basis the NGSV Garfish stock is classified as recruitment **overfished**.

The spatial resolution of the current 'GarEst' fishery assessment model is too broad to assess the key biological performance indicators for Southern Spencer Gulf (SSG) and Southern Gulf St. Vincent (SGSV). However, their relatively low levels of fishing activity and commercial catch, extensive netting closures and a population structure that includes relative old (3+) Garfish, suggests that these stocks are unlikely to be over-exploited. Consequently, these stocks are classified as **sustainable**.

Negligible amounts of Garfish were landed by the commercial sector in the South East (SE) and West Coast (WC), with the State-wide contribution of these regions rarely exceeding 0.3%. Consequently, there is insufficient information available to confidently classify the status of these stocks. On this basis these stock are classified as **undefined**.

The dynamic management approach established to rebuild Garfish stocks and ensure their long-term sustainable harvest appears to be succeeding in NSG but not in NGSV. The amount of fishable area for commercial net fishers is markedly different between the two regions, and may explain the divergence in their relative performance.

The current assessment of South Australia's Garfish Fishery is based entirely on fishery-dependent data collected from spatially limited areas. There remains considerable uncertainty about the relative abundances and population size and age structures in the 'unfished', off-shore and southern waters of the gulfs. This is because there is limited fishery-based information, from the commercial and recreational sectors, that can be used to inform assessment of their relative status. Furthermore, the population connectivity between adjacent unfished and fished areas in the two gulfs is unknown. Consequently, it is not clear whether the commercial fishery data used in this assessment accurately reflects the status of the broader resource. A new jointly funded (FRDC, PIRSA and industry) Garfish project began in 2015/16 to resolve this uncertainty.

1. INTRODUCTION

1.1. Overview

Stock assessments for the South Australian Southern Garfish (*Hyporhamphus melanochir*, hereafter referred to as Garfish) Fishery have been produced triennially since 1997 (McGlennon and Ye 1999); this is the sixth report in that 18-year period. These reports have two aims: (1) to present information from the fishery and biology of the species; and (2) to provide a current assessment of the status of the Garfish stocks. The last stock assessment was completed in October 2012 (Steer et al. 2012) and reported data up to June 2011. Unlike previous reports, which assessed the stocks over financial years, this report analyses catch and effort and biological data over calendar years, extending the assessment up to the end of December 2014.

1.2. Description of the fishery

1.2.1. Access

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

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

1.2.2. Management arrangements

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

Regulations 2007, Fisheries Management (Marine Scalefish Fisheries) Regulations and licence conditions.

The commercial MSF has undergone considerable management changes over the past 40 years that has seen the fishery restructured and limited through gear restrictions and configuration, licensing, spatial and temporal closures, and size limits. Although most of these management changes have been generic in nature there have been a few that have largely impacted the Garfish fishery. The most notable of these have been a series of net fishing spatial closures. Areas closed to netting were first implemented on the West Coast in 1958 and were subsequently followed by a depth-delimited ban in the early 1970s when net fishers were restricted to operate in coastal waters <5 m deep. Further netting closures were implemented in 1983, 1994, 1995, 1997 and 2005. In addition, deep water netting exemptions for a few commercial operators were revoked in 2006. These closures have significantly restricted the commercial Garfish hauling net fishers to relatively small areas within the northern gulfs. Currently, it is estimated that net fishers in Northern Gulf St. Vincent have access to 465 km^2 of fishable area, which is approximately 55% less than the 1,028 km^2 available in Northern Spencer Gulf (Table 1.1; Figure 1.1).

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

In May/June 2005, the State Government implemented a voluntary net buy-back scheme that aimed to reduce fishing effort amongst the commercial haul netters with a particular emphasis on those that harvest Garfish. Of the 113 MSF hauling net licence holders, 61 (54%) accepted the offer and their endorsements or licences were surrendered. The licences bought back accounted for approximately 45% of commercial hauling net fishing effort during 2000 to 2003.

More recently, specific harvest strategies for each of the primary Marine Scalefish species were developed as part of a new Management Plan for the South Australian Commercial Marine Scalefish Fishery which was released in October 2013 (PIRSA 2013). The principal aim of the Garfish harvest strategy was to ensure the long-term sustainable harvest of Garfish. Although no specific management arrangements were prescribed in the Management Plan to achieve these targets, a range of tools were identified and an adaptive management approach outlined to consider the management arrangements needed to meet the targets over time. These included gear modifications, spatial and temporal closures, and effort/catch management (PIRSA 2013).

Through collaborative research and consultation amongst PIRSA, SARDI and the commercial fishing industry it was agreed that a combination of effort and gear-based management strategies should be adopted to reach the operational targets. Furthermore, it was agreed that these strategies should be dynamic and altered in response to the status of the fishery. Initially, two 20-day seasonal closures that alternated between the gulfs were implemented in 2012. The duration of these closures were subsequently increased to 38 days in 2013 and 40 days in 2014. Similarly, the minimum regulated mesh size of the pocket component of the hauling nets was sequentially increased from 30 mm to 32 mm in 2013 and to 35 mm in 2015. Furthermore, the LML of Garfish for commercial fishers was increased from 230 mm to 250 mm in 2015, with a further increase to 260 mm planned to commence from 1 April 2016.

1.2.3. Marine parks

In alignment with international and national commitments, the South Australian Government introduced 19 multiple-use marine parks on 1 October 2014. This network covers a total area of 27,526 km^2, encapsulating approximately 46% of South Australia's waters (DEH 2009). The overarching aim of these parks is to protect and conserve marine biological diversity. The marine park network includes four levels of protection. They are: general and managed use zones, habitat protection zones, sanctuary zones and restricted zones. Of these the sanctuary and restricted zones are the most relevant to fisheries as they are areas of high conservation status and prohibit any forms of fishing within their boundaries. These zones account for approximately 6% of the State's waters (Figure 1.1). Twelve MSF licences were surrendered as part of the implementation process.

Table 1.1. Availability of area (km^2) to commercial hauling net fishers in South Australia in 2015.

Region	< 5m	Netting Closures	Sanctuary Zones	Restricted Access Zones	Available	%
Northern Spencer Gulf	1,501.3	440.7	32.2	0.0	1,028.4	68.5
Northern Gulf St. Vincent	736.6	134.5	50.9	85.8	465.4	63.2
South East	287.5	5.2	11.7	0.0	270.5	94.1
Southern Spencer Gulf	980.5	916.2	2.8	0.0	61.5	6.3
Southern Gulf St. Vincent	313.9	250.3	6.1	0.0	57.4	18.3
West Coast	1,211.8	1,117.6	12.0	26.7	55.5	4.6

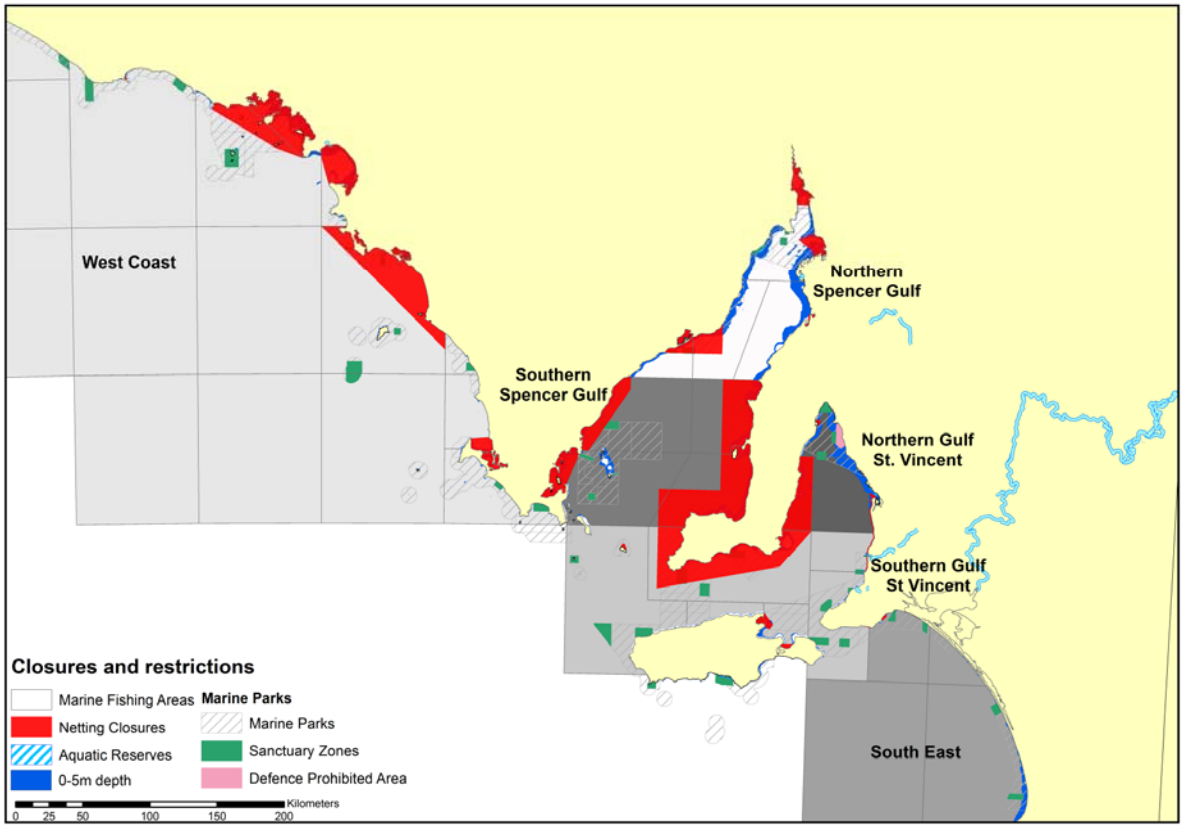

Figure 1.1. Map of the netting closures and restrictions relevant to South Australia's MSF hauling net sector. Note: the dark blue (0-5m depth) areas indicate where commercial haul netters are permitted to operate.

1.3. Biology of Southern Garfish

1.3.1. Distribution

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

1.3.2. Reproductive biology

Spatial and temporal analysis of gonadosomatic indices indicated that Garfish have an extended spawning season that spans approximately six months (from October to March) and within this season only a small proportion (10 – 20%) of the population are in spawning condition at any given time (Giannoni 2013). This indicates that reproductive activity within the population is asynchronous, consequently the extended spawning season is sustained by a series of small pockets of spawning activity.

The estimated size at maturity ($L_{50\%}$) for female Garfish in South Australia is 215 mm TL, which is equivalent to the mean age of 17.5 months (Ye et al. 2002). This is smaller in comparison to Victorian and West Australian Garfish.

1.3.3. Early life history

There have been several attempts to find Garfish eggs in the field (Ling 1958, Noell 2003). In northern Gulf St. Vincent (GSV), samples of a variety of seagrass species, including *Zostera muelleri, Posidonia sinuosa, P. angustifolia, Amphibolis antarctica* and *Heterozostera tasmanica* were collected and examined for adhering Garfish eggs. However, no eggs were found. Garfish eggs have, however, been consistently sampled using a beam trawl in Great Oyster Bay, Tasmania (Jordan et al. 1998).

1.3.4. Age structure

Natural demographic processes such as growth, recruitment and mortality govern the relative strength and age composition of fish populations. For an unexploited species, losses due to mortality are generally balanced by gains through recruitment, and stock abundance would typically fluctuate around a mean level (King 1995). For highly exploited species, the composition of the population may become unbalanced, as the harvesting of adult fish may be at a level where

reproduction and recruitment are unable to replace the numbers lost. Fishers generally harvest the larger and older fish from a population (or stock) and it is a challenge for fishery managers and scientists to ensure that the quantity of the harvest does not reach a level that compromises the sustainability of the stock. Reduced biomass and truncation in the size and age structures of a population are indications that the fishery has been over-exploited. Consequently, understanding the life history of a species and tracking population demography trends in terms of size and age data are fundamental components of fishery assessment.

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

1.3.5. Stock structure

In 2009, a study adopted a combined approach to delineate potential Garfish sub-populations, and determine the extent of mixing within South Australia's coastal waters, through the integration of multiple otolith-based techniques (Steer et al. 2009a). Spatial differences in otolith chemistry (trace elements and stable isotopes) and morphometrics indicated that there were several groups of Garfish that had spent significant parts of their lives in different environments and that there was some level of restriction that prevented complete mixing among the regions (Steer et al. 2009b, 2010; Steer and Fowler 2015). At least five regional divisions were identified. Three of these were clearly defined as they exhibited negligible levels of inter-regional mixing: West Coast; Northern Spencer Gulf; and South-Western Spencer Gulf. The remaining two, however, were less distinct: Northern Gulf St. Vincent and Southern Gulf St. Vincent, but demonstrated a level of population structuring that would regard them as separate as a precautionary management measure. A concurrent study examining the spatial variation in parasite abundance in Garfish inferred a similar population structure (Hutson et al. 2011). This level of population structuring was sufficient to suggest that the historical management framework of two discrete, gulf-specific, stocks should be restructured to align with these five smaller, semi-discrete, regional units.

1.4. Research program

SARDI maintains an on going catch sampling program for three of the four primary marine scalefish species (i.e. Snapper, King George Whiting and Garfish). This program largely relies on routinely collecting biological samples from the South Australian Fishermen's Co-operative Limited (SAFCOL) fish market, however, samples are also collected opportunistically either from the recreational sector or fishery-independent research programs. There have been numerous projects that have focused on addressing key knowledge gaps in our understanding of Garfish biology and ecology over the years. They have covered aspects of Garfish population dynamics (Jones 1990; Ye et al. 2002; Fowler et al. 2008; Noell 2005; Earl 2007; Fowler and Ling 2010; Earl et al. 2011; Giannoni 2013); stock structure (Steer et al. 2009a; Hutson et al. 2011); gear selectivity (Steer et al. 2011) and fisheries modeling (McGarvey and Feenstra 2004; McGarvey et al. 2007). Current research, funded through the Fisheries Research and Development Corporation (FRDC), Primary Industries and Regions, South Australia (PIRSA) and industry, is investigating whether the commercial fishery data used in the stock assessment process accurately reflects stock status in South Australia's Garfish fisheries (FRDC Project 2015/018).

1.5. Information sources used for assessment

1.5.1. Commercial catch and effort data

The South Australian Marine Scalefish Fishery (MSF) is divided into 58 Marine Fishing Areas (MFAs) for the purpose of statistical reporting and monitoring of commercial fishing activity (Figure 1.1). All licenced fishers are required to log their fishing activities, recording specific details such as MFA fished, number of fishers on board, species targeted, species caught, weight of catch, and method of capture. This level of detail was initially recorded on a monthly basis, but since 2003 fishers have been required to provide a daily log of fishing activity. These records must be submitted monthly to SARDI Aquatic Sciences where they are entered into a database which is routinely reviewed and cross-checked to ensure that the data satisfy management and research needs. The current database is a compilation of catch and effort data collected from 1983/84 to the present and provides the primary source of data used for stock assessment of the primary MSF species. The data used in this assessment were finalised up to 31 December, thus providing a 30 calendar-year dataset.

1.5.2. Recreational catch and effort data

Quantifying the recreational sector's contribution to the State's total catch is important in determining the overall status of fish stocks and resolving resource allocation issues. There have

been four extensive recreational fishing surveys carried out in South Australia over the past 20 years. The first was a creel survey that was undertaken throughout 1994 to 1996 (McGlennon and Kinloch 1997) and State-wide telephone/diary surveys in 2000/01 (Henry and Lyle 2003), 2007/08 (Jones 2009) and 2013/14 (Giri and Hall 2015). Of these four surveys, only the results from the three most recent can be reliably compared as these data were collected using the same methodology.

1.5.3. Size and age data

SARDI has relied heavily on the SAFCOL market to access the commercial catch and gain valuable biological information that is used to determine the population structure for South Australia's primary marine scalefish species. There have been several market sampling programs for Garfish throughout the history of the fishery that have provided demographic data. Size and age data have been previously collected for Garfish in 1954/55 for both GSV and Spencer Gulf (SG) (Ling 1958); 1977/78 for SG (Jones 1979); 1986/87 for GSV (Jones et al. 1990); and 1998/99 for both gulfs (Ye et al. 2002). In 2005/06, SARDI initiated a new market-measuring program as part of the core research activities of the MSF (McGarvey et al. 2006). With the exception of a six month hiatus from July to December 2008 and again in 2012, SARDI's market sampling program for Garfish has occurred almost weekly since July 2005 and has primarily targeted samples from the northern gulfs (i.e. NGSV and NSG).

1.5.4. 'GarEst' stock assessment model

A computer-based fishery stock assessment model, 'GarEst', was developed for the South Australian Garfish fishery as part of an FRDC-funded project (McGarvey and Feenstra 2004). This model covers the fisheries in the two South Australian gulfs, which have accounted for 96% of the State-wide Garfish catch over the past five years. The GarEst model accounts for fish numbers broken down into length bins within each age group, through time. Representing fish population numbers by both age and length through time considerably improves the accuracy of the model, as it accounts for the ongoing gradual recruitment of Garfish into the fishery and so more accurately estimates their growth and mortality rates (McGarvey et al. 2007). This dynamic, age- and length-structured model is used to assess the performance of the fishery in terms of its total fishable (legal) biomass, egg production, estimated recruitment and harvest fraction (i.e. exploitation rate). These four outputs are assessed against the biological performance indicators and trigger reference points that are identified in the Management Plan (PIRSA 2013; Table 1.2) to ensure the long-term sustainable harvest of Garfish.

1.6. Harvest strategy

1.6.1. Management plan

A new Management Plan for the South Australian Commercial Marine Scalefish Fishery was released in October 2013 with a scheduled revision in 2022 (PIRSA 2013). A draft harvest strategy was developed in 2011 by the Garfish Working Group (GWG), which consists of representatives from industry, PIRSA and SARDI and implemented prior to the approval of the Management Plan in 2013. The Plan includes specific harvest strategies for the four primary species (Snapper, King George Whiting, Southern Garfish and Calamary). The aim of these harvest strategies is to set a process for monitoring the performance of the species and to measure the effectiveness of the management arrangements which govern the commercial harvest. Species-specific performance indicators, operational objectives and reference points have been developed to assess the respective fisheries and ensure their long-term sustainable harvest.

Two key objectives for managing the harvest of Garfish within the commercial MSF will be considered in this assessment, they are: (1) ensure the long-term sustainable harvest of Garfish by rebuilding stocks during specified time frames; and (2) maintain catches within agreed allocations for each sector.

1.6.2. Performance indicators

Three tiers of indicators have been established to monitor the performance of the fishery over time and address the first management objective. Each performance indicator explicitly identifies a set of operational targets and trigger reference points that, if breached, elicits a management response. The nature of this response will be determined by fisheries management. Trends in model estimates of 'harvest fraction' and 'egg production' constitute the primary performance indicators within the Garfish fishery, with their operational objectives set to reach ≤30% and ≥30% by 2020, respectively (Table 1.2). The secondary performance indicators relate to rebuilding Garfish stocks through improving the overall age structure of the population and reducing effort within the fishery. The specific operational objectives are to display an increasing trend in the relative proportion of older (ages 3+) Garfish within the population through each triennial stock assessment cycle and to reduce total hauling net effort by ≥13% by 2014 (Table 1.2). There are also a range of other performance indicators and trigger reference points relating to trends in commercial catch and effort statistics and biological metrics (Table 1.2). Although there is no formal management response linked to these indicators, they provide triggers for the development

of further management actions to meet the objectives of the harvest strategy. In addition, the indicators provide measures for assessing the stock rebuilding strategy that can be relied on to measure the relative performance of the fishery through a 'weight-of-evidence' approach (PIRSA 2013).

Table 1.2. Performance indicators used to monitor the performance of South Australia's Garfish fishery as prescribed in the MSF Management Plan (PIRSA 2013). Biological (B) and General (G) indicators are identified.

