Fisheries

Southern Garfish (*Hyporhamphus melanochir*) Fishery

J. Earl, J. Feenstra, K. Mark, R. McGarvey,
D. Matthews and C. Noell

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SARDI Aquatic and Livestock Sciences
PO Box 120 Henley Beach SA 5022

August 2024

Stock Assessment Report to PIRSA Fisheries and Aquaculture

Government of South Australia
Department of Primary Industries and Regions

SARDI
SOUTH AUSTRALIAN RESEARCH AND DEVELOPMENT INSTITUTE

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EXECUTIVE SUMMARY

This report provides an assessment of South Australia's Southern Garfish stocks for 2022/23. The aims of this report were to: (i) provide brief synopses of the biology of Southern Garfish (*Hyporhamphus melanochir*) and management of the fishery; (ii) review the performance of the fishery; (iii) determine the status of the Garfish resource in the four regional fishing zones – Spencer Gulf (SG), Gulf St Vincent/ Kangaroo Island (GSV/KI), West Coast (WC) and South East (SE); and (iv) identify research needs. Stock status for each zone was determined using a weight-of-evidence approach and the National Fishery Status Reporting Framework (Piddocke et al. 2021).

The stock assessments used fishery and biological data up to 30 June 2023. The stock assessment model ('GarEst') integrated fishery-dependent and biological datasets to produce a time series of 'biological' performance indicators for the SG and GSV/KI fishing zones up to 30 June 2022. Collectively, the indicators of modelled (i) fishable biomass, (ii) harvest fraction (i.e., exploitation rate), (iii) recruitment, and (iv) egg production, underpinned the assessments.

The State-wide commercial catch of Garfish declined to 140 t in 2022/23 (*cf.* 157 t in 2021/22). Like previous years, most of the catch was taken from the SG (53%) and GSV/KI (46%) fishing zones with minor contributions from the WC and SE fishing zones. The low catch was likely associated with a combination of low targeted effort, reflecting a long-term decline in the number of active licences in the fishery and management initiatives aimed at reducing exploitation rates for the two gulf stocks, and constraints in quota trading and/or market-related issues.

Spencer Gulf Fishing zone

Commercial catches in the SG fishing zone are dominated by females, have been low since 2015/16, and were managed within a total allowable commercial catch (TACC) in 2021/22 and 2022/23. The total catch of 74 t in 2022/23 was the lowest on record. Targeted haul net catch per unit effort (CPUE) declined steeply from 2010/11 to 2015/16 but has since recovered to the historic mean, while targeted dab net CPUE was above the historic mean in 2022/23. These results reflect an increasing abundance of Garfish across the zone in recent years.

Modelled fishable biomass (Garfish ≥ 230 mm total length (TL)) increased to 280 t (± 54 t, 95%CI) in 2021/22, which was below the historic mean of 287 t (± 38 t, 95%CI). Harvest fraction continued to decline and reached a low of 35% but has not yet reached the operational target of 30%. Egg production remained at a moderate level. There were slight changes in the age structure for 2022/23 which reflected a reduction in legal minimum length from 250 to 230 mm TL since 1 July 2021 and marginally higher recruitment (i.e., number of fish reaching the 1+ age class) in the last two years.

Despite favourable trends in fishable biomass, harvest fraction and catch rates since 2020 (Smart et al. 2022), harvest fraction has not yet reached the operational target of 30% and there has been no improvement in population age structure. While there is not yet sufficient evidence to warrant a change in status from recovering to sustainable, the management arrangements in place to recover this stock are taking effect and recovery is occurring. This stock is classified as **recovering**.

Gulf St Vincent / Kangaroo Island Fishing Zone

Commercial catches from the GSV/KI fishing zone are dominated by females and have been managed within an annual TACC of 71 t in 2021/22 and 79.8 t in 2022/23. The total catch of 64 t in 2022/23 was the lowest on record. The low catch was associated with low targeted haul net and dab net effort. Targeted catch rates for haul nets (the gear that accounted for 92% of the catch) and dab nets were among the highest on record, reflecting high abundance of Garfish across the zone in 2022/23.

Modelled fishable biomass (Garfish ≥ 230 mm TL) increased for the eighth consecutive year and reached a 15-year high of 248 t (± 56 t, 95%CI) in 2021/22. This represents a biomass increase of 39% since 2014/15 and was associated with a long-term decline in harvest fraction and a steady increase in egg production since 2014/15. Harvest fraction reached 29% in 2021/22 and achieved the operational target of 30%. Egg production has increased steadily since 2014/15 and reached its third highest level on record in 2021/22, while recruitment increased for the second consecutive year. Despite this, there were no signs of improvement in the age structures for 2022/23, which likely reflects the higher proportions of smaller, younger fish in the catch since the reduction in legal minimum size from 250 to 230 mm TL from 1 July 2021.

The current assessment indicates that changes in management arrangements over the last 15 years have effectively recovered the Garfish stock in the GSV/KI fishing zone. Since the last stock assessment, targeted catch rates have increased to historically high levels, fishable biomass has increased to its highest level since 2005/06, harvest fraction has reached the operational target of 30%, and egg production and recruitment have increased. This indicates that biomass is unlikely to be depleted, recruitment is unlikely to be impaired, and the current low level of fishing mortality is unlikely to cause the stock to become recruitment impaired. This stock is classified as **sustainable**.

West Coast Fishing Zone

Southern Garfish catches in the WC fishing zone have been < 3 t in most years since implementation of extensive spatial netting closures across the region in 2005/06, with most of the catch taken using dab nets. The total catch of 0.96 t in 2022/23 was the fourth lowest on record and was associated with historically low targeted effort. Targeted dab net catch rates have been at or above the historic mean over at least the last four years, reflecting a moderate–high relative abundance of Garfish in the areas fished. This stock is classified as **sustainable**.

South East Fishing Zone

The SE fishing zone has been the least productive zone for South Australia’s Southern Garfish fishery since 1983/84. Total annual catches have generally been < 2 t, with contributions to total State-wide commercial catches rarely exceeding 0.3%. As only two licences targeted and landed Garfish in this zone in 2022/23, the catch data are confidential. The total catch of 2.2 t in 2021/22 was associated with record-high targeted dab net catch rates reflecting high abundance of Garfish in the areas fished. This stock is classified as **sustainable**.

Keywords: *Hyporhamphus melanochir*, stock assessment, haul nets, dab nets, halfbeak.

Summary – 2022/23

Southern Garfish

Hyporhamphus melanochir

Species description	Southern Garfish are a productive, fast-growing hemiramphid species (commonly known as ‘halfbeaks’) that is endemic to southern Australia. They form large schools in shallow, inshore marine waters and their abundance is associated with seagrass beds. They are particularly abundant in South Australia’s northern gulfs.
Fishery description	In South Australia, fishing for Garfish predominantly occurs in the two gulf zones with biomass highest in the northern region of each gulf. Haul nets are the dominant commercial gear type. However, due to extensive netting restrictions, dab nets are the dominant gear types used in the southern areas of each gulf and the SE and WC fishing zones where smaller catches occur.
Current assessment program	• Annual catch and effort statistics and trends in a stock summary report. • Length and age structures from market (Adelaide) and industry (regional) samples. • Application of a fully integrated assessment model (‘GarEst’) and production of a stock assessment report every two or three years. • Recreational catch estimates obtained every several years. • Current assessment by weight of evidence. • No information is currently available for Aboriginal and traditional fishing.

Commercial fishery statistics (State-wide)

Fishing Season	Total catch *t*	Total effort *Fisher-days*
2018/19	192	4,873
2019/20	168	4,193
2020/21	182	4,128
2021/22	157	4,295
2022/23	140	3,903

Recreational Catch

Survey	Catch *t (SE)*	Retained *%*	Released *%*
2000/01	133 (14.7)	87%	13%
2007/08	75.1 (13.8)	81%	19%
2013/14	79.2 (21.8)	89%	11%
2021/22	24 (21.8)	81%	19%

	Tier 1 stocks		Tier 3 stocks	
Stock status (fishing zones)	**Spencer Gulf**	**Gulf St Vincent/ Kangaroo Island**	**West Coast**	**South East**
	Recovering	Sustainable	Sustainable	Sustainable
Performance indicators	Catch, effort, CPUE trends, biomass, harvest fraction, egg production, recruitment, age structure		Catch, effort, CPUE trends	

Research needs	The most important research needs for the Southern Garfish fishery and its management include: • Investigate alternative stock assessment model outputs using the Stock Synthesis framework. • Investigate the spatial segregation of male and female Garfish in time and space in both gulfs, relative to the long-term removals of each sex in these areas, and the cumulative effects of this harvesting on virgin egg production and recruitment. • Supplement market sampling with regional and industry-direct sampling to obtain more representative samples (commenced in 2023/24). • Develop appropriate reference points for the new harvest strategy framework that will be linked to definitions of stock status. • Investigate alternative models for CPUE standardisation. • More regular and reliable estimates of recreational catch. • Application of the harvest strategy framework when finalised under the next management plan.

1. INTRODUCTION

1.1. Overview

Stock assessments for South Australia's Southern Garfish (*Hyporhamphus melanochir*) fishery have been produced since 1999, as part of the South Australian Research and Development Institute (SARDI) Aquatic and Livestock Sciences' *Stock Assessment and Monitoring Program* for the South Australian Commercial Marine Scalefish Fishery (MSF) (McGlennon and Ye 1999; McGarvey et al. 2006; 2009; Steer et al. 2012; 2016; 2018). The last stock assessment was completed in 2022 and reported data up to 31 December 2020 (Smart et al. 2022a). Unlike the 2022 report, which assessed stocks over calendar years, this report considers fishery and biological data over financial years (to align with quota management arrangements following a reform of the MSF), extending the assessment up to the end of June 2023. The aims of this report were to: (i) provide brief synopses of the biology of Southern Garfish and management of the fishery; (ii) review the performance of the fishery; (iii) determine the current status of the Southern Garfish resource in the four regional fishing zones – Spencer Gulf (SG), Gulf St Vincent/ Kangaroo Island (GSV/KI), West Coast (WC) and South East (SE); and (iv) identify future research directions.

1.2. Biology of Southern Garfish

1.2.1. Taxonomy and distribution

Southern Garfish (*Hyporhamphus melanochir*) is a surface-associated marine teleost species of the Hemiramphidae family. They are elongated in body shape and have a distinctive lower jaw that forms an extended beak which is much longer than the upper jaw (Figure 1-1). This species is endemic to coastal waters of southern Australia. It is distributed from Shark Bay in Western Australia, along the southern coast of Australia including Tasmanian waters, and as far east as Eden in New South Wales (Kailola et al. 1993). The species forms schools in sheltered bays and shallow, inshore, marine waters to depths of around 30 m, and are often associated with seagrass beds (Robertson and Klumpp 1983; Edgar and Shaw 1995; Earl et al. 2011). They are particularly abundant throughout South Australia's gulf regions (Noell 2005; Noell and Ye 2008; Fowler 2019).

Figure 1-1. Southern Garfish (*Hyporhamphus melanochir*).

1.2.2. Reproductive biology

Southern Garfish has a bipartite life history that is characteristic of most marine fish species. It is a multiple batch spawning species that has a protracted spawning period of six months from October to March (Ye et al. 2002). During the spawning period, only a small proportion (10–20%) of the population are in spawning condition at any given time (Giannoni 2013). This indicates that reproductive activity is asynchronous with small pulses of spawning activity, which is likely a consequence of the large size of the developing oocytes (~3 mm in diameter) and the time required for them to mature (Noell 2005; Fowler 2019). The estimated total length (TL) and age at which 50% of the female population is mature is 215 mm total length (TL) and 17.5 months, respectively (Ye et al. 2002).

The sex ratio of inshore populations of Southern Garfish in South Australia, Victoria, Western Australia, and Tasmania have been consistently biased towards females, with males generally more abundant in offshore waters (Ling 1958; Jordan et al. 1998; Noell 2005; Jones et al. 2002; Fowler 2008; Steer et al. 2012; Fowler 2019). In South Australia, females tended to form large schools in shallow inshore waters (<5 m deep), where they are easily targeted by commercial haul net fishers, while males were relatively dispersed and patchier in distribution, with higher proportions occupying deeper, offshore waters (>5 m deep) (Jones et al. 2002; Fowler 2019). The uneven dispersion of fish by sex at different localities likely reflects differences in active habitat selection and spawning behaviour between the sexes. Early life stages

The eggs of Southern Garfish are negatively buoyant and are adapted for attachment to substrate such as seagrass and macroalgae (Jordan et al. 1998; Noell 2005). Although it is possible that the eggs are moved through attachment to drifting substrate, there is assumed to be greater potential for large-scale transport during the pelagic larval stage. The developing larvae remain near the surface and their movement is likely to be heavily influenced by the physical environment (i.e., tides and wind-driven currents) until the completion of fin formation at around 20 days post-hatch (Noell 2005; Fowler 2019). Thereafter, the late-stage larvae and juveniles can actively influence their dispersal. The juvenile fish develop quickly and, like the adults, are considered largely sedentary in their movement. It is possible that the limited movement of adult fish is a consequence of their obligate relationship with the intertidal seagrass *Zostera muelleri* which constitutes a significant component of the adult diet (Robertson and Klumpp 1983; Earl 2007; Earl et al. 2011).

In 1999 and 2000, a total of 2,079 Southern Garfish from commercial catches in South Australia were aged for a study on age and growth (Ye et al. 2002). There were seven age classes (0+ to 6+ years) that contributed to the commercial catches, but the catches were dominated (89%) by fish from 1+ and 2+ age classes. 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 those of the 1950s (Ling 1958), indicated that historically the fishery was once dominated by fish from 4+ and 5+ age classes, but over numerous years of exploitation, the age structure has become considerably truncated to consist primarily of fish from 1+ and 2+ age classes (Fowler and Ling 2010).

1.2.3. Stock structure

The population dynamics and stock structure of Southern Garfish in South Australia has been investigated using a variety of different approaches. Movement has not been investigated directly through a tagging study because of their fragile nature and susceptibility to injury and mortality as a result of capture and handling. Consequently, movement was inferred through a multi-disciplinary otolith study that involved the analysis of otolith microchemistry (trace elements and stable isotopes) (Steer et al. 2009a) and otolith morphometrics (Steer et al. 2009b; Steer and Fowler 2015), and a concurrent study that considered parasite assemblages (Hutson et al. 2011). The results of these studies suggested that the movement of adult fish was limited and that they remained associated with a particular area or bay during the first few years of their lives. This evidence of restricted movement and site-fidelity underpinned the conceptual model of stock structure for Southern Garfish in South Australia, i.e., that the State-wide distribution was divided into numerous populations that were largely discrete. These populations were: the bays along the West Coast of Eyre Peninsula (WC), Northern Spencer Gulf (NSG), Southern Spencer Gulf (SSG), Northern Gulf St Vincent (NGSV), Southern Gulf St Vincent (SGSV), and the South East (SE) (Steer et al. 2018).

More recently, Fowler (2019) examined the demographics and population connectivity of Southern Garfish in Gulf St Vincent. The study provided fishery-independent evidence that the highest abundances of adult fish were in the northern part of the gulf and that abundance decreased moving southward. This spatial distribution of adults aligned with the distribution and abundance of the seagrass *Z. muelleri* and is consistent with the limited movement of adult fish inferred from the previous otolith-based studies. Furthermore, Fowler (2019) also investigated the spatial distribution of Garfish larvae to provide insight into the processes that replenish the two regional populations (i.e., NGSV and SGSV). The results indicated that there was local retention of larvae in each region. However, the study also identified that a large proportion of larvae produced in SGSV were transported northward and contributed to the replenishment of the population in NGSV (Fowler 2019). Consequently, the conceptual model of stock structure was updated to recognise the importance of larval supply from SGSV to the NGSV population, and the two populations were classified as a single biological stock (i.e., the Gulf St Vincent stock). Although the demographic processes of Garfish in Spencer Gulf were not investigated, it is likely that the processes responsible for population replenishment are similar.

1.3. Description of the fishery

Like other species of ‘halfbeaks’, the Southern Garfish is of excellent eating quality and a highly desired product for consumers. It is an important fishery species of southern Australia, with fisheries also existing in Victoria, Tasmania, and Western Australia. Historically, the national commercial catch for this species has been dominated by South Australia where recent annual catches have been 157–192 t with an approximate value of $2M (EconSearch 2023). This species is also a popular target amongst recreational anglers in these States, with the highest catches taken in South Australia (Lyle et al. 2021).

In South Australia, licence holders from four different commercial fisheries have access to Southern Garfish, i.e., the MSF, the Northern Zone and Southern Zone Rock Lobster Fisheries (NZRLF, SZRLF) and the Lakes and Coorong Fishery (PIRSA 2013). In most years, the MSF accounts for

> 99% of the State's total annual commercial catch of this species, with small catches taken by the NZRLF and SZRLF (Smart et al. 2023).

The MSF is a multi-species, multi-sector fishery that operates in all coastal waters of South Australia, excluding the Coorong Estuary. As of 1 February 2024, there were 197 licence holders in the fishery, who are permitted to take around 60 species using 30 types of fishing gear/devices (PIRSA 2013). Southern Garfish is a major contributor to overall fishery production (by weight) in the MSF (Smart et al. 2022a). Other species such as Southern Calamari (*Sepioteuthis australis*), King George Whiting (*Sillaginodes punctatus*), Western Australian Salmon (*Arripis truttaceus*) and Yellowfin Whiting (*Sillago schomburgkii*) are also major contributors to the catch. The MSF is divided into 58 Marine Fishing Areas (MFAs) for the purpose of statistical reporting and monitoring of commercial fishing activity (Figure 1-2). Some MFAs have been further divided into separate 'sub-blocks'.

South Australia's Garfish fishery, as part of the MSF, is principally located in Spencer Gulf and Gulf St Vincent (Figure 1-2) where commercial fishers target the species using haul nets and dab nets (Figure 1-3). Haul net fishers account for most (80–90%) of the catch in the gulfs, even though their fishing activities are restricted by regulation to waters < 5 m deep. The fishery in the northern parts of the gulfs is dominated by haul net fishing while most areas in the southern parts of the gulfs are closed to haul netting. Subsequently, the dab net fisheries account for most of the catch in the southern parts of the gulfs. Small catches are taken in the State's South East and West Coast.

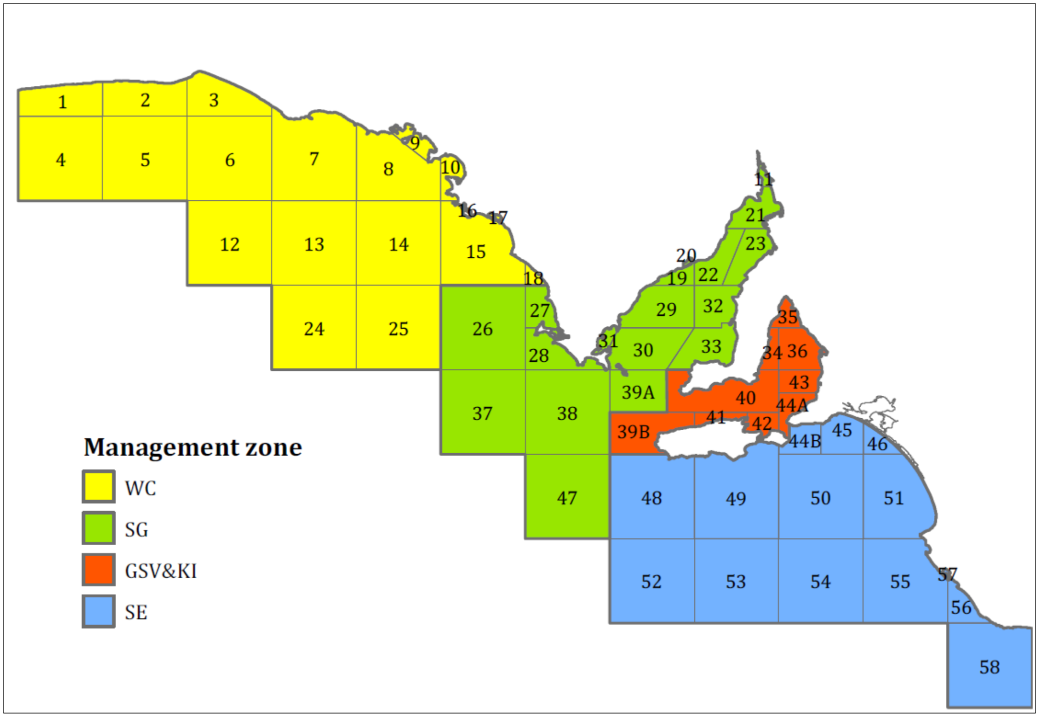

Figure 1-2. The four fishing zones implemented through the commercial MSF reform in July 2021. These are the Spencer Gulf fishing zone (SG), Gulf St Vincent/Kangaroo Island fishing zone (GSV/KI), West Coast fishing zone (WC) and South East fishing zone (SE). The boundaries of each zone are delineated by existing MFA blocks or sub-blocks.

The recreational sector accounts for approximately 12% of South Australia's total catch of Southern Garfish (Beckmann et al. 2023). Fishers from this sector are permitted to use dab nets to target this species, but predominately use line fishing techniques from boats and shore-based platforms.

Garfish are a minor component of Charter Boat catches in South Australia (Durante et al. 2022). A description of the South Australian Charter Boat Fishery is provided in Durante et al. (2022). Estimates of annual catches of Garfish are not available for the Aboriginal traditional fishery.

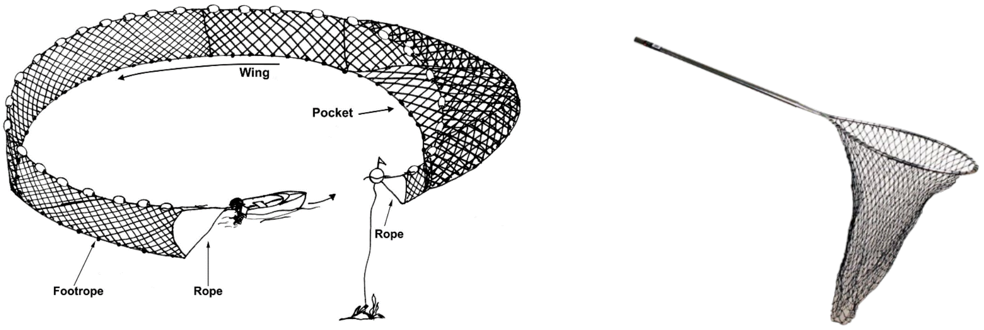

Figure 1-3. Schematic illustrations of a typical haul net (left) and hand-held dab net (right) used by commercial fishers to target Southern Garfish in South Australia.

1.4. Management of the fishery

1.4.1. Legislation

The MSF is managed by the South Australian Government Department of Primary Industries and Regions (PIRSA) Fisheries and Aquaculture in accordance with the ‘Management Plan for the South Australian Commercial Marine Scalefish Fishery’ (PIRSA 2013, hereafter referred to as the ‘Management Plan’) and legislative framework provided within the *Fisheries Management Act 2007*, and subordinate *Fisheries Management (General) Regulations 2017*, *Fisheries Management (Marine Scalefish Fishery) Regulations 2017*, and licence conditions.

1.4.2. Commercial sector

The commercial fishery for Garfish has undergone substantial management changes over the past 50 years that has seen it restructured and limited through gear restrictions and configuration, licensing, spatial and temporal closures, size limits and total allowable commercial catches (TACCs) (Table 1-1, PIRSA 2013). Although most of these changes have been applied broadly to the MSF, there have been a few that have directly impacted the Garfish fishery. Among the most significant changes has been a series of net fishing spatial closures, the first of which were implemented on the West Coast of Eyre Peninsula in 1958. These were followed by a depth-delimited ban in the 1970s when net fishing was restricted to coastal waters less than 5 m deep. Further closures were implemented in 1983, 1994, 1995, 1997 and 2005. In addition, deepwater netting exemptions for a few operators were revoked in 2006. These closures, combined with the implementation of a network of Marine Parks in 2012, have significantly restricted commercial haul net fishers to small areas in the northern parts of SG and GSV (Figure 1-4). In 2015, it was estimated that haul net fishers had access to 465 km^2 of fishable area in GSV, which is 55% less than the 1,028 km^2 that was available in SG (Steer et al. 2016). The fishable area in GSV was further reduced in 2022 following an increase in the size of the Clinton Wetlands Sanctuary Zone (DEW 2022).

An equally significant management change that directly impacted the Garfish fishery was the voluntary buy-back of commercial MSF licences with net endorsements in 2005, with the result of effectively halving the commercial fishing effort through a reduction of licences from 113 to 52, and of effort by 44.7% (Brooks 2010). In addition to the removal of net fishing capacity, six priority areas were closed to net fishing, and as a result, a large number of fishers who did not participate in the licence buy-back were displaced and had to move their operations to adjacent areas. This management initiative was prompted by concerns for the sustainability of Garfish stocks in the northern parts of the gulfs (McGarvey et al. 2006; Brooks 2010).

Table 1-1. Key historical management changes for the Southern Garfish commercial fishery since 2001.