	PERFORMANCE INDICATOR	TYPE	OPERATIONAL OBJECTIVE	TRIGGER REFERENCE POINT
PRIMARY	HARVEST FRACTION	B	≤ 60% 2014	> 60% 2014
		B	≤ 45% 2017	> 45% 2017
		B	≤ 30% 2020	> 30% 2020
	EGG PRODUCTION	B	25% 2017	< 20% 2017
		B	30% 2020	< 30% 2020
SECOND.	AGE COMPOSITION	B	↑ Prop. Age 3+	No change
	TOTAL HAULING NET EFFORT	G	↓ ≥ 13% 2014	↓ < 10% 2014
OTHER	TOTAL CATCH	G	No Target	3rd Lowest / 3rd Highest
		G	No Target	Greatest % interannual change (+/-)
		G	No Target	Greatest 5 year trend
		G	No Target	Decrease over 5 consecutive years
	TARGET HAULING NET CPUE	G	No Target	3rd Lowest / 3rd Highest
		G	No Target	Greatest % interannual change (+/-)
		G	No Target	Greatest 5 year trend
		G	No Target	Decrease over 5 consecutive years
	TARGET DAB NET CPUE	G	No Target	3rd Lowest / 3rd Highest
		G	No Target	Greatest % interannual change (+/-)
		G	No Target	Greatest 5 year trend
		G	No Target	Decrease over 5 consecutive years
	FISHABLE BIOMASS	B	No Target	3 year average is +/- 10% of previous years
	RECRUITMENT	B	No Target	+/- 10% than the average of previous 5 years

1.6.3. Allocation of access

The *Fisheries Management Act 2007* states that the Management Plan must specify the allocation of the resource among the various sectors within the MSF. Allocated shares were derived from the catch data collected in 2007/08, as this year also contained the most recent recreational survey catch information (Jones 2009). Three trigger limits have been determined for the primary species. The first trigger limit (Trigger 1) relates to the allocated shares of the entire fishery and is assessed at least once every five years to encompass up-dated recreational catch and effort statistics (Table 1.3). The remaining two trigger limits (Trigger 1 and 2) consider the commercial shares only and can be assessed on an annual basis. The trigger limits have been set at levels that are commensurate with the initial allocation and allows for variability in catches. Trigger 2 relates to exceeding the commercial sector allocation by the relevant percentage in three consecutive years or in four of the previous five years. Trigger 3 relates to exceeding the commercial sector allocation by the relevant percentage in any one year. The recreational fishery triggers will be described in the Management Plan for the Recreational Fishery, which is currently being drafted.

Table 1.3. Commercial allocation of Garfish among the sectors as prescribed in the MSF Management Plan (PIRSA 2013).

FISHERY ALLOCATION	MSF	SZRL	NZRLF	REC.	CHARTER	ABT
	79.30%	0.13%	0.04%	19.50%	-	1.00%
TRIGGER 1	*84.00%*	*1.00%*	*1.00%*	-	-	-
COMMERCIAL ALLOCATION	**MSF**	**SZRL**	**NZRLF**	**REC.**	**CHARTER**	**ABT**
	99.79%	**0.16%**	**0.05%**	**n/a**	**n/a**	**n/a**
TRIGGER 2	*na*	*0.75%*	*0.75%*	-	-	-
TRIGGER 3	*na*	*1.00%*	*1.00%*	-	-	-

1.7. Stock status classification

A national stock status classification system was recently developed for the consistent assessment of key Australian fish stocks (Flood et al. 2014). It considers whether the current level of fishing pressure is adequately controlled to ensure that the stock abundance is not reduced to a point where the production of juveniles is significantly compromised. The system combines information on both the current stock size and level of exploitation into a single classification for each stock against defined biological reference points. Each stock is then

classified as either: 'sustainable', 'transitional-recovering', 'transitional-depleting', 'overfished', 'environmentally limited', or 'undefined' (Table 1.4). PIRSA has adopted this classification system to determine the status of all South Australian fish stocks (PIRSA 2015). This classification system was not referred to in previous stock assessments for Garfish.

Table 1.4 Stock status terminology (Flood et al. 2014).

	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 catch and effort statistics

For this stock assessment the catch and effort data were aggregated across commercial fishers to provide annual totals (calendar year) and catch per unit of fishing effort (CPUE) at the State and stock level. State waters were partitioned into six regions; West Coast, Northern and Southern SG, Northern and Southern GSV and the South East (Figure 1.1). These data were also interrogated across the two main gear types; hauling nets and dab nets.

Fishing effort was reported in fisherdays, which relates to the number of days a licenced vessel fished multiplied by the number of personnel working on board. There are two components to fishing effort, targeted and untargeted. Targeted effort in this fishery is a more accurate indicator of fisher behaviour than total fishing effort. It is also the metric that is used, along with targeted catch, to calculate CPUE, which provides an index of the relative abundance of Garfish. Determining target effort in the hauling net sector, however, is problematic as fishers can catch multiple commercial species in a single fishing event and are sometimes non-specific in their target species. Although one species may dominate their catch, these fishers typically nominate "any species" (or record "000") as their fishing target in their catch returns. The effort category of the non-specific hauling net fishers was then determined on the basis of what they caught. This was calculated in relation to the contribution of Garfish by weight to the total catch in comparison to fishers who either targeted Garfish or other species. If Garfish constituted more than half (≥50%) of the non-specific fishers' total daily catch, then these records were re-defined as targeting Garfish ("Hauling Net Target Plus"). Although not as prevalent, there were situations where Dab net fishers were non-specific with their catch. For consistency, they were also re-defined as "Dab Net Target Plus" according to the ≥50% catch composition rule. These refined effort categories were included in all subsequent regional analysis of the commercial catch and effort statistics in this chapter, and could only be calculated from 2004 onwards as this was when fishers began reporting their daily fishing activities.

2.2. Recreational catch and effort statistics

The specific details of the methodology used in the three recreational surveys considered in this chapter can be found in their respective reports (2000/01: Henry and Lyle 2003, 2007/08: Jones 2009, 2013/14: Giri and Hall 2015). Unfortunately, not all of the regional reporting boundaries that were used in the surveys aligned with South Australia's MFAs. For consistency the recreational survey data were re-partitioned to correspond as closely as possible to the two gulfs

(SG and GSV), the West Coast and South East regions. The 2000/01 survey data have also been re-analysed using more precise expansion weights (used to scale-up the regional estimates in proportion to the local population) and, as a consequence, the results differ slightly from previous reports.

Although data were collected over 12 months in each survey, their timing did not correspond with either a calendar or financial year. The 2000/01 survey collected data from May 2000 to April 2001 and the 2007/08 and 2013/14 surveys from November to October. In order to accurately determine the relative contribution of the recreational sector to the State-wide Garfish catch, data from the commercial sector were extracted from the same time periods.

2.3. Biological sampling

Each week a small team of SARDI researchers accessed the commercial catch of Garfish at the SAFCOL market prior to the morning auction. Efforts were made to access the available catches from the northern regions of both gulfs to ensure that the information collected was representative of the fishery. Occasionally, samples from the southern gulfs were also obtained; however, these sample sizes were typically much lower than for the other two regions.

The sampling methodology followed the protocol developed by Ye et al. (2002). All Garfish purchased from the SAFCOL market were measured for both TL and standard length (SL) to the nearest mm, and weighed individually to the nearest 0.01 g. Each Garfish was dissected to determine its sex and stage of reproductive development using the criteria of Ling (1958). The largest pair of otoliths (i.e. sagittae) were removed and subsequently used for age determination, as per the methods described in Ye et al (2002).

2.4. Integrated stock assessment model

The principal input data for the GarEst model are (1) commercial catch and effort statistics; (2) population demographic information (i.e. sex, age and length composition) derived from the Garfish market sampling program; and (3) estimated recreational catch from the National Recreational and Indigenous Fishing Survey (NRFIS) (Henry and Lyle 2003) and South Australian Recreational Fishing Surveys (Jones 2009, Giri and Hall 2015). The model partitions the time-series of data into 'biological' years to align with the recruitment schedule of Garfish, extending from 1 October 1984 to 30 September 2014. The time-series is further resolved into half-yearly (6 monthly) time steps to account for the seasonal variation in the fishery.

Given the multi-gear and multi-sectorial nature of the fishery, the model partitions the catch and effort into four categories; (1) hauling net fishers who target Garfish; (2) hauling net fishers who

catch (non-target) Garfish; (3) dab net fishers; and (4) recreational fishers. Catch rates (CPUE) for the 'hauling net fishers who target Garfish' category incorporates the refined effort type "Target Plus" from October 2005 onwards, to reflect the changes in the reporting structure, when commercial fishers refined the resolution of their catch returns from monthly to daily (see section 2.1).

Three surveys of South Australia's recreational fishery (2000/01 - Henry and Lyle 2003; 2007/08 - Jones 2009; 2013/14 – Giri and Hall 2015) were used to model the contribution of this sector to the Garfish catches. Estimates of recreational catch in the intervening years between the three surveys were assumed to vary linearly between the estimates of 2000/01 and 20013/14. For all preceding years, estimates of recreational catch and effort were assumed to be constant at the 2000/01 level.

The model estimates four biological performance indicators; fishable biomass, egg production, recruitment and harvest fraction (i.e. exploitation rate). Fishable biomasses and harvest fractions are given as yearly averages. Annual fishable biomass is computed as the mean of the half-yearly estimates in each 'biological' year. The harvest fraction is the proportion of the fishable biomass harvested by the fishery. The annual harvest fraction is calculated as the sum of the model catch in weight of the fishery in each 'biological' year divided by the annual fishable biomass. Annual recruitment is defined as the number of Garfish spawned in each summer year class that survive to age 1. In the recruitment time-series figures, the year shown on the x-axis represents the year the cohort was spawned.

Percent virgin egg production was computed as a ratio of yearly egg production divided by a measure of average 'virgin' egg production that the fishery would produce in the absence of exploitation. Virgin egg production was computed from a run of GarEst with *F* (and so all fishing effort) set equal to 0 as the average egg production over the years from 2000 to 2011. For this run of the virgin population, recruitment was fixed at the average from the years 1988 to 2000, prior to the longer-term recruitment decline that occurred around 2001.

Further details of the GarEst Garfish stock assessment model are provided in McGarvey and Feenstra (2004), McGarvey et al. (2007) and Appendix A, B and C. The biological performance indicators generated by the GarEst model are estimated by fitting to commercial catch totals by weight, recreational catch data by numbers in the three survey years, and to commercial catch proportions by sex, length and age. The respective fits of the model to these data sources are presented in Appendix E.

2.5. Assessment of fishery performance

Two types of performance indicators, general and biological, are used to assess the fishery as specified by the Management Plan (PIRSA 2013).

2.5.1. General Performance Indicators

For Garfish, there are four general fishery performance indicators that were calculated from the commercial fishery statistics; total hauling net effort, total commercial catch, targeted hauling net CPUE, and targeted dab net CPUE. With the exception of total hauling net effort, the general performance indicators were assessed against the following trigger reference points:

1. the 3rd highest and 3rd lowest values of the reference period (1984 to 2014);
2. the greatest (%) inter-annual variation (+ and -) over the reference period;
3. the greatest rate of change (+ and -) over a five year period; and
4. decrease over five consecutive years.

Given South Australia's Garfish fishery is spatially segregated by gear, i.e. hauling nets predominantly operate in the northern gulfs and dab nets in the southern gulfs, it was necessary to assess the general performance indicators in each of the four key regions (NSG, SSG, NGSV and SGSV). Estimates of targeted CPUE were calculated for hauling nets in NSG and NGSV and for dab nets in SSG and SGSV. In each case, the trigger reference points were derived from the time-series of catch and effort data from the 1984 to 2014 (calendar years) reference period. Note that the new 'Target Plus' haul net effort type which was available from 2003 onwards, could not be used in the assessment of the general performance indicators, as the time series of catch and effort data does not cover the entire reference period.

A specific operational objective in the Management Plan was to reduce total hauling net effort by ≥13% since 2011 (i.e. the development of the Draft Management Plan) to promote the recovery of the resource. This indicator was assessed against a trigger reference point of <10% reduction by 2014.

2.5.2. Biological Performance Indicators

The spatial and temporal series of data considered by the 'GarEst' model to derive the biological performance indicators differs slightly from the data series used to generate the general performance indicators. It partitions the time-series into 'biological' years, extending from 1 October to 30 September, to align with the recruitment schedule of Garfish. Furthermore, given the lack of data to inform the model about the population size and age composition of Garfish

from the southern gulf regions, the model decreases its spatial resolution to the Gulf level, i.e. SG and GSV.

In this assessment, the five biological performance indicators that were assessed were harvest fraction, egg production, fishable biomass, recruitment, and population age structure. Harvest fraction was compared against the trigger reference point of <60% by 2014%. The indicator for yearly egg production is expressed as a percentage of virgin egg production. The trigger reference point for this indicator, however, does not come into effect until 2017 when the operational target is set at 25%. The trigger reference point for the fishable biomass performance indicator is triggered if the average value over the last three years was a ± 10% change from the average of the previous years (1984 – 2013). The trigger reference point for recruitment (model estimates of 1-year olds for each cohort), is triggered if the indicator is ± 10% change from the average of the previous five years (2009 – 2013). The final biological indicator is an evaluation of whether there had been no change or a reduction in the modeled population age structure over the past stock assessment cycle (since 2011).

2.6. Quality assurance of data

Validation of the MSF commercial catch and effort data is extensive and includes manual cross-checking during the collation and processing phases and code-driven queries which are activated during the data entry phases and reporting operations (see Knight and Vainickis 2009). Furthermore, regular random checks of current and historic data are carried out as standard procedure. Extracted commercial catch and effort data were aggregated and graphed into their necessary spatial/temporal/gear/effort categories and cross-checked with previous assessments (McGarvey et al. 2009, Steer et al. 2012). The contributing authors held regular meetings to discuss data handling procedures and interpretation. Tabulated results were further cross-checked against the computer 'GarEst' output. The draft stock assessment report was reviewed by two SARDI scientists and a PIRSA manager prior to release.

The processing of Garfish otolith and subsequent age estimation typically occurred in large batches and there were often significant time periods between processing events. To ensure that the readers were interpreting the otolith structure consistently through time, each reader was reacquainted with garfish methodology and otolith characteristics before an ageing session by testing their interpretations against a random selection of Garfish otoliths from the reference collection.

3. RESULTS

3.1. State-wide

3.1.1. Distribution of catch among sectors

Commercial Marine Scalefish sector has historically dominated (>75%) the fishery (Figure 3.1). Although Rock Lobster licence holders are permitted to harvest Garfish in State waters their relative contribution is negligible, with Southern Zone and Northern Zone Rock Lobster fishers accounting for less than 1.3% and 0.5% of the total catch, respectively (Figure 3.1). Estimates of the recreational harvest have ranged from 18% in 2000/01 to 23% in 2013/14.

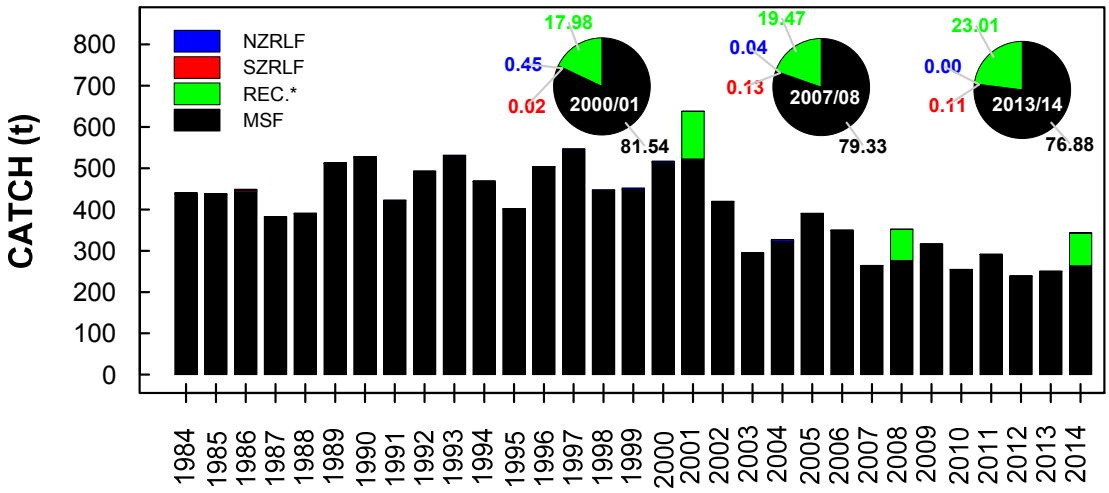

Figure 3.1. The relative contribution to the total statewide catch of Garfish across the shared sectors. * Recreational data are aggregated across financial years.

3.1.2. Commercial sector

Two management strategies have reduced the number of licence holders in South Australia's MSF. The first was the licence amalgamation scheme implemented in 1994, which has contributed significantly to the long term decline in the number of commercial fishers who land Garfish. The second was the voluntary hauling net buy-back initiative, implemented in 2005. These two strategies have contributed to the 57% reduction in the number of commercial fishers landing Garfish from 1995 to 2011 (Figure 3.2). There has, however, been an increase in the number of fishers landing and targeting Garfish over the last three years (98 and 78 licences, respectively). The relative proportion of commercial fishers that nominated Garfish as their specific target has remained relatively consistent at 75% of fishers landing Garfish throughout the last 20 years (Figure 3.2).

The total commercial catch of Garfish was 264.4 t in 2014, combined across all gear types, including both targeted and untargeted catch (Figure 3.2). This was the second consecutive year where catches increased from the historic low of 239.1 t in 2012, representing annual increases of 4.8% and 5.5%, in 2013 and 2014, respectively. The hauling net sector has traditionally dominated total catch, having consistently accounted for approximately 90% of the State-wide harvest since 1984 (Figure 3.2). Catches in this sector oscillated between 325 t to 500 t from 1984 to 2002, averaging 413 $t.yr^{-1}$ and has dropped to 263 $t.yr^{-1}$ since 2013. The dab net sector accounts for most of the remaining catch (~10%). This sector yielded higher than average catches throughout the 1990s (~62 $t.yr^{-1}$) compared to the last decade where catches have rarely exceeded 30 $t.yr^{-1}$ (Figure 3.2).

Total fishing effort for Garfish has steadily declined from a peak of 18,433 fisherdays in 1984 to a low of 4,855 fisherdays in 2012 (Figure 3.2). This represents a 73.7% decrease over 28 years declining at a rate of 487 fisherdays per year. This decline can largely be attributed to a sequential reduction in hauling net effort. Over the past two years fishing effort has slightly increased, rising 7% to 5,197 fisherdays in 2013 and a further 6.1% to 5,512 in 2014 (Figure 3.2). This trend was consistent for both gear types.

Catch rates have remained relatively high in the hauling net sector over the past decade averaging 50.2 $kg.fisherday^{-1}$, which was 11.9 $kg.fisherday^{-1}$ more than the average catch rates of the preceding decade (Figure 3.2). Catch rates in this sector peaked at 56.4 $kg.fisherday^{-1}$ in 2009 and have remained relatively stable over the past three years, declining by <4% from 51.3 $kg.fisherday^{-1}$ in 2012 to 49.2 $kg.fisherday^{-1}$ in 2014. Dab net catch rates displayed a long-term increasing trend from 1984 to 2002, rising from 18.9 $kg.fisherday^{-1}$ in 1984 to a peak of 58.6 $kg.fisherday^{-1}$ in 2001 (Figure 3.2). This increase, however, was not sustained dropping to 31.9 $kg.fisherday^{-1}$ in 2007. Contemporary catch rates in the dab net sector have remained below 41 $kg.fisherday^{-1}$.

Most of the State-wide catch of Garfish has historically been landed in the NGSV and NSG (Figure 3.1). Marine Fishing Areas 21 in SG and 35 in GSV have each consistently supported annual catches that have exceeded 60 t since 1984. During the 1980s and 1990s, the collective catch from these two MFAs accounted for approximately 45% of the State-wide commercial total. Since 2001, this relative contribution has increased to approximately 56% and has remained relatively steady, which emphasises the importance of these two areas to the commercial fishery. There has been a clear spatial contraction of the fishery over the past decade, catches from many regional centres in the WC (i.e. Venus Bay (MPA 17); Coffin Bay (MPA 27)) and SSG (i.e.

Wallaroo (MPA 32); and Port Victoria (MPA 33)) have substantially decreased. This was primarily a result of the implementation of spatial netting closures. The contemporary fishery is now largely confined to the NSG and NGSV (Figure 3.3).

The seasonality of Garfish catch is different for each of the gear types and has undergone considerable change over the past 30 years. From 1984 to 1999, most of the Garfish caught by the hauling net sector was landed during autumn (Figure 3.3). This was followed by two years during which high catches uncharacteristically peaked in mid–winter (July/August). Since then, overall monthly catches have declined considerably from the regular 40 t harvests during autumn, to 10 to 30 t monthly catches spread from January to August (Figure 3.3). Catches in the dab net sector, however, historically peaked during late spring and summer. This trend was most evident from 1992 to 2002, when peak catches in excess of 10 t were most frequent during November. Although dab net fishers are capable of targeting Garfish throughout the year, the temporal trends in their monthly catches have gradually diminished to < 4 t and appear to be constrained to the warmer half of the year (Figure 3.3).

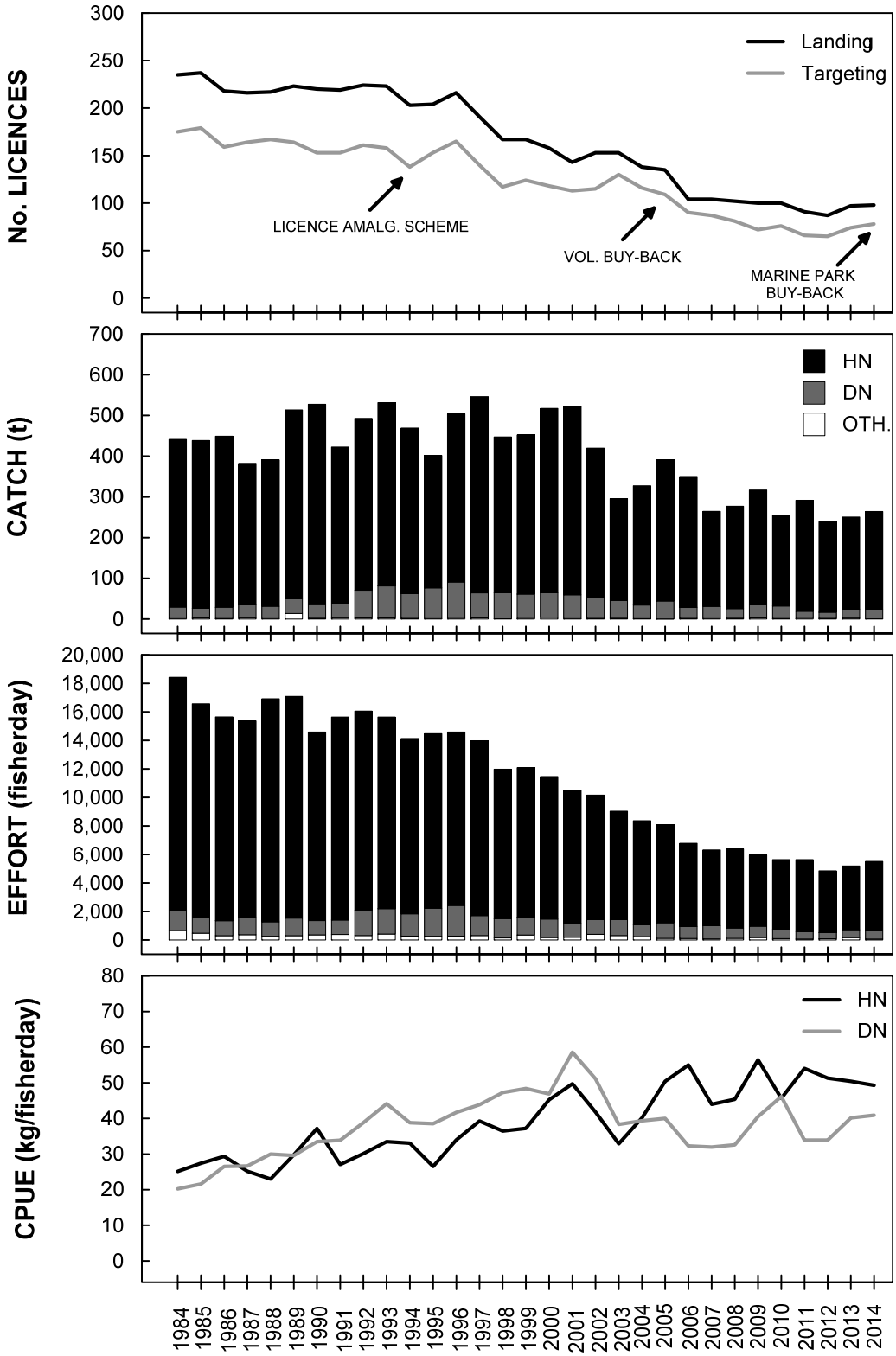

Figure 3.2. State-wide trends in the number of MSF licences landing or targeting Garfish; commercial Garfish catch, effort and CPUE by gear from 1984 until 2014.

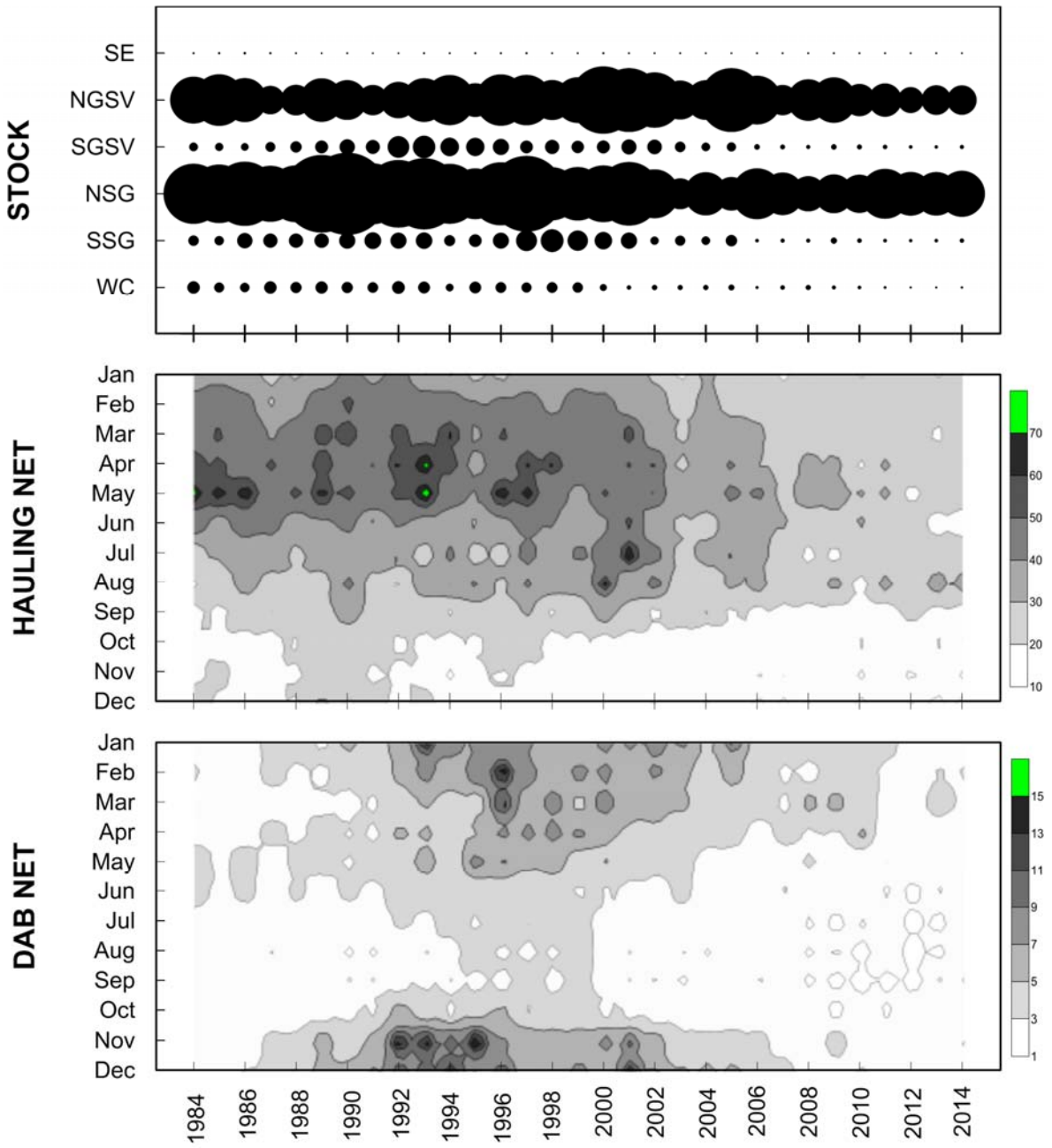

Figure 3.3. Relative proportion of the statewide commercial catch of Garfish by Region (top). The size of the bubble indicates its relative proportion of the total annual catch. Long-term trends in seasonal commercial catch (t) of Garfish by hauling net (middle) and dab net (bottom) from 1984 until 2014.

3.1.3. Recreational sector

The estimated State-wide recreational harvest of Garfish by South Australian residents in 2015 was 870,147 individuals with a combined weight of 79.18 t (Figure 3.4). This was 5.5% greater than the 2007/08 survey and 31.3% less than the estimate for 2000/01. Approximately half (49%) of the recreational harvest was taken from Spencer Gulf. Similar quantities (approximately 35 t) of Garfish were harvested from Spencer Gulf in the two previous surveys; however, Gulf St. Vincent provided most of the catch (57.6 t) in 2000/01.

The relative contribution of the recreational harvest of Garfish to the total State-wide catch has increased from 18% in 2000/01 to 23% in 2013/14 (Figure 3.4). The proportions of the Garfish catch harvested from Spencer Gulf increased from 5.2% to 11.3% over the three survey periods. The trend was reversed in Gulf St. Vincent. The relative contributions of the recreational catch of Garfish from the West Coast and South East have consistently accounted for <5% of the State-wide catch.

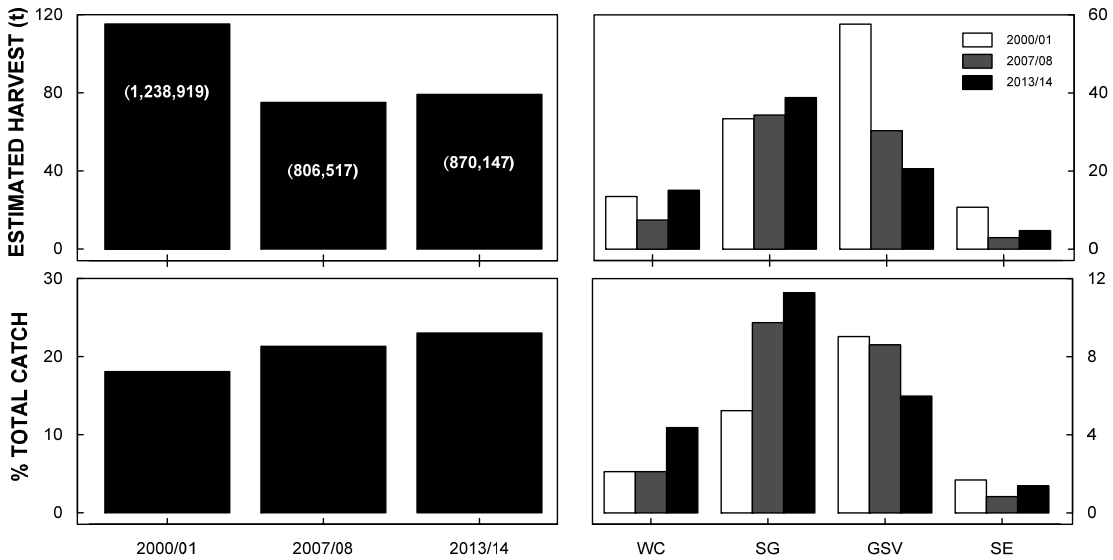

Figure 3.4. Estimated statewide and regional harvest of Garfish by the recreational sector as estimated through three telephone/diary surveys (Henry and Lyle 2003, Jones 2009, Giri and Hall 2015) and their relative contribution to the total state-wide catch.

3.2. Stocks

3.2.1. Northern Spencer Gulf

Northern Spencer Gulf has been the most productive fishing ground for Garfish in South Australia since 1984. The highest recorded catch was 256.8 t in 1990 and the lowest 98.3 t in 2003 (Figure 3.5). There was a relatively rapid decline in catch from 1997 to 2003, where it dropped 61% from 250 t to 98 t. Annual catches exceeded 160 t twice since 2003 (2006 and 2011) and remained relatively stable at approximately 145 t from 2012 until 2014. There has been a long-term trend of decreasing fishing effort in this region, declining from a peak of 7,500 fisherdays in 1988 to 2,129 fisherdays in 2012, at a rate of approximately 215 fisherdays.yr^{-1}. This trend has been driven by the hauling net sector, which has consistently contributed to >95% of the fishing activity. Catch rates for target hauling net fishers have trended upwards since 2003 rising from 44.5 kg.fisherday^{-1} to 109 kg.fisherday^{-1} in 2012, representing a 144% increase over nine years. Catch rates have reduced to 94.8 kg.fisherdays^{-1} in 2014.

There has been virtually no change in the modelled age structure over the past three stock assessment cycles, with estimates indicating that two year-old Garfish have consistently accounted for approximately 60% of the population. Similarly the relative composition of three and four year-old Garfish has remained stable at approximately 23% and 6%, respectively (Figure 3.5). Similar proportions of three-year old Garfish were evident in 'unfished' population, however there was considerably greater representation of older Garfish, indicating the capacity of the current population's age structure to expand.

The harvest fraction has historically been high exceeding 100%[1] but declined to 51.3% in 2013 and 53.5% in 2014, well below the 60% operational objective set in the MSF Management Plan (PIRSA 2013) (Figure 3.5). Egg production remained consistent from 1984 to 2006 at approximately 8% of 'unfished' levels; however it increased to peak at 12.9% in 2014, increasing at a rate of approximately 0.3% per year.

The fishable biomass declined 29.9% between 2001 and 2003, from 321.9 t to 225.7 t (Figure 3.5). Since then, the fishable biomass has increased at a rate of approximately 7.3 t per year, culminating to 320.8 t in 2014. The marked decrease in fishable biomass in 2001 was linked to poor recruitment in 2000, which dropped 39% from 7.6 to 3.5 million recruits (Figure 3.5).

[1] This value exceeds 100% because it accounts for the full year, rather than the half-yearly time step used in the model (i.e. sum of half-yearly catches/average of half-yearly biomasses). For some half-years well over half of the recruits were harvested during peak exploitation (winter).

Recruitment has since remained relatively stable at approximated 4 million recruits per year, increasing to a 10 year peak of 4.3 million recruits in 2013.

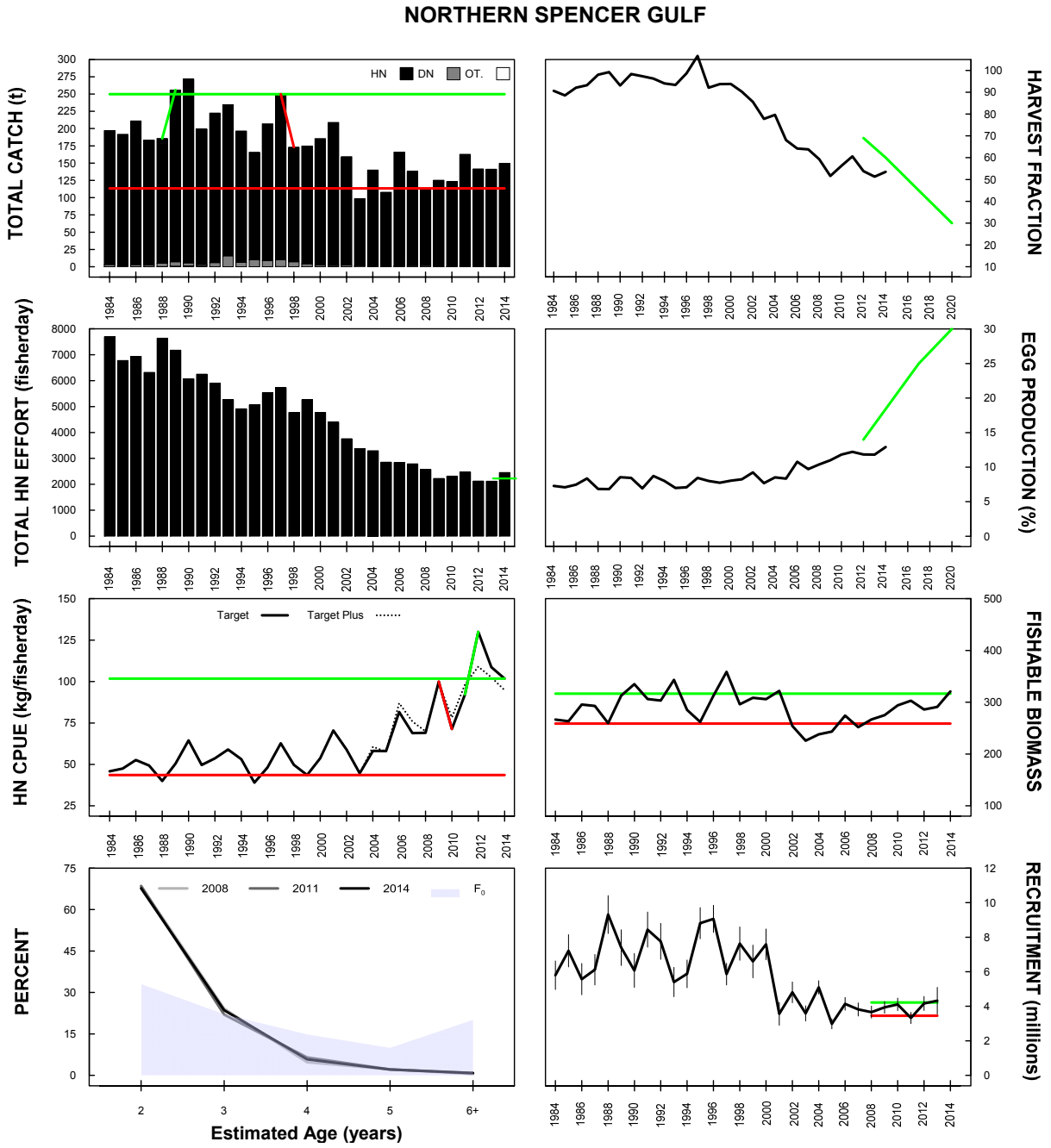

Figure 3.5. Key outputs used to assess the status of the NSG Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and modelled age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. HN = Hauling Net, DN = Dab Net, OT = Other, F_0 = Unfished age structure.

3.2.2. Northern Gulf St. Vincent

Northern Gulf St. Vincent is the second most productive region in the State, accounting for ~35% of the State's annual catch. Annual catches have exceeded 200 t twice in the past 31 years; 221.4 t in 2000 and 209.6 in 2005 (Figure 3.6). Annual catch fell to 96.7 t in 2007, a 53.9% decline over three years. This decline corresponded with a 22% decline in hauling net effort and a 35% reduction in CPUE. Annual catch and effort were at their lowest in 2012 (81.9 t and 2,156 fisherdays, respectively) when winter closures were first implemented and increased by approximately 15% to 93.8 t and 2,515 fisherdays in 2014. Targeted CPUE within the hauling net sector exceeded 110 kg.fisherday^{-1} for two consecutive years in 2000 and 2001, followed by minor peaks of 75.9 kg.fisherday^{-1} in 2005 and 71.7 kg.fisherday^{-1} in 2009 and stabilising at approximately 60 kg.fisherday^{-1} from 2010 to 2013. In 2014, catch rates within this sector declined by 11% to 49.8 kg.fisherday^{-1}.

There have been minor changes in the modelled age structure over the past three stock assessment cycles, with the relative proportions of the three and four year-old Garfish increasing by approximately 13% and 5%, respectively (Figure 3.6). The relative proportion of two-year-olds, however, has declined by approximately 20% over the same time period. Approximately 8% of the 2014 Garfish population consists of fish older than four years of age; this is 37% less than the 'unfished' population.

Harvest fraction peaked at 91.4% in 2002 and again at 90.0% in 2005 (Figure 3.6). Since then, rates of exploitation have decreased, falling to a record low of 55.3% in 2013, before inflecting upwards to 57.6% in 2014, 2.4% lower than the operational objective of 60% prescribed in the MSF Management Plan (PIRSA 2013). Egg production has remained within 7.8% to 13.5% of 'unfished' levels since 1984, and has stabilised at approximately 10% over the past seven years (Figure 3.6).

Like Northern Spencer Gulf, fishable biomass in Northern Gulf St. Vincent declined steeply from 2001 to 2003, declining 33.2% from a peak of 391.1 t to 261.1 t (Figure 3.6). With the exception of a minor peak of 293.3 t in 2005, fishable biomass has trended downwards to a record low of 200.8 t in 2014. This most recent estimate represents 13.7% of the 'unfished' biomass and is the lowest on record. Similarly, with the exception of a moderate peak in 2004, estimates of recruitment have also trended downwards from a peak of 7.08 million recruits in 1999 to a record low of 1.8 million recruits in 2014 (Figure 3.6).