YEAR	MANAGEMENT MEASURE	REGION / ZONE	DETAILS
2001	LML change	State-wide	LML increased from 210 to 230 mm TL.
2005	Fleet reduction	State-wide	Voluntary buy-back of licences = 44.7% reduction of net fishing effort.
	Spatial closures	SG & GSV/KI	Netting closures implemented, largely restricting net fishing to the northern gulfs.
2012–2020	Seasonal closures	SG & GSV/KI	Annual fishery closures in each gulf of 20–80 days.
2015	LML change	State-wide	LML increased from 230 to 250 mm TL for the commercial sector from 1 April 2015. LML remained at 230 mm TL for the recreational sector.
	Gear restriction		Minimum mesh size of haul net pockets increased from 32 to 34 mm for standard knot meshes and from 34 to 35 mm for knotless meshes.
2016	Gear restriction	State-wide	Minimum mesh size of haul net pockets increased from 34 to 35 mm for standard knot meshes.
	Bag and boat limit		Recreational bag and boat limit reduced from 60 and 180 fish, respectively, to 30 and 90 fish.
2017	Gear restriction	State-wide	Only knotted meshes were permitted for haul nets.
2019	Gear restriction	State-wide	Minimum mesh size of haul net pockets increased from 35 to 36 mm.
2021/22	TACC	SG & GSV/KI	ITQs and TACC management commenced
	Seasonal closure		Seasonal closures removed
	Fleet reduction	State-wide	Voluntary licence surrender program
	LML change		LML reduced to 230 mm TL for all sectors
	Gear restriction	WC & SE	Minimum mesh size of haul net pockets reduced from 36 to 32 mm in waters outside of the gulfs. 36 mm maintained for waters inside the gulfs.

In 2001, the legal minimum length (LML) for Southern Garfish was increased from 210 to 230 mm TL. This increase was made to ensure that at least 50% of Garfish at that size would be reproductively mature and therefore had the opportunity to spawn at least once prior to capture (Ye et al. 2002). In 2005, the State Government implemented a voluntary net buy-back scheme that aimed to reduce commercial haul net fishing effort with an emphasis on those that targeted Garfish (PIRSA 2013). Of the 113 licence holders with haul net endorsements at that time, 61 (54%) accepted the offer and their endorsements or licences were surrendered. The surrendered licences accounted for 45% of haul net effort from 2000 to 2003 (Steer et al. 2016).

In 2013, a new Management Plan was enacted for the MSF (PIRSA 2013). This plan included a harvest strategy for the Garfish fishery that acknowledged the poor status of the stocks at that time and whose principal aim was to ensure the long-term sustainability of the catches. It involved a scheme of operational objectives, time frames, biological performance indicators (BPIs) and trigger reference points (TRPs) that aimed to reduce the high levels of exploitation rate and increase egg production to acceptable levels. Although no specific management arrangements were prescribed to achieve these TRPs, an adaptive management approach was outlined to consider the management arrangements to reach the operational targets. Through collaborative research and consultation amongst PIRSA, SARDI and the industry, it was agreed that a combination of effort and gear-based management strategies should be adopted (PIRSA 2013). 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 for both gulfs was subsequently increased to 38 days in 2013, 40 days in 2014, 60 days in 2016 and 80 days in both 2018 and 2019, although no seasonal closure was applied to Spencer Gulf in 2019. Similarly, the minimum regulated mesh size of the pocket of haul nets was sequentially increased from 30 mm in 2013 to 36 mm in 2019, while the LML for commercial fishers was increased from 230 to 250 mm TL in 2015.

In 2021, the MSF underwent a major reform that included ‘three pillars’: regionalisation, rationalisation, and unitisation (Smart et al. 2022b). Four regional fishing zones were created – Spencer Gulf (SG), Gulf St Vincent/Kangaroo Island (GSV/KI), the West Coast (WC) and the South East (SE) (Figure 1-2). Garfish stocks are now managed according to these zones through a tiered management framework that assigns each stock to a tier based on its importance according to several biological, social, and economic indicators (Smart et al. 2022b). Stocks in Tier 1 are managed using a TACC with some stocks further managed via individual transferable quotas (ITQs). Tier 2 and Tier 3 stocks are managed via input controls without TACCs. Through this process, Garfish stocks in the GSV/KI and SG fishing zones were assigned a Tier 1 status, while the WC and SE stocks were assigned a Tier 3 status. The TACCs for 2021/22 for the GSV/KI and SG fishing zones were set at 71 t and 100 t, respectively, as recommended by the Marine Scalefish Fishery Management Advisory Committee (MSFMAC) based on the 5-year average catch from 2015 to 2019. As a result of post-reform quota allocation reviews undertaken for a small number of licences, subsequent adjustments were made to these TACC levels for 2022/23, which increased them to 79.8 t and 107.2 t, respectively.

Several management measures were also reconsidered in 2021, following the implementation of TACCs for the Tier 1 stocks. The haul net pocket mesh size was maintained at 36 mm for the GSV/KI and SG fishing zones but reduced to 32 mm in all other areas. Additionally, all seasonal closures were removed and the LML was reduced to 230 mm TL to reduce discarding from the larger mesh size in the gulf zones. Full details of the reform and its implications for future assessments are available in Smart et al. (2022b).

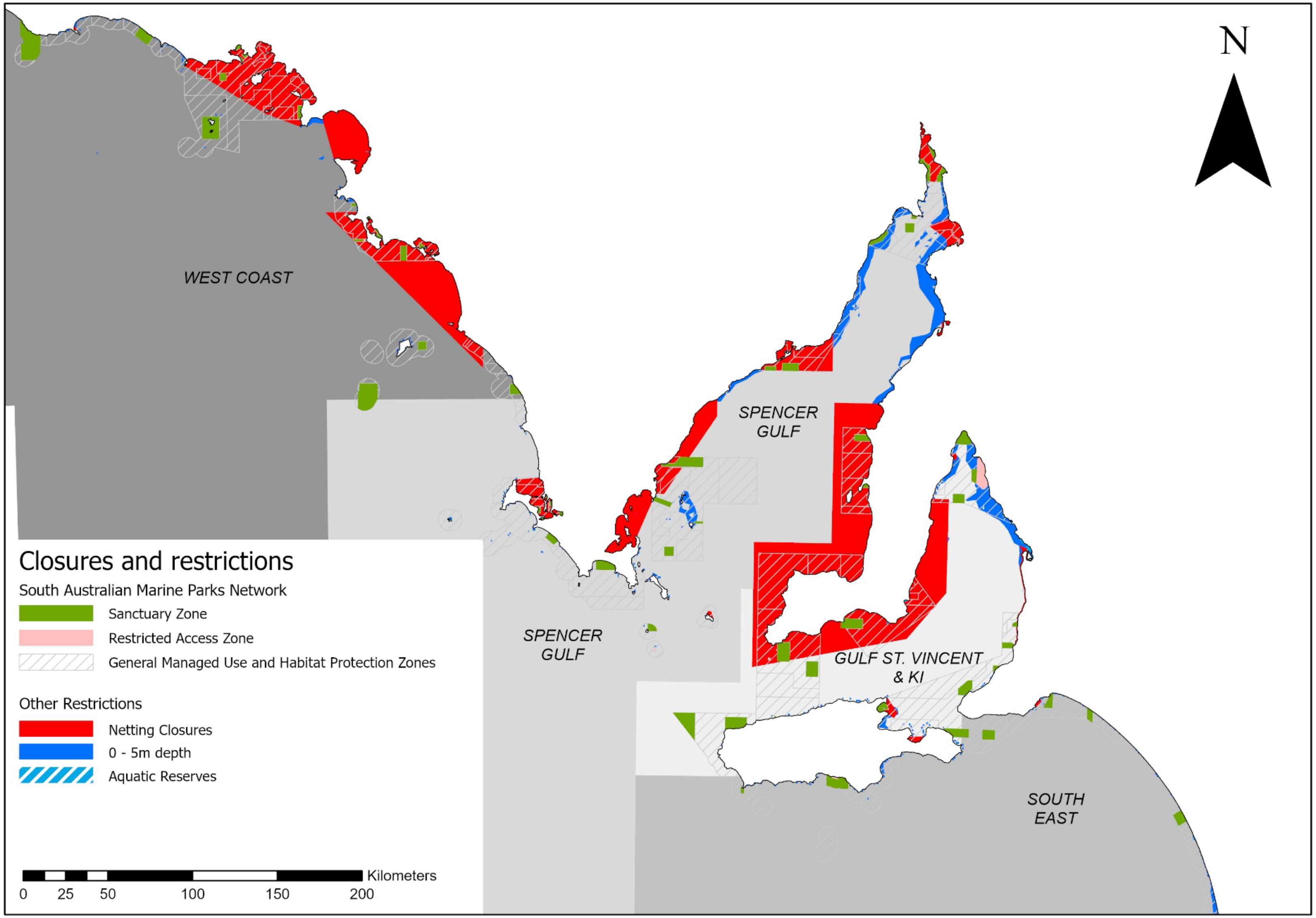

Figure 1-4. Map of South Australian coastal waters showing the four Marine Scalefish Fishery fishing zones (grey shaded) – West Coast, Spencer Gulf, Gulf St. Vincent/ Kangaroo Island and South East, the netting closures and restrictions that relate to the commercial haul net sector for Southern Garfish, including those associated with the South Australian Marine Parks Network, and the areas in the northern parts of the gulfs that remain open to haul net fishing (i.e., areas 0–5 m depth).

1.4.3. Recreational sector

The recreational fishery for Garfish is not licensed and is managed through a combination of input and output controls. These controls aim to ensure that total catch is maintained within sustainable limits and that recreational access to the fishery is equitably distributed between recreational participants (PIRSA 2013). Bag and boat limits (when three or more people are onboard) apply to all State waters. In 2016, the recreational bag and boat limit of Garfish was halved from 60 and 180 fish to 30 and 90 fish, respectively. The LML of 230 mm TL applies to the recreational sector and has remained consistent since 2001, despite changes for the commercial sector (Table 1-1). Management arrangements also comprise general gear restrictions. All management measures in place for the recreational sector apply to the Aboriginal traditional fishing sector for Garfish.

The South Australian Charter Boat Fishery is a commercial operation that provides recreational fishers access to South Australia's fisheries resources, including Garfish. It is a limited-entry fishery with 82 licence holders of which 47 were active in 2022/21 (Durante et al. 2022). Management arrangements include both input and output controls. Input controls include gear limits per passenger, seasonal and spatial closures, and the prohibition of licence holders or crew undertaking fishing activities whilst operating a charter (other than assisting clients). Output controls for Garfish include a LML of 230 mm TL and a bag limit of 30 fish, consistent with the recreational sector.

1.5. Research program

There are three primary components to the research program for Southern Garfish provided by SARDI Aquatic and Livestock Sciences to PIRSA Fisheries and Aquaculture. These are to: (1) analyse and interrogate the commercial catch and effort data reported in logbooks; (2) maintain the ongoing catch sampling program at the South Australian Fishermen's Co-operative Limited (SAFCOL) fish market in Adelaide; and (3) periodic stock assessment reports that integrate the fishery and biological data, including outputs from the computer-aided fishery assessment model (GarEst), and identify knowledge gaps and future research priorities. The research program for 2022/23 was discussed at various times with fisheries managers and industry representatives, and subsequently presented as research scopes to confirm their understanding of proposed research and deliverables. This ensured that the proposed research was consistent with the needs of PIRSA Fisheries and Aquaculture and met the obligations in the *Fisheries Management Act 2007*.

There have been numerous projects focused on addressing knowledge gaps in the understanding of Southern Garfish biology and ecology identified in previous assessment reports. These have covered aspects of population dynamics (Jones et al. 1990; Ye et al. 2002; Noell 2005; Earl 2007; Fowler et al. 2008; Fowler and Ling 2010; Earl et al. 2011; Giannoni 2013; Fowler 2019); stock structure (Steer et al. 2009a; Hutson et al. 2011); gear selectivity (Steer et al. 2011); and fisheries modelling (McGarvey and Feenstra 2004; McGarvey et al. 2007).

1.6. Information sources

1.6.1. Commercial fishing logbooks

The main source of information about the commercial MSF for Garfish is from logbooks that are completed by licensed fishers at the end of each fishing day. Fishers are required to log specific details about their fishing activities including 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 monthly, but since 2003 fishers have been required to provide a daily log of fishing activity. These records must be submitted monthly to PIRSA Fisheries and Aquaculture where they are entered into the Marine Scalefish Fishery Information System. This database is routinely reviewed and cross-checked to ensure that the data satisfy management and research needs (Vainickis 2010). The current database is a compilation of catch and effort data collected from 1 July 1983 to the present and provides the primary source of data used for stock assessment of Southern Garfish. The fishery data used in this assessment were finalised up to 30 June 2023.

1.6.2. Recreational fishing surveys

Quantifying the recreational sector's contribution to the State's catch is important to determine stock status. There have been five recreational fishing surveys carried out in South Australia over the past 30 years. The first was a creel survey undertaken during 1994–1996 (McGlennon and Kinloch 1997), and subsequent telephone/diary surveys were undertaken in 2000/01 (Henry and Lyle 2003), 2007/08 (Jones 2009), 2013/14 (Giri and Hall 2015) and 2021/22 (Beckmann et al. 2023). Of these five surveys, only the results from the four telephone/diary surveys can be reliably compared as the data were collected using similar methodology. Estimates of recreational catch from these surveys include those taken onboard charter boats (Beckmann et al. 2023).

1.6.3. Charter Boat Fishery logbooks

All charter boat operators are required to record data relating to their fishing activities, including the number of fishers on board, species targeted, species caught, number of each species caught, weight of catch for some species, method of capture and MFA fished (Durante et al. 2022). The logbook records are submitted monthly to PIRSA Fisheries and Aquaculture, where data is entered into a database that is routinely reviewed to ensure it meets the needs of management and researchers (Vainickis 2010). Charter boat data used in this assessment were collected from 1 July 2007 to 30 June 2023.

1.6.4. Sampling of commercial catches for biological data

There have been several sampling programs for Garfish throughout the history of the fishery that have provided biological data for assessment. Size and age data were collected in 1954/55 for both Gulf St Vincent and Spencer Gulf (Ling 1958); 1986/87 for Gulf St Vincent (Jones et al. 1990); 1998/99 for both gulfs (Ye et al. 2002); and 2016–2018 for Gulf St Vincent (Fowler 2019). Since 2005/06, SARDI has relied heavily on the SAFCOL fish market to access commercial catch samples of Garfish from across South Australia (McGarvey et al. 2006). With the exception of a 6-month hiatus in 2008 and again in 2012, this market sampling program for Garfish has occurred almost weekly since July 2005 and has primarily targeted samples from the northern parts of the gulfs, where the majority of the catches are taken (Smart et al. 2022a). The biological data presented in this assessment were finalised up to 30 June 2023, while those up to September 2022 were input to the stock assessment model ('GarEst').

1.6.5. 'GarEst' stock assessment model outputs

A computer-aided fishery stock assessment model, 'GarEst', was developed for the South Australian Southern 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 consistently accounted for > 98% of the State-wide Garfish catch over time (Smart et al. 2022a). The 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 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 estimates of fishable (legal-sized) biomass, egg production, recruitment, and harvest fraction (PIRSA 2013).

1.7. Harvest strategy

The harvest strategy for Garfish outlined in the Management Plan (PIRSA 2013) reflects sustainability concerns raised for both gulf stocks in the 2009 stock assessment (McGarvey et al. 2009). These concerns related to the lack of older fish in catches taken in the northern parts of the gulfs as a result of sustained high levels of exploitation, and GarEst model outputs for both gulf stocks that indicated low fishable biomass, high exploitation rates, and a sustained period of low recruitment and low egg production. As such, the harvest strategy outlines the process for monitoring fishery performance and measuring the effectiveness of the management arrangements that have been implemented to rebuild the stocks in the GSV/KI and SG fishing zones. It defines operational objectives, performance indicators and reference points to assess the regional fisheries and enable their long-term sustainable harvest. Two key objectives for managing the harvest of Garfish within the commercial MSF are considered in this assessment. These are: (1) ensure the long-term sustainable harvest of Garfish by rebuilding stocks during specified timeframes; and (2) maintain catches within agreed allocations for each sector.

1.7.1. Performance indicators

To address the first management objective, the harvest strategy defines three tiers of performance indicators to monitor the performance of the Garfish fishery over time. Linked to each performance indicator is a set of operational targets and trigger reference points that, if breached, elicit a management response to be determined by fisheries management. Trends in model estimates of ‘harvest fraction’ and ‘egg production’ constitute the primary performance indicators, with their operational objectives set to reach ≤ 30% and ≥ 30% by 2020, respectively. The secondary performance indicators relate to rebuilding stocks through improving the overall age structure of the population and reducing effort within the fishery. The specific operational objectives were to display an increasing trend in the relative proportion of older (ages 3+) fish within the populations through each triennial stock assessment cycle and to reduce total haul net effort by ≥ 13% by 2014. There are also a range of other performance indicators and trigger reference points relating to trends in commercial catch and effort statistics and model estimates of ‘fishable biomass’ and ‘recruitment’. The performance indicators and reference points are not explicitly linked to stock status. Rather, collectively, they contribute to a ‘weight-of-evidence’ approach to determine stock status, consistent with the National Fishery Status Reporting Framework (Section 1.8.1; Piddocke et al. 2021).

1.7.2. Allocation of access

The *Fisheries Management Act 2007* states that the Management Plan must specify the allocation of the Southern Garfish resource among the various sectors within the MSF. Allocated shares were derived from the catch data collected in 2007/08 (Jones 2009). To address the second management objective, three trigger limits have been determined for Garfish. The first trigger limit (Trigger 1) relates to the allocated shares of the entire fishery and is assessed approximately every five years to encompass up-dated recreational catch and effort statistics. The remaining two trigger limits (Trigger 2 and 3) 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.

1.7.3. Development of new harvest strategy framework

A draft harvest strategy framework (HSF) for the MSF developed in 2023 is currently being refined and is expected to be implemented as part of the next Management Plan in 2025 (PIRSA 2023). The HSF describes the performance indicators for measuring status for Tier 1 (e.g., Garfish in SG and GSV/KI fishing zones), Tier 2 and Tier 3 (e.g., Garfish in WC and SE fishing zones) stocks. It also describes the use of these indicators, and reference points and decision rules for determining the recommended biological catch (RBC), recommended biological commercial/recreational catch (RBCC/RBRC) and, where in place, total allowable commercial/recreational catch (TACC/TARC) for stocks ranging from ‘data rich’ (category 1) to ‘data poor’ (category 6). Where possible, the framework will aim to determine the level at which stock biomass becomes depleted relative to the unfished biomass and associated reference points, and determine the appropriate level of fishing mortality (or harvest fraction) that theoretically ensures the relative biomass is at or moving towards a target reference point. The decision rule that describes this relationship between relative biomass and the subsequent harvest fraction is known as the ‘hockey stick rule’.

1.8. Determination of stock status

The status of South Australia's Southern Garfish stocks is assigned using the National Fishery Status Reporting Framework (Table 1-2, Piddocke et al. 2021). The current harvest strategy for Garfish in the Management Plan (PIRSA 2013) lacks an index that explicitly defines stock status and does not provide a pre-defined limit reference point that determines when the stocks are depleted (i.e., recruitment is impaired because the fishable biomass no longer has the reproductive capacity to replenish itself). Consequently, assessments of stock status for Southern Garfish use a weight-of-evidence approach that considers: (i) commercial fishery statistics; (ii) recreational fishery data, including charter boat data; and (iii) fishery size and age structures. This information is considered at two spatial scales, i.e., the State-wide scale, and the scale of regional fishing zone. For the SG and GSV/KI fishing zones (Figure 1-2), these data sources are incorporated into the GarEst stock assessment model which provides estimates of four biological performance indicators (fishable biomass, recruitment, harvest fraction and egg production) specified in the Management Plan (PIRSA 2013). Estimates of these indicators are assessed against prescribed trigger reference points, which along with recent trends in commercial fishery statistics, provide the fundamental information for the weight-of-evidence assessments of stock status. For the WC and SE fishing zones (Figure 1-2), the weight-of-evidence assessment of stock status place considerable emphasis on recent trends in commercial fishery statistics and the assessments of these data against trigger points prescribed in the Management Plan (PIRSA 2013).

1.8.1. National Fishery Status Reporting Framework

A national stock status classification system is used for the assessment of key Australian fish stocks (Piddocke et al. 2021). 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 and subsequent growth is significantly compromised. The system combines information on both the current stock size and level of exploitation into a single classification for each stock against defined biological reference points. Each stock is then classified as: sustainable, depleting, recovering, depleted, undefined, or negligible (Table 1-2). PIRSA has adopted this classification system to determine the status of all South Australian fish stocks.

Table 1-2. Classification scheme used to assign fishery stock status. The description of each stock status and its potential implications for fishery management are also shown (Piddocke et al. 2021).

	Stock status	Description	Potential implications for management of the stock
🟩	**Sustainable**	Biomass (or proxy) is at a level sufficient to ensure that, on average, future levels of recruitment are adequate (recruitment is not impaired) and for which fishing mortality (or proxy) is adequately controlled to avoid the stock becoming recruitment impaired (overfishing is not occurring).	Appropriate management is in place.
🟨	**Depleting**	Biomass (or proxy) is not yet depleted and recruitment is not yet impaired, but fishing mortality (or proxy) is too high (overfishing is occurring) and moving the stock in the direction of becoming recruitment impaired.	Management is needed to reduce fishing mortality and ensure that the biomass does not become depleted.
🟧	**Recovering**	Biomass (or proxy) is depleted and recruitment is impaired, but management measures are in place to promote stock recovery, and recovery is occurring.	Appropriate management is in place, and there is evidence that the biomass is recovering.
🟥	**Depleted**	Biomass (or proxy) has been reduced through catch and/or non-fishing effects, such that recruitment is impaired. Current management is not adequate to recover the stock, or adequate management measures have been put in place but have not yet resulted in measurable improvements.	Management is needed to recover this stock; if adequate management measures are already in place, more time may be required for them to take effect.
▨	**Undefined**	Not enough information exists to determine stock status.	Data required to assess stock status are needed.
	Negligible	Catches are so low as to be considered negligible and inadequate information exists to determine stock status.	Assessment will not be conducted unless catches and information increase.

2. METHODS

The information sources considered in this stock assessment were: commercial fishery statistics; recreational fishery data; charter boat fishery statistics; annual length and age data from commercial catch sampling; and estimates of the performance indicators prescribed for Garfish in the Management Plan (PIRSA 2013), including fishable biomass, harvest fraction, virgin egg production and recruitment.

2.1. Commercial fishery statistics

All commercial catch and effort data relating to Garfish reported by MSF, NZRLF and SZRLF licence holders from 1 July 1983 to 30 June 2023 were aggregated to provide annual totals (by financial year) at the State and fishing zone levels (Figure 1-2), and estimates of catch per unit effort (CPUE) at the fishing zone level. For the SG, GSV/KI and WC fishing zones, these data were also interrogated for the two main gear types used to target Garfish – haul nets and dab nets, while only the data for dab nets were considered for the SE fishing zone. Fishing effort was reported in 'fisher-days', which equates to the number of days a licensed 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 targeted CPUE ($kg.fisher\text{-}day^{-1}$) for each gear type, which provide indices of relative abundance.

Since 2003, a second gear-specific measure of fishing effort has been reported in logbooks by fishers using haul nets and dab nets. The additional effort measure for haul nets is the number of hauls, while for dab nets, it is the number of hours fished. This enabled calculations of additional measures of targeted CPUE for haul nets and dab nets, based on $kg.haul^{-1}$ and $kg.net\text{-}hour^{-1}$, respectively. These new indices of relative abundance for Garfish are considered more reliable than those based on fisher-days, because they account for differences in fisher behaviour (e.g., the number of haul net hauls, and number of dab net hours fished) among fishing days. The presentation of commercial fishery data was limited by constraints of confidentiality, i.e., data could only be presented when aggregated for five or more fishers.

2.2. Recreational fishery statistics

The specific details of the methodology used in each of the four recreational fishing surveys considered in this assessment can be found in their respective reports (2000/01: Henry and Lyle 2003, 2007/08: Jones 2009, 2013/14: Giri and Hall 2015, 2021/22: Beckmann et al. 2023). Unfortunately, not all the regional reporting boundaries that were used in the surveys aligned with South Australia's MFAs. For consistency, the recreational survey data were arranged to align as closely as possible to the four fishing zones considered in this assessment (GSV/KI, SG, WC, SE).

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, the 2007/08 and 2013/14 surveys from November to October, and the 2021/22 survey from March 2021 to February 2022. To accurately determine the relative contribution of the recreational sector to the total State-wide catch, data from the commercial sector were extracted from the same periods.

The 2000/01 survey data were re-analysed by Steer et al. (2016) using more precise region-specific mean harvest weight for Southern Garfish, and as a consequence, the results differ slightly from those in the 2000/01 report (Henry and Lyle 2003). For the 2021/22 survey, regional average weights of Garfish landed by recreational fishers were obtained through on-site sampling to estimate the total harvest weight for each fishing zone (Table 2-1). For example, separate estimates of average fish weight for NSG and SSG were multiplied by the total number of Southern Garfish harvested from each region to estimate the total harvest weight for the Spencer Gulf Fishing Zone.