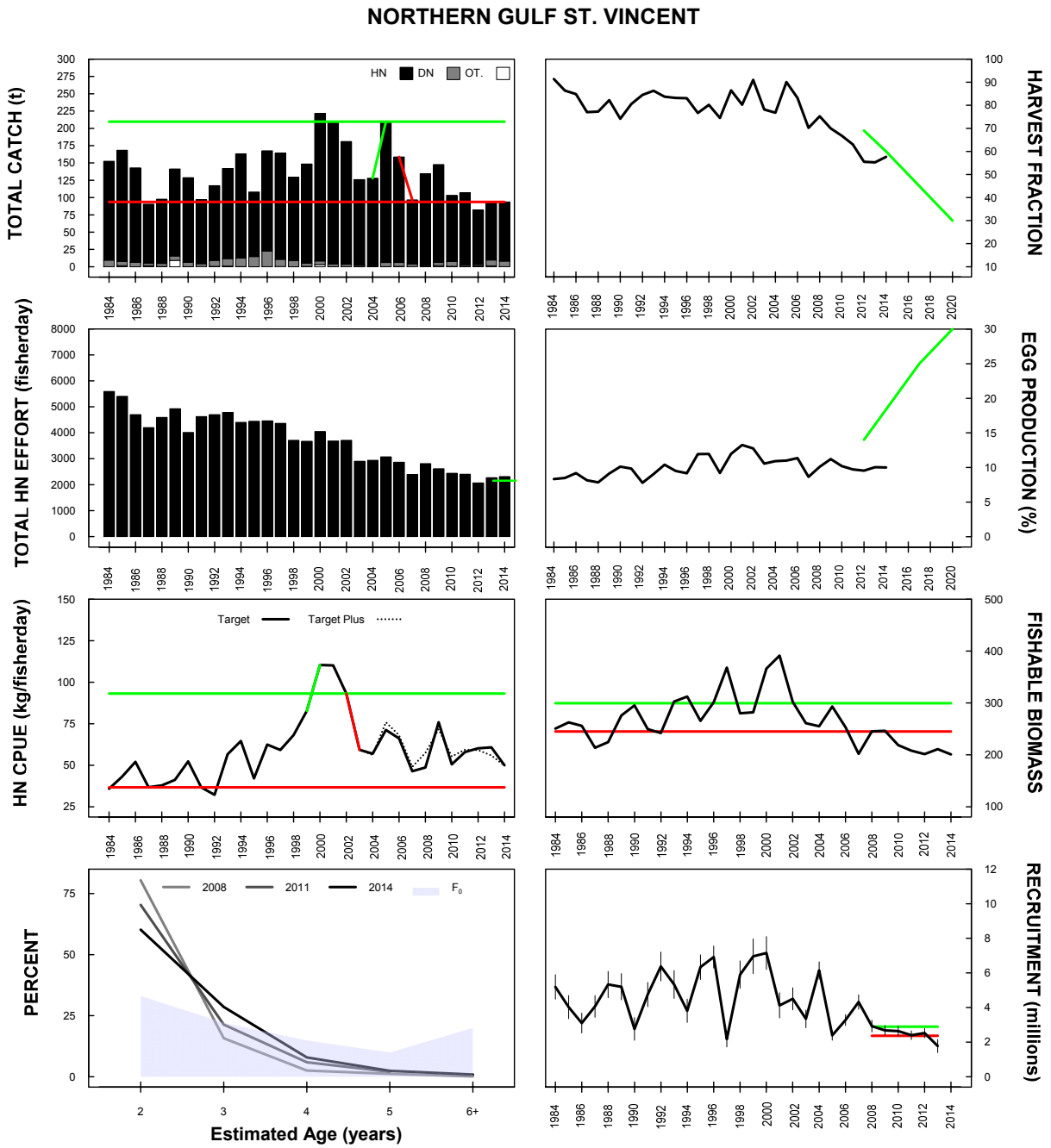

Figure 3.6. Key outputs used to assess the status of the NGSV Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and modelled age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. HN = Hauling Net, DN = Dab Net, OT = Other, F_0 = Unfished age structure.

3.2.3. Southern Spencer Gulf

Large areas of Southern Spencer Gulf have been closed to commercial hauling net fishing since 2005, and as a result the relative contribution of this region to the state-wide catch has decreased from approximately 10% up to 2005 to 3% over the past nine years. Most hauling net fishers (up to 90%) who operated in this region were non-specific in their target species. This sector historically accounted for >60% of the total catch which peaked at 71.2 t in 1998 (Figure 3.7). However, it has been considerably eroded through spatial restrictions imposed in 2005 to become almost exclusively fished by the dab net sector. Total catch of Garfish in this region has not exceeded 10 t since 2009 (Figure 3.7). Dab net effort has remained relatively stable at approximately 130 fisherdays over the same period. Close to all dab netters (>90%) have specifically recorded Garfish as their fishing target. Targeted dab net CPUE recently peaked at 55.6 kg.fisherdays^{-1} in 2010, dropping to 38.5 kg.fisherdays^{-1} in 2012 before returning to 51.7 kg.fisherdays^{-1} in 2014 (Figure 3.7).

A total of 695 Garfish have been measured from this region over the past ten years, 64% of which were sampled from 2012 to 2014. Despite the low sample sizes, the age structure of Garfish caught from this region have consistently included high proportions of three year-olds, accounting for up to 31% of the sample in 2014 (Figure 3.7).

There are no model-based estimates of fishable biomass, recruitment, egg production and harvest fractions for the Southern Spencer Gulf stock.

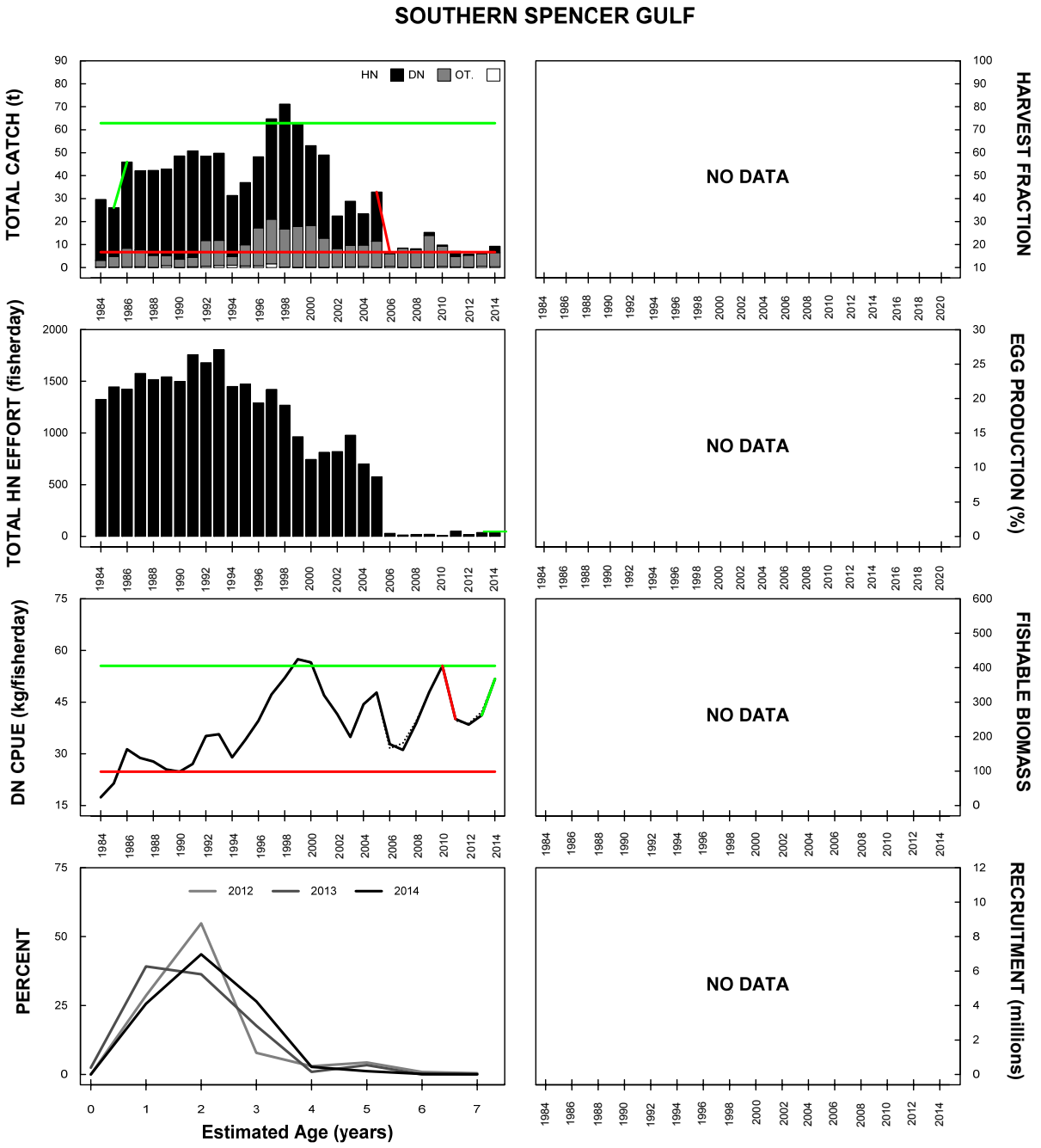

Figure 3.7. Key outputs used to assess the status of the SSG Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. . HN = Hauling Net, DN = Dab Net, OT = Other.

3.2.4. Southern Gulf St. Vincent

The relative contribution of the commercial Garfish catch from this region to the annual state-wide total has rarely exceeded 10%. Annual catches steadily increased from 24 t in 1984 to 70 t in 1993 with both the hauling net and dab net sectors contributing equally (Figure 3.8). From 1993, the contribution of Garfish catch by the hauling net sector declined as a result of a steady reduction in effort (Figure 3.8). From 2005 onwards the dab net sector accounted for >75% of annual commercial fishing effort in this region as the implementation of netting restrictions virtually removed all hauling net activity from the region. Dab net effort has also recently declined, dropping from 329 fisherdays in 2010 to a record low of 196 fisherdays in 2014. Consequently, total catches in this region have remained <10 t over the past four years. Catch rates within the dab net sector have slightly increased over this time period, increasing 35%, from 37 to 50 kg.fisherdays^{-1} (Figure 3.8).

Like Southern Spencer Gulf, accessing commercial catches of Garfish in Southern Gulf St. Vincent is challenging, as there is relatively little fishing activity in this region and most of the catch is distributed outside of the SAFCOL market. Consequently, no Garfish were sampled in 2014 as part of the market sampling program, however a moderate quantity (n = 389) were accessed in 2013. The age structure of the Garfish population in 2013 was similar to that observed in NGSV (Figure 3.8). Both regional populations contained relatively high proportions (approximately 15%) of three years old.

There are no model-based estimates of fishable biomass, recruitment, egg production and harvest fractions for the Southern Gulf St. Vincent stock.

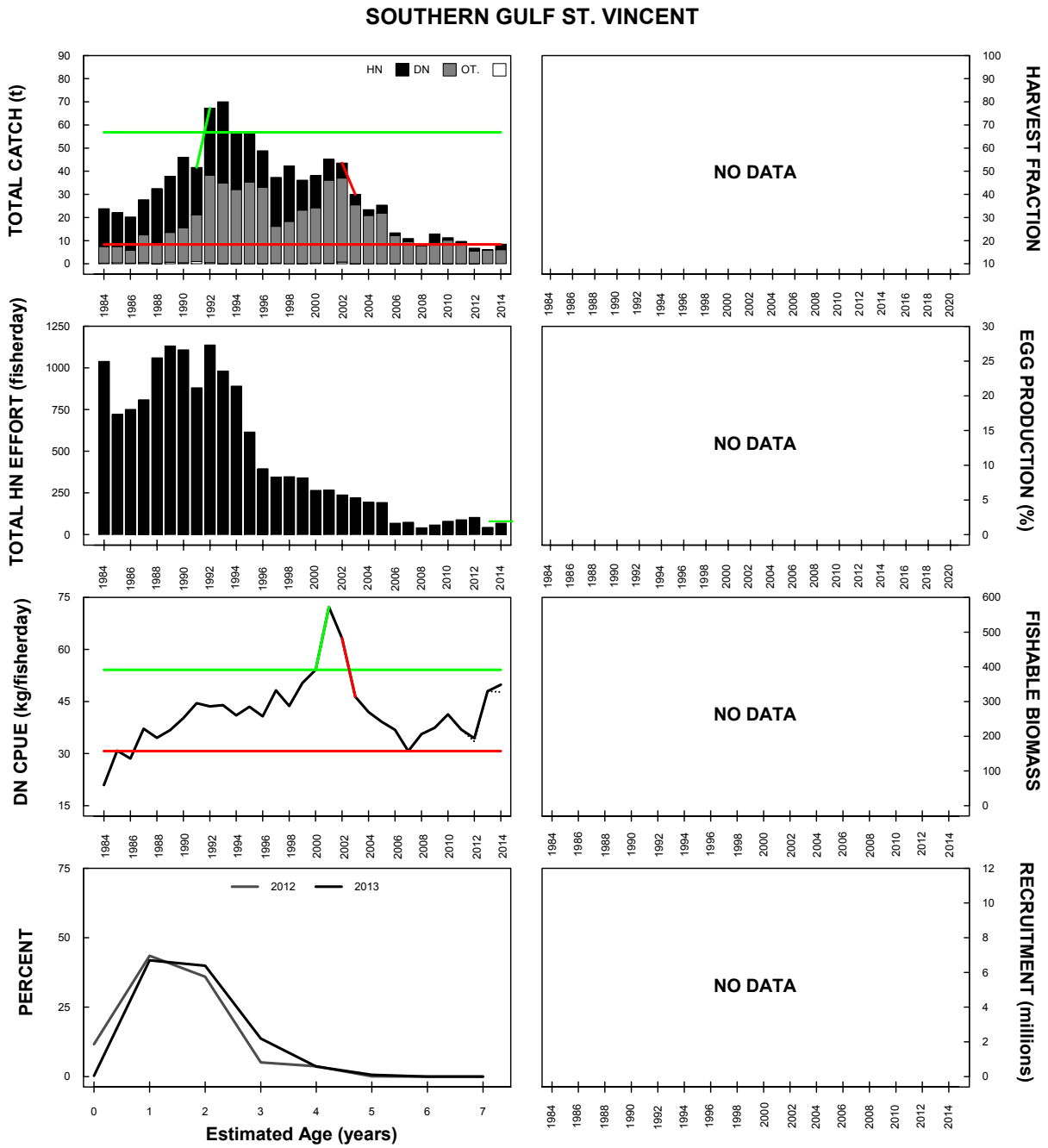

Figure 3.8. Key outputs used to assess the status of the SGSV Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. . HN = Hauling Net, DN = Dab Net, OT = Other.

3.2.5. West Coast

From 1984 to 1999, the annual commercial catch of Garfish from the West Coast accounted for approximately 7% of the State's catch. This has since declined to <1% in 2014 and has been driven by a continuous reduction in hauling net effort through the implementation of commercial netting restrictions (Figure 3.9). Annual Garfish catch peaked at 37.2 t in 1992 of which hauling net sector landed 86% (Figure 3.9). Over the past three years, catches have remained below 3 t, falling to the lowest recorded level of 1.3 t in 2013, before increasing by 90% in 2014 to 2.5 t. Dab nets emerged as the dominant gear type in 2006, and in 2014 this sector accounted for a record high 86% of the total regional catch (Figure 3.9). Most of the remaining hauling net activity in this region have targeted Garfish, and their relative catch rates peaked at 111.3 kg.fisherdays^{-1} in 2007 and again in 2011 at 101.0 kg.fisherdays^{-1}. Dab netters have consistently landed approximately 35 kg.fisherdays^{-1} since 2000 (Figure 3.9).

There was no biological sampling, nor model output for the WC Garfish stock.

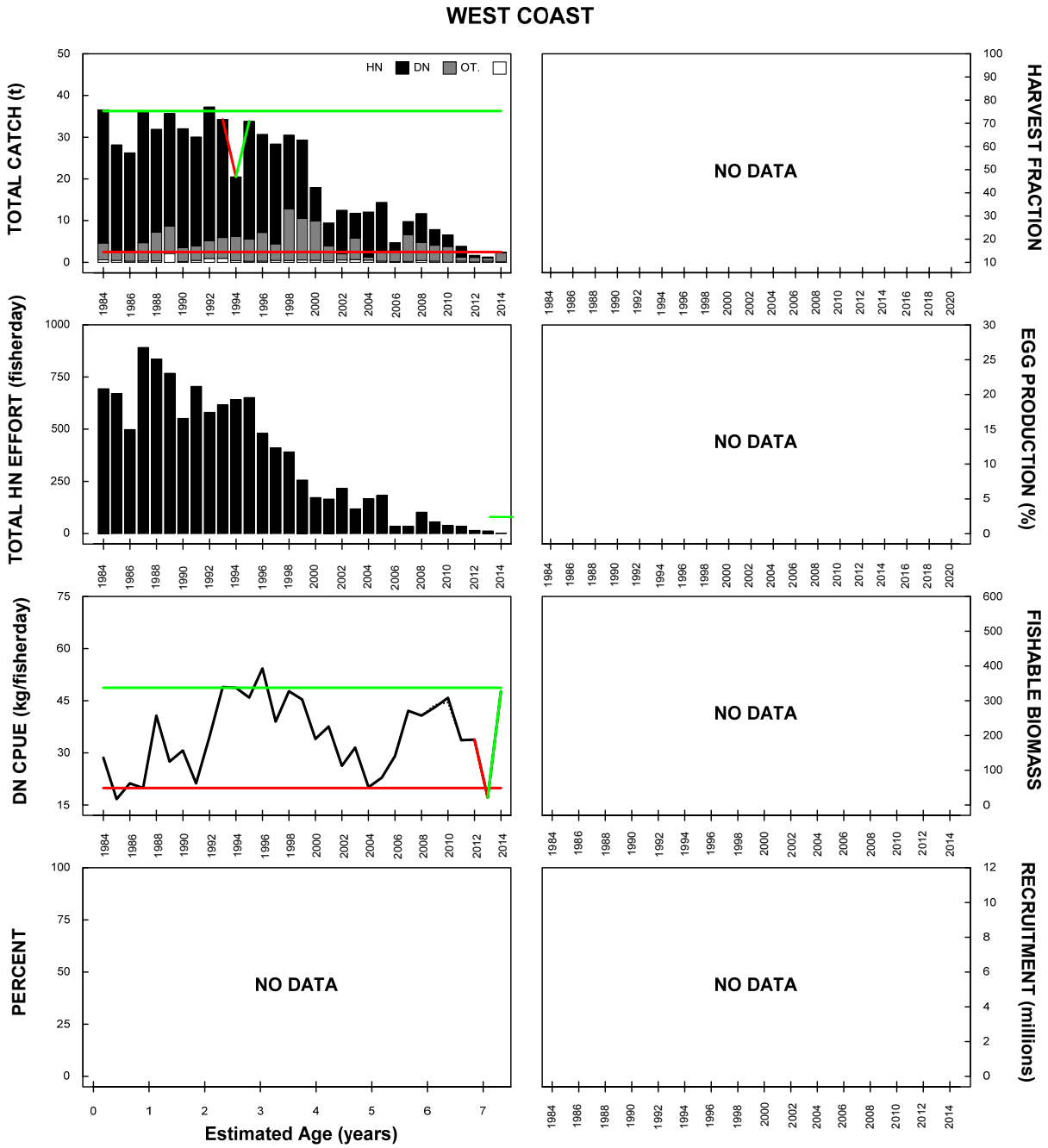

Figure 3.9. Key outputs used to assess the status of the WC Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. . HN = Hauling Net, DN = Dab Net, OT = Other.

3.2.6. South East

A negligible amount of Garfish is landed by the commercial sector in the South East, with the annual State-wide contribution rarely exceeding 0.3%. Despite some low level hauling net activity during the 1980s and 1990s, most the Garfish has been landed by dab net fishers (Figure 3.10). Annual catch peaked at 2.7 t in 1986 and have subsequently fluctuated below 1 t. Catch rates within the dab net sector peaked at 31.7 kg.fisherdays^{-1} in 2007, but have susequently declined to 10.6 kg.fisherdays^{-1} in 2014 (Figure 3.10).

There was no biological sampling, nor model output for the SE Garfish stock.

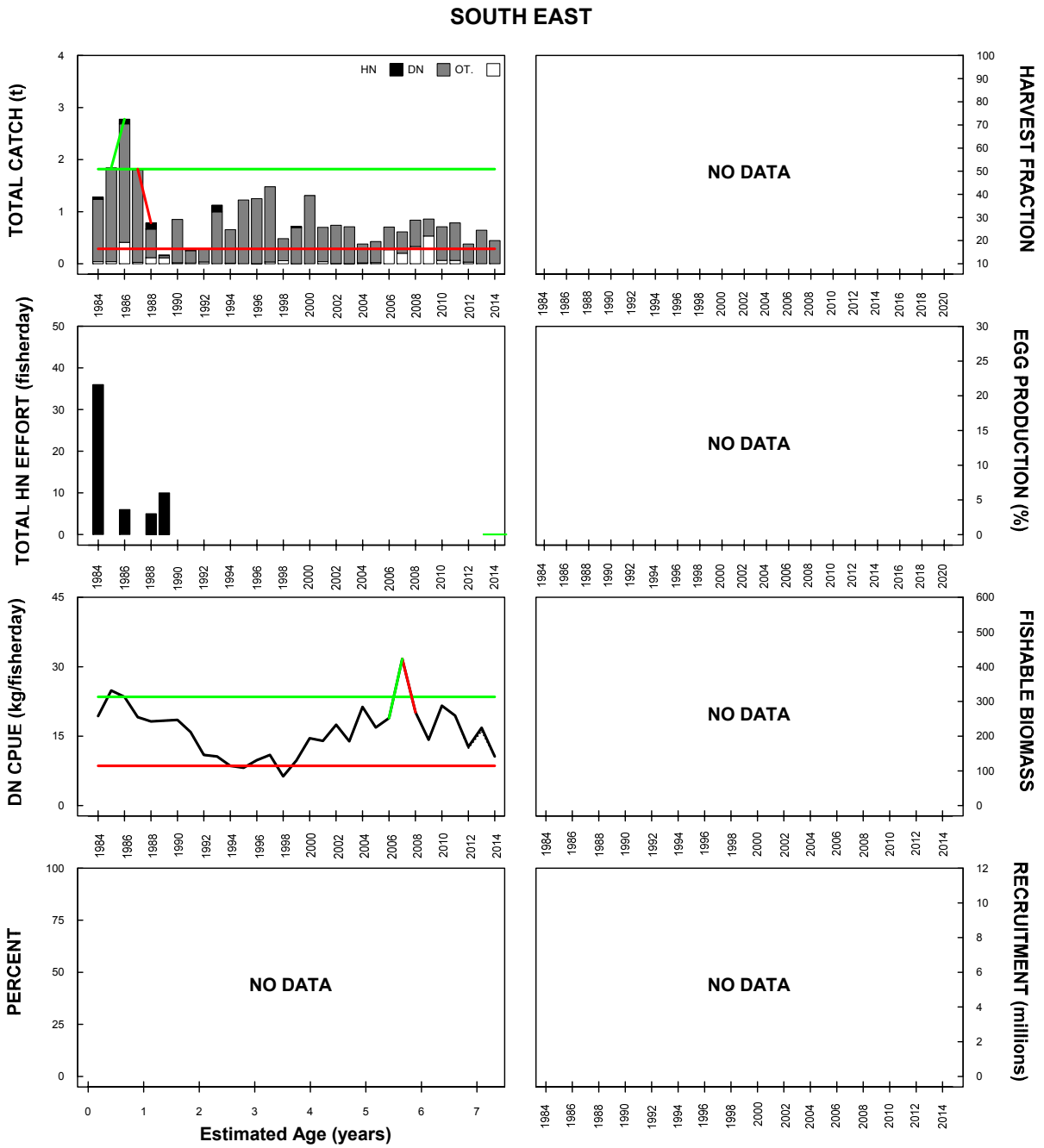

Figure 3.10. Key outputs used to assess the status of the SE Garfish stock. (Left) Trends in total catch, total hauling net effort, catch rates (CPUE) and age composition. (Right) Model output: Harvest fraction, egg production (%), fishable biomass and average (± sd) recruitment. Green and red lines represent the upper and lower trigger reference points identified in Table 1.2. . HN = Hauling Net, DN = Dab Net, OT = Other.

3.3. Fishery performance

3.3.1. Allocation of access

The relative contributions to the total Sate-wide catch from the three commercial fisheries have been relatively stable over the past five years (Table 3.1). The two notable, yet minor, exceptions were SZRLF which exceeded 0.2% in 2013 and the NZRLF which exceeded 0.15% in 2011. These minor irregularities were not large enough to breach any of the prescribed trigger limits (Table 3.2).

3.3.2. General Performance Indicators

The general performance indicators were assessed at regional and gulf-wide scales. A reduction of the hauling net effort by ≥13% in 2014 since 2011 was the highest priority for the general performance indicator; this was not achieved at either spatial scale. The trigger reference point (TRP) of achieving an effort reduction of greater than 10% by 2014 was breached, with decreases in hauling net effort of 0.5% and 3.8% in NGSV and NSG, respectively. As hauling net effort in the southern gulfs was negligible, these breaches do not warrant the same level of concern as the northern gulfs. From a gulf-wide perspective, total hauling net effort declined by 1.2% in Spencer Gulf and 4.5% in Gulf St. Vincent (Table 3.3).

Two other general performance TRPs were breached in 2014 at the regional level. The total catch of Garfish in 2014 was the third lowest on record in NGSV. Targeted catch rates of Garfish within the hauling net sector were the third highest on record in NSG (Table 3.3). Overall catch of Garfish in GSV was also the third lowest on record (Table 3.3).

3.3.3. Biological Performance Indicators

Modeled estimates of harvest fraction and egg production are the primary performance indicators used in this assessment to determine the status of South Australia's Garfish fishery. Although both indicators have clear operational objectives and TRPs, only the harvest fraction estimate is relevant in the current assessment. Egg production targets come into effect in the following 2017 stock assessment where levels are required to exceed 20% of virgin biomass. The operational objective of achieving a harvest fraction of ≤60% by 2014 was accomplished in both gulfs, estimated at 57.7% and 53.7% for GSV and SG, respectively (Table 3.3).

No improvement in the age structure of the Garfish population was observed in 2014 in SG, whereas a minor increase (6.6%) in the relative proportion of three year-old Garfish was observed in GSV. Given that 'no change' in the age structure is identified as the TRP for this secondary

performance indicator, the observed changes indicate a negative breach for SG and positive breach for GSV (Table 3.3).

Estimates of fishable biomass and recruitment constitute the remaining biological performance indicators and contribute to the 'weight-of-evidence' approach in determining the status of the resource. Average fishable biomass over the past three years was reduced by 26.8% in GSV in comparison to the average of the preceding years, negatively breaching the TRP (Table 3.3). Similarly estimates of recruitment declined by 33.0% in GSV, in comparison to the preceding five-year average, also negatively breaching the TRP. Estimates of recruitment in SG, however, increased by 12.4%, positively breaching the TRP.

Table 3.1. Southern Garfish Fishery allocation.

FISHERY ALLOCATION	MSF 79.30%	SZRL 0.13%	NZRLF 0.04%	REC. 19.50%	CHARTER n/a	ABT 1.00%
TRIGGER 1	*84.00%*	*1.00%*	*1.00%*	-	-	-
2000/01	81.54	0.02	0.45	17.98	-	-
2007/08	79.33	0.13	0.04	19.47	-	-
2013/14	76.88	0.11	0.00	23.01	-	-

Table 3.2. Commercial allocation within the Southern Garfish Fishery.

COMMERCIAL ALLOCATION	MSF 99.79%	SZRL 0.16%	NZRLF 0.05%	REC. n/a	CHARTER n/a	ABT n/a
TRIGGER 2	*na*	*0.75%*	*0.75%*	-	-	-
TRIGGER 3	*na*	*1.00%*	*1.00%*	-	-	-
2010	99.82%	0.18%	0.00%	-	-	-
2011	99.68%	0.15%	0.17%	-	-	-
2012	99.86%	0.11%	0.04%	-	-	-
2013	99.72%	0.25%	0.03%	-	-	-
2014	99.89%	0.11%	0.01%	-	-	-

Table 3.3. Comparison of trends in South Australia's Garfish fishery against the performance indicators prescribed in the MSF Management Plan (PIRSA 2013). Red = negative breach; green = positive breach, grey = not applicable; arrows indicate directional shift.

	PERFORMANCE INDICATOR	TYPE	OPERATIONAL OBJECTIVE	TRIGGER REFERENCE POINT	NSG	SSG	NGSV	SGSV	SG	GSV
PRIMARY	HARVEST FRACTION	B	≤ 60% 2014	> 60% 2014					53.5%	57.6%
		B	≤ 45% 2017	> 45% 2017					-	-
		B	≤ 30% 2020	> 30% 2020					-	-
	EGG PRODUCTION	B	25% 2017	< 20% 2017					*12.9%**	*10.0%**
		B	30% 2020	< 30% 2020					-	-
SECOND.	AGE COMPOSITION	B	↑ Prop. Age 3+	No change or reduction	↓1.1%		↑6.6%		↓1.1%	↑6.6%
	TOTAL HAULING NET EFFORT	G	↓ ≥ 13% 2014	↓ < 10% since 2011	↓0.5 %	×	↓3.8 %	×	↓1.2%	↓4.5 %
OTHER	TOTAL CATCH	G	No Target	3rd Lowest / 3rd Highest	×	×	3rd	×	×	3rd
		G	No Target	Greatest % interannual change (+/-)	×	×	×	×	×	×
		G	No Target	Greatest 5 year trend	×	×	×	×	×	×
		G	No Target	Decrease over 5 consecutive years	×	×	×	×	×	×
	TARGET HAULING NET CPUE	G	No Target	3rd Lowest / 3rd Highest	3rd		×		×	×
		G	No Target	Greatest % interannual change (+/-)	×		×		×	×
		G	No Target	Greatest 5 year trend	×		×		×	×
		G	No Target	Decrease over 5 consecutive years	×		×		×	×
	TARGET DAB NET CPUE	G	No Target	3rd Lowest / 3rd Highest		×		×	×	×
		G	No Target	Greatest % interannual change (+/-)		×		×	×	×
		G	No Target	Greatest 5 year trend		×		×	×	×
		G	No Target	Decrease over 5 consecutive years		×		×	×	×
	FISHABLE BIOMASS	B	No Target	3 year average is +/- 10% of previous years					↑4.0%	↓24.9%
	RECRUITMENT	B	No Target	+/- 10% than the average of previous 5 years					↑12.6%	↓32.7%

4. DISCUSSION

4.1. Stock status

The overall assessment of South Australia's Garfish fishery relies heavily on data obtained from the hauling net sector which accounts for approximately 90% of the State-wide commercial catch. Similarly, the assessment places considerable emphasis on analysing catch and effort trends in the northern gulfs since commercial hauling net fishers are restricted to these regions. The current harvest strategy for Garfish (PIRSA 2013) does not provide a pre-defined limit reference point that determines when the stock is recruitment overfished (i.e., when the adult biomass no longer has the reproductive capacity to replenish itself). Instead, the performance of the fishery is assessed against the modeled trends in the harvest fraction of the fishable biomass and egg production.

4.1.1. Northern Spencer Gulf

Historically, Northern Spencer Gulf has been the most productive region for Garfish in South Australia and, in 2014, contributed 55% of the State-wide catch. Annual catch in this region has been relatively stable over the past three years averaging approximately 145 t. Targeted catch rates in the dominant hauling net sector have also remained high, with each fisher harvesting an average of 94.8 $kg.day^{-1}$ in 2014, and although this is a 6.3% decline from the 2013 estimate, it still represented the third highest catch rate on record. Despite the predetermined objective to reduce total hauling net effort by ≥13% since the 2011 assessment, effort levels decreased by 0.5%, and was largely counteracted by a 17% increase in targeted hauling net effort. Fishers have suggested that this increase in targeted effort was an indirect function of the seasonal closure which allowed Garfish to accumulate into large schools over favourable grounds, and because of their increased market demand and catchability, were heavily targeted once the fishery re-opened. This dynamic fishing behaviour appeared to negate the expected effect of the seasonal closures on total fishing effort, rendering them ineffective. The schooling nature of this species also reduces our confidence in using CPUE as an index of relative abundance.

The sharp decline in catch in 2001, coupled with high exploitation rates, declines in fishable biomass, relatively poor recruitment and truncated age structures were identified as concerns in previous stock assessment reports (McGarvey et al. 2006, 2009, Steer et al. 2011) culminating in the fishery being classified as 'transitional-depleting' in the most recent State-wide and national assessments (Flood et al. 2014, PIRSA 2015).

Modeled estimates of exploitation rate and egg production constitute the primary performance indicators in this fishery. Over the past decade both proxies have trended favourably, with harvest fractions declining at a rate of 3% per year to 53.5% and virgin egg production gradually increasing by 0.4% per year, to 12.9%. Consequently, this stock has achieved the operational objective of reducing the harvest fraction to ≤60% by 2014. Although this rate of decline is indicative of the success of long-term management strategies implemented to sustain marine scalefish resources (i.e. licence amalgamations scheme, net-buy backs), it is unlikely to be sufficient to achieve the operational target of reducing the harvest fraction to ≤30% by 2020. Similarly, the trajectory of increase in egg production will require considerable improvement if it is to achieve its operational objective of 25% by 2017 (Figure 3.5). According to these indicators the NSG stock has demonstrated sustained improvement since 2003; however, this recovery is off a low base and has occurred despite the fact that effort has not declined as intended under the harvest strategy.

The changes in the minimum mesh size of hauling net pockets was specifically implemented to promote the recovery of the resource by reducing fishing mortality rates of small Garfish (Steer et al. 2011). It was expected that, over time, this change would contribute to the accumulation of fishable biomass, concomitant improvement in recruitment and a population structure that consists of older, larger Garfish (Steer et al. 2011). The flow-on population effects have only had 18 months to occur (prior to this assessment) and given this short time frame the results are unlikely to be detected in the current assessment. Fishable biomass has, however, steadily increased since 2003 and was most likely in response to declining exploitation rates. The stock size was estimated to be 18.3% of virgin biomass, and although still 1.7% below the theoretical threshold of 20%, this is the highest level since 2001. Recruitment also increased to a level that positively breached the prescribed trigger reference point, exceeding 10% above the average of the previous five years. Although positive, from a historical context, contemporary rates of recruitment were 50% less than those observed pre-1999 further indicating the fishery has considerable capacity to increase. The fact that recruitment appears relatively stable despite increasing egg production and fishable biomass is indicative of a poor stock-recruitment relationship and suggests that environmental processes may be influencing recruitment levels. The anticipated improvement in the age structure, where the population was expected to consist of a greater proportion of three and four year-old Garfish, was not observed. In fact, the population composition has remained virtually identical over the last three stock assessment cycles (i.e. 2008, 2011 and 2014), with two year-old Garfish continuing to dominate samples. This stability in the population structure reaffirms the consistent levels of recruitment within the stock, as the

relative proportion of young (one- and two-year-old) Garfish would be expected to increase with increasing recruitment levels and conversely decline with poor recruitment.

A previous management strategy evaluation exercise indicated that increases in the hauling net mesh size were likely to promote stock recovery through increases in biomass, value and egg production (Steer et al. 2011). The benefits were projected to increase with increasing mesh size and could be further enhanced by combining effort reduction strategies. Additional management changes have been implemented in response to the status of the fishery and include further increases in the minimum mesh size of the hauling net pockets from 32 mm to 35 mm in 2015, and increases in the LML from 230 mm to 250 mm in 2015 and from 250 mm to 260 mm in 2016.

Long-term management changes have resulted in a reduction in the exploitation rate below the operational target of 60%; sustained increases in egg production and fishable biomass; and improved recruitment. Management measures (i.e. further increases in mesh size and LML) are also in place to promote stock recovery. On this basis the current status of the NSG Garfish stock is classified as **transitional-recovering**.

4.1.2. Northern Gulf St. Vincent

Northern Gulf St. Vincent is the second most productive region in the State, accounting for 35% of the commercial catch. Historically, the performance of this fishery has followed a similar pattern to Northern Spencer Gulf. This is because they share similar environments, have experienced comparable fishing pressure and were exposed to equivalent management strategies. Like NSG, hauling net effort in NGSV had only marginally decreased (3.8%) since 2011, failing to meet the operational objective of reducing by ≥13% by 2014. It also indicates that the seasonal closures have been ineffective for this region. Total catch has remained relatively stable, but is still the 3rd lowest on record and unlike NSG, targeted catch rates have declined by 18% over the last year to 50 kgs.fisherdays^{-1}.

High exploitation rates have also been a major concern for this stock peaking at 90.0% in 2006. Since, then the annual harvest fraction has steadily declined to 57.6% in 2014, satisfying the operational objective to drop below 60% by 2014. Although this reduction in exploitation rate is encouraging, the overall performance of this stock remains concerning as the trajectories of the key biological performance indicators remain unfavourable. Rates of recruitment and estimates of fishable biomass are the lowest on record, both falling well below their respective trigger reference points. Fishable biomass has steadily decreased over the past six years to 200.8 t in 2014, contributing to a three-year average that is 24.9% lower than the historical average.

Similarly, recruitment levels have declined 32.7% below the average of the previous five years. This decline is clearly reflected in the comparative age structure where there has been a sequential reduction in the relative proportion of two-year-olds over the past three assessment cycles. Furthermore, egg production remains low, but stable, at 10% of virgin levels with little indication that it will achieve its operational target of 25% by 2017.

A clear divergent trend now exists between the two gulf fisheries, indicating that the current level of fishing pressure in NGSV may be at a point where the resilience of the Garfish stock has been compromised (Figure 4.1). Research into the stock structure of South Australian Garfish has indicated that individuals tend to be relatively site attached during their first two years of life (Steer et al. 2009a) and, as such, are susceptible to localised fishing pressure. Since the enforced netting closures in 2005 that encompassed a relatively large proportion of shallow waters off Yorke Peninsula, the remaining net fishers within Gulf St. Vincent have been concentrated within a small area (approximately 515 km^2) in the northern gulf (see Table 1.1; Figure 1.1). It is possible that the reduction in the biological performance indicators in GSV is indicative of the depletion of Garfish on the key fishing grounds in the small accessible area. The same outcome is not apparent in NSG where fishers have access to more extensive fishing grounds (approximately 1,028 km^2, Table 1.1) and are capable of distributing their effort more widely. The available fishing area in NGSV was further reduced to approximately 465 km^2 through the implementation of a marine park sanctuary zone in the upper gulf on 1 October 2014 (Table 1.1; Figure 1.1). This zone is estimated to account for approximately 7.5% of the State's total hauling net effort (Ward et al. 2012). It is unknown at this stage whether the new sanctuary zone will benefit the fishery by providing a spawning refuge for a component of the local stock, or will be detrimental to the surrounding area through displaced fishing effort. However, 12 MSF licences (including 4 net licences) were removed in a State-funded Marine Parks voluntary catch and effort buy-back with the intention of mitigating any increase in displaced effort. The ramifications of this closure will become clear over time.

The management regime that has been established in NGSV appears to have been insufficient to recover the stock as evidenced by negative breaches in fishable biomass and recruitment against the TRPs; persisting low rates of egg production; relatively high exploitation rates coupled with increased effort and declining catch rates. On this basis the NGSV Garfish stock is classified as recruitment **overfished**.

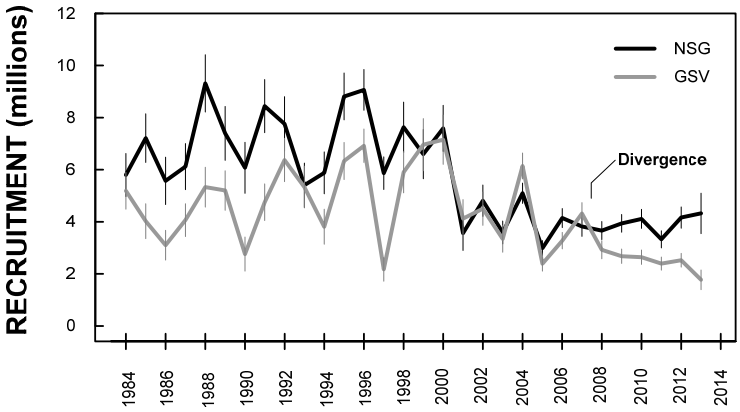

Figure 4.1. Comparison of average annual recruitment levels (±1.96*SE) for both Gulfs.

4.1.3. Southern Spencer Gulf

Large areas of Southern Spencer Gulf have been closed to hauling net fishing, with the most recent closure being implemented around southern Yorke Peninsula in 2005. Consequently, the hauling net sector has been effectively removed from this region and it has become predominantly fished commercially by dab netters. The relative contribution of this region to the statewide catch has consequently decreased to <5%. The commercial catch of Garfish from this region was 9.3 t increasing from 2013 by 38%. Fishing effort and catch rates in the dab net sector have remained relatively stable since the 2005 management restructure. Given the relatively small size of this regional fishery it is generally difficult to sample meaningful quantities of Garfish to ascertain trends in the local population demography. Opportunistic biological samples collected in 2013 and 2014, however, have indicated the commercial resource consists of greater proportions of larger and older (>3+) Garfish in comparison to the northern Spencer Gulf stock.

Although the spatial resolution of the current 'GarEst' fishery assessment model is too broad to assess the key biological performance indicators for this region, its relatively low levels of fishing activity and commercial catch, extensive netting closures and a population structure that consists of older (3+) Garfish, indicates that this stock is unlikely to be over-exploited. Consequently, this stock is classified as **sustainable**.