Table 2-1. Regional average weights (g) for Southern Garfish sampled during on-site sampling for the 2021/22 recreational fishing survey (from Beckmann et al. 2023). Regions: NSG (Northern Spencer Gulf), SSG (Southern Spencer Gulf), SGSV/KI (Southern Gulf St Vincent/Kangaroo Island), NGSV (Northern Gulf St Vincent). SE = standard error.

Fishing Zone	Region	Sample (*n*)	Average weight (g)	SE
Spencer Gulf	NSG	155	74.90	1.44
	SSG	240	90.67	1.73
Gulf St Vincent/KI	SGSV/KI	179	94.61	2.34
	NGSV	247	83.53	3.81
West Coast		51	105.57	3.61
South East		179	94.61	2.34

2.3. Garfish length and age data

Commercial catch sampling for Garfish has been done weekly at the SAFCOL fish market since July 2005, when it was initiated in the lead up to the 2006 stock assessment (McGarvey et al. 2006). Catches from around South Australia arrive at SAFCOL in the morning of each weekday and are auctioned to seafood retailers and wholesalers on the same morning. Generally, once per week a team of SARDI researchers sample and/or obtain biological information from the catches prior to the morning auction. Efforts were made to access catches from the northern regions of both gulfs to ensure that the information collected was representative of the fishery. Occasionally, samples from the southern parts of the gulfs were also obtained, although these sample sizes were typically much smaller than for the northern parts of the gulfs.

A two-stage sampling protocol was used to process the individual catches. First, up to 50% of the boxes containing Garfish caught by a licence holder were randomly selected for sampling. Then, from each box, a random sample of fish with combined weight of 1 kg were measured to obtain size information, whilst a separate random sample of up to three fish were purchased for further analysis, including ageing. In the laboratory, each purchased fish was measured for TL and standard length to the nearest mm, weighed to the nearest 0.01 g, and then dissected to determine its sex and stage of reproductive development using the criteria of Ling (1958). The sagittae (i.e., the largest pair of otoliths) were removed and subsequently used for age determination. For this, one otolith from each fish was embedded in resin and sectioned using a diamond saw to produce a thin transverse section. This was mounted on a microscope slide and its structure was interpreted using low power microscopy by counting opaque zones.

The process of age determination was developed by Ye et al. (2002), who determined that the periodicity of increment formation in the otoliths of Southern Garfish was annual, and that opaque zones formed during spring (September–December). It involved interpretation of opaque zone counts, determination of edge types, assumption of a universal birthdate of 1st January (the middle of the spawning season for Southern Garfish) and a formula that considers this information and capture date to estimate age in months (Ye et al. 2002). Otolith edge types were assessed to be either opaque or translucent (hyaline from 2005 to 2008), whilst those with translucent edges were judged to be either narrow (0–30%), medium (30–70%) or wide (>70%), based on the distance from the last opaque zone to the otolith edge, relative to the width of the preceding increment.

The formula used to estimate age (in months) was:

$$Age_m = 12N^* + M_c,$$

where Age_m is age in months, N^* is the modified number of opaque zones (N) modified by edge type and capture date, and M_c is the calendar month number of the capture date. The modified value N^* was a function of the observed number of opaque zones N that is dependent on the edge type and capture date of the fish. For fish caught between August and December with otolith edges of translucent-narrow, opaque or hyaline (H+), 12 months was subtracted from the estimated age (i.e., $N^* = N - 1$), as the last opaque zone had only recently formed. This also applied to fish caught in November/December with a translucent-medium edge. Alternatively, for fish captured in January with edges of translucent-wide or hyaline (H), 12 months was added to the estimated age (i.e., $N^* = N + 1$), as they were expected to have deposited a new opaque zone by this time.

Annual estimates of fishery size and age structures were generated for the GSV/KI and SG fishing zones. For each zone, separate size and age structures were produced for haul net and dab net catches. An age-length key was developed to convert the sample proportions by TL into proportions by age for each zone. Monthly ages were transformed to integer ages by converting them to decimal ages in years and rounding down to the nearest whole age.

2.4. Stock assessment model – 'GarEst'

2.4.1. Model inputs - fitting the model to data

The stock assessment of Garfish is supported by a sex-age-and-length-structured stock assessment model – 'GarEst'. This model uses the slice partition algorithm (McGarvey et al. 2007) and a quarterly model timestep to account for length selective exploitation from gear selectivity and the LML. As with the last assessment, the two GarEst model regions were aligned with the new fishing zones implemented through the reform of the MSF (Figure 1-2). Specifically, the model was fitted to data from the MFAs that belong to the SG and GSV/KI fishing zones. These fishing zones combined both the northern and southern areas from each gulf (Figure 1-2), with most of the data on population structure and fishing activity for each zone corresponding with the northern areas from each gulf where fishable biomass and fishing activity is highest. The model outputs are used to support the stock status classifications of the SG and GSV/KI fishing zones, as per the previous assessment (Smart et al. 2022a).

The principal quarterly input data for the GarEst model parameter estimation program are: (1) commercial catch and effort totals from October 1983 to September 2022, (2) fish sex, length, and age distributions from commercial catch samples from July 2005 to September 2022, (3) total recreational catch estimates based on the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) and South Australian Recreational Fishing Surveys (Jones 2009; Giri and Hall 2015; Beckmann et al. 2023), (4) charter boat logbook catch and effort totals from July 2007 to September 2022, (5) fish sex, length, and age distributions from fishery-independent samples (Fowler 2019) and (6) fish sex, length, and age distributions from commercial catch samples from an FRDC Project completed in 2002 (Ye et al. 2002).

Given the multi-gear and multi-sector nature of the fishery, the GarEst model partitions catch and effort data into five ‘effort types’. These are: ‘Effort type 1’ – commercial MSF effort using haul nets to target Garfish; ‘Effort type 2’ – commercial MSF effort using haul nets to target species other than Garfish, including with ‘Any target’ recorded in logbooks and less than half (<50%) of the total catch weight was Garfish; ‘Effort type 3’ – commercial MSF effort using dab nets and other minor gears, regardless of the target species; ‘Effort type 4’ – charter boat fishing effort from 2007 onwards; and ‘Effort type 5’ – recreational fishing effort. Note, that ‘Effort type 1’ also includes commercial MSF effort using haul nets from 1 October 2005 onwards (subsequent to the voluntary net buy-back scheme) with ‘Any target’ recorded in logbooks and half or more (≥50%) of the total catch weight was Garfish. This was to account for fishers who can catch multiple commercial species in a single fishing event and are sometimes non-specific in their target species. These ‘effort types’ were also used to stratify catch and effort metrics used in the model.

The GarEst model treats a ‘model year’ as beginning on 1 October to align with the summer spawning of Garfish, and defines the quarters of a model year as October-December, January-March, April-June, July-September. Model runs were conducted in quarterly time steps to account for seasonal variation in CPUE, growth and recruitment, and extended from 1 October 1983 to 30 September 2022. The previous assessment also used quarterly time steps (Smart et al. 2022a), but prior to that a half-yearly time step was used. A quarterly time step increases the model’s temporal resolution, permitting: (1) the capture of seasonality in growth, which is now estimated and accounted for, (2) separation of the catch, effort and CPUE by quarter, which show relatively distinct and consistent seasonal differences (see monthly trends plotted in Figure 3.7, McGarvey et al. 2009), and (3) an increase in the length-partition resolution by computing Garfish number for twice as many slices spanning each cohort's length-at-age distribution.

Four surveys of South Australia's recreational fishery – undertaken in 2000/01 (Henry and Lyle 2003), 2007/08 (Jones 2009), 2013/14 (Giri and Hall 2015) and 2021/22 (Beckmann et al. 2023) – were used to model the contribution of this sector to the total Garfish catches. Recreational catch totals in the years between the three surveys were assumed to vary linearly between the quarterly estimates of 2000/01 and 2007/08, between 2007/08 and 2013/14, and between 2013/14 and 2021/22 (Appendix 2). For all preceding years, estimates of recreational catch were assumed to be constant at the 2000/01 level. The 2022/23 catch was fixed at the 2021/22 estimate.

Two levels of effort standardisation were undertaken for GarEst (Appendix 1). First, the catch rate for 'Effort type 1' was standardised using a generalised linear model (GLM) to then derive a standardised effort from the catch statistics. Second, catchability parameters were directly estimated by GarEst commercial effort type, seasonal half-year, gulf, and sex (Appendix 6.1.2). The catchability parameters for the haul net effort types (1 and 2) were estimated separately for the periods < 2005 and ≥ 2005. This allowed the model to account for long-term changes in modelled catch rates that were not related to changes in Garfish abundance, such as the fishery management changes implemented in 2005 (Table 1-1) and which may not have been fully captured by the effort standardisation process.

As per the previous assessment, the model also includes sex, length, and age data from an FRDC fishery-independent sampling project (Fowler 2019). Between 2016 and 2019, in Gulf St Vincent, Garfish were sampled near the surface using dab nets. Sampling was performed in 13 localities, each of which involved 15 transects divided between shallow (depth of 0–5 m), mid (depth of 5–10 m), and deep water (depth of 10–15 m) up to 20 km from shore. Sampling was undertaken twice at each location, once during spring/summer and once during autumn/winter. Sampled fish were measured for length, and a subset were aged and sexed. These proportions by sex and age were fitted in the present assessment model for adult Garfish, specifically those ≥ 210 mm TL, whose population numbers are represented by length slice in GarEst. These data were fitted over quarterly model time steps from October-December-2016 to July-September-2018 (Appendix 5). For full details on the fishery-independent sampling, refer to Fowler (2019).

2.4.2. Model outputs - estimates of performance indicators

After the GarEst model has been fit to the input data, annual model estimates were produced for four BPIs: fishable biomass, egg production, recruitment, and annual harvest fraction. Annual model estimates are presented in financial years, consistent with the rest of this stock assessment report, even though the GarEst model uses quarterly timesteps based on 'model years'.

Fishable biomass in each financial year was computed as the mean of the four quarterly biomass estimates of Garfish equal to and above the LML at the time. The sizes of fish that constitute the fishable biomass has changed over time due to the changes in LML that occurred in 2001 (from 210 to 230 mm TL), 2015 (from 230 to 250 mm TL) and 2021/22 (from 250 to 230 mm TL). For comparison, modelled estimates of biomass comprising fish of 210 mm TL and above (i.e., 'biomass ≥ 210 mm TL'), were also produced and presented to provide comparable biomass estimates across time. However, from 2015/16 onwards when the LML was increased, this 210+ definition of adult biomass includes a component of the population below the LML and was not considered useful given the current LML of 230 mm TL. The annual harvest fraction was computed as the sum of the model estimated catch in weight of the fishery in each financial year divided by the annual fishable biomass.

Annual recruitment is defined as the number of Garfish of each sex in each summer year class that survived to age one year (i.e., the age when the fastest growing fish are expected to reach 210 mm TL) and contributed to the harvestable biomass (Appendix 6.4.1). The total number of recruits in each cohort is apportioned into male and female based the proportion of each sex in catches. This approach approximates biological processes that influence the size, age and sex of Garfish available to harvest in areas < 5 m water depth. In the recruitment time-series figures, the year shown on the x-axis is the year (the January birthdate) the cohort was spawned (Figure 3-6c; Figure 3-10c). As the biomass of each stock is typically dominated by a single year class in any given year, estimates of fishable biomass and other BPIs require that year class to be fully available to the fishery before those estimates can become reliable. This requires data from subsequent years where each year class is tracked through the annual age structures. As this cannot occur for the 2022-year class, this assessment presents model BPI estimates up to the 2021/22 financial year (July 2021-June 2022).

Percent virgin egg production by region was computed as a ratio of estimated yearly total 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 100-year projection run of GarEst with catchability (and therefore also fishing mortality) set equal to zero, and with recruitment fixed at the estimated average from 1988 to 2000, prior to the longer-term recruitment decline that occurred around 2001, consistent with previous assessments.

Further details of the GarEst stock assessment model are provided in McGarvey and Feenstra (2004), McGarvey et al. (2007) and Appendices 1, 2, 3 and 4. The respective fits of the model to these data sources are presented in Appendix 5. Sensitivity analyses of model outputs to: (i) alternate standardised effort type 1 effort data; (ii) removal of separate haul net gear (effort type 1 and 2) catchability parameters for pre- and post- 2005 periods; and (iii) removal of fitting to the FRDC fishery-independent sampling project data, are presented in Appendix 6.

2.5. Fishery performance indicators

2.5.1. General performance indicators

The Management Plan (PIRSA 2013) prescribes three tiers of indicators to monitor the performance of the fishery and address the first management objective: ensure the long-term sustainable harvest of Garfish by rebuilding stocks during specified time frames. It identifies a set of operational targets and trigger reference points for each performance indicator 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, with their operational objectives set to reach targets of ≤ 30% and ≥ 30% by 2020, respectively (Table 2-2). 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 haul net effort by at least 13% by 2014 (Table 2-2). 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 2-2). 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 2-2. Biological (B) and General (G) performance indicators used to monitor the performance of South Australia's Garfish Fishery as prescribed in the Management Plan (PIRSA 2013). (#) = GarEst outputs.

PERFORMANCE INDICATOR		TYPE	OPERATIONAL TARGET	TRIGGER REFERENCE POINT
PRIMARY	HARVEST FRACTION #	B	≤ 30% by 2020	35% by 2020
	EGG PRODUCTION #		30% by 2020	< 30% by 2020
SECONDARY	AGE COMPOSITION	B	↑ prop. of age 3+ Garfish since last assessment	No change or reduction
OTHER	FISHABLE BIOMASS #	B	No targets	3-year average is ± 10% of long-term average
	RECRUITMENT #	B	No targets	± 10% of previous 5-year average
	TOTAL CATCH	G	No targets	3rd Lowest / 3rd Highest
				Greatest % interannual change (±)
				Greatest 5-year trend
				Decrease over 5 consecutive years
	TARGET HAULING NET EFFORT	G	No targets	3rd Lowest / 3rd Highest
				Greatest % interannual change (±)
				Greatest 5-year trend
				Decrease over 5 consecutive years
	TARGET HAULING NET CPUE	G	No targets	3rd Lowest / 3rd Highest
				Greatest % interannual change (±)
				Greatest 5-year trend
				Decrease over 5 consecutive years
	TARGET DAB NET EFFORT	G	No targets	3rd Lowest / 3rd Highest
				Greatest % interannual change (±)
				Greatest 5-year trend
				Decrease over 5 consecutive years
	TARGET DAB NET CPUE	G	No targets	3rd Lowest / 3rd Highest
				Greatest % interannual change (±)
				Greatest 5-year trend
				Decrease over 5 consecutive years

2.6. Commercial catch allocations

Allocated shares of South Australia's Southern Garfish resource are assessed against trigger limits prescribed in the Management Plan (PIRSA 2013; Table 2-3). The first trigger limit (Trigger 1) relates to the allocated shares of the entire fishery and are assessed periodically against contemporary recreational catch and effort statistics as they become available. The remaining two trigger limits (Trigger 2 and 3) consider the commercial shares only and are assessed annually. 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.

Table 2-3. Commercial allocation of Southern Garfish among the sectors as prescribed in the Management Plan (PIRSA 2013).

FISHERY ALLOCATION	**MSF**	**SZRL**	**NZRLF**	**REC.**	**CHARTER**	**ABT**
	79.33%	**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	*n/a*	*0.75%*	*0.75%*	-	-	-
TRIGGER 3	*n/a*	*1.00%*	*1.00%*	-	-	-

2.7. Quality assurance of data

2.7.1. Commercial logbook data

Validation of the MSF commercial catch and effort data is extensive. It includes manual cross-checking during the collation and processing phases and code-driven queries which are activated during the data entry (i.e., when the data are entered into the Marine Scalefish Fishery Information System database that is managed by PIRSA Fisheries and Aquaculture) and reporting phases (Vainickis 2010). Furthermore, regular random checks of current and historic data are done as standard procedure. Extracted commercial catch and effort data were aggregated and graphed (using Excel and R programming language) into their necessary spatial/temporal/effort categories and cross-checked with previous assessments (McGarvey et al. 2006; McGarvey et al. 2009; Steer et al. 2012; Steer et al. 2016; Smart et al. 2022a). The contributing authors held regular meetings to discuss data handling procedures and interpretation. Tabulated results were further cross-checked against the outputs of the GarEst model. The draft stock assessment report was reviewed by three SARDI scientists prior to release.

2.7.2. Garfish age data

The processing of Garfish otoliths and subsequent age estimation typically occurred in large batches and there were often significant periods of time in between processing events. To ensure that the readers were interpreting the otolith structure consistently through time, each had to be reacquainted with the methodology and otolith characteristics before an ageing session. This was achieved through testing their interpretation against a random selection of Garfish otoliths from a reference collection, which is updated periodically to ensure it includes contemporary samples (Campana 2001).

3. RESULTS

3.1. State-wide fishery statistics

3.1.1. Commercial sector

Total annual State-wide commercial catch peaked at 532 t in 2000/01 and has since progressively declined to a low of 140 t in 2022/23 (*cf.* 157 t in 2021/22) (Figure 3-1a). The 2022/23 season was the eighth consecutive season with catches below 200 t. The gross value production (GVP) of the commercial catch in 2022/23 was $1.59M, which is 12% below the mean GVP since 2013/14.

The SG fishing zone has consistently accounted for around 55% (range: 38–66%) of the annual State-wide commercial catches since 1983/84 (Figure 3-1b), with around 42% (range: 28–61%) taken in the GSV/KI fishing zone. The remaining catches were taken in the WC (~3%) and SE fishing zones. Since 2018/19, catches have been highest in NGSV (MFA 35) and NSG (MFA 23) (Figure 3-2), followed by the southern areas of both gulfs, with small catches from the WC and in the SE.

The long-term decline in commercial catch has been associated with a decline in targeted effort (Figure 3-1c). Targeted effort declined by 76% from 7,886 fisher-days in 1983/84 to 1,868 fisher-days in 2022/23. This decrease reflects a consistent reduction in haul net effort across the fishery, but particularly in the SG and GSV/KI fishing zones, which accounted for around 50% (range: 35–63%) and 44% (range: 28–63%) of all targeted effort during that period, respectively. Targeted effort has also declined in the WC fishing zone, while targeting in the SE fishing zone has been stable at low levels.

3.1.2. Recreational sector

Estimates of recreational catch for Southern Garfish in South Australia were available from surveys in 2000/01, 2007/08, 2013/14 and 2021/22 (Figure 3-1a). The State-wide recreational harvest of Garfish in 2021/22 was 264,506 individuals with a combined weight of 24 t (SE = 21.8 t) (Figure 3-1a). The total harvest weight in 2021/22 was 68% and 70% lower than the estimates for 2007/08 (75.1 t, SE = 13.8 t) and 2013/14 (79.2 t, SE = 21.8 t), respectively, and 82% lower than the estimate for 2000/01 (133 t, SE = 14.7 t). The relative contribution of the recreational harvest of Garfish to the total State-wide catch increased from 18% in 2000/01 to 23% in 2013/14, and then decreased to 13% in 2021/22.

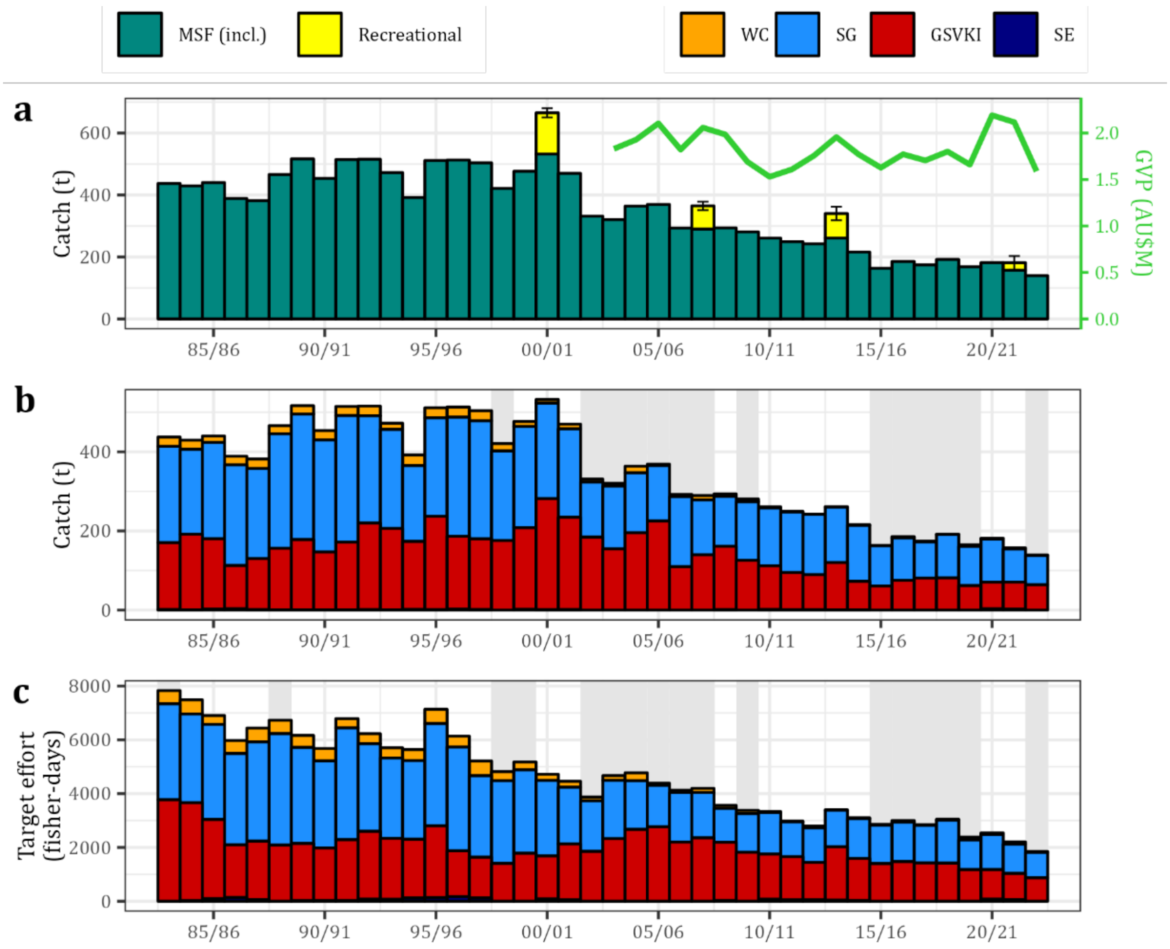

Figure 3-1. Fishery statistics for South Australia's Southern Garfish Fishery. Long-term trends in annual estimates of: (a) total catch for the commercial sector (MSF, SZRLF, NZRLF combined) and the recreational sector from surveys in 2000/01, 2007/08, 2013/14 and 2021/22 (error bars = standard error), and gross value of production (GVP); (b) total commercial catch, by fishing zone – West Coast (WC), Spencer Gulf (SG), Gulf St Vincent/Kangaroo Island (GSVKI) and South East (SE); and (c) total commercial effort targeting Garfish, by fishing zone. Grey shading indicates years when data for one or more fishing zones are confidential.

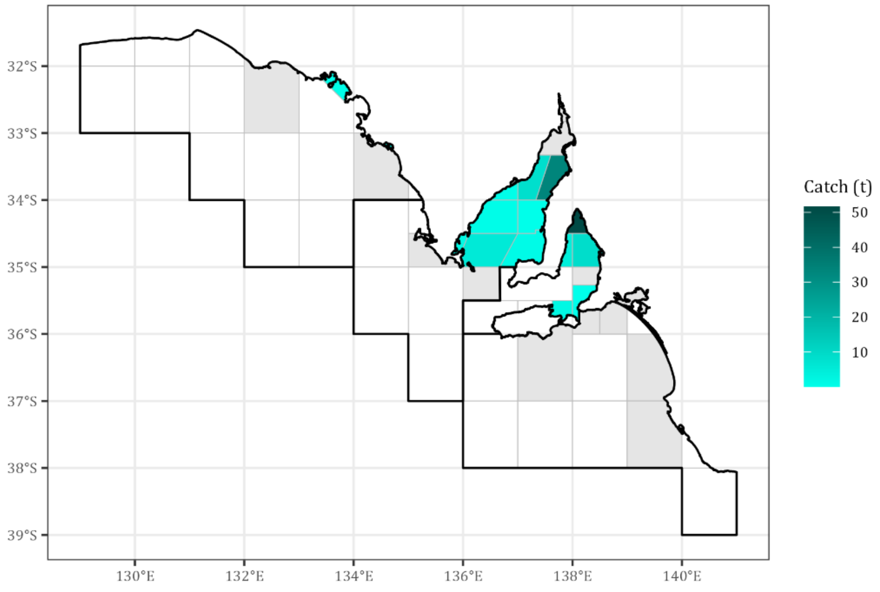

Figure 3-2. Spatial distribution of Southern Garfish catches taken by the commercial sector, by MFA block (Figure 1-2) from 2018/19 to 2022/23. Green shadings represent the average annual catches for that period. Grey shading indicates MFA blocks where the catch data are confidential.

3.2. Spencer Gulf Fishing Zone

3.2.1. Commercial fishery statistics

The SG fishing zone has been the most productive of the four fishing zones for Garfish in South Australia since 1983/84. Annual catches were > 250 t in most years during the 1980s and 1990s, including several years when they exceeded 300 t (Figure 3-3a). The highest catch was 320 t in 1991/92. Catch declined (by 53%) from 298 t in 1997/98 to 139 t in 2002/03, and then averaged around 147 t per year (SE = 3.4 t) before decreasing and stabilising at around 100 t from 2015/16 to 2020/21. The total catch of 74 t in 2022/23 (*cf.* 83.7 t in 2021/22) was 69% of the TACC. On average since 1983/84, catches taken using haul nets and dab nets have accounted for 92% and 7.7% of annual catches in this zone, respectively, and this continued in 2022/23 (Figure 3-3b).

The long-term declining trends in total catch reflect the trends in targeted fishing effort for the SG fishing zone (Figure 3-3b). Targeted effort was high prior to 2001/02, peaking at 4,156 fisher-days in 1991/92, declined sharply during the 2000s and has been < 1,500 fisher-days in most of the last 15 years. It dropped to 941 fisher-days in 2022/23, which was the lowest on record. Haul nets have consistently accounted for most (76–92%) of the targeted fishing effort. In 2022/23, targeted effort using haul nets and dab nets was 804 and 136 fisher-days, respectively.

Annual estimates of catch per unit of targeted effort (CPUE) for haul nets in $kg.fisher\text{-}day^{-1}$ and $kg.haul^{-1}$ have followed the same trends since 2003/04 (Figure 3-3c). Both indices increased to historical peaks between 2009/10 and 2011/12, then declined to 20-year lows in 2015/16 and have since recovered. In 2022/23, targeted haul nets CPUE increased to 87.4 kg.haul^{-1}, which was 6% above the mean catch rate since 2003/04. Estimates of targeted dab net CPUE have also increased over recent years and reached 10.7 kg.net-hour^{-1} in 2022/23, which was the third highest since 2003/04 (Figure 3-3d).

The long-term declines in catch and targeted effort using haul nets reflect declines in the numbers of licences taking and targeting Garfish (Figure 3-3e). The most significant decline (of 50%) in the number of licences taking Garfish occurred as a result of the net buy-back and subsequent netting restrictions in 2005/06. Prior to that, around 60% of the licences that caught Garfish were targeting them, whereas this proportion has since increased to around 90%. In 2022/23, 17 licences landed Garfish in the SG fishing zone, of which 15 targeted the species. Since 1983/84, most licences that have landed Garfish using dab nets were targeting Garfish, and the numbers of licences that have done so each year have been relatively stable over time.

Since 2013/14, there has been no clear seasonality in the average monthly catches of Garfish using haul nets (Figure 3-3f). Monthly haul net catches have been moderate to high (7–12 t) during July–September and January–June, and lowest during October–December (~4.5 t). The dab net sector has been more seasonal, with catches highest from December to April and lowest from May to November.

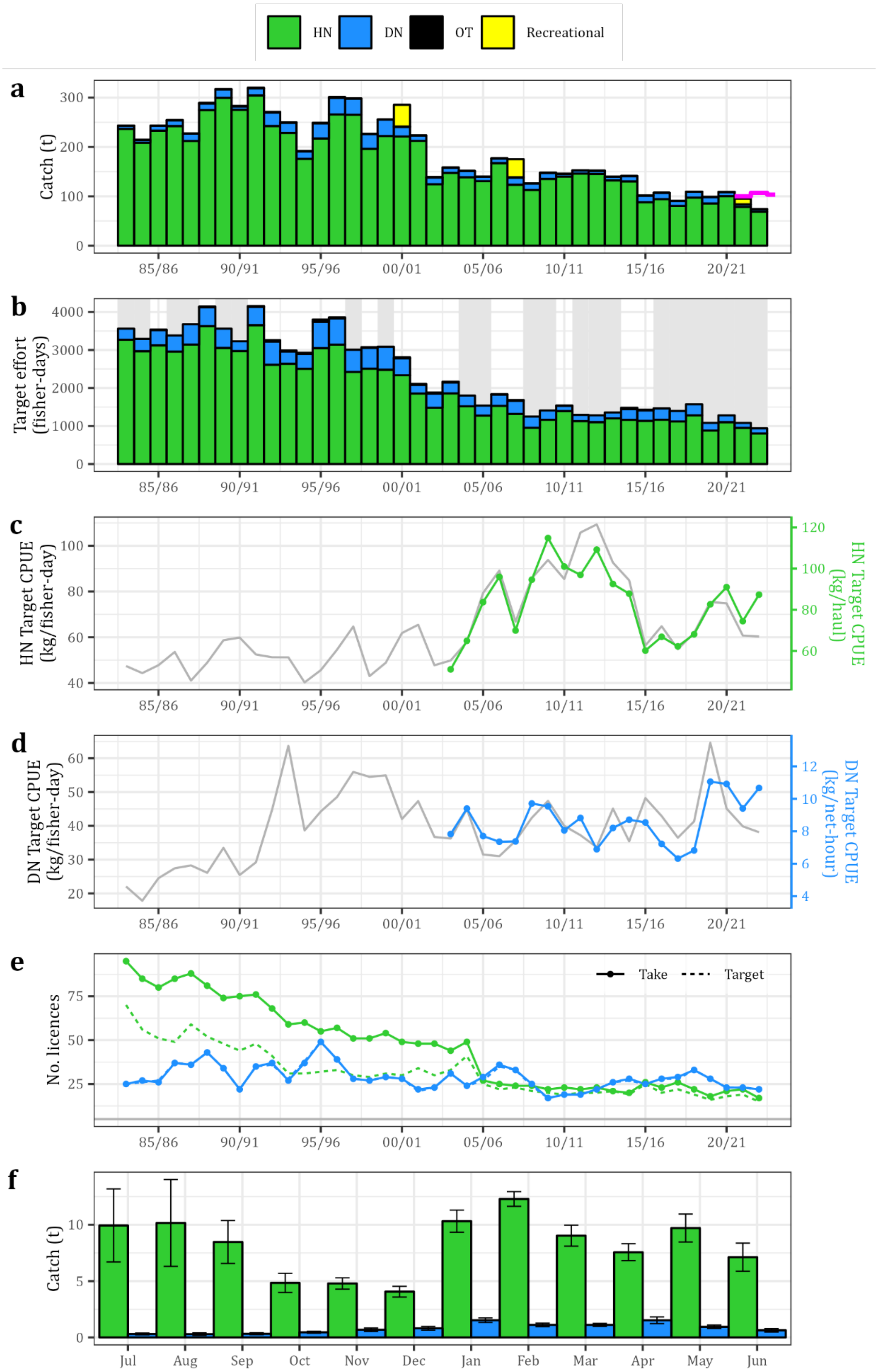

Figure 3-3. Key fishery statistics for Southern Garfish in the Spencer Gulf fishing zone from 1983/84 to 2022/23, including for the commercial sector by key gear categories – haul nets (HN), dab nets (DN), all other gears combined (OT). Statistics are: (a) total catch, including for the recreational sector from surveys in 2000/01, 2007/08 and 2021/22; (b) total commercial effort targeting Garfish; (c) HN catch per unit targeted effort; (d) DN catch per unit targeted effort; (e) number of commercial licences that take and target Garfish; and (f) average catch by month (error bars = SE) for 2013/14–2022/23. Grey shading indicates years when data for one or more gear categories are confidential. Purple line in (a) indicates TACC.

3.2.2. Recreational fishery statistics

The SG fishing zone has been the most productive zone for the recreational fishery for Garfish, accounting for 44.9% of the total annual State-wide recreational harvest in 2021/22 (Beckmann et al. 2023). Total recreational harvest of Garfish in the SG fishing zone in 2021/22 was 10.8 t, which was 79% and 69% lower than the estimates from the surveys in 2000/01 (52.6 t) and 2007/08 (34.7 t), respectively (Figure 3-3a).

3.2.3. Length and age structures

Since 2005/06, up to 5,500 Garfish caught by commercial fishers in the SG fishing zone have been measured for TL annually. On average, 17% of the fish measured each year were processed to obtain fish age data required to develop annual length-age keys for the zone. In this report, annual length and age frequency data are presented for 2018/19–2022/23 for Garfish sampled from haul net catches, and for 2015/16–2018/19 and 2022/23 for Garfish sampled from dab net catches. Earlier length and age distributions are available in published stock assessment reports (McGlennon and Ye 1999; McGarvey et al. 2006; 2009; Steer et al. 2012; 2016; 2018).

In 2022/23, a total of 2,899 Garfish from the SG fishing zone were measured for TL, of which 18% were subsequently processed to determine fish age from their otoliths. Consistent with previous years, the samples were obtained primarily (95%) from haul net catches.

Haul net catches

The length structures from haul net catches taken in the SG fishing zone from 2018/19 to 2020/21 were similar, i.e., they generally ranged from the LML of 250 mm TL to 360 mm TL and were dominated by fish between 260 and 290 mm TL (Figure 3-4). The distributions for 2021/22 and 2022/23 included small proportions (5.6 and 13.3%, respectively) of fish less than 250 mm TL, reflecting the decrease in LML from 250 to 230 mm TL implemented from 1 July 2021. The 2022/23 distribution was similar to previous years with most fish between 250 and 290 mm TL, a mode at 270 mm TL, and included fish up to 390 mm TL.

Since 2018/19, the annual age structures for haul net catches have involved fish aged between one and six years and were dominated (39–56%) by two-year-old fish (Figure 3-4). Fish aged three years or older constituted between 38 and 46% of all fish sampled from 2018/19 to 2020/21, although the proportions of these older age classes was lower in the age structure for 2021/22 (15%) and 2022/23 (21%).

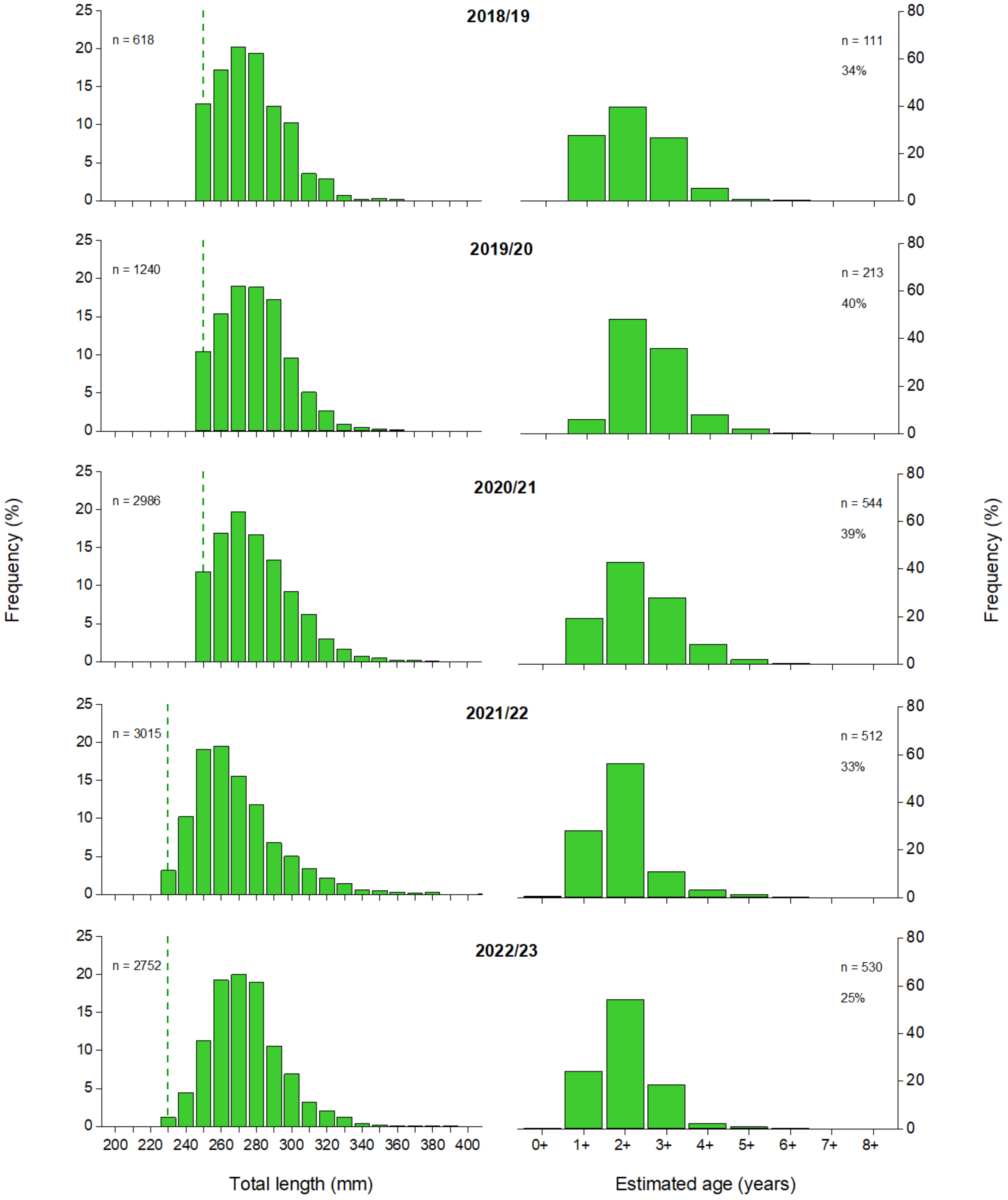

Figure 3-4. Annual length and age structures for Southern Garfish sampled from haul net catches taken in the Spencer Gulf fishing zone from 2018/19 to 2022/23, based on age-length key. Vertical green lines indicate legal minimum lengths. The secondary performance indicator for 3-year mean percentage of fish aged three or more years is shown on the age structure for each year (i.e., the percentage shown for 2022/23 represents the average annual percentage of fish aged three or more years from 2020/21 to 2022/23), as prescribed in the Management Plan (PIRSA 2013).

Dab net catches

The length and age structures from dab net catches taken in the SG fishing zone since 2015/16 involved smaller sample sizes and comprised larger and older fish than those from haul net catches (i.e., they were dominated by fish between 270 and 320 mm TL, with higher proportions of fish above 350 mm TL). (Figure 3-5) The length distribution for 2022/23 was broader than those for previous years – it involved fish from 240 to 380 mm TL and included modes at 300 and 320 mm TL.

The annual age structures for dab net catches in the SG fishing zone since 2015/16 were based on small sample sizes and so should be interpreted with caution (Figure 3-5). They were consistently dominated by two and three-year old fish, with low proportions of fish aged four years and older. The age structure for 2022/23 involved fish from one to five years of age and was dominated (47%) by the 2+ age class.

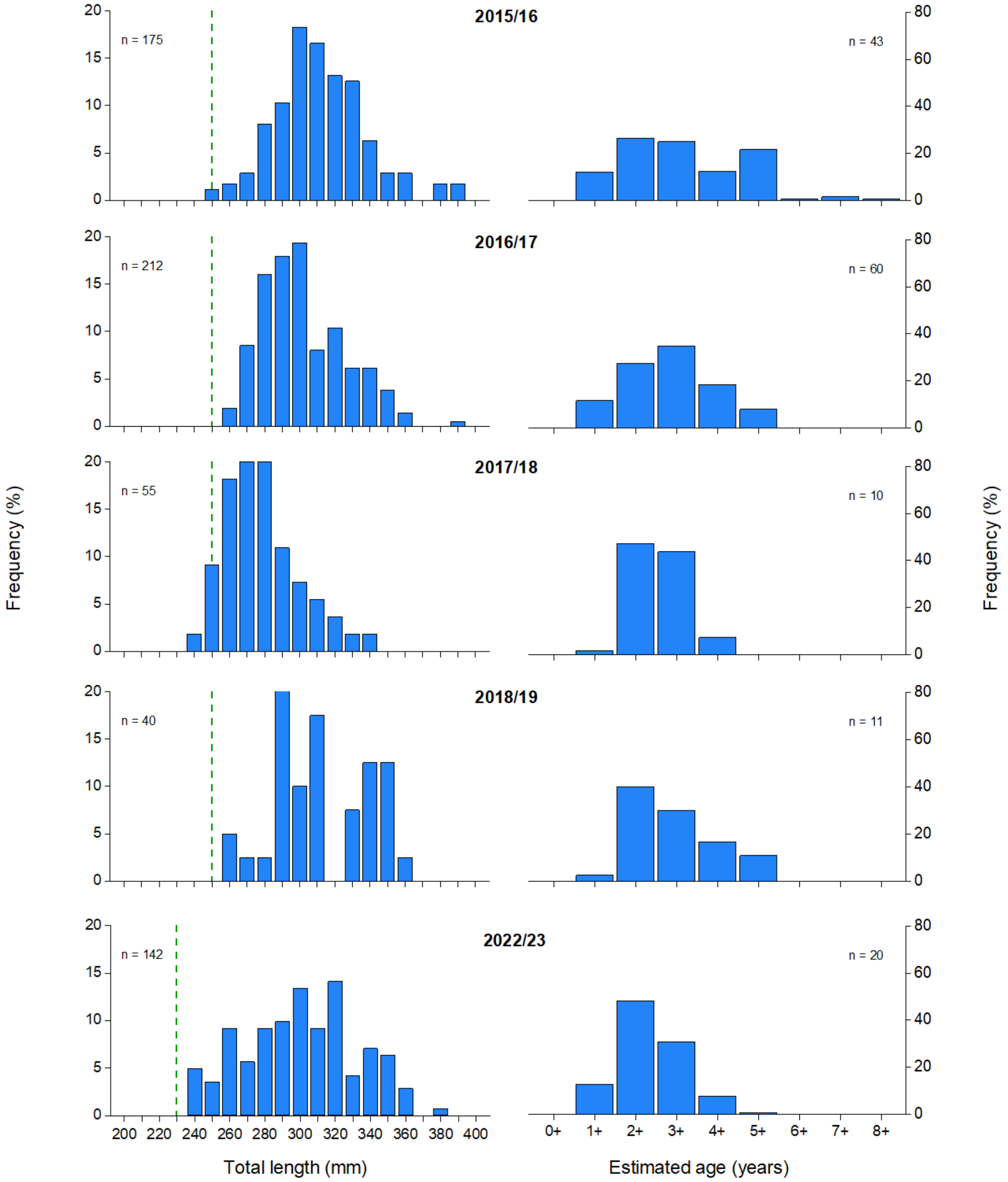

Figure 3-5. Annual length and age structures for Southern Garfish sampled from dab net catches taken in the Spencer Gulf fishing zone from 2015/16 to 2018/19 and 2022/23, based on age-length key. Vertical green lines indicate legal minimum lengths.

3.2.4. ‘GarEst’ model outputs

Fishable biomass includes all Garfish equal to or above the LML. Modelled fishable biomass in the SG fishing zone progressively declined by 62% from 487 t (± 49 t, 95%CI) in 1989/90 to 186 t (± 30 t, 95%CI) in 2020/21, and then sharply increased to 280 t (± 54 t, 95%CI) in 2021/22 (Figure 3-6). The long-term decline up to 2020/21 was partly attributable to increases in the LML in 2001 (from 210 to 230 mm TL) and 2014 (from 230 to 250 mm TL), while the increase in 2021/22 was likely augmented by the LML reduction (from 250 to 230 mm TL) implemented on 1 July 2021. Overall, these trends, and those for ‘biomass ≥ 210 mm TL’, reflect increases in Garfish biomass in 2021/22.

In 2021/22, the LML of 230 mm TL applied to Southern Garfish. Modelled ‘biomass ≥ 230 mm TL’ peaked at 390 t (± 47 t, 95%CI) in 1990/91 before dropping to 235 t (± 16 t, 95%CI) in 1995/96. The recent trends involved a gradual decline to a low of 232 t (± 53 t, 95%CI) in 2019/20 and subsequent successive increases to 280 t (± 54 t, 95%CI) in 2021/22, which was marginally below the long-term average of 287 t (± 38 t, 95%CI). This represents a 21% increase in modelled ‘biomass ≥ 230 mm TL’ since 2019/20.

Modelled estimates of harvest fraction for SG peaked at 92% in 1991/92 before progressively decreasing to 57% in 2005/06 (Figure 3-6). Annual harvest fractions were relatively stable during 2008/09–2014/15, ranging from 56% to 67%, and then declined to 49% in 2019/20. The decline continued in 2021/22, falling to 35% which was its lowest level on record.

Recruitment to the fishery was stable at low–moderate levels during 2001/02–2013/14 and then declined to a historical low of approximately 2.2 million individuals in 2019/20 (Figure 3-6). Recruitment increased 63% to 3.6 million in 2020/21 before decreasing to 3.2 million in 2021/22, which was similar to average recruitment over the past decade. As estimates of recruitment are determined based on age structure information from subsequent years, the 2021/22 estimate of recruitment is less certain than other years, because it is based on fewer data.

The percentage of virgin egg production has averaged 15% over the history of the fishery with no long-term trend (Figure 3-6). Previous stock assessments have identified that the target percentage virgin egg production of > 30% by 2020 was unlikely to be met (Steer et al. 2016; Steer et al 2018), which has been supported by this assessment.

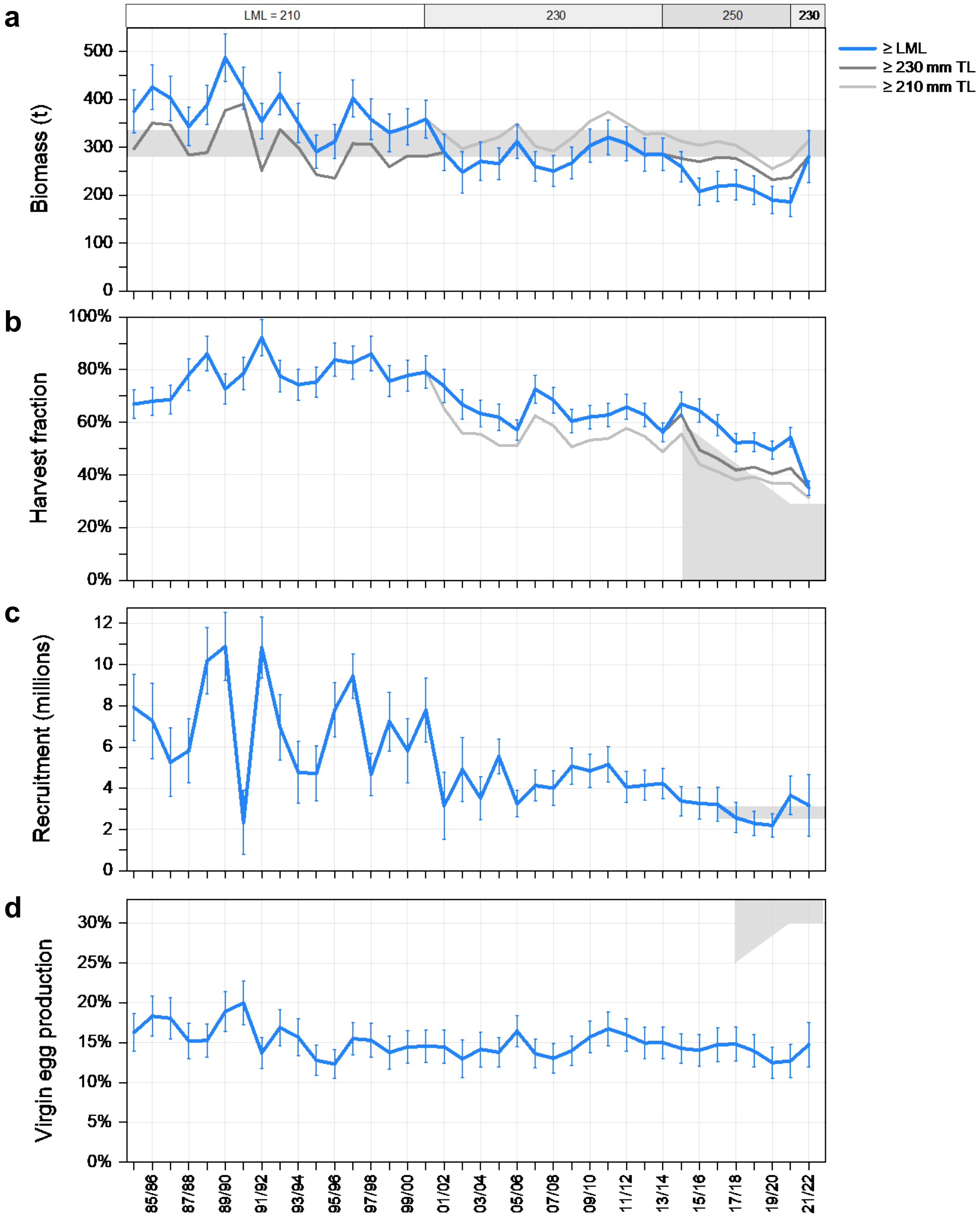

Figure 3-6. GarEst model outputs for the SG fishing zone from 1984/85 to 2021/22. The blue lines represent the model estimates of (a) fishable biomass (i.e., biomass of Garfish ≥ LML; shaded bar at top indicates LML changes), (b) harvest fraction, (c) recruitment, and (d) virgin egg production. Error bars represent 95% confidence intervals. Modelled estimates of biomass and harvest fraction using LML of 210 mm TL (light grey line) and 230 mm TL (dark grey line) are also provided. Shaded areas represent the range between the upper and lower reference points for each performance indicator, as prescribed in the Management Plan (PIRSA 2013). Annual estimates of recruitment, represent the number of individuals spawned in that year (cohort) which survived to age one and recruited to the fishable biomass.