4.1.4. Southern Gulf St. Vincent

Prior to 1993, the commercial catch of Garfish from Southern Gulf St. Vincent was equally shared between the hauling net and dab net sectors. Since then, the hauling net sector declined as a function of a steady reduction in fishing effort and in 2006 dab nets became the dominant gear

type. Hauling nets were removed from his region by the implementation of the voluntary net buy-back scheme and spatial netting closures in 2005. Prior to this management restructure, the commercial Garfish catch from this region rarely exceeded 10% of the statewide harvest, however, after its implementation this was considerably reduced to <5%. The history of this regional fishery and its current status is almost identical to SSG, characterised by relatively low levels of fishing activity and commercial catch, extensive netting closures and a population structure that consists of relative old (3+) Garfish. On this basis the SGSV stock is classified as **sustainable**.

4.1.5. West Coast

A negligible amount of Garfish is landed by the commercial sector on the West Coast, with the statewide contribution rarely exceeding 2%. Consequently, there is insufficient information available to confidently classify the status of this stock. On this basis the West Coast Garfish stock is classified as **undefined**.

4.1.6. South East

Like the West Coast, a negligible amount of Garfish is landed by the commercial sector in the South East, with the statewide contribution rarely exceeding 0.3%. Consequently, there is insufficient information available to confidently classify the status of this stock. On this basis the South East Garfish resource is classified as **undefined**.

4.2. Management implications

The management strategy established in NSG appears to be achieving its aim of rebuilding the Garfish stocks to ensure its long-term sustainability. The rate of recovery is currently meeting the operational objectives outlined in the harvest strategy; however, this improvement will need to be accelerated if subsequent objectives are to be met (i.e. harvest fraction ≤45% and egg production >20% by 2017). The decision to partition future seasonal closures into multiple short-term blocks to counter a 'gold rush' response once the fishery re-opens seems logical. The decision to further increase hauling net mesh sizes and the legal minimum length of Garfish in 2016 is likely to enhance the stock recovery which is already occurring under the current management regime. Similarly, the pre-existing gear and effort-based management changes implemented in 2013 are yet to manifest in the fishery.

The situation is different in NGSV. Despite achieving the desired reduction in harvest fraction, fishable biomass and recruitment are continuing to decline and egg production rates are not

displaying any signs of improvement. It is clear that the current management strategies which have been successful in NSG have not been sufficient to facilitate the recovery in NGSV. The fishable area available to net fishers is markedly different between the two stocks, and may explain the divergence in their relative performance. Concentrating fishing effort within a small area, where Garfish are known to be relatively site attached (see Steer et al. 2009a; 2009b; 2010; Steer and Fowler 2015) poses the risk of localised depletion. This is of particular concern for a schooling species such as Garfish in which CPUE is considered hyperstable (i.e. catch rates remain high despite actual declines in abundance as fishers continue to target a diminishing school until the last fish is caught (Erisman et al. 2011)).

The most recent estimate of catch by the South Australian recreational fishing sector has been included in this assessment (Giri and Hall 2015). There was a minor increase (5.5%) in its relative contribution to the total State-wide catch of Garfish in comparison to the last survey. Similarly, the relative contribution of the various sectors within the commercial fishery (i.e. NZRLF, SZRLF, and MSF) has remained stable, maintaining their respective allocations.

4.3. Current performance indicators and reference points

Assessing the status of the Garfish fishery through multiple lines of evidence that describe fishery performance from a combination of general and biological indicators is of considerable value. Tracking the relative trends in these indicators is particularly informative, and the trigger reference points serve as ‘precautionary limits’ that indicate further management action may be required.

The reference period used to assess trends in recruitment which compares the latest estimate against the average of the previous five years appears too short. This is clearly evident for Northern Spencer Gulf; where recruitment historically oscillated around 8 million recruits and was halved in 2000 and has since remained relatively stable (Figure 3.5). The contemporary five-year reference period does not adequately capture these early years and consequently constrains the trigger reference points (±10%) to a narrow range. Extending the reference period to account for all previous years, similar to that used to assess fishable biomass (Table 1.2) may provide more informative trigger reference points.

Tracking the mean proportion of three-year-old Garfish in the population over successive stock assessment cycles is misleading. Ideally, this metric was developed to assess the flow-on benefits of the imposed increases in hauling net mesh size which reduces the mortality of small (young) Garfish. The lack of young Garfish in the population due to poor recruitment, however, masks the interpretation of this performance indicator, as the proportion of older fish will be

artificially inflated. So although it would appear that the population is responding well to the gear-based changes, the age structure is actually altered by unfavourable recruitment of young fish into the population. It would be more informative to compare the model derived number of Garfish in each of the age classes over the successive assessment cycles, rather than their relative proportions.

4.4. Future directions

The current assessment of the Garfish Fishery is entirely based on fishery-dependent data. The relative abundances and age structures of Garfish in areas not accessed by commercial fishers are unknown. Consequently, it is not known whether recruitment from outside key fishing areas may help explain the resilience of Garfish to prolonged and intense fishing pressure. A new jointly funded (FRDC, PIRSA and industry) Garfish project began in July 2015. It aims to resolve the relative abundance and population structure of Garfish outside of the spatially limited fishing areas to determine whether the commercial fishery data used to assess the resource accurately reflects the status of the broader resource. It is expected that the data obtained from this project will considerably improve the spatial resolution of the GarEst fishery model, increasing its capacity to provide key biological outputs for the hauling net dominated fisheries in the northern gulfs (i.e. NSG and NGSV), as well as for the dab net dominated fisheries in the south (i.e. SSG and SGSV). Such segregation will also align with the structure of the Garfish biological stocks (Steer et al. 2009a). In addition, it is planned that the GarEst model will be modified to increase its temporal resolution, refining the model time steps from half-yearly to finer scale quarterly intervals.

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6. APPENDIX A: ANNUAL SIZE AND AGE STRUCTURE

SARDI has relied heavily on the South Australian Fisherman's Co-Operative Limited (SAFCOL) market to access the commercial catch and gain valuable biological information that is used to determine the population structure for South Australia's primary Marine Scalefish Species. This section displays the annual size and age structure of Garfish for each of the key regions.

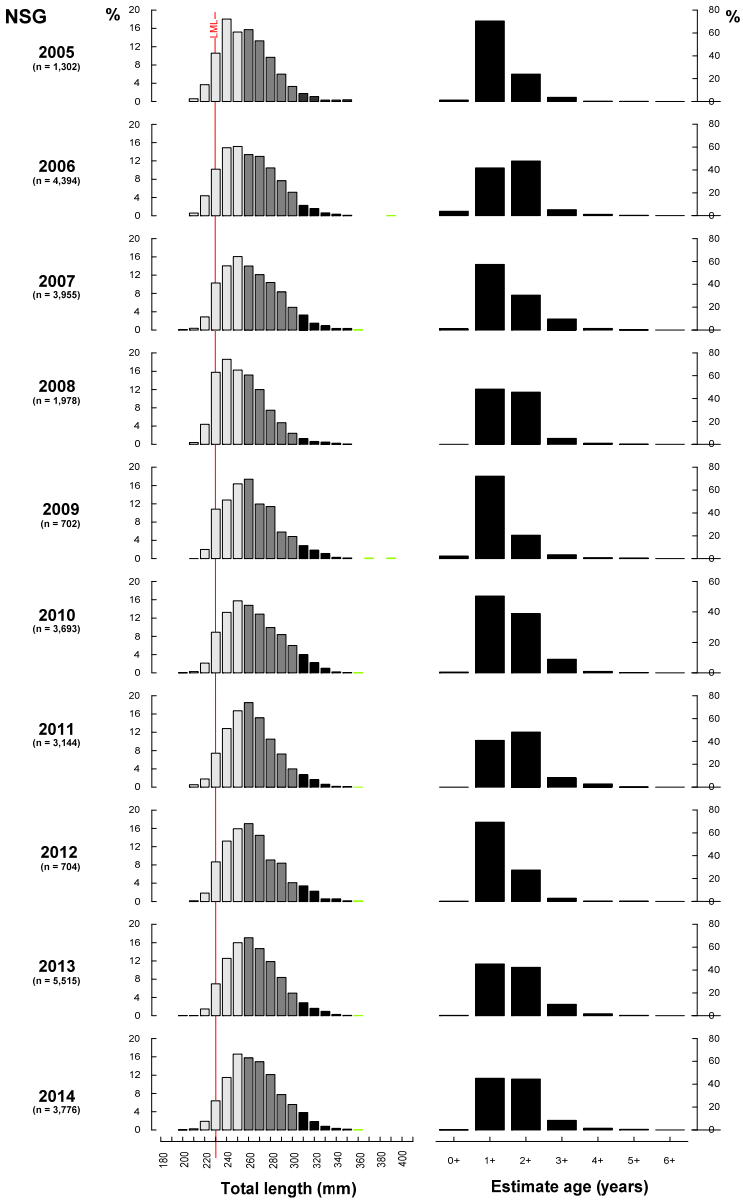

Figure 6.1. Annual size and age structures for Garfish sampled from Northern Spencer Gulf from 2005 to 2014. The red line denotes the legal minimum length (LML).

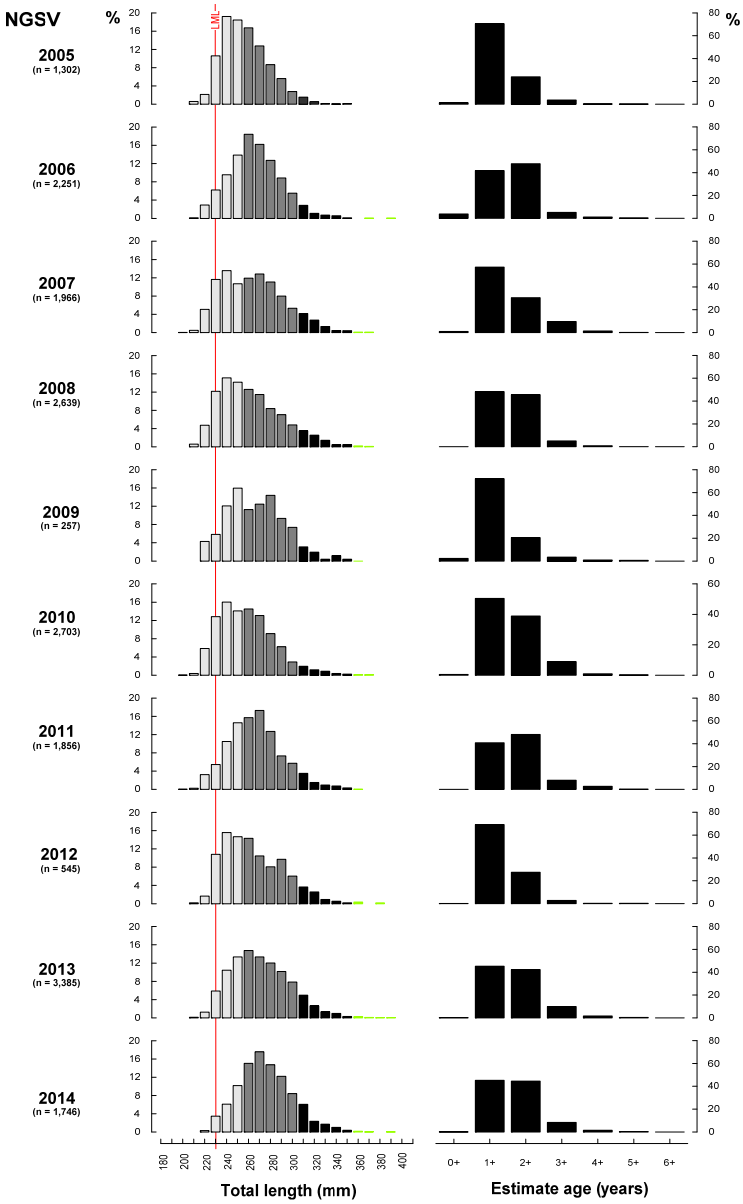

Figure 6.2. Annual size and age structures for Garfish sampled from Northern Gulf St. Vincent from 2005 to 2014. The red line denotes the legal minimum length (LML).

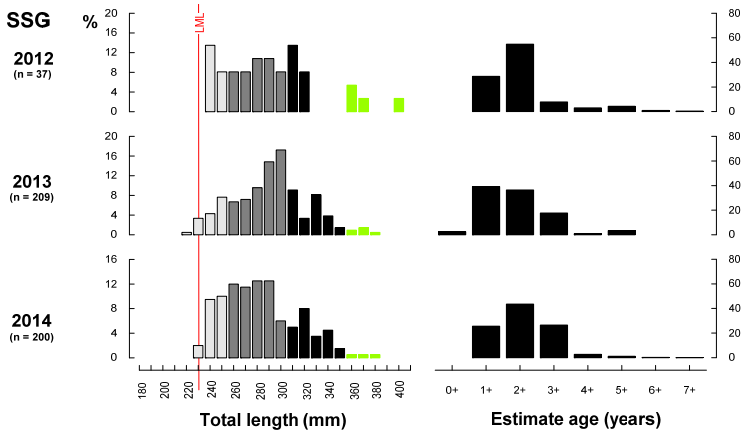

Figure 6.3. Annual size and age structures for Garfish sampled from Southern Spencer Gulf from 2012 to 2014. The red line denotes the legal minimum length (LML).

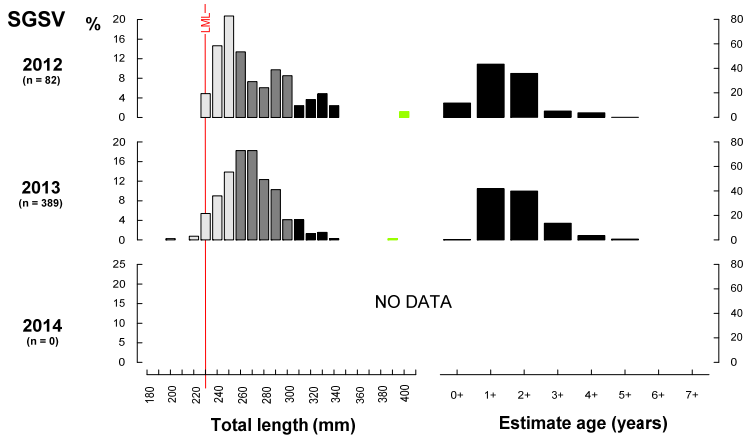

Figure 6.4. Annual size and age structures for Garfish sampled from Southern Gulf St. Vincent from 2012 to 2013. The red line denotes the legal minimum length (LML).

7. APPENDIX B: EFFORT STANDARDISATION

In previous assessments, 2012 and earlier, effort data were not standardised. Two changes in the fishery have increased the benefit of an external GLM-based standardisation procedure: (1) some Garfish hauling net operators have changed the target species reported, in some cases reporting 'Any' when the proportions of Garfish taken are high, and (2) in the management restructure of 2005, more than half of the hauling net endorsements were removed, introducing a break in the CPUE time trend. A GLM-based standardisation procedure where the effect of individual licences is explicit was implemented this year (2015) to account for the removal of those licences.

Because GarEst is an effort-conditioned model, a standardised effort time series is required. The method (Maunder and Punt 2004) is to estimate a half-yearly standardised CPUE using conventional GLM methods, and obtain the standardised effort by dividing data catches by the standardised CPUE. We standardised effort for only the target-plus hauling net (EType=1) effort type, but not for non-target hauling nets, dab nets, or recreational effort types.

The procedure followed to generate a half-yearly time series of standardised hauling net plus effort, separately for each gulf, is as follows:

1. For EType=1, include all hauling net records where Garfish was the reported target species and also any hauling net records where Garfish constituted 50% or more of the landed catch.
2. In R, fitting to all EType=1 records, run the GLM fit to these catch records. The model that predicts the catch rate of each record was CPUE ~ 0 + HalfYear + ModelMonth + LicenceNo + MFABlock with a Gamma residual error structure and an inverse (canonical) link function. We note:
    a. The "0" indicates that no overall intercept was fitted.
    b. All four data covariates are treated as factors, meaning an intercept is estimated for each level of each factor. So for each LicenceNo, the relative catching power was a freely estimated intercept.
    c. The standardised CPUE value taken for use in the assessment is the back-transformed HalfYear intercept for each half-yearly model time step and region.
3. Divide each standardised CPUE value by the reported effort for EType=1.

8. APPENDIX C: AGE-LENGTH 'SLICE' PARTIONING METHOD

The GarEst model is based on a method for representing the population structure of Garfish numbers, for each region, gulf and time step, broken down by age, and also by the lengths of fish within each age group, each recruited cohort. Representing population structure by both age and length improves model accuracy in a stock such as Garfish, where legal minimum length separates fish of very high fishing mortality from those incurring only natural mortality. As shown in Figure 7.2, faster growing Garfish, because they reach legal size sooner, incur 60-70% exploitation rates one or two years sooner than the slower growing fish in each cohort. The slice-partition stock assessment model formalism was developed (McGarvey and Feenstra 2004; McGarvey et al. 2007) to account for this length-asymmetric mortality explicitly, in a dynamic fashion, with a method that is computationally efficient. In addition, the three principal data sources, catch totals in weight, age proportions, and length proportions, are from the catch, and so include only Garfish above legal size. Cleanly separating sublegal from legal fish in the slice partition method thus permits a much more accurate prediction of these data quantities to be fitted.

The programming steps for calculating the three slice partition quantities used by GarEst are outlined in this appendix, summarizing the coding algorithm for implementing a slice partition in an age-based model. The main difference of this approach is that fish are not moved between fixed length bins. Rather it is the length bins themselves that grow. The Garfish within each bin, once assigned to it as they reach legal size, incur only mortality. This greatly improves model computational efficiency.

Additional computational efficiency was achieved by (1) employing the normal score for each slice partition point (fish lengths separating each slice), and (2) making midpoint approximations in place of more exact integrals under the pdf (for mean weights). (1) As the cohort of lengths grows to the right with each model time step, a standardized normal variate (the *z*-score or normal score) is assigned to each slice in the time step when it is first created, as that segment of the length-at-age pdf grows in the legal size range, each *z* given by the position of legal minimum length (LML) along the standardized normal length-at-age pdf, designating the left boundary of that new slice. This normal score value for each slice is unchanged thereafter as the mean and standard deviation of the cohort length pdf's grow with age. Thus, given the mean and standard deviation for all subsequent cohort ages, the fish lengths specifying slice left-hand partition points are calculated from the *z*-scores. The use of the normal score obviates the need for solving integral equations for lower limits of integration. However, this short-cut requires an assumption of

normally distributed fish lengths. A fixed P_{slice} probability under the pdf curve for each slice, which remains unchanged for all subsequent ages underlies the definition of slices, and also explains why the *z*-scores uniquely specify the slice partition for any chosen model age. (2) The fish mean weight in each slice is approximated by the weight-length function evaluated at the midpoint length of each slice (or, for the upper tail slice, the median probability length) rather than numerically integrating weight versus length across each slice subinterval.

The slice partition algorithm has 6 basic steps, coded by 6 iteration loops in ADMB. In each loop, calculations iterate over cohort age (for each region and sex, that is, for each distinct set of length-at-age growth parameters):

Step 1. Calculate the (1.1) mean length, $\bar{l}(a)$, and (1.2) standard deviation, $\sigma(a)$, and thus, also, the (1.3) *z*-score, $z(a) = (LML - \bar{l}(a)) / \sigma(a)$, for every age (a) of growth. This step requires the input of growth submodel parameters specifying $\bar{l}$ and σ, given *a*. In this loop, calculate also (1.4) $P_{sublegal}(a) = \int_{-\infty}^{LML} p(l \mid \theta; a)\, dl$, and (1.5) $P_{legal}(a) = 1 - P_{sublegal}(a)$. For calculating the $P_{sublegal}(a)$ normal cumulative probabilities, we used the AD Model Builder cumd_norm function, which encapsulates the Abramowitz and Stegan (1965, formula 26.2.17) polynomial approximation and takes the standardized *z*-score as input.

Step 2. Calculate slice probabilities, $P_{slice}(a)$, the proportions of the cohort reaching legal size in each model age, $P_{slice}(a) = P_{legal}(a) - P_{legal}(a-1)$, $a = a_b+1, \ldots, a_{max}$, where, for GarEst, the birth age of cohort creation, $a_b = 3$, at the start of the third half-year (1 October in the summer following the summer of spawning) for all cohorts.

Step 3. Calculate the first of 3 output quantities, the fish transfer coefficients, $f_{transfer}(a) = P_{slice}(a) / P_{sublegal}(a-1)$, $a = a_b+1, \ldots, a_{max}$. No transfer coefficient is needed for birth age a_b cohorts, the population number for their one legal (upper-tail) slice given by $P_{slice}(a_b)$ (= $P_{legal}(a_b)$) times the total recruit number estimated for that cohort.