3.3. Gulf St Vincent / Kangaroo Island Fishing Zone

3.3.1. Commercial fishery statistics

Total annual commercial catches taken in the GSV/KI fishing zone were between 150 and 235 t in most years between 1983/84 and 1999/00, and then increased to a peak of 281 t in 2000/01 (Figure 3-7a). Catches then gradually declined to 60 t in 2015/16 and have since been stable at 62–81 t. The total catch of 64 t in 2022/23 (*cf.* 69 t in 2021/22) represented 80% of the TACC.

Catches taken using haul nets have consistently accounted for most (71–93%) of commercial catches from the GSV/KI fishing zone since 1983/84, with most of the remaining catches taken using dab nets (Figure 3-7a). In 2022/23, haul nets accounted for around 92% of the total catch, while dab nets and all other gears combined accounted for around 7% and 1% of the catch, respectively.

Total targeted fishing effort in the GSV/KI fishing zone peaked at 3,772 fisher-days in 1983/84 with a secondary smaller peak of 2,767 fisher-days in 2005/06, and then gradually declined to 871 fisher-days in 2022/23 (Figure 3-7b). Since 1983/84, haul nets have been the dominant gear type used to target Garfish in GSV/KI and have accounted for the majority of targeted effort with most of the remaining effort attributed to dab nets. This continued in 2022/23, with haul nets and dab nets accounting for 88% and 11% of all targeted effort for Garfish in this zone, respectively.

Annual estimates of catch per unit of targeted effort (CPUE) for haul nets and dab nets in *kg.fisher-day*$^{-1}$ for the GSV/KI fishing zone have followed similar trends since 1983/84 (Figure 3-7c,d). Both indices increased to historical peaks around 2000/01, then declined through to 2006/07, and have since been near or above their respective long-term average, with increases over recent years.

For haul nets, there was a strong relationship between CPUE based on *kg.fisher-day*$^{-1}$ and CPUE based on *kg.haul*$^{-1}$ since 2003/04, when units of effort have been reported in logbooks (Figure 3-7c). In 2022/23, the haul net CPUE increased to 112 kg.haul^{-1} which was the highest on record.

Similarly for dab nets, there was a strong relationship between CPUE based on *kg.fisher-day*$^{-1}$ and CPUE based on *kg.net-hour*$^{-1}$ (Figure 3-7d). Dab net CPUE has increased over the last two years, reaching 9.5 kg.net-hour^{-1} in 2022/23, which was the third highest since 2003/04.

Several management initiatives have reduced the number of licence holders actively taking and targeting Garfish using haul nets and dab nets in the GSV/KI fishing zone (Figure 3-7e, Table 1-1). During 2022/23, 15 licences landed Garfish using haul nets, and of these, 13 actively targeted the species, which was the lowest on record. The numbers of licences that landed and targeted Garfish using dab nets declined to 10 in 2022/23, which were also the lowest recorded in the fishery.

The haul net fishery for Garfish has been seasonal over the last decade, with the highest catches taken from February to June and the lowest catches taken during December (Figure 3-7f). For the dab net fishery, most of the catches have been taken from December to February, and from March to May, and negligible landings in the cooler months of July, August, and September.

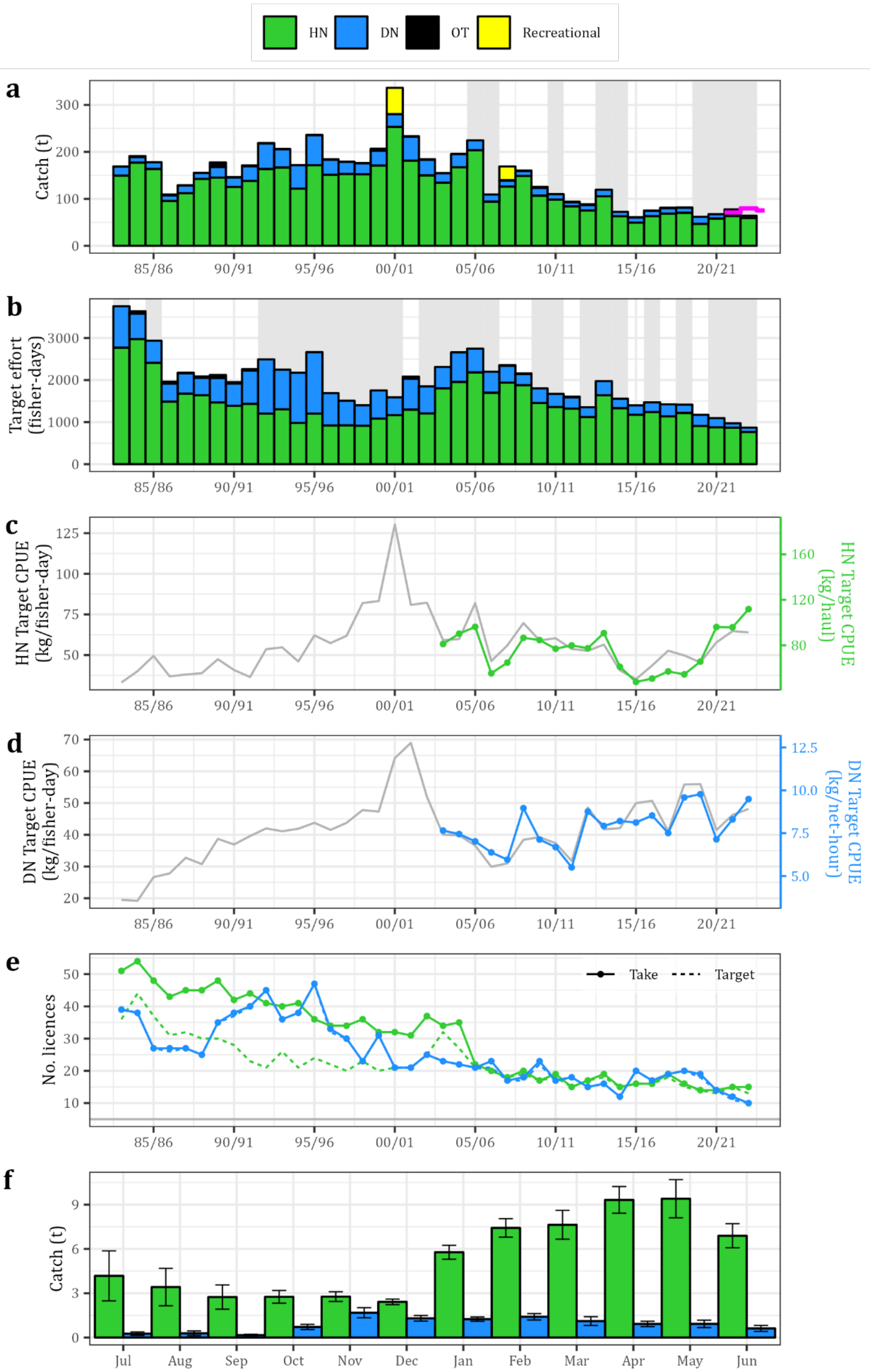

Figure 3-7. Key commercial fishery statistics for Southern Garfish in the Gulf St Vincent/Kangaroo Island fishing zone, divisible into key gear categories – haul nets (HN), dab nets (DN) and all other gears combined (OT). Long-term trends in annual estimates of: (a) total catch, including for the recreational sector from surveys in 2000/01, 2007/08 and 2021/22; (b) targeted effort; (c) HN catch per unit targeted effort; (d) DN catch per unit targeted effort; (e) number of licences that take and target Garfish; and (f) average catch by month (error bars = SE) for 2013/14–2022/23. Grey shading indicates years when data for one or more gear categories are confidential. Purple line in (a) indicates TACC.

3.3.2. Recreational fishery statistics

The GSV fishing zone has been the second most productive zone for the recreational fishery for Garfish (behind the SG fishing zone), accounting for 37.3% of the total annual State-wide recreational harvest in 2021/22 (Beckmann et al. 2023). Total recreational harvest of Garfish in the GSV/KI fishing zone in 2021/22 was 8.9 t, which was considerably lower than the estimates from the surveys in 2000/01 (65.8 t) and 2007/08 (30.1 t) (Figure 3-7a).

3.3.3. Length and age structures

Since July 2005, up to 4,229 Garfish captured in the GSV/KI fishing zone have been measured annually as part of the market sampling program. Between 16 and 30% of the fish measured each year were then processed to obtain age data that was used to develop annual length-age keys for the zone. In this report, annual length and age frequency data for Garfish from the GSV/KI fishing zone are presented for 2018/19–2022/23 for haul net catches, and for 2017/18–2022/23 for dab net catches (dab net samples were not available for 2021/22). Earlier length and age distributions are available in published stock assessment reports (McGlennon and Ye 1999; McGarvey et al. 2006; 2009; Steer et al. 2012; 2016; 2018).

In 2022/23, a total of 2,394 Garfish from the GSV/KI fishing zone were measured for TL, of which 21% (*n* = 500) were processed to determine their age. The samples were mostly from haul net catches (~91%), as this sector constitutes most of the catch and effort in this zone.

Haul net catches

There were negligible differences between the annual length structures from haul net catches from 2018/19 to 2020/21 when the LML was 250 mm TL, i.e., they were all positively skewed with a mode at 270–280 mm TL and few fish above 330 mm TL (Figure 3-8). The length structures from 2021/22 and 2022/23 were more broadly distributed than previous years as they included fish from the revised LML of 230 mm TL (from 1 July 2021) up to 390 mm TL, with a mode at 280 mm TL.

The age structures from haul net catches in 2018/19, 2019/20 and 2020/21 were consistently dominated (57–59%) by two-year-old fish with smaller proportions of one-year-old (13–18%) and three-year-old (17–25%) fish, while older fish were rare (2–5% combined) (Figure 3-8). The age structures from 2021/22 and 2022/23 involved higher proportions of one-year-old fish (27% and 41%, respectively) compared to previous years, likely reflecting the lower LML from 1 July 2021 onward, while two-year-old fish continued to be well represented. The combined proportions of fish aged three years or older was slightly lower in 2021/22 (21%) and 2022/23 (22%) than in 2018/19 (27%), 2019/20 (23%) and 2020/21 (23%).

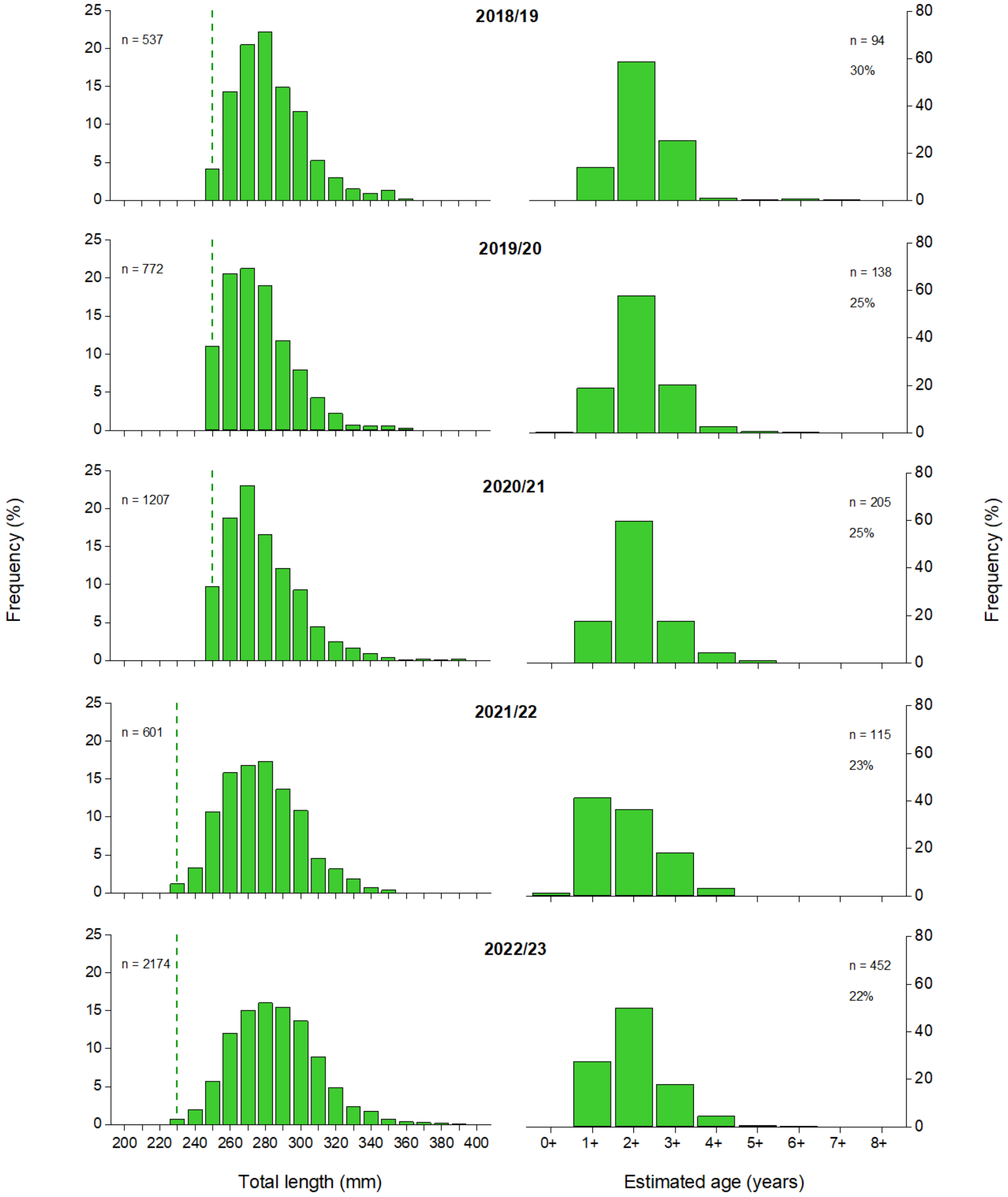

Figure 3-8. Annual length and age structures for Southern Garfish sampled from haul net catches taken in the Gulf St Vincent/ Kangaroo Island fishing zone from 2018/19 to 2022/23, based on age-length key. Vertical green lines indicate legal minimum lengths. The secondary performance indicator for 3-year mean percentage of fish aged three or more years is shown on the age structure for each year (i.e., the percentage shown for 2022/23 represents the average annual percentage of fish aged three or more years from 2020/21 to 2022/23), as prescribed in the Management Plan (PIRSA 2013).

Dab net catches

The length structures from dab net catches taken in the GSV/KI fishing zone from 2017/18 to 2020/21 comprised mostly fish between the LML of 250 mm TL and 300 mm TL (Figure 3-9), although the annual modal lengths progressively declined from 300 mm TL in 2017/18 to 250 mm TL in 2020/21 (Figure 3-9). The length distribution for 2022/23 was broader than those for previous years, with a modal length of 300 mm TL and higher proportions of fish above 330 mm TL.

The annual age structures for dab net catches taken in the GSV/KI fishing zone since 2015/16 were consistently dominated by two-year-old fish, with low proportions of fish aged three years and over (Figure 3-9). The age structure for 2022/23 involved fish from one to five years of age and was dominated by age 2+ fish (41%) and 1+ fish (33%).

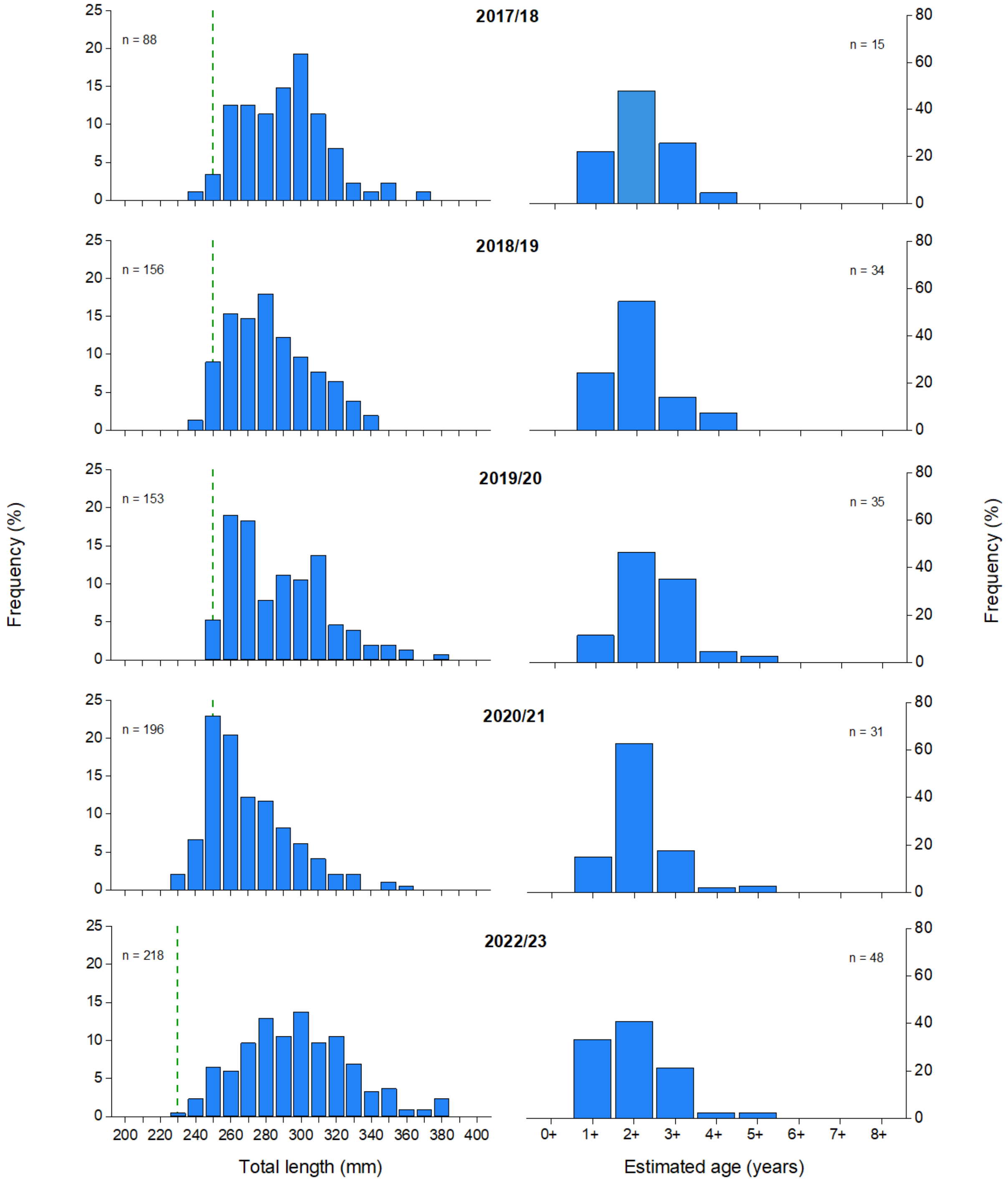

Figure 3-9. Annual length and age structures for Southern Garfish sampled from dab net catches taken in the Gulf St Vincent/ Kangaroo Island fishing zone from 2017/18 to 2022/23, based on age-length key. No dab net samples were available for 2021/22. Vertical green lines indicate legal minimum lengths. The running 3-year mean percentage of fish aged three or more years is shown on the age structure for each year (i.e., the percentage shown for 2022/23 represents the average annual percentage of fish aged three or more years from 2019/20 to 2022/23, no age data were available for 2021/22).

3.3.4. ‘GarEst’ model outputs

For the GSV/KI fishing zone, modelled fishable biomass increased to a peak of 377 t (± 40 t, 95%CI) in 2000/01, before progressively declining to an historic low of 155 t (± 24 t, 95%CI) in 2015/16 (Figure 3-10). Since then, fishable biomass has gradually increased and reached a 15-year high of 249 t (± 56 t, 95%CI) in 2021/22. Although these trends were partly attributable to the LML changes in 2001, 2014 and 2021, they are similar to the long-term trends for ‘biomass ≥ 210 mm TL’, and both reflect a progressive increase in Garfish abundance since 2015/16.

In 2021/22, the LML of 230 mm TL applied to Garfish. Modelled ‘biomass ≥ 230 mm TL’ peaked at 309 t (± 36 t, 95%CI) in 2001/02 before dropping to 179 t (± 26 t, 95%CI) in 2014/15 (Figure 3-10). The recent trends involved a progressive increase to 248 t (± 56 t, 95%CI) in 2021/22, which was 8% above the historic mean of 228 t (± 32 t, 95%CI). This represents a 39% increase in modelled ‘biomass ≥ 230 mm TL’ from 2014/15 to 2021/22.

Modelled harvest fractions of fishable biomass in GSV/KI peaked at 94% (± 7%, 95%CI) in 1995/96, and remained above 70% before rising to a secondary peak at 94% (± 8%, 95%CI) in 2005/06 (Figure 3-10). Since then, annual harvest fractions have steadily declined at a rate of around 6% per year, reaching a historical low of 29% (± 3%, 95%CI) in 2021/22. A similar long-term decline in harvest fraction was also evident in modelled harvest fraction of the Garfish ‘biomass ≥ 210 mm TL’.

Modelled estimates of annual recruitment represent the number of individuals spawned in each year (cohort) which survived to age one. Prior to 2009/10, recruitment was episodic around a mean of 4.8 million individuals (range: 1.6–7.4 million) (Figure 3-10). From then, it slowly declined to 1.6 million (± 0.5 million, 95%CI) in 2019/20, before increasing to 2.2 million (± 0.7 million, 95%CI) and 2.3 million (± 1.4 million, 95%CI) in 2020/21 and 2021/22, respectively. As estimates of recruitment are determined based on age structure information from fish sampled in subsequent years, the 2021/22 estimate of recruitment is based on fewer age data than previous years, and so has wider confidence bands than most years.

The percentage of virgin egg production for the Garfish stock in GSV/KI increased from 13% (± 1%, 95%CI) in 1984/85 to 18% (± 2%, 95%CI) in 2001/02, and then declined to a low of 10% (± 2%, 95%CI) in 2006/07 (Figure 3-10). Since then, it has followed an increasing trend, peaking at a 20-year high of 16% (± 4%, 95%CI) in 2021/22, which was the fourth highest on record.

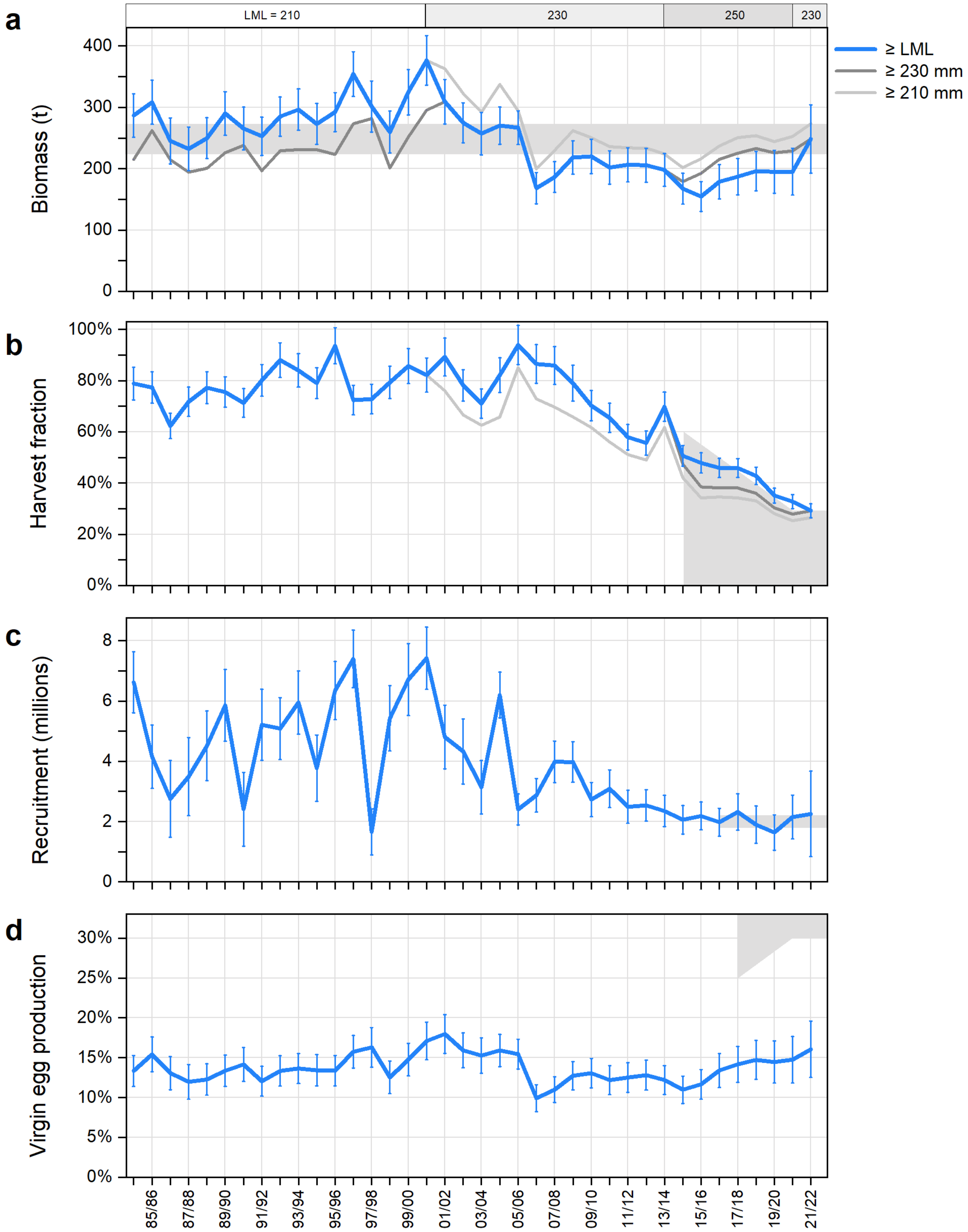

Figure 3-10. GarEst model outputs for the GSV/KI fishing zone from 1984/85 to 2021/22. The blue lines represent the model estimates of (a) fishable biomass (i.e., biomass of Garfish ≥ LML; shaded bar at top indicates LML changes), (b) harvest fraction, (c) recruitment and (d) virgin egg production. Error bars represent 95% confidence intervals. Modelled estimates of biomass and harvest fraction using LML of 210 mm TL (light grey line) and 230 mm TL (dark grey line) are also provided. Shaded areas represent the range between the upper and lower reference points for each performance indicator, as prescribed in the Management Plan (PIRSA 2013). Annual estimates of recruitment, represent the number of individuals spawned in that year (cohort) which survived to age one.