Step 4. Calculate the slice partition points, specifically the left-hand sides of each slice subinterval, specified as a triangular matrix by age and slice number, $l_{lhs}(a, s)$. The number of slices, for each legal cohort age, is given by $n_s(a) = a - a_b + 1$, $a = a_b, \ldots, a_{max}$. (4.1.) For newly created slices, whose slice subscript number equals the total number of legal slices, $n_s(a)$, the

left-hand-side partition point is, by definition, the legal minimum length (LML): $l_{lhs}(a,\ s = n_s(a))$ = LML, $a = a_b, \ldots, a_{max}$. (4.2) Looping over all other slices in each cohort age group, s = 1 to $n_s(a) - 1$, the slice left-hand-sides are derived using the z-scores: $l_{lhs}(a,s) = \overline{l}(a) + \sigma(a) \cdot z(s - 1 + a_b)$.

Step 5. Calculate the second slice partition output quantity, the triangular matrix of central lengths for each slice, $l(a,s)$. (5.1) For all slices except upper-tail slices, the midpoints were used: $l(a,s) = \left(l_{lhs}(a,s) + l_{lhs}(a,\ s-1)\right)/2$. (5.2) For the upper tail slices, the central length was chosen to be the median probability value of the upper tail, whose z-score was calculated by $z_{median}(a, s = 1) = \text{inv\_cumd\_norm}\left(1 - P_{legal}(a_b)/2\right)$. The inv_cumd_norm function in AD Model Builder (Abramowitz and Stegan 1965, formula 26.2.23) gives a standardized normal z-value for any given probability.

Step 6. Calculate the mean weights, evaluating the weight-length formula at each slice central length: $w(a,\ s) = \alpha\left(l(a,s)\right)^{\beta}$.

A graphical description of how these slice partition length bins are constructed is given in Figures 7.1 and 7.2.

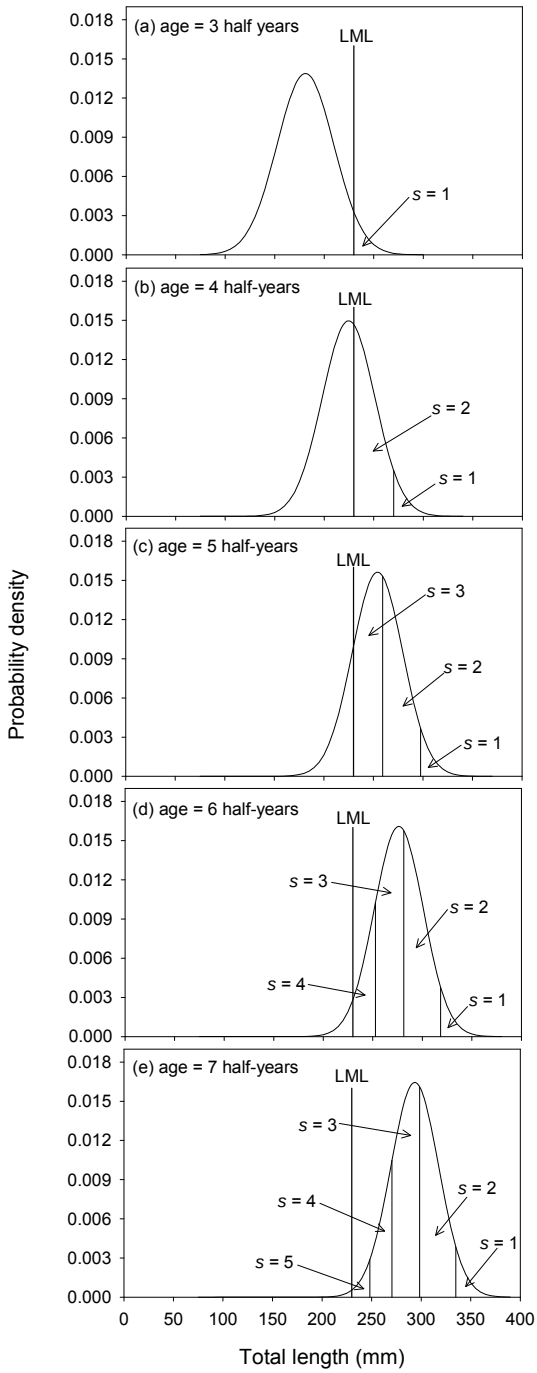

Figure. 7.1. The growth of a normal length-at-age Garfish cohort is shown in successive panels. With each time step, a new slice, as the fish of length newly grown above LML, numbered *s*=1, 2, etc., is created as shown. See Steps 1 and 2 above.

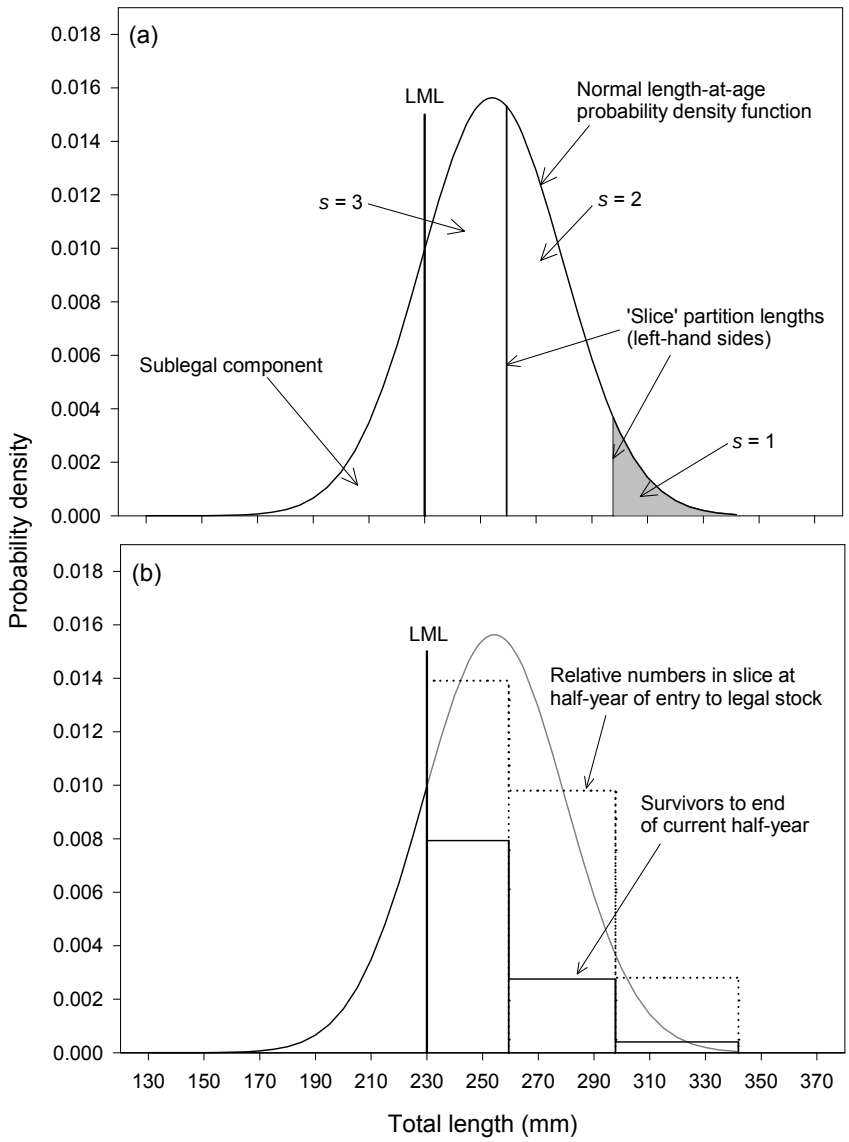

Figure. 7.2. (a) The transfer of Garfish from sublegal sizes (left of LML) to each newly created slice, is done using Step 3. (b) Subsequently, the proportional reductions in the population number in each slice differ depending on how long it has been exposed to fishing mortality, and on the length selectivity applying to each slice, in each model time step. In this Garfish stock, high fishing mortality causes population numbers the faster growing slice (*s* = 1, farthest slice to the right) to be greatly reduced compared to the more slowly growing members of their cohort.

9. APPENDIX D. GARFISH 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 was described in Appendix B.

9.1. 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 cohort age, a, we employed a 4-parameter exponent-generalized von Bertalanffy mean length-at-age curve: $\bar{l}(a) = L_\infty \left\{1 - \exp\left[-K\left(\frac{a-t_0}{12}\right)\right]\right\}^r$ (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 Garfish 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 B) 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.

9.2. Recruitment

Recruitment is defined as the creation of the (normal) length-at-age cohort at age a_b = 3 half-years (at age 1 year) 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 Garfish above legal minimum length at age a_b (in the upper tail of the length at age pdf) are computed (Appendix B) 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 B).

9.3. Model population array

The model Garfish population array $N(t,r,x,c,s)$ is 5-dimensional, fish numbers broken down by (1) half-yearly model time step, t, (2) spatial region, r, (3) sex, x, (4) cohort (i.e. year-class, given by year of spawning), c, and (5) 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 3 to 12+ half-years, the oldest age being a 'plus' group. Garfish catch and effort, for data and model, were divided into four effort types, i_E: (i) hauling nets targeting Garfish, (ii) hauling nets not targeting Garfish, (iii) dab nets and minor gears, and (iv) recreationals. The two commercial gears, g, each with separate length selectivity, are hauling net and dab net. Data quantities, such as reported effort $\tilde{E}$, are denoted by a tilde.

9.4. 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 Garfish. 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) $$F(t,r,x,c,s,i_E) = q(r,\ t_{season},\ x,\ i_E)\ \cdot \tilde{E}(t,r,i_E)\ \cdot s_{len}(g(i_E),s)\,.$$

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

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

Logistic length selectivity is varied in time to model recent regulated increases in hauling net pocket mesh size from 30 mm to 32 mm implemented in winter 2013 to reduce capture rates of undersize Garfish. Prior to winter 2013, hauling nets were assumed to retain all legal size Garfish. With the mesh size increase in winter 2013, the $l_{50}\left(g(i_E = 1\ \&\ 2)\right)$ for hauling net gear (first two effort types) is given by regressions relating mesh size to l_{50} derived from a series of mesh selectivity experiments undertaken by SARDI and industry:

(B.3) $$l_{50}\left(g(i_E = 1\ \&\ 2)\right) = \begin{cases} 7.9684\cdot meshsize - 29.203 & \text{in summer} \\ 6.4785\cdot meshsize + 32.246 & \text{in winter} \end{cases}.$$

For commercial effort, the catchability was written:

(B.4) $$q(r,t_{season},x,i_E) = q_{CSE}(r,t_{season},i_E)\cdot\ s_{SS}(t_{season},x)\cdot\left(1+q'\cdot(t-t_{mid})\right)$$

with q_{CSE} being the absolute catchability given as function of region, season, and effort type, a relative selectivity coefficient $s_{SS}(t_{season},x)$ describing the specifically sex-dependent seasonality of catchability, notably strong differences in sex ratios in the catch between summer and winter.

A linear time trend in catchability (changing effective effort) from the model start in 1983 to winter of 2001 was estimated as q', the rate of catchability increase relative to the time step t_{mid} = 22 half-years; q' = 0.01065 or 1.06% increase per half year, is retained from the 2012 estimate.

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

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

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

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 = 0.4 yr^{-1} (Jones 1990).

9.5. Estimation: Parameters and model likelihood

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

9.5.1. Parameters

Estimated parameters for the model fall into seven categories: (1) yearly recruit numbers by region, (2) recruitment sex proportion (of females) by region, (3) catchabilities, (4) relative selectivities by sex and season, (5) logistic length selectivity, (6) growth, and (7) likelihood standard deviations of fits to half-yearly catch totals.

9.5.2. Likelihood for catch totals by weight

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

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

where the weights by age and slice $w(a(t,c),s)$ are derived in Appendix B.

The likelihood factor for each combination of region, *r*, and commercial effort type (i_E up to $n_E - 1$), is written:

$$\text{(B.8)} \quad L_C = \prod_{t=1}^{n_t} \prod_{i_E=1}^{n_E-1} \prod_{r=1}^{n_r} \frac{1}{\sqrt{2\pi} \cdot \sigma_C \cdot \tilde{C}(t,r,i_E)} \exp\left[-\frac{1}{2} \left(\frac{\ln\left(\hat{C}(t,r,i_E)\right) - \ln\left(\tilde{C}(t,r,i_E)\right)}{\sigma_C} \right)^2 \right]$$

where

σ_C = the single estimated catch-likelihood standard deviation parameter;

$\tilde{C}(t,r,i_E)$ = 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.

This lognormal likelihood form is also fitted to recreational ($i_E = n_E$) catch survey numbers (Section 2.2), from telephone and diary surveys run in 2001/02, 2007/08 and 2013/14. Between those survey years, recreational catch and effort totals, by region and season, were assumed to vary linearly between the survey-estimated values, and to retain the values of 2001/02 prior to that first survey, and retain the values of 2013/14 subsequently. 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 of 15% for Spencer Gulf and 20% for Gulf St. Vincent, and (2) effort varied relative to 2007/08 values with the same slopes by gulf and season observed for catches.

9.5.3. Likelihood for catch samples by age and sex

A two-dimensional multinomial likelihood is used to fit to catch-sample proportions by sex and age, since both are attributes of a single catch sample data set. The fitted data, from the principal gear, hauling nets, in the two time steps and regions where catch was monitored, consists of the counts of sampled fish falling into each possible combination of sex and half-yearly age, $\tilde{n}(a,\ x;\ t,r)$. The multinomial likelihood factor is written:

(B.9) $$L_{AX} = \prod_{i_{AX}=1}^{n_{AX}} \prod_{a=a_b}^{12+} \prod_{x=0}^{1} \hat{p}(a,\, x;\, i_{AX})^{\tilde{n}(a,\, x;\, i_{AX})}$$

where

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

$\hat{p}(a,\, x;\, i_{AX})$ = two-dimensional array of model-predicted fish proportions captured by age and sex, for each sampled half-year and region, indexed by i_{AX} ;

$\tilde{n}(a,\, x;\, i_{AX})$ = fish numbers for each age and sex, observed in the catch-at-age sample i_{AX} .

9.5.4. Likelihood for catch samples by length

A normal likelihood is 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 is written:

(B.10) $$L_{mp} = \prod_{i_{AX}=1}^{n_{AX}(i_{mp})} \prod_{i_{mp}=1}^{4} \prod_{sex=0}^{1} \prod_{a=a_b}^{12+} \prod_{g=1}^{2} \left\{ \frac{\exp\left[-\frac{1}{2} \left(\frac{\left\{ \begin{array}{l} \tilde{b}(i_{mp}, x, a, g; i_{AX}) - \\ \hat{b}(i_{mp}, x, a, g; i_{AX}) \end{array} \right\}}{\sigma_{mp}(g)} \right)^2 \right]}{\sqrt{2\pi} \cdot \sigma_{mp}(g)} \right\}^{\tilde{n}_a(x,a,g;\, i_{AX})} .$$

We weighted each factor in the log-likelihood by the uncorrected sample size ($\tilde{n}_a(x, a, g;\, i_{AX})$), 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_{AX} , from the L_{mp} likelihood, depending on the moment property fitted. Thus the number of qualifying data sets, $n_{AX}(i_{mp})$, decreased with increasing moment property i_{mp}. We required at least 16 aged fish for kurtosis, 8 for skewness, 4 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.

10. APPENDIX E. MODEL FITS TO DATA

Parameters and thus stock performance indicators in the GarEst model are estimated by fitting to data for commercial catch totals by weight, recreational catch total numbers for years when recreational surveys are run (see Methods Section 2.4), and to commercial catch proportions by age and sex, in each half-yearly time step when sampling occurred. In this Appendix, graphs comparing fitted model and data indices are presented.

In Figure 9.1, model fits to the reported monthly Garfish catch totals are plotted for commercial catch in weight landed, for the 4 Garfish effort types in the two gulfs. Plots of fit to the proportions landed by age (Figure 9.2) and to sex ratios (Figure 9.3) from catch sampling are also shown below.

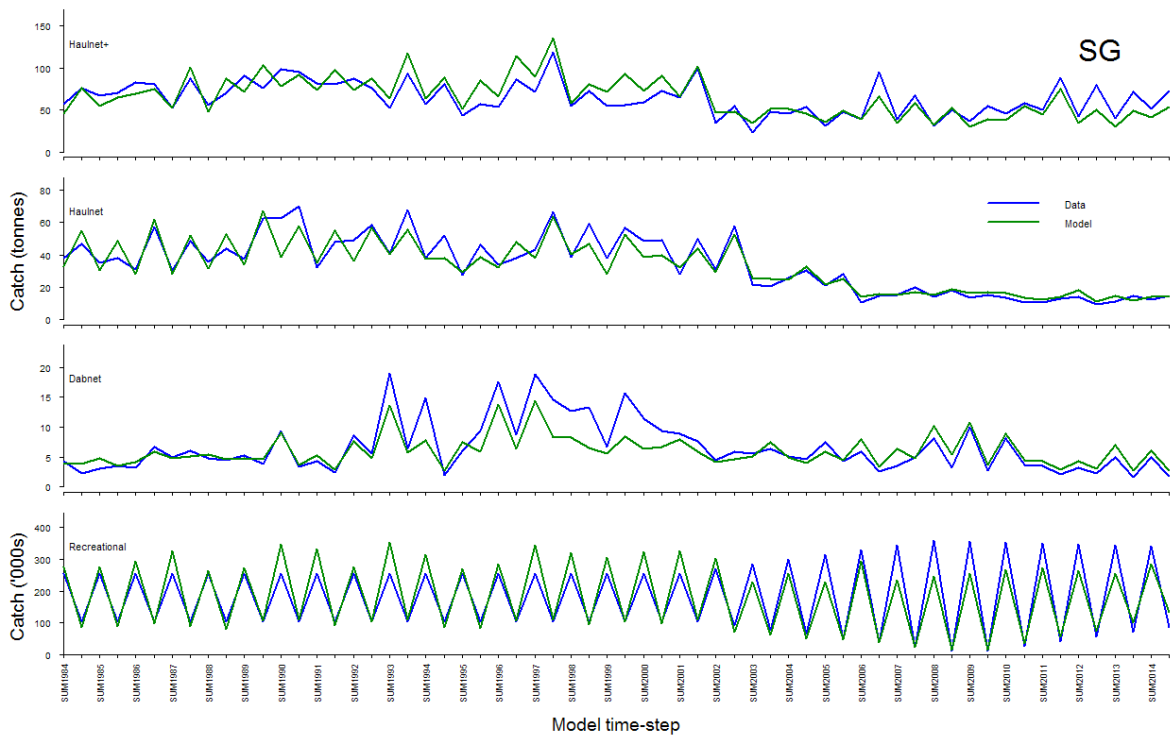

Figure 9.1a. Fits of Spencer Gulf model to data half-yearly catch totals for the 4 effort types.

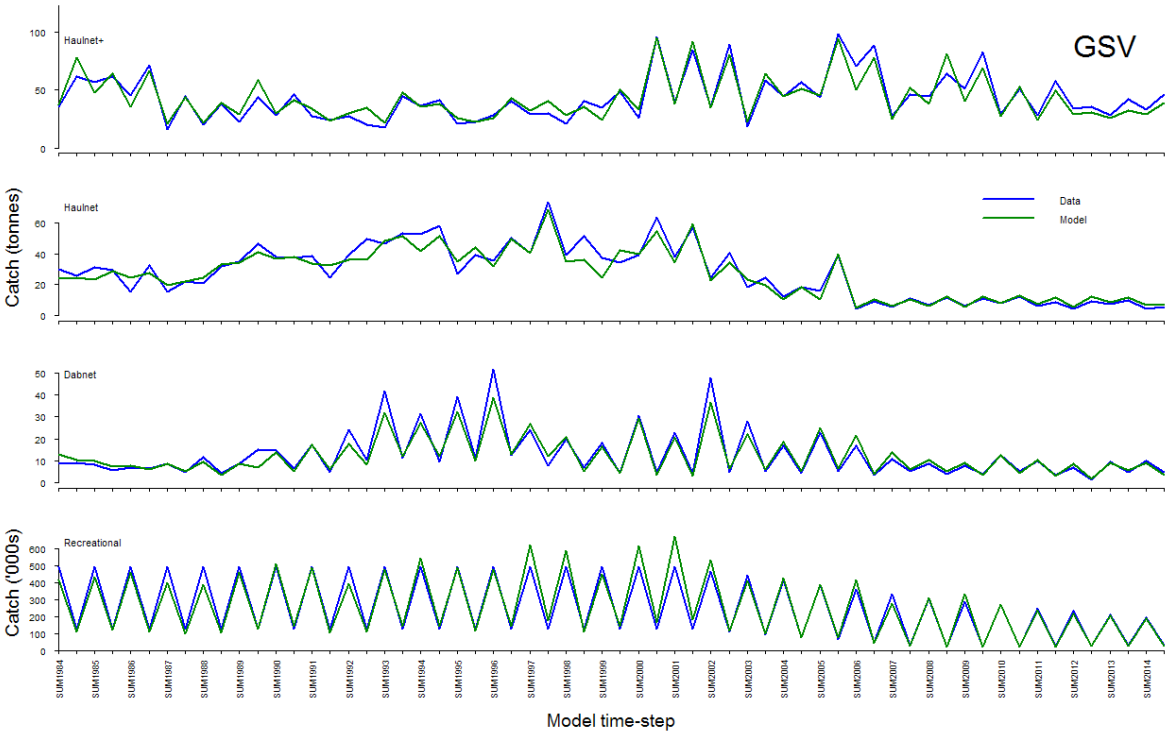

Figure 9.1b. Fits of Gulf St. Vincent model to data half-yearly catch totals for the four effort types.