3.4. West Coast Fishing Zone

3.4.1. Commercial fishery statistics

The WC fishing zone has been the third most productive fishing zone for Garfish since 1983/84. Annual catches from this zone averaged 22.5 t (SE = 0.8 t) in the 1980s and 1990s, peaking at 26.8 t in 1994/95, with around 85% of catches taken using haul nets (Figure 3-11a). From 1999/00 to 2004/05, haul nets continued to account for most of the catch, which fluctuated between 9 and 16.7 t per year. Since 2005/06, catches have been < 3 t in most years and dab nets have become the main gear used to catch Garfish. The total catch of 0.96 t in 2022/23 was fourth lowest on record (*cf.* 2.9 t in 2021/22), of which 93% was taken using dab nets.

The trends in total catch reflect the trends in targeted effort (Figure 3-11b). Effort was highest during the 1990s, peaking of 548 fisher-days in 1997/98, and declined during the 2000s. Targeted effort has been < 70 fisher-days in most of the last 10 years, most of which was reported by dab net fishers.

Estimates of annual targeted CPUE using haul nets since 2005/06 are confidential (Figure 3-11c,e). For dab nets, targeted CPUE has been highly variable over the past decade, ranging from 11.1 kg.net-hour^{-1} in 2014/15 to 5.1 kg.net-hour^{-1} in 2020/21 (Figure 3-11d). Similar high interannual variability is also evident in the long-term annual time series for targeted dab net CPUE based on *kg.fisher-day*$^{-1}$. In 2022/23, both targeted dab net CPUE measures were similar to their respective long-term averages, although CPUE based on *kg.net-hour*$^{-1}$ increased for the second successive year.

Up to 13 licences per year landed Garfish using haul nets in the WC fishing zone prior to the implementation of commercial netting restrictions in this region in 2005/06 (Figure 3-11e). Since then, there have been less than three active haul netters operating in this region in most years, whereas the number of licences using dab nets to target and take Garfish has been relatively consistent at between three and seven since 1983/84.

The Garfish fishery in the WC fishing zone has been seasonal over the last decade, with most of the catch each year taken during the cooler months from April to August (Figure 3-11f).

3.4.2. Recreational fishery statistics

The WC fishing zone accounted for 8.2% of the total annual State-wide recreational harvest of Garfish in 2021/22 (Beckmann et al. 2023). The total recreational harvest of 2 t in 2021/22 was considerably lower than the peak estimate of 7.3 t in 2007/08 (Figure 3-11a).

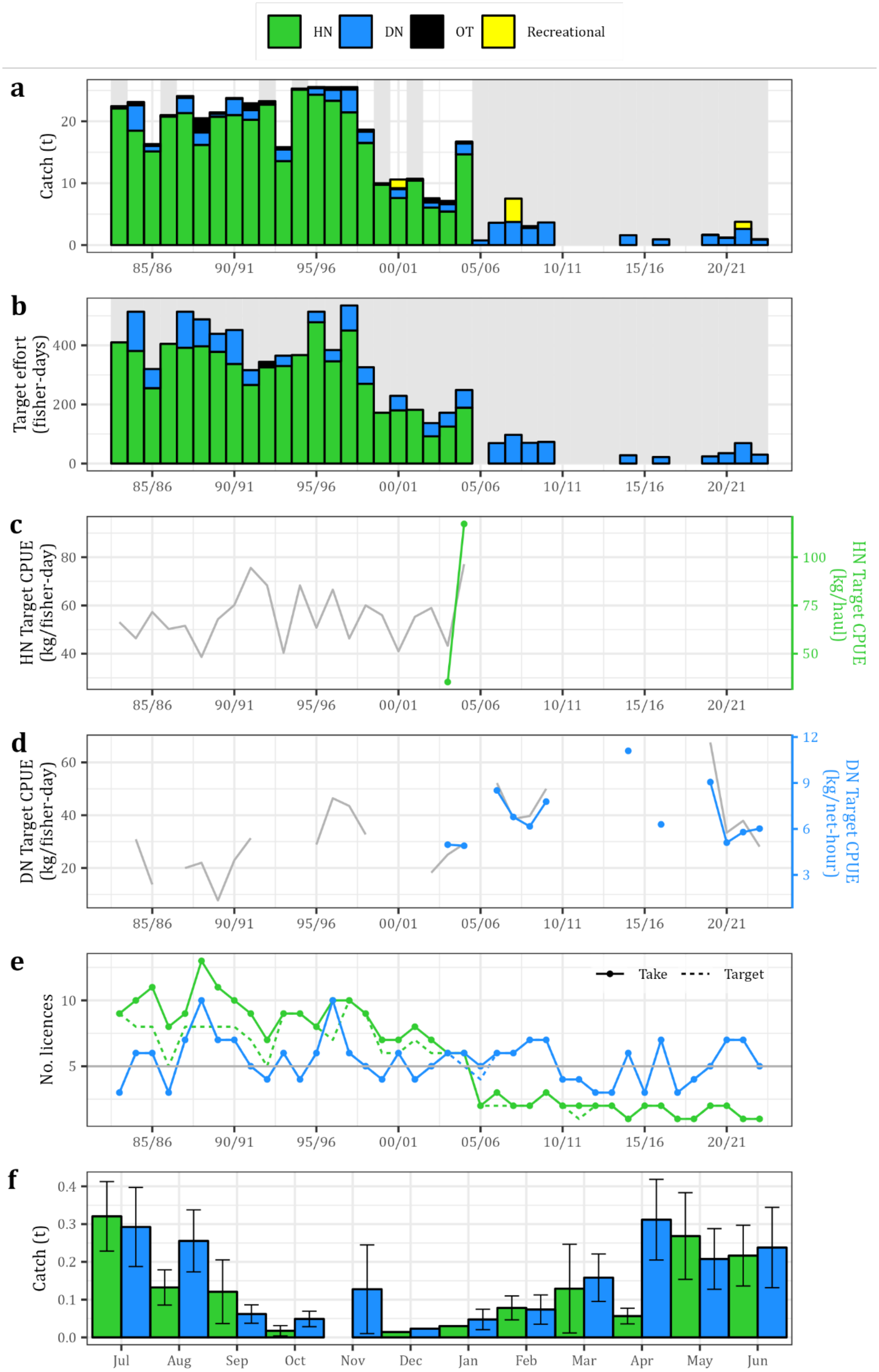

Figure 3-11. Key commercial fishery statistics for Southern Garfish in the West Coast fishing zone, divisible into key gear categories – haul nets (HN), dab nets (DN) and all other gears combined (OT). Long-term trends in annual estimates of: (a) total catch; (b) targeted effort; (c) HN catch per unit targeted effort; (d) DN catch per unit targeted effort; (e) number of licences that take and target the species; and (f) average catch by month (error bars = SE) for 2013/14–2022/23. Grey shading indicates years when data for one or more gear categories are confidential.

3.5. South East Fishing Zone

3.5.1. Commercial fishery statistics

Total annual commercial catches from the SE fishing zone have been negligible since 1983/83, exceeding 3 t in only three years – 1986/87, 2019/20 and 2020/21 (Figure 3-12a). Most of the catch is taken using dab nets and targeted effort by dab net fishers has rarely exceeded 50 fisher-days per year (Figure 3-12b), with 2–6 fishers targeting the species each year (Figure 3-12d). Total catch, targeted effort and CPUE data for 2022/23 are confidential. The commercial Garfish fishery in the SE has been seasonal over the last decade, with the highest catches taken during the warmer months from October to February (Figure 3-12e).

3.5.2. Recreational fishery statistics

Recreational catch estimates for all four surveys are uncertain given the low number of households that reported catching Southern Garfish in the SE fishing zone. Therefore, these results are not presented.

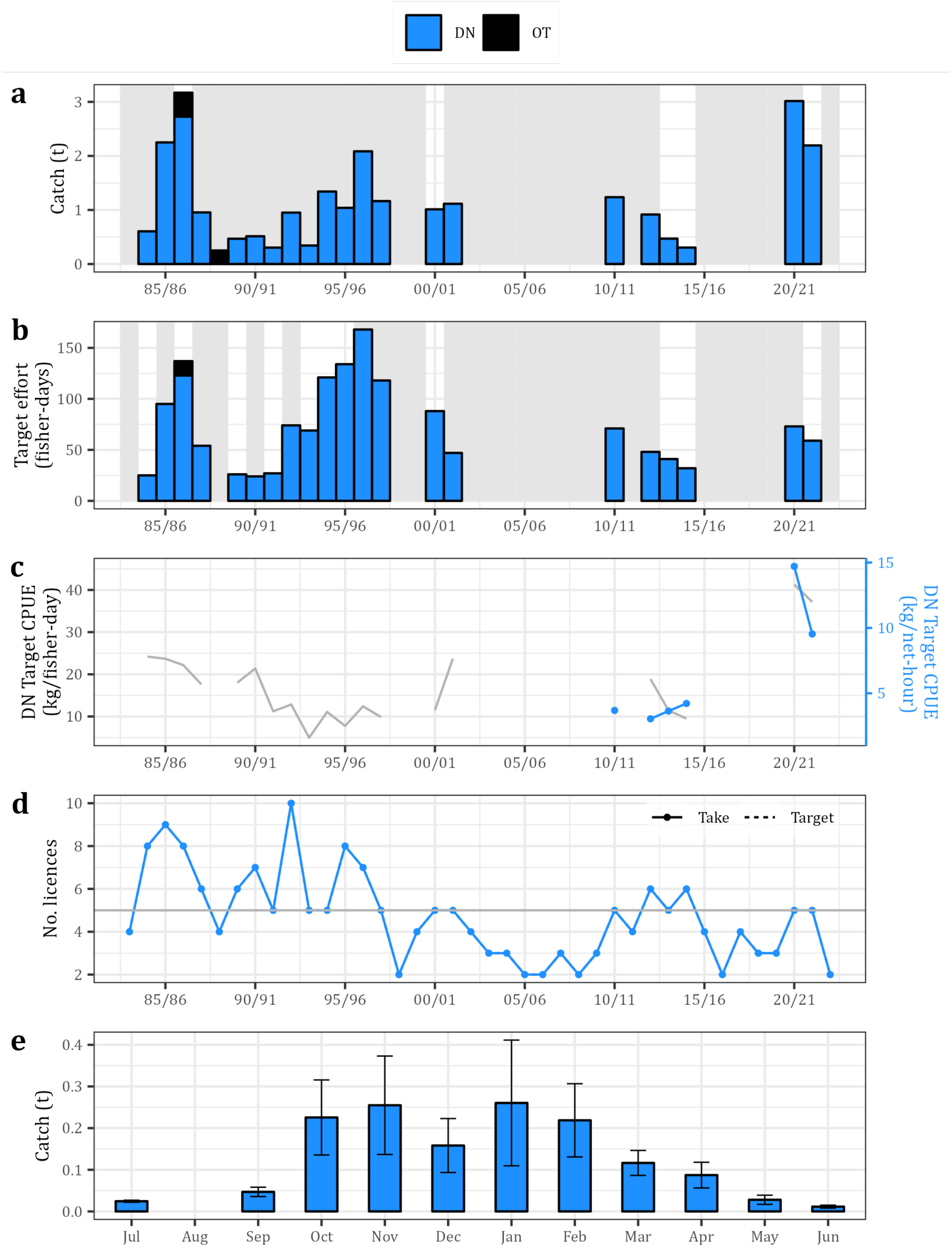

Figure 3-12. Key commercial fishery statistics for Southern Garfish in the South East fishing zone, divisible into key gear categories – dab nets (DN) and all other gears combined (OT). Long-term trends in annual estimates of: (a) total catch; (b) targeted effort; (c) DN catch per unit targeted effort; (d) number of licences that take and target the species; and (e) average catch by month (error bars = SE) for 2013/14–2022/23. Reliable estimates of recreational catch are not available. Grey shading indicates years when data for one or more gear categories are confidential.

3.6. Fishery performance indicators

The general performance indicators were assessed at the regional fishing zone level for 2022/23. Several trigger reference points (TRPs) were breached across the GSV/KI and SG fishing zones (Table 3-1). For the GSV/KI fishing zone, total catch was the third lowest on record, while targeted haul net effort and targeted dab net effort were the lowest on record. For the SG fishing zone, total catch and targeted haul net effort declined to historical lows, while targeted dab net effort was marginally above the historical low recorded in 2021/22. There were no TRP breaches across the WC and SE fishing zones, although these zones were characterised by low catches and targeted fishing effort, consistent with previous years.

Modelled estimates of harvest fraction and egg production are the primary biological performance indicators (BPIs) prescribed for Garfish in the Management Plan (PIRSA 2013). In this assessment they have been assessed for the GSV/KI and SG fishing zones. While the zonal operational objectives for harvest fraction of < 30% by 2020 were not achieved, they continued to trend downward in 2021/22, falling to historical lows of 29% and 35% in GSV/KI and SG, respectively (Table 3-1). The egg production operational target of 30% by 2020 was also not achieved for both zones, although both have evidently supported increased egg production over the last two years. While there have been no appreciable changes in the fishery age structures for either fishing zone since 2017 (Table 3-4), these data must be interpreted with caution because they were impacted by the LML reduction from 250 to 230 mm TL from 1 July 2021, which contributed to shifts in the size and age structures for both zones toward smaller, younger fish (Figure 3-8 and Figure 3-9). Consequently, the proportions of age 3+ fish in the age structures, averaged over the three years to 2021/22, declined by 14% and 3% since the last assessment for SG and GSV/KI, respectively (Table 3-1).

Modelled estimates of fishable biomass and recruitment constitute the remaining BPIs for the GSV/KI and SG fishing zones. Fishable biomass in GSV/KI increased 23% in 2021/22 from the previous year and this contributed to a 3% increase in the three-year average fishable biomass, which was within the upper and lower TRPs (Table 3-1). The estimate of fishable biomass for SG in 2021/22 was 40% higher than 2020/21, although the three-year average to 2021/22 was 14% below the lower TRP for the zone. The GarEst modelled estimates of fishable biomass for both zones should be interpreted with caution, because they were impacted by the LML reduction from 250 to 230 mm TL since 1 July 2021.

Modelled estimates of recruitment for GSV/KI and SG have increased over the last three years and were above their respective upper TRPs in 2021/22 (Table 3-1). The estimates of recruitment for GSV/KI and SG were 12% and 13% higher than the average recruitment over the previous 5 years, respectively.

Table 3-1. Comparison of recent trends in South Australia's Southern Garfish Fishery against the biological (B) and general (G) performance indicators prescribed in the Management Plan (PIRSA 2013). Green = operational target achieved, orange = operational target not achieved, grey = trigger reference point breached, (N) = trigger reference point not breached, black = not assessed due to no data, CONF = confidential data; arrows indicate directional shift, (#) = GarEst model outputs. Targeted effort based on fisher-days; targeted CPUE based on kg.fisher-day. Age compositions relate to annual age structures from haul net catches taken from each fishing zone; no age data is available for the WC and SE fishing zones.

PERFORMANCE INDICATOR		TYPE	OPERATIONAL TARGET	TRIGGER REFERENCE POINT	SG	GSV/KI	WC	SE
PRIMARY	HARVEST FRACTION #	B	≤ 30% by 2020	35% by 2020	35%	29%	■	■
	EGG PRODUCTION #		30% by 2020	< 30% by 2020	14%	16%	■	■
SECONDARY	AGE COMPOSITION	B	↑ prop. of age 3+ Garfish since last assessment	No change or reduction	–14%	– 3%	■	■
OTHER	FISHABLE BIOMASS #	B	No targets	3-year average is ± 10% of long-term average	– 14%	+ 3%	■	■
	RECRUITMENT #	B	No targets	± 10% of previous 5-year average	+ 13%	+ 12%	■	■
	TOTAL CATCH	G	No targets	3rd Lowest / 3rd Highest	LOWEST	3RD LOWEST	N	N
				Greatest % interannual change (±)	N	N	N	N
				Greatest 5-year trend	N	N	N	N
				Decrease over 5 consecutive years	N	N	N	N
	TARGET HAULING NET EFFORT	G	No targets	3rd Lowest / 3rd Highest	LOWEST	LOWEST	CONF	■
				Greatest % interannual change (±)	N	N	CONF	■
				Greatest 5-year trend	N	N	CONF	■
				Decrease over 5 consecutive years	N	N	CONF	■
	TARGET HAULING NET CPUE	G	No targets	3rd Lowest / 3rd Highest	N	N	CONF	■
				Greatest % interannual change (±)	N	N	CONF	■
				Greatest 5-year trend	N	N	CONF	■
				Decrease over 5 consecutive years	N	N	CONF	■
	TARGET DAB NET EFFORT	G	No targets	3rd Lowest / 3rd Highest	2ND LOWEST	LOWEST	N	CONF
				Greatest % interannual change (±)	N	N	N	CONF
				Greatest 5-year trend	N	N	N	CONF
				Decrease over 5 consecutive years	N	N	N	CONF
	TARGET DAB NET CPUE	G	No targets	3rd Lowest / 3rd Highest	N	N	N	CONF
				Greatest % interannual change (±)	N	N	N	CONF
				Greatest 5-year trend	N	N	N	CONF
				Decrease over 5 consecutive years	N	N	N	CONF

3.7. Commercial catch allocations

The proportional contributions of the three commercial fisheries to the State-wide commercial catch have been relatively stable over the past five years (Table 3-2). For the assessment of the catches by each sector against their allocations prescribed in the Management Plan (PIRSA 2013), their percentage contributions to annual State-wide commercial catches were compared using TRPs. From 2018/19 to 2022/23, one TRP was activated by the SZRLF in 2021/22, when its total catch contribution of 1.14% exceeded the TRP3 of 1%. No other trigger reference points were breached.

Table 3-2. Commercial fishery sector allocations of Southern Garfish from 2018/19 to 2022/23, including trigger reference points (TRPs) prescribed in the Management Plan (PIRSA 2013). Annual values represent the percentages of the total catch taken by each sector. MSF = Marine Scalefish Fishery, SZRLF = Southern Zone Rock Lobster Fishery, NZRLF = Northern Zone Rock Lobster Fishery. TRP 2 is breached if the respective sector allocation is breached for three consecutive years or in four of the previous five years. TRP 3 is breached if the respective sector allocation is breached in any one year. Breaches of TRP 3 are in red. There have been no breaches of TRP 2 since 2018/19.

COMMERCIAL ALLOCATION	**MSF**	**SZRLF**	**NZRLF**
	99.79%	**0.16%**	**0.05%**
TRP 2	-	0.75%	0.75%
TRP 3	-	1.00%	1.00%
2018/19	99.97%	0.02%	0.01%
2019/20	99.53%	0.47%	0.00%
2020/21	99.62%	0.38%	0.00%
2021/22	98.85%	1.14%	0.01%
2022/23	99.42%	0.25%	0.33%

4. DISCUSSION

4.1. Context of this assessment

During the 1990s, the status of South Australia’s Southern Garfish stocks was assessed based on trends in commercial fishery statistics and basic understanding of the biology of the species (Jones 1995; McGlennon and Ye 1999). The relatively stable catches throughout the 1980s and 1990s identified in these assessments were associated with declining trends in fishing effort due to declining numbers of fishers and a consequence of several management initiatives including the licence amalgamation scheme (Steer et al. 2018; Fowler 2019). While increasing trends in targeted haul net catch rates in NSG and NGSV reflected increases in Garfish abundance in these areas, the stocks were considered to be fully exploited and a conservative approach to management was recommended to ensure catch did not increase (Fowler 2019).

Subsequent assessments in the 2000s, which involved the first applications of the fully integrated ‘GarEst’ stock assessment model (McGarvey and Feenstra 2004), highlighted considerable issues with the status of the Garfish stocks in the main fishing areas of NGSV and NSG. Model outputs for these areas indicated declining levels of biomass reflecting successive years of poor recruitment, and a long period of harvest fractions well above internationally accepted standards of around 30% (PIRSA 2013). As such, in 2005, the gulf stocks were considered to be in poor health (McGarvey et al. 2006). These findings led to the implementation of significant management changes, including the net buy-back and introduction of extensive spatial closures for net fishing in 2005, which effectively restricted the use of haul nets to the northern parts of the gulfs (McGarvey et al. 2009). Despite this approach, subsequent assessments of stock status showed no evidence of stock recovery, and the stocks were considered to remain over-exploited (Steer et al. 2012).

Since 2012, additional management intervention has been implemented to recover the stocks in the northern parts of GSV and SG, including temporary spatial closures, increases to the minimum mesh size of haul nets, and changes to the LML (Smart et al. 2022a). In the 2016 stock assessment, some benefit of this intervention had become evident in SG, where biomass, egg production and recruitment had increased marginally, whilst harvest fraction had declined (Steer et al. 2016). These positive signs were sufficient to warrant a change in status to ‘transitional recovering’ in 2016 (Steer et al. 2016) and ‘recovering’ in 2018 (Steer et al. 2018). The status of ‘recovering’ for the stock was retained through to 2022 (Smart et al. 2022a), and was assigned to the stock in the SG fishing zone in 2023 (Smart et al. 2023). In contrast, the status of the Garfish stock in northern GSV continued to decline and was subsequently assigned the status of ‘recruitment overfished’ in 2016 (Steer et al. 2016) and ‘depleted’ in 2018 (Steer et al. 2018), before some positive signs were detected in 2022 (Smart et al. 2022a). For the first time, the GarEst model outputs indicated that while recruitment remained impaired in GSV, biomass had increased and harvest fraction had declined and was approaching the target level (PIRSA 2013). These results were evidence that the management arrangements that were implemented to recover the stock were taking effect, and this culminated in change in status to ‘recovering’ in 2022 (Smart et al. 2022a), which was retained in 2023 (Smart et al. 2023).

Since the last stock assessment, there have been several management changes that have directly affected the commercial fishery for Garfish. The most significant of these were implemented on 1 July 2021 and included: (i) implementation of a quota management system for the SG and GSV/KI fishing zones; (ii) the removal of the seasonal fishery closures; (iii) reduction of the LML from 250 to 230 mm TL; and (iv) reduction of the minimum mesh size of haul net pockets from 36 to 32 mm for the WC and SE fishing zones, while the minimum mesh size of haul net pockets for the SG and GSV/KI fishing zones of 36 mm was retained.

Preliminary work has recently been undertaken by Haddon (2024) to investigate alternative assessment stock assessment models for South Australia’s Garfish stocks using the Stock Synthesis framework (Methot and Wetzel 2013). This work was initiated to address the need for alternative biological performance measures for comparison with selected limit and target reference points and decision rules to inform a new harvest strategy framework for the MSF to be introduced in 2025 (Haddon 2024). A key piece of assessment information from this work was the effect of the fishery becoming focussed primarily on female Garfish (i.e., the egg producers), such that modelled female biomass is now much less than male biomass, with consequent negative impacts on egg production and recruitment. Whilst the timing of this work by Haddon (2024) was such that this assessment information was not considered in this stock assessment, it is important context when considering the GarEst modelled trends in recruitment and virgin egg production presented in this assessment.

4.2. Information sources used for assessment

This report assessed the current status of the Southern Garfish stocks in South Australia’s four regional fishing zones – SG, GSV/KI, WC and SE. The status of the stocks was assigned using the National Stock Status Reporting Framework (Piddocke et al. 2021; Table 1-2). The current harvest strategy for Southern Garfish (PIRSA 2013) lacks an index that explicitly defines stock status and does not provide pre-defined limit reference points that determine when the stocks are depleted (i.e., recruitment is impaired when the fishable biomass no longer has the reproductive capacity to replenish itself). Consequently, the assignment of stock status used a weight-of-evidence approach that included performance indicators and trigger reference points prescribed in the Management Plan (PIRSA 2013). These include biological performance indicators that are based on outputs from the GarEst model and fishery age structures, and general performance indicators that are based on trends in the commercial fishery statistics (Table 2-2).

Extensive information was available for this stock assessment. This included: (1) comprehensive understanding of the biology of the species and its population structure in South Australia; (2) management arrangements for the fishery (PIRSA 2013); (3) commercial fishery statistics up to 30 June 2023; (4) recreational fishery data from surveys in 2000/01, 2007/08, 2013/14 and

2021/22; (5) annual length and age data from commercial catch sampling up to 30 June 2023; and (6) estimates of the performance indicators in the Management Plan (PIRSA 2013), including GarEst model outputs for fishable biomass, harvest fraction, recruitment, and egg production.

4.3. Stock status

4.3.1. Spencer Gulf Fishing Zone

Historically, the SG fishing zone has produced more than half of South Australia's total catch of Garfish. Over 90% of the catch is taken by haul net fishers operating in NSG, with minor contributions from dab net fishers operating across the zone. The last stock assessment was completed in 2022 and classified the NSG stock as 'recovering' and the SSG stock as 'sustainable' (Smart et al. 2022a). The 'recovering' status for NSG reflected favourable reductions in harvest fraction up to 30 June 2019, while adult biomass and egg production had remained relatively stable since 2015. Signs of recovery were also evident in the 2023 assessment for the SG fishing zone (Smart et al. 2023).

Annual catches from the SG fishing zone have been low since 2015/16 and were managed within TACCs in 2021/22 and 2022/23. The total catch of 74 t in 2022/23 represented 69% of the TACC and was the lowest on record. The low catch was likely associated with a combination of low targeted effort, reflecting a long-term decline in the number of active licences in the fishery and management initiatives aimed at reducing exploitation rates, and constraints in quota trading and/or market-related issues. Targeted haul net CPUE declined steeply from 2010/11 to 2015/16 but has since recovered to the historic mean, while targeted dab net CPUE was above the historic mean in 2022/23. These results reflect increasing abundance of Garfish across the region in recent years.

Higher abundances were also evident in modelled fishable biomass (i.e., biomass ≥ 230 mm TL) for the first time in several years, with an increase from 232 t (± 53 t, 95%CI) in 2019/20 to 280 t (± 54 t, 95%CI) in 2021/22. Modelled adult biomass (i.e., biomass ≥ 210 mm TL) has also increased (by 23%) since the last stock assessment. Despite these positive trends, fishable biomass remained below the historic mean, while egg production was stable at a moderate level. Harvest fraction continued to decline and reached 35% in 2021/22 but remained above the operational target of < 30%.

A slight change in the age structure of fishery catches was detected in this assessment. The shift partly reflected an increase in Garfish between 230 and 250 mm TL retained by fishers in 2021/22 compared to previous years (a function of the LML reduction implemented on 1 July 2021), along with marginally higher modelled numbers of Garfish reaching the 1+ age class (i.e., recruitment) in 2020/21 and 2021/22 compared to previous years. Nevertheless, low proportions of fish aged three years and older indicate that the age structure of the stock remains truncated.

Since the previous stock assessment (Smart et al. 2022a), modelled fishable biomass in the SG fishing zone has increased to its highest level since 2015/16, harvest fractions have continued to trend downwards but are yet to reach the operational target, egg production and recruitment have remained relatively stable at low levels, and there has been no evidence of a positive shift in population age structure. As such, there is not yet sufficient evidence to warrant a change in status from 'recovering' to 'sustainable'. On this basis, the Southern Garfish stock in the SG fishing zone is classified as **recovering**.

4.3.2. Gulf St Vincent/Kangaroo Island fishing zone

The GSV/KI fishing zone has been the second most productive region for Garfish in South Australia and, in 2022/23, contributed 45% of the State's total commercial catch. Most of the catch is taken by haul net from NGSV, with smaller catches taken by dab net across the zone. The 2022 stock assessment classified the NGSV stock as 'recovering' and the SGSV stock as 'sustainable' (Smart et al. 2022a). The first assessment of Garfish in the GSV/KI fishing zone was completed in 2023 and assigned the status of 'recovering' (Smart et al. 2023).

The current assessment indicates that changes in management arrangements over the last 15 years have continued to recover the Garfish stock in the GSV/KI fishing zone. Since 2022, commercial catches from this zone have been managed within annual TACCs. The total catch of 64 t in 2022/23 represented 80% of the TACC, was the lowest on record, and was associated with historically low targeted haul net and dab net effort. Estimates of targeted haul net and dab net CPUE for 2022/23 were the highest and third highest on record, respectively, reflecting high abundance of Garfish across the region.

Modelled fishable biomass (i.e., biomass ≥ 230 mm TL) has followed an increasing trend since 2006/07. The rate of this increase has been highest since 2014/15, during which time biomass increased 39% to a 15-year high of 248 t (± 56 t, 95%CI) in 2021/22, which was above the historic mean. Modelled 'biomass ≥ 210 mm' has also increased by 12% since the last stock assessment and by 36% since 2014/15. These results reflect a long-term decline in harvest fraction and a steady increase in egg production since 2014/15. Harvest fraction has trended favourably since 2005/06, declining at a rate of around 4% per year to a record low of 29% in 2021/22 and reaching the operational target of < 30% for the first time. Egg production has increased to 16% of an unfished stock in 2021/22, which is the third highest level on record, while the numbers of Garfish that reached the 1+ age class (i.e., recruitment) increased for the second consecutive year in 2021/22.

Age structures for 2021/22 and 2022/23 demonstrated higher proportions of age 1+ Garfish compared to the immediately preceding years, while the proportions of older fish (i.e., age 3+) have declined. However, it is unlikely these changes reflect further age truncation in the population given the recent LML reduction has resulted in smaller, younger fish in the catches.

Since the 2022 stock assessment, targeted haul net catch rates in the GSV/KI fishing zone have increased to historically high levels, fishable biomass has increased by 27% to its highest level since 2005/06, harvest fraction has declined to below the operational target of 30% for the first time in at least 38 years, egg production has increased to its third highest level on record and recruitment has increased. This indicates that the biomass of this stock is unlikely to be depleted, recruitment is unlikely to be impaired, and the current low level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On this basis, Southern Garfish in the GSV/KI fishing zone is no longer in a ‘recovering’ state, but rather is classified as a **sustainable** stock.

4.3.3. West Coast Fishing Zone

Prior to the implementation of extensive spatial netting closures across the WC fishing zone in 2005/06, this region supported a small commercial fishery for Garfish that regularly produced annual catches of 20–25 t using predominantly haul nets. Since then, catches have been < 3 t in most years and dab nets have become the main gear used to target and catch Garfish. The total catch of 0.96 t in 2022/23 was fourth lowest on record. The recent low catches have been associated with historically low levels of targeted fishing effort. Targeted catch rates by dab net fishers have been at or above the historic average over at least the last four years, reflecting a moderate–high relative abundance of Garfish in the region. The above evidence indicates that the biomass of this stock is unlikely to be depleted, recruitment is unlikely to be impaired, and the current low level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On this basis, Southern Garfish in the WC fishing zone is classified as a **sustainable** stock.

4.3.4. South East Fishing Zone

The SE fishing zone has been the least productive region for South Australia’s Southern Garfish fishery since 1983/84. Total catches have generally been < 2 t, with contributions to total annual State-wide commercial catches rarely exceeding 0.3%. As only two licences reported targeting and landing Garfish in the SE fishing zone in 2022/23, the catch data are confidential. In 2021/22, the total catch of 2.2 t was all taken by dab net. The targeted dab net CPUE of 9.5 kg.net-hour^{-1} in 2021/22 was among the highest on record, reflecting relatively high abundance of Garfish in the areas that were fished. The above evidence indicates that the biomass of this stock is unlikely to be depleted, recruitment is unlikely to be impaired, and the current level of fishing mortality is unlikely to cause the stock to become recruitment impaired. On this basis, Southern Garfish in the SE fishing zone is classified as a **sustainable** stock.

4.4. Assessment uncertainties

As with most stock assessment models, uncertainty exists around the estimate of natural mortality (M) assumed in the GarEst model. The M value of 0.4 used in the current assessment represents a conservative approach for recommending TACCs based on modelled biomass (Smart et al. 2022a). The sensitivity analysis in the last stock assessment identified that incremental changes in M from 0.2 to 0.5 did not affect trends in model estimated biomass, but had a considerable influence on the scale of modelled biomass (e.g., lowering M from 0.4 to 0.3 produced decreases in average biomass of -12% in SG and GSV, whereas increasing M to 0.5 produced increases in average biomass of approximately +15% in both gulfs). Consideration should be given to reviewing the value of M used in the stock assessment model for each of the two gulf zones in the context of contemporary biological, demographic and fishery information prior to future assessments to ensure they remain appropriate.

Uncertainty also exists around the reliability of GarEst modelled annual recruitment from 1983/84 to 2003/04. This is because age and length data were only available from routine market sampling done at SAFCOL since 2005 and during 1999-2000 from a FRDC-funded project (Ye et al. 2002). Age structures are particularly informative of relative recruitment as they provide the model with information on year class strength as well as total mortality, and so model estimated recruitment is more certain for years where reliable data are available. Nonetheless, the historical biological data obtained from the market sampling program since 2005 was comprehensively reviewed for this stock assessment. The review improved the quality of the age data used in GarEst through the identification and resolution of anomalies or incorrectly entered values. While this is likely to have had some small impact to the annual age structures developed for each fishing zone, the trends in model outputs for this assessment, including for recruitment, are consistent with those from previous assessments. This indicates that the ‘data tidying’ had minimal influence on the model outputs.

An observation of the Garfish in catches since at least 2005 was the consistent imbalance of the sex ratios, where there have been significantly higher proportions of females than males in the catches (Figures 6-12 and 6-13). This leads to an important source of uncertainty around the long-term implications of the fishery on the spawning component of the fishable biomass and subsequent egg production, which was recently highlighted by Haddon (2024). The potential effect of the fishery being focused primarily on female Garfish, is such that female biomass may now be considerably less than it once was, which may explain the low recruitment since the mid-2000s and the consistent low levels of virgin egg production since at least 1983/84 for both gulfs. One potential hypothesis to account for the observed sex ratio imbalance, relates to potential spatial segregation of sexes that reflects social factors, such as schooling of females in areas that make them more susceptible to haul net fishers. In GSV, Fowler (2019) found that patterns of dispersion of male and female fish differed across depth zones, and that these dispersion patterns varied among locations. For example, at Port Wakefield (NGSV) during spring/summer, females were more prevalent in the waters < 5 m deep and males in the deeper areas between 5 and 15 m. This segregation was also evident at several other localities, including Port Vincent and West Beach, but was not consistent across all locations, and it varied between summer/spring and autumn/winter. Contemporary information on the degree spatial segregation of sexes occurs in time and space in both gulfs, relative to the long-term removals of females and males in these areas, would improve understanding of the long-term implications of this harvesting regarding the spawning biomass and subsequent egg production.

A further uncertainty relates to the poor understanding of the temporal trends in catch and effort by the recreational sector. This sector's total harvest has been estimated through telephone/diary surveys that are undertaken on a five-year cycle (Henry and Lyle 2003, Jones 2009, Giri and Hall 2015, Beckmann et al. 2023). Although these surveys adopt a reasonably consistent methodology that allows the results to be compared through time, their estimates of catch and effort are typically imprecise. This imprecision has implications for stock assessments. It also has implications for determining resource shares against prescribed allocations, which can ultimately lead to changes in the management of the resource among the fishing sectors. Improving the precision of recreational catch estimates, through more frequent surveys and retention of high participation rates, will broadly benefit the assessment and management of the Southern Garfish resource in South Australia.

Finally, since the last assessment there have been concerns from industry that the Garfish catches at SAFCOL may not be representative of the commercial fishery catch. This is because some fishers grade their catch into size classes (e.g., small, medium, large) and send different components of their catch to different fish processors (e.g., larger fish are sometimes transported to interstate markets where they fetch a higher price). Sampling of graded catches that are missing fish of a particular size range can bias the data considered for assessment. To address industry concerns, the catch sampling program has been extended to involve regional fish processors at key fishing ports around the State (e.g., Wallaroo, Port Broughton, Port Pirie, Port Lincoln, Streaky Bay and Ceduna) and regular direct contact with fishers that target Garfish. The expanded program, which will still include the SAFCOL market, commenced in 2023/24 and will be fundamental in improving biological data for future assessments.

4.5. Future research needs

The most important research needs for the Southern Garfish fishery and its management include: (i) investigate alternative assessment model outputs for Garfish stocks using the Stock Synthesis framework (Methot and Wetzel 2013); (ii) investigate the degree of spatial segregation of male and female Garfish in time and space in both gulfs, relative to the long-term removals of each sex in these areas, and the cumulative effects of this on egg production and recruitment; (iii) supplement market sampling with regional and industry-direct sampling to obtain more representative samples (commenced in 2023/24); (vi) develop appropriate reference points for the new harvest strategy framework that will be linked to definitions of stock status; (v) investigate alternative CPUE standardisation models; (vi) more regular and reliable estimates of recreational catch (various proposals are being considered); and (vii) application of the harvest strategy framework when finalised under the next Management Plan.

The preliminary work recently undertaken by Haddon (2024) to investigate alternative models to assess Garfish stocks using the Stock Synthesis framework highlighted that the sex ratio imbalance in the catches could have serious implications regarding the spawning biomass and subsequent egg production and recruitment. Any long-term cumulative effects of harvesting significantly higher proportions of females than males are not evident in the GarEst model outputs presented in this assessment, because the modelled estimates of fishable biomass are not presented by sex. Furthermore, in its current form, GarEst apportions recruitment to the fishable biomass by sex according to the sex ratio of the catch, most of which comes from areas where the biomass available to the fishery is dominated by females (i.e., waters < 5 m deep), and lacks input information about the age-sex proportions of Garfish in deeper areas. Consequently, it estimates recruitment of larger numbers of females than males, with both recruitment (as well as catchability but not length selectivity) modelled as differing by sex, which may not be indicative of recruitment at the stock level. An alternative approach may be to force a 50:50 sex ratio for recruits in GarEst and modelling only length selectivity as sex-specific to investigate the potential impact of the fishery becoming focussed on female garfish. Further sampling of the population in and out of the fished areas, to build on the preliminary work done by Fowler (2019), would improve understanding of recruitment of both sexes in these areas and the demographic processes that influence the availability of males and females to the fishery.

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6. APPENDICES

6.1. Appendix 1: Effort Standardisation for GarEst

There are two stages of effort standardisation, as detailed in this Appendix. The first stage applies the conventional catch rate standardisation method based on a Generalised Linear Model (GLM) fitted to logbook returns data. This standardisation is run only for the first model effort type, i.e., ‘Effort type 1’ – all commercial MSF effort using haul nets to target Garfish, as well as commercial MSF effort using haul nets from 1 October 2005 onwards (subsequent to the voluntary net buy-back scheme) with ‘Any target’ recorded in logbooks and half or more (≥50%) of the total catch weight was Garfish. The second stage is integrated within the overall GarEst model structure as extra freely estimable parameters. There, a separate catchability parameter is estimated for every combination of the three commercial effort types, summer and winter half-years, and the two gulfs. For haul net, the catchability was estimated separately for periods < 2005 and ≥ 2005.

6.1.1. Stage 1: Effort type 1 standardisation using the GLM method

In the assessments done prior to 2015, effort data were not standardised. Since then, two changes in the fishery have increased the usefulness of an external GLM-based standardisation procedure: (1) some Garfish haul 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 haul net endorsements were removed, introducing a break in the CPUE time trend. To account for the removal of those licences, a GLM-based standardisation procedure where the effect of individual licences is explicit has been implemented since 2015 in Steer et al. (2016). This year (2024), the procedure for effort data standardisation has been updated.

As GarEst is an effort-conditioned model, a standardised effort time series (rather than a standardised CPUE time series) is required. The method was to estimate a quarterly standardised CPUE time series using conventional GLM-based methods (Maunder and Punt 2004), and then obtain the standardised effort by dividing recorded catches by the standardised CPUE. Note that standardisation of effort was conducted for only ‘Effort type 1’ (as defined above). The procedure from this method is as follows: For ‘Effort type 1’ and for each fishing zone (GSV/KI and SG):

1. Use records from logbooks (reported monthly or daily) with a positive CPUE to fit a GLM using the formula:

   CPUE ~ 0 + QuarterYear + Month + LicenceNo_RegisteredMaster + MFA,

   with a Gamma error structure and logarithm link function. The ‘0’ in the formula indicates that no overall intercept was estimated. All four data covariates are treated as factors. The term LicenceNo_RegisteredMaster is a variable that designates a separate level for every combination of licence number and registered master, thus accounting for variation in both licence number and registered master. Master is the skipper of the vessel fishing under each licence as recorded in the PIRSA licencing (PIMS) database. Because data on registered master is only available since PIMS started in 2008; for data points before 2008, this variable is equivalent to LicenceNo. This model differs from the previous assessment (Smart et al. 2022a) in the choice of link function. Previously, the ‘inverse’ link function (which is canonical for the Gamma distribution) was used. However, this is the suboptimal function to transform a multiplicative CPUE model into a linearised statistical model for the GLM. The logarithm transformation is the appropriate modelling choice, e.g., see Hilborn and Walters (1992), and is now used for the link function of the GLM.

2. From the fitted model, use the estimates of the coefficient for each level of the QuarterYear factor and back-transform them with the exponential function to estimate the quarterly ‘time effect’ (Hilborn and Walters 1992) to be the index of relative abundance time series. This index of relative abundance is scaled by multiplying it by the average nominal CPUE values and then dividing by the average index values, where the two averages are taken over all quarterly time steps. The result is called the standardised CPUE time series.
3. The standardised effort for each quarter is calculated as the recorded quarterly catch divided by the standardised CPUE value calculated for that quarter in step 2.

6.1.2. Stage 2: Separate catchability estimates by effort type, summer/winter, and gulf.

A second stage of standardisation is expressed in the wide array of catchability parameters estimated as part of the overall GarEst model fit. A separate absolute parameter is estimated for each combination of the three commercial effort types (i.e., effort types 1 to 3; Section 2.4.1), summer/winter season (October-March, April-September), and each gulf. Absolute catchability is the coefficient (q_{CSE} in Eq. 6.4) that relates data-reported fishing effort to model-estimated fishing mortality for a given combination of effort type, quarterly time step, and region, after having accounted for selectivity by sex and length (Eq. 6.1 and 6.4). In this role, these catchability parameters reflect the relative fishing power of a unit of effort from each effort type in contributing to the total instantaneous fishing mortality rate for Garfish (Eq. 6.1 and 6.6), given each respective level of reported fishing effort.

The implementation of this highly detailed catchability array permits GarEst to use all the available data, namely logbook catch totals and catch samples by age-sex-length, for informing catchability. For the ‘Effort type 1’, this supplements the standardisation based on logbook variations of CPUE used in the GLM of stage 1 above, whereas for effort types 2 and 3, it forms the only method of accounting for heterogeneity in catchability. GarEst incorporates biological variation in catchability doing so by sex-specific, quarterly season selectivity, and by gear-specific length selectivity (Eq. 6.2 and 6.4). In order to concisely illustrate the impact on total fishing mortality by different effort type components Figure 6-1 was created, which displays yearly time series of maximum fishing mortality calculated as the average over the quarterly annual-scaled maximum fishing mortalities within each model year. In each quarterly time step, *t*, the maximum fishing mortality is modelled, for example up to 2001, by $q_{CSE}(r,t_{season},i_E)\cdot\left(1+q'\cdot(t-t_{mid})\right)\cdot\tilde{E}(t,r,i_E)$ for the commercial sector, or just $q_{CSE}(r,t_{season},i_E)\cdot\tilde{E}(t,r,i_E)$ for the recreational sectors, these factors appearing in Eq. 6.1 and 6.4 and as described in Appendix 6.4. The values shown in Figure 6-1 are on the annual scale because in the calculation of population depletion for a quarterly time step *t* (Eq. 6.7), fishing mortality is multiplied by the proportion of the year time step *t* comprises. Note that absolute levels of these average fishing mortalities do not directly relate to population depletion modelled by GarEst because this occurs at the quarterly time step resolution and recruitment and growth occur during each year; for quarterly harvest fractions and catch values refer to Appendices 7 and 8. Furthermore, the construction of maximum fishing mortality excludes selectivity by sex and length (which predominantly are valued less than 1), this implies that the mortality levels shown in Figure 6-1 are biased upwards in terms of representing fishing mortality applied per region, time step, and effort type.

Figure 6-1 indicates that effort types 2 and 3 (other haul nets, and dab nets) from around 2005 and onwards contributed substantially less to total fishing mortality compared to effort type 1 (targeted haul nets, i.e., ‘Haulnet+’). For recreational fishing mortality, in GSV/KI the levels prior to around 2000 indicate a contribution similar to that of Effort types 1 and 2 (~0.4). Recreational fishing mortality after 2000 in both regions was of reasonable size comparable to that of effort types 2 and 3, although from 2015 onwards it is decreasing towards notably low levels.

Figure 6-2 indicates that the trends in commercial sector fishing mortality and effort data broadly align for each of Effort types 2 and 3 differing most near start or end of time series, but for effort type 1 such alignment is less strong. Differences in trends between fishing mortality and effort data are primarily influenced by two attributes of GarEst, namely (1) the imposed linear temporal trend in catchability up to 2001 (Eq. 6.4), and (2) separate absolute haul net catchability (q_{CSE} in Eq. 6.4) being estimated for periods < 2005 and ≥ 2005. The linear trend in catchability is positive and the ≥ 2005 period’s catchability was estimated greater than for < 2005 period, explaining why fishing mortality trend is at or below that of effort data for < 2005 and vice versa for ≥ 2005.

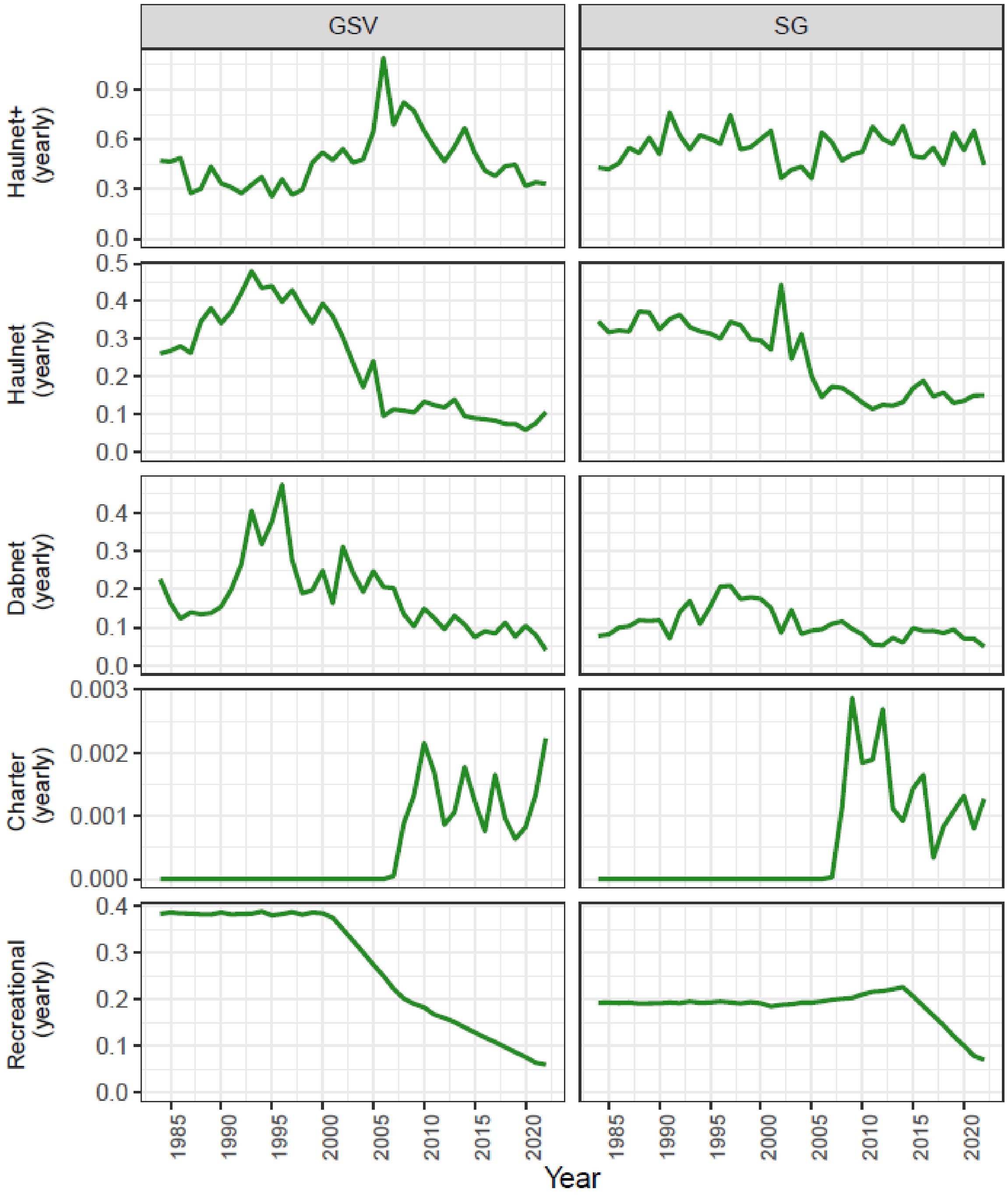

Figure 6-1. GarEst estimates of annual average maximum fishing mortality (*F*) by effort type for Gulf St Vincent (GSV, left) and Spencer Gulf (SG, right). Years begin with “1984” (spanning 1 October 1983 to 30 September 1984).