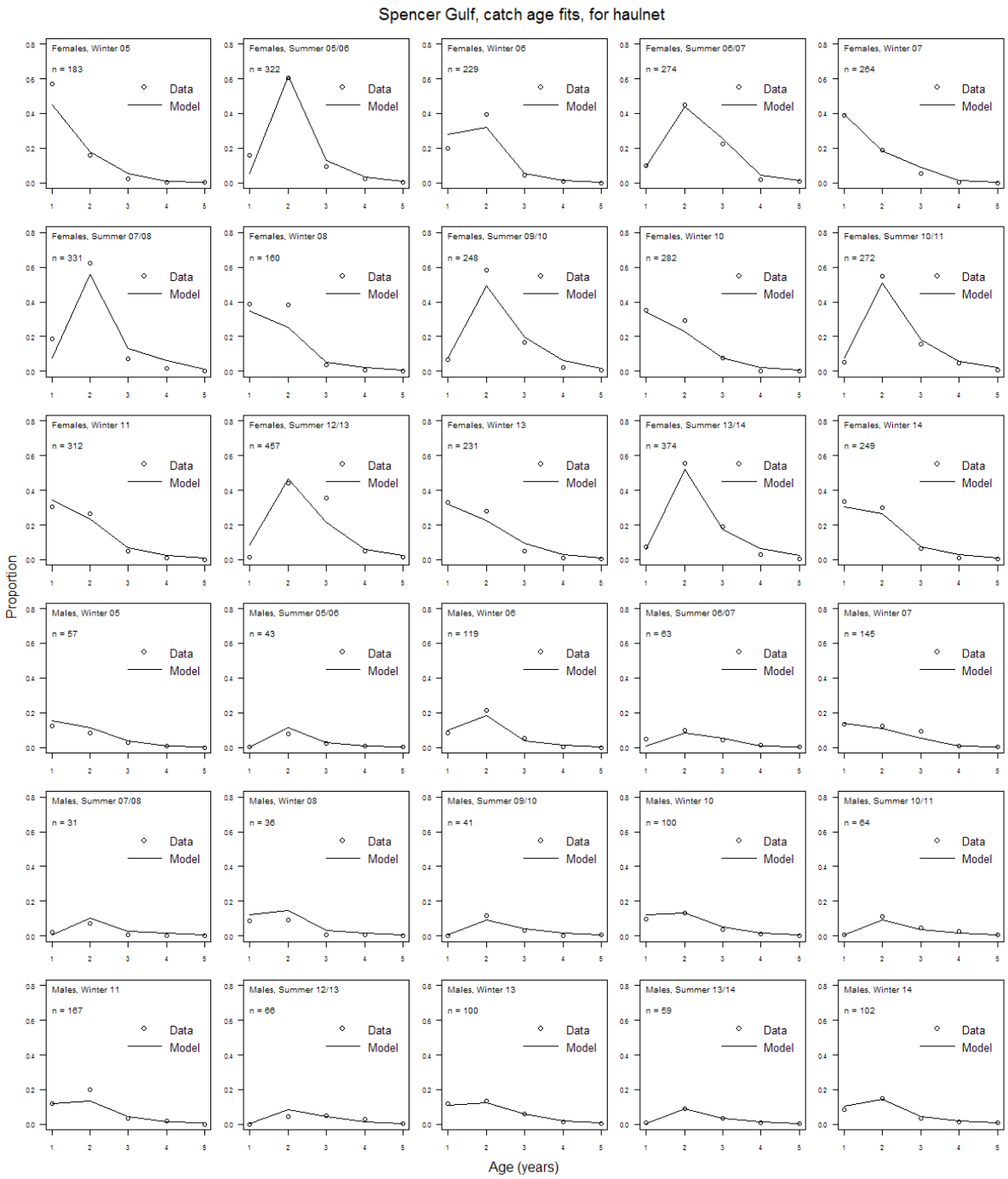

Figure 9.2a. Model fits to age proportions from catch samples. The 30 most recent Spencer Gulf data sets are shown by sex and half-yearly model time step.

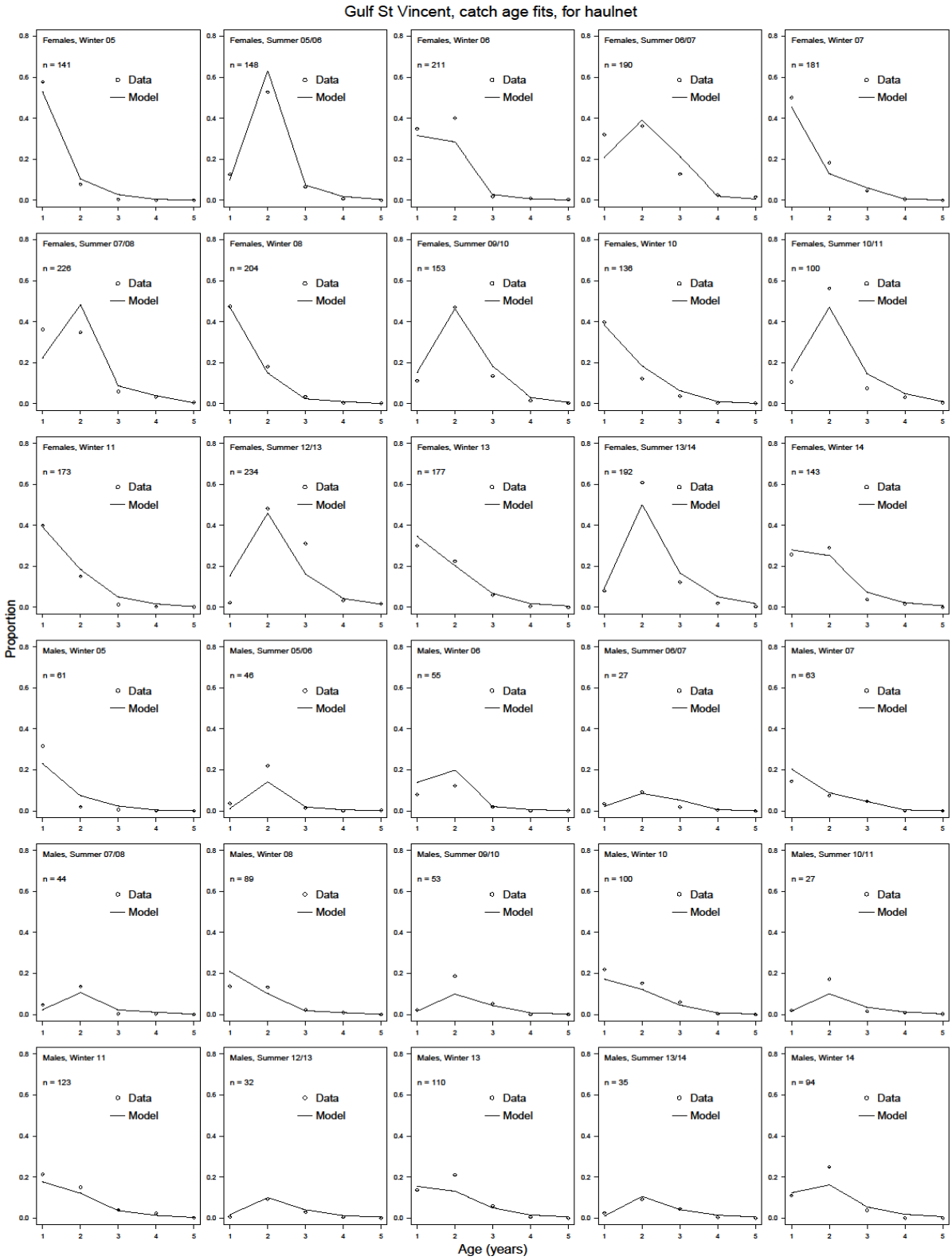

Figure 9.2b. Model fits to age proportions from catch samples. The 30 most recent Gulf St. Vincent data sets are shown by sex and half-yearly model time step.

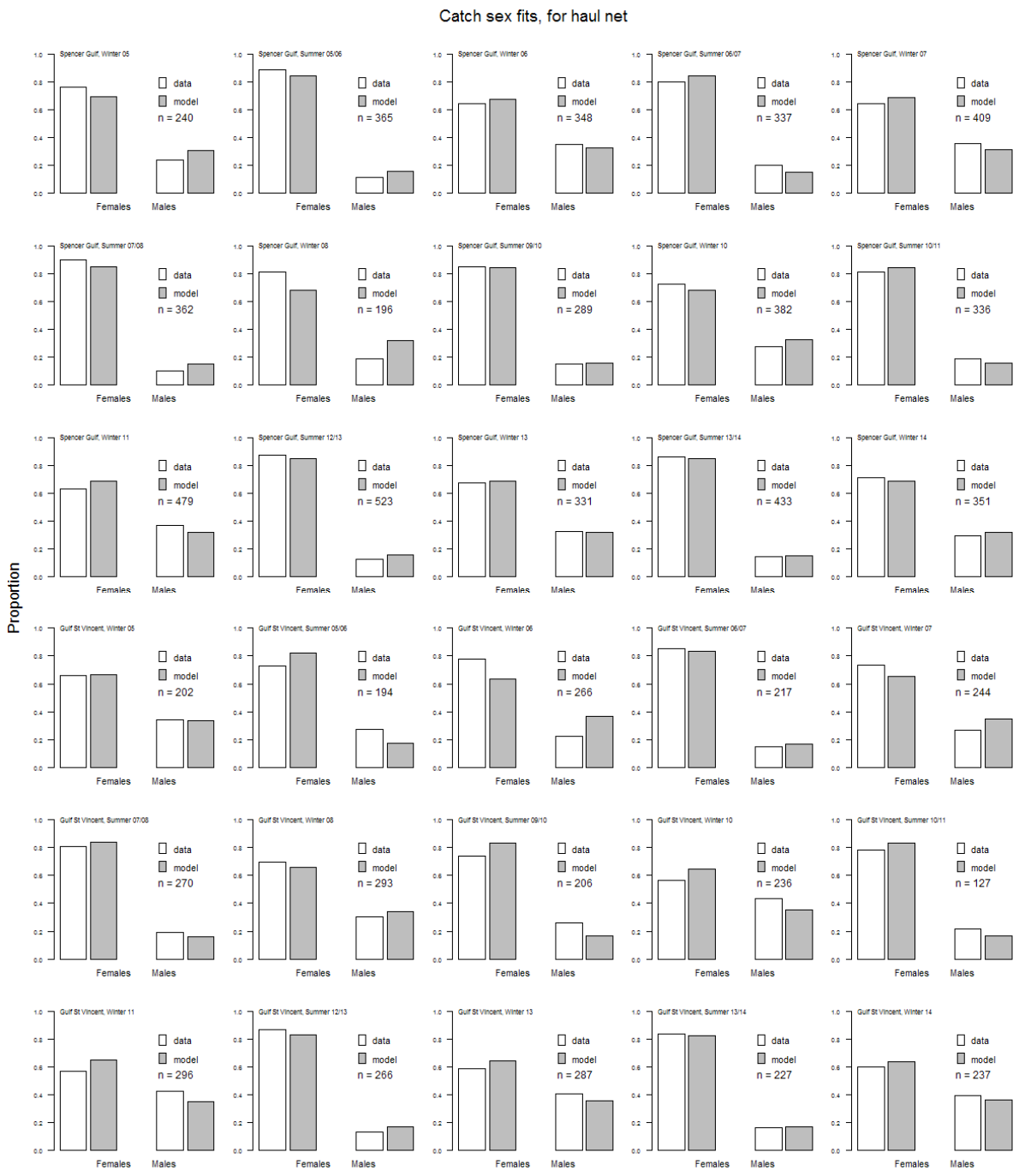

Figure 9.3. Model fits to sex ratios from SAFCOL market samples. The 30 most recent for Spencer Gulf are shown by gulf and half-yearly model time step.

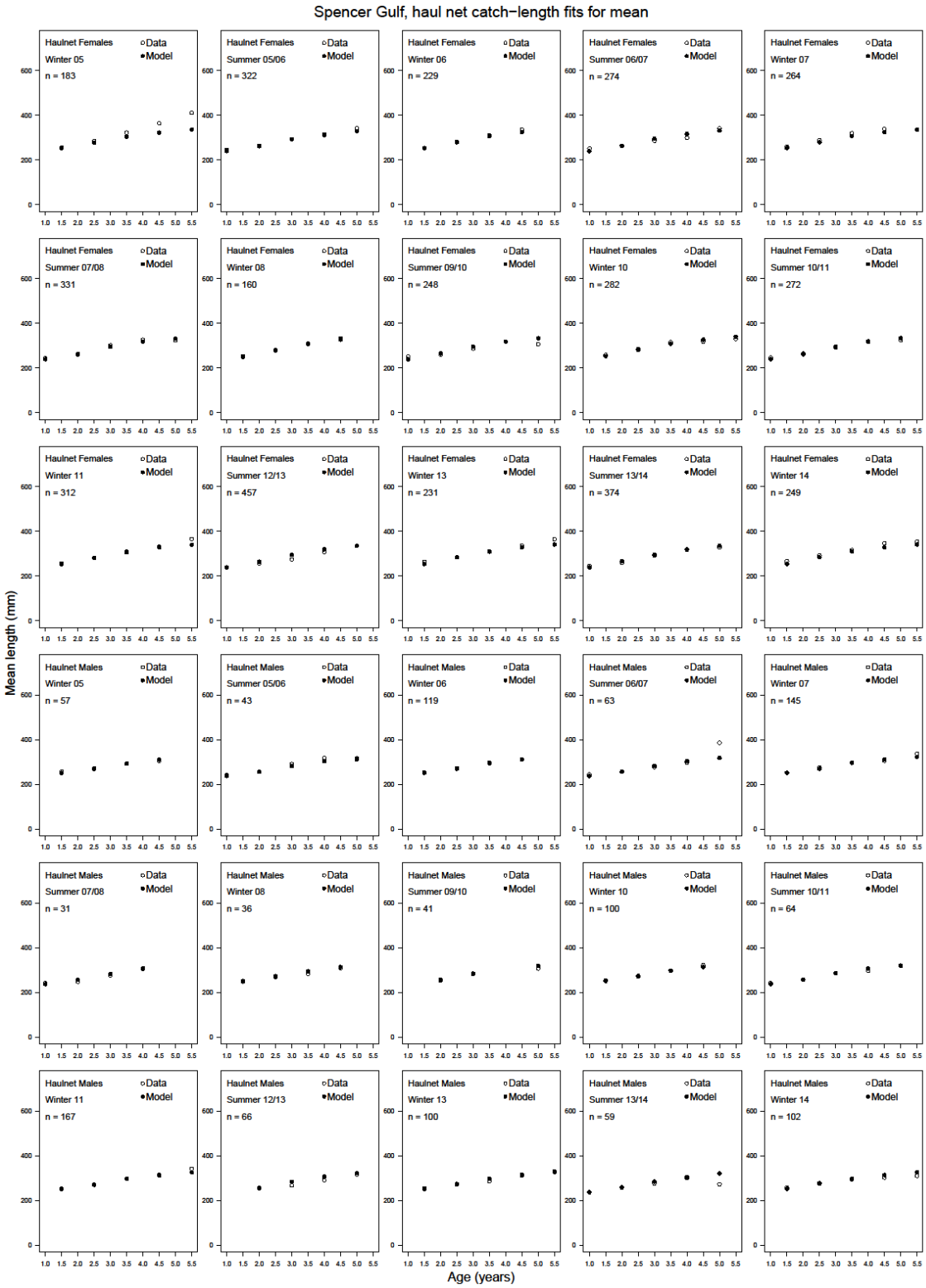

Figure 9.4a. Model fits to catch mean lengths of modelled cohorts from catch samples. The 30 most recent Spencer Gulf data sets are shown by sex and half-yearly model time step.

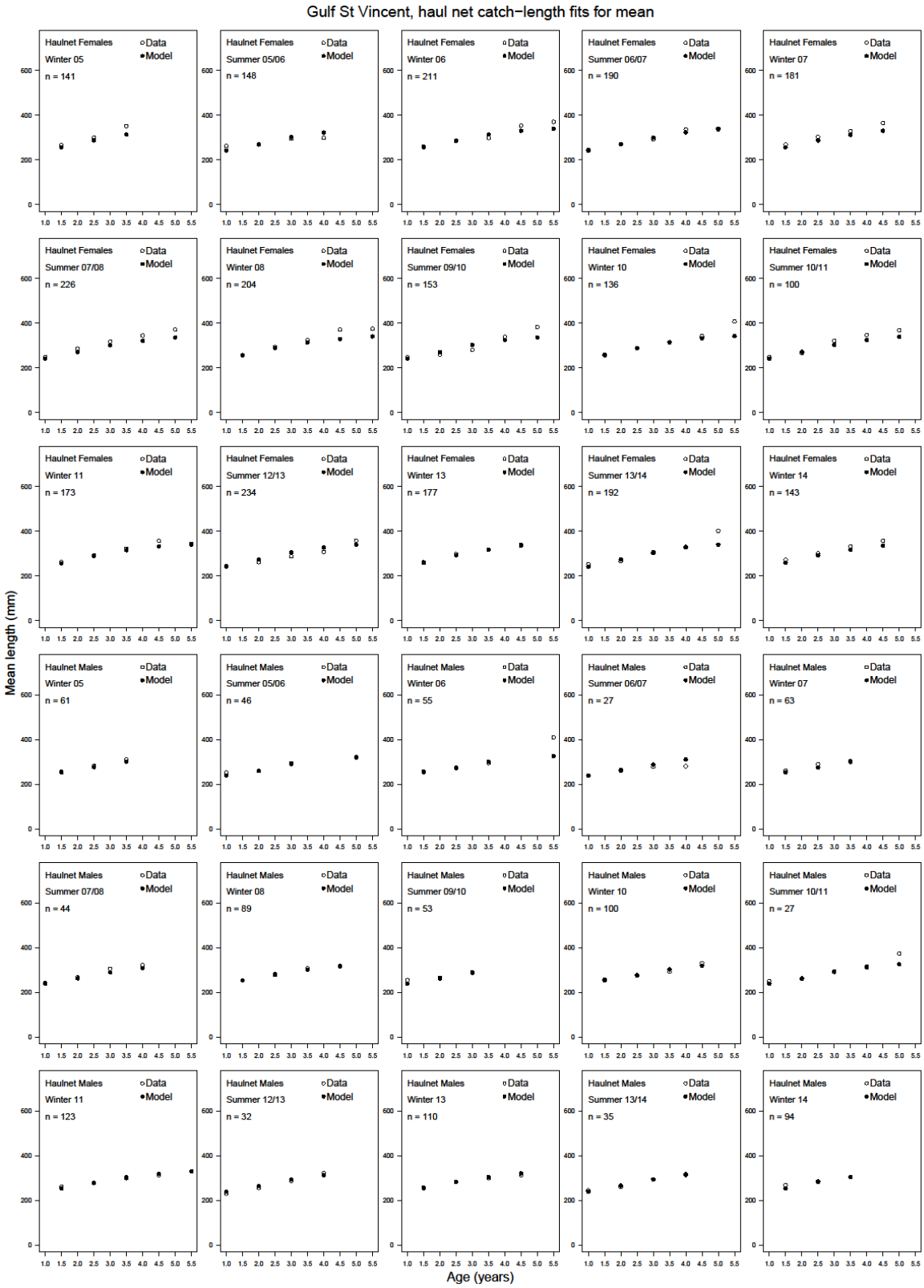

Figure 9.4b. Model fits to catch mean lengths of modelled cohorts from catch samples. The 30 most recent Gulf St. Vincent data sets are shown by sex and half-yearly model time step.