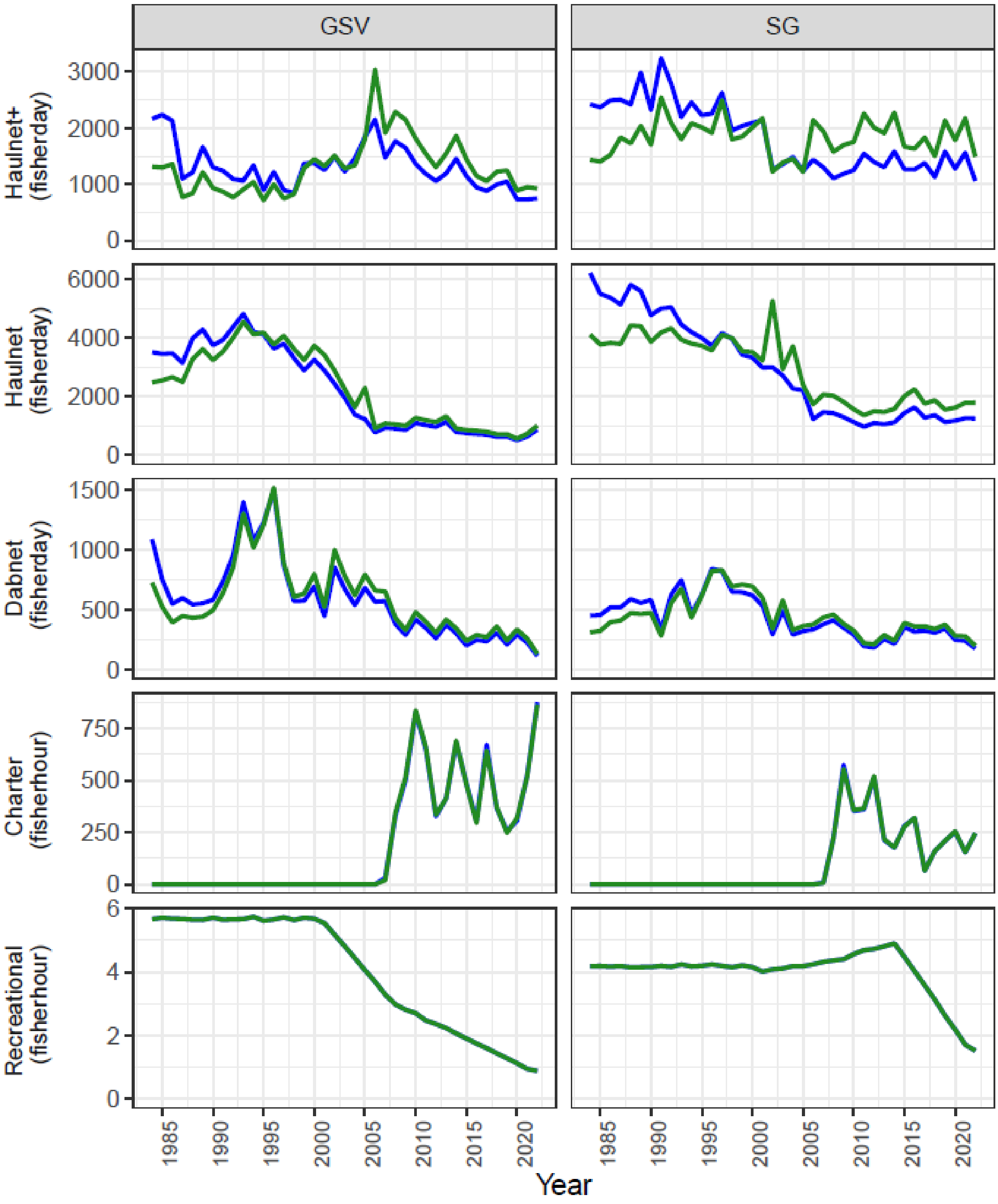

Figure 6-2. Annual effort data (blue) by effort type for Gulf St Vincent and Spencer Gulf, for comparison with the same estimates of maximum *F* (green) shown in Figure 6-1. Years begin with “1984” (spanning 1 October 1983 to 30 September 1984).

6.2. Appendix 2. Recreational and charter boat catch and effort data in 'GarEst'

Recreational data constitute a large proportion of the catch of Garfish in South Australian waters. However, the data available to inform the catch from that sector is relatively limited and imprecise, provided predominantly from four telephone and diary surveys conducted in 2000/01 (Henry and Lyle, 2003), 2007/08 (Jones, 2009), 2013/14 (Giri and Hall, 2015) and 2021/22 (Beckmann et al., 2023). Since 2007, charter boats have reported their monthly catch totals in logbooks and since the 2018 assessment charter boats have been included as a fifth model effort type in GarEst. In this Appendix, the handling of these data for use as input to the GarEst stock assessment model is summarised.

The recreational fishing survey (Giri and Hall, 2015) that covered 2013/14 did not provide the estimated Garfish catch number broken down by month, as the two previous surveys had done. As GarEst uses a quarterly time step, we introduced several additional steps of data pre-processing to obtain the required data inputs for recreational catch by region and quarter year over the 2013/14 survey period. We give details of this pre-processing in first subsection below.

In the second subsection, we outline modifications to the GarEst model fitting procedure undertaken in the absence of recreational monthly effort data for the 2013/14 survey. Surveys and charter boats report all catches in number rather than weight landed. Accordingly, the model fits to recreational and (from 2007 onward separately) to charter boat catches in numbers landed. In the third subsection we outline the inclusion of catch and effort data from the South Australian charter boat fishery.

Giri and Hall (2015, Table 8) reported a single total number of Garfish harvested (870,147) by recreational fishers (including charter boats and onshore) for the 12-month period covered by the telephone and diary survey from December 2013 to November 2014. They also reported percentages by region (Giri and Hall 2015, p. 36, Figure 13) that we applied to the total yearly harvest number, giving estimates of total yearly Garfish recreational harvest by region for the year, namely 49% for SG, 26% for GSV/KI. The 19% for WC and 6% for SE of Garfish harvested in South Australia were not included in the model.

6.2.1. Pre-processing to obtain catches by quarterly time step for the 2013/14 recreational survey

The 2013/14 survey (Giri and Hall, 2015) provided the sample estimate of the yearly catch (in number) $\hat{C}_{2013/14,r}$ of Garfish by recreational fishers in each region r (GSV/KI and SG). To obtain quarterly numbers from the yearly total estimate by region, we inferred quarterly proportions harvested by fitting to the quarterly recreational catch estimates available from the three other recreational surveys of 2000/01, 2007/08, and 2021/22 from which quarterly estimates were available. Once estimated, these four estimates of quarter-year recreational catch proportions were applied for all model years.

Specifically, we fitted the following statistical linear model formula in R,

Catch_Number_Est ~ 0 + Season : Region,

to the dataset of quarterly survey estimates of recreational Garfish catches by region. The response is the survey sample estimated recreational catch in a quarter and region, and only the interaction terms of the Season (October-December, January-March, April-June, and July-September) and Region (SG and GSV) factors are the regressors. Furthermore, the "0" in the formula indicates the y-intercept parameter is excluded from the model.

After fitting the linear model, the predicted catch for each quarter and region was calculated. Then the predicted proportion of catch taken in each quarter for both regions was calculated from these predicted catch estimates. These predicted proportions were then used to distribute the total annual catch estimate of the 2013/14 survey into region- and quarter-specific catches.

For non-survey years, quarterly catch estimates were estimated by interpolating the seasonal catch estimate values linearly between survey years. Prior to the first survey in 2001/02 the four quarterly values of 2001/02 were retained unchanged. Beyond the last survey, the quarterly 2021/22 catch estimates are carried forward up to the current model time step (Figure 6-3).

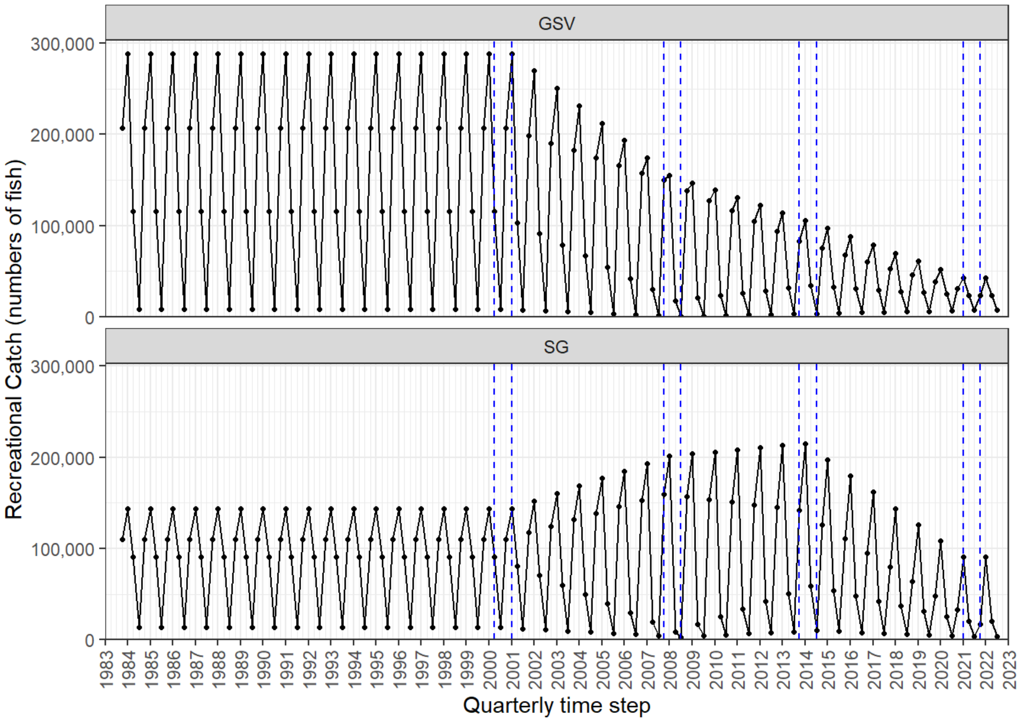

Figure 6-3. Recreational Garfish catch totals estimated from four surveys (2000/01, 2007/08, 2013/14, and 2021/22) for Gulf St Vincent and Spencer Gulf. Catches between survey years are interpolated linearly for each quarter. The catch estimates from the last survey are carried forward to the current model time step. Vertical blue dashed bars indicate telephone and diary survey periods. Estimates include catch by recreational fishers on charter boats.

6.2.2. Recreational effort inputs

For recreational effort as an input to this effort-conditioned model, the current stock assessment uses an updated approach. It is important to account for the removal of recreational catch from the Garfish stock. However, recreational catch data have relatively high uncertainty, and recreational effort (and catch-per-unit-effort) data do not appear to contain any information about Garfish stock abundance because effort was not reliably estimated by the recreational fishing surveys (e.g., Giri and Hall 2013). Therefore, it is desirable for GarEst to remove the recreational catch from the model population without considering recreational effort data when estimating Garfish abundance.

To achieve this, for each region, a time-series of recreational effort values was generated in each quarter as the recreational catch in that quarter-year (as calculated per section 6.2.1) divided by the mean recreational catch over all quarter-year time steps. A very small amount of random noise with a normal distribution with mean 1 and standard deviation 0.01 was multiplied to this effort time series to prevent issues regarding numerical convergence. This way, the recreational effort varies in direct proportion to survey recreational catch.

Later in constructing the GarEst model, a single recreational catchability value was estimated. The recreational component of the model likelihood was given a low weighting, which means its CPUE has negligible impact on estimates of Garfish abundance. This enabled the model to remove the recreational catch of Garfish in each quarterly time step while removing any influence of recreational effort in model assessment.

6.2.3. Incorporating charter boat catch and effort data into GarEst

Since 2007, the South Australian charter boat fishery has recorded catch and effort information in daily logbooks. This permitted the inclusion of charter boats as a fifth effort type in GarEst. With this separate, much higher quality information, charter catches were modelled separately from other recreational catch from October 2007 onward. Because charter boat catches were included in the totals estimated by the recreational fishing surveys (Henry and Lyle, 2003; Jones, 2009; Giri and Hall, 2015; Beckman et al., 2023), from 2007 onward, these charter boat catch totals were subtracted from the survey totals to obtain the (non-charter) recreational catches for each regional and quarterly time step.

Because charter boats targeting Garfish had substantially higher CPUE than those not targeting Garfish, a total charter effort measure was constructed that accounted for this difference. This was performed by multiplying the non-targeted effort by a scaling factor (0.235 for GSV and 0.186 for SG) determined from the ratio of non-targeted CPUE to targeted CPUE (thus converting non-targeted effort into units of catching power equivalent to targeted effort) and adding it to the targeted effort to get total charter fishing effort, i.e., for quarterly time step t and region r

$$TotalCharterEffort_{t,r} = TargetEffort_{t,r} + NonTargetEffort_{t,r} * ScalingFactor_r \, .$$

The scaling factor was computed as a ratio, dividing the CPUE of non-target by the CPUE of target averaged over all available quarterly time steps t (since 2007). This was performed for each region (r),

$$ScalingFactor_r = \frac{\sum_t NonTargetCatch_{t,r} \Big/ \sum_t NonTargetEffort_{t,r}}{\sum_t TargetCatch_{t,r} \Big/ \sum_t TargetEffort_{t,r}}$$

where *TargetEffort* and *TargetCatch* include days where charter boat operations targeted Garfish and *NonTargetEffort* and *NonTargetCatch* include days when charters targeted other species (or did not explicitly target Garfish) but caught Garfish. $TotalCharterEffort_{t,r}$ (Figure 6-4) was used as the charter effort data input in the GarEst model.

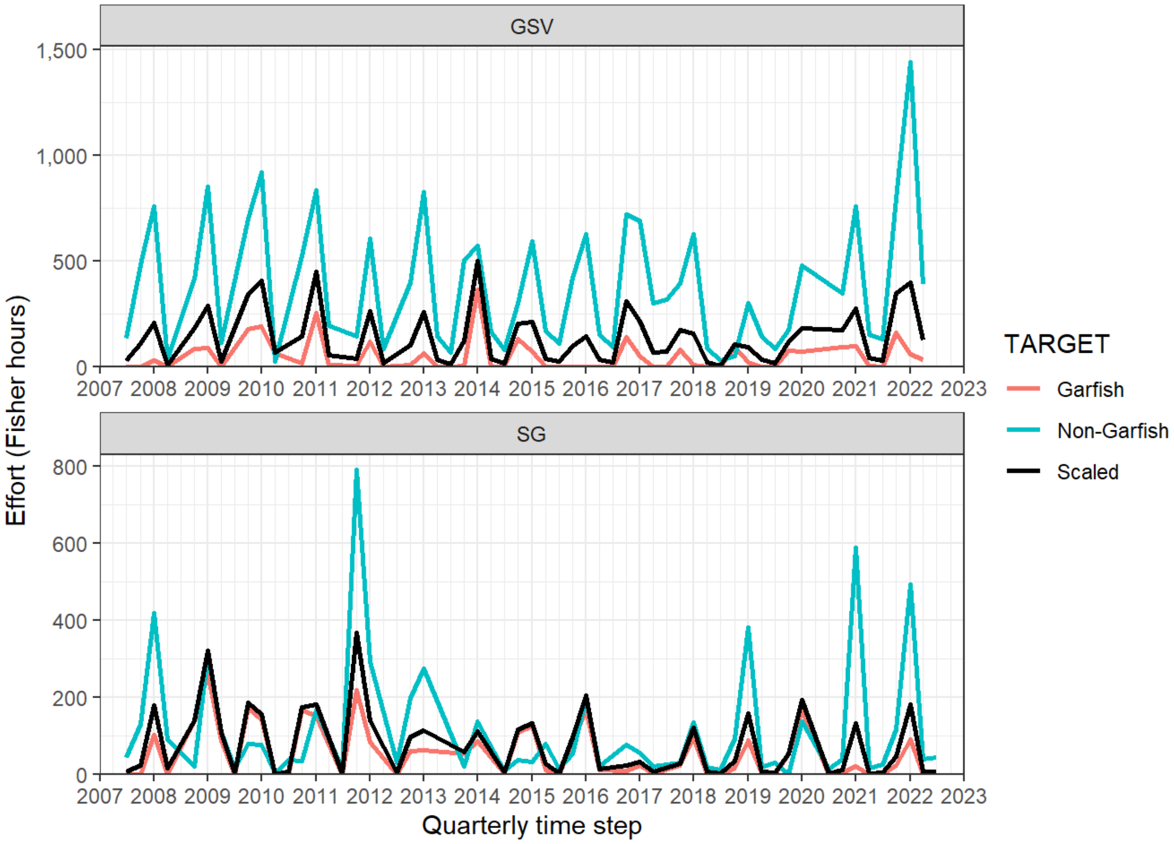

Figure 6-4. Total effort (number of fisher hours) quarterly time series since July 2007 for the South Australian charter boat fishery, by targeting of Garfish (red), non-targeting of Garfish (blue), with the calculated scaled total charter effort (black). The scaled total charter effort was used in the GarEst stock assessment model.

6.3. Appendix 3: Age-length 'slice' partitioning method

The GarEst model is based on the slice partition method for representing the population structure of Garfish numbers, breaking down model population number by age, and also by the lengths of fish within each recruited cohort. Representing population structure by both age and length-within-age, for each region, gulf, and time step, improves model accuracy in a stock such as Garfish, where legal minimum length separates fish of high fishing mortality from those incurring only natural mortality. As shown in Figure 6-5, faster growing Garfish, because they reach legal size sooner, incur the higher exploitation levels of mortality 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 dynamically account for this length-asymmetric mortality with a method that is computationally efficient. In addition, the three principal data sources, catch totals in weight, age proportions, and length moments, are from the landed catch and so include only Garfish above legal size. Cleanly separating sublegal from legal fish in the slice partition method, therefore permits a much more accurate prediction of these catch-specific data quantities to be fitted. Note that in the 2022 Garfish stock assessment and for current assessment, in order to provide an adult biomass defined over a single consistent Garfish size range (>210 mm TL) for all model years, changes in legal minimum length (LML) are modelled by a modification of length selectivity (see Appendix 4). The slice partition length (denoted in figures of this Appendix as 'LML') is maintained at 210 mm TL for all years.

The programming steps for calculating the three slice partition quantities used by GarEst are outlined in this appendix, summarising the coding algorithm for adding slice partition to an age-based model. In a slice model approach, fish are not moved between fixed length bins as in a length-based assessment model. Rather it is the length bins themselves that grow. The Garfish within each bin, once assigned to it when they reach legal size, incur only mortality. Not requiring movement of fish among length bins 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 length-at-age distribution grows to the right with each model time step, a standardised 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 standardised 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 distribution pdf grows with age. Thus, given the mean and standard deviation for all subsequent cohort ages from estimated growth parameters, 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 to obtain lower limits of integration for each slice. This computational short-cut requires an assumption of normally distributed lengths-at-age, though this is generally a quite good approximation. A fixed P_{slice} probability under the length-at-age pdf curve for each slice, which remains unchanged for all subsequent ages, underpins the overall slice partition and explains why the *z*-scores uniquely specify the slice partition for all model ages, given the mean and standard deviation of lengths for each 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, $\overline{l}(a)$, and (1.2) standard deviation, $\sigma(a)$, and thus, also, the (1.3) *z*-score, $z(a) = (LML - \overline{l}(a)) / \sigma(a)$, for every age (a) of growth. This step requires the input of growth submodel parameters specifying $\overline{l}$ and σ, given *a*. In this loop, calculate also (1.4) $P_{sublegal}(a) = \int_{-\infty}^{LML} p(l \,|\, \theta;\, a)\, dl$, 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 Stegun) (1965, formula 26.2.17) polynomial approximation and takes the standardised *z*-score as input.

Step 2. Calculate slice probabilities, $P_{slice}(a)$, the proportions of the cohort reaching legal size in each model age, $P_{slice}(a) = P_{legal}(a) - P_{legal}(a-1)$, $a = a_b + 1, ..., a_{max}$, where, for GarEst, the birth age of cohort creation, a_b = 5, at the start of the fifth quarter of age (1 October of the summer following the summer of spawning) for all cohorts. If time steps instead were half-yearly (October-March, April-September) then a_b = 3.

Step 3. Calculate the first of 3 output quantities, the fish transfer coefficients, $f_{transfer}(a) = P_{slice}(a) / P_{sublegal}(a-1)$, $a = a_b + 1, ..., a_{max}$. 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 $n_s(a) = a - a_b + 1$, $a = a_b,...,a_{max}$. (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, $a = a_b,...,a_{max}$. (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 Stegun 1965, formula 26.2.23) gives a standardised 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 6-5 and 6-6.

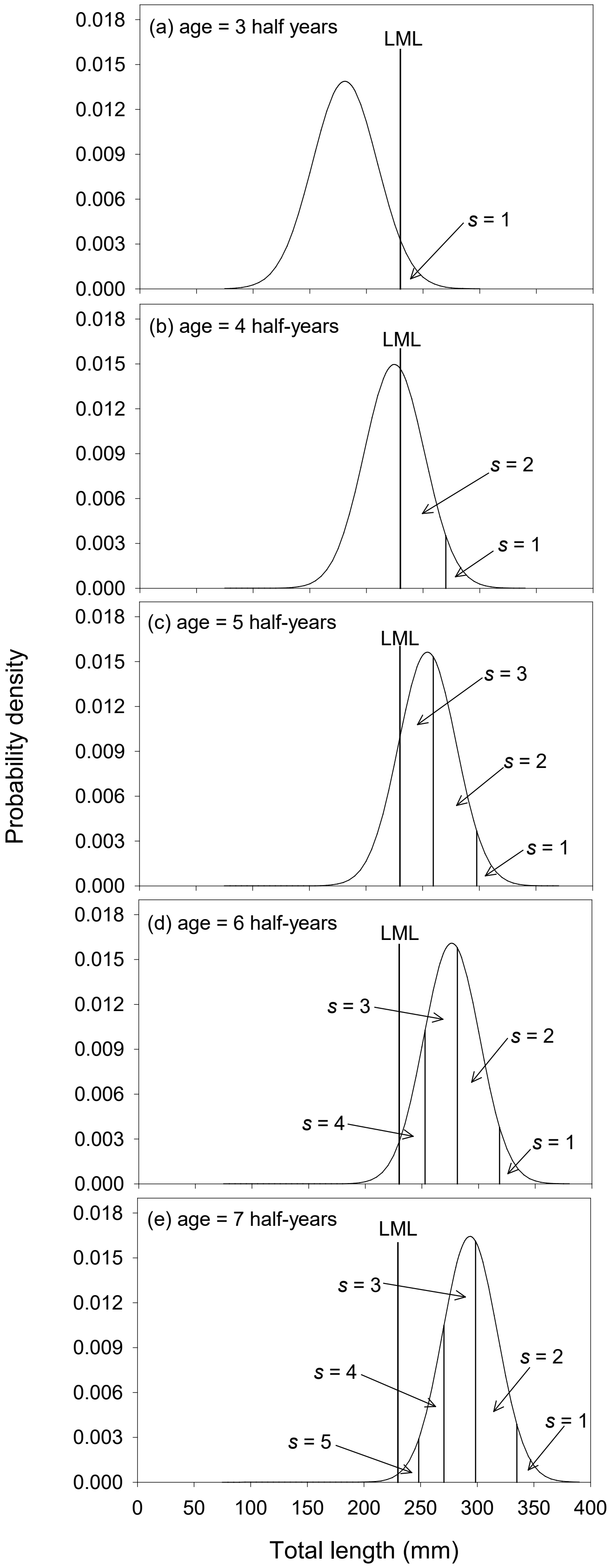

Figure 6-5. The growth of a normal length-at-age Garfish cohort is shown in successive panels. Here assuming a half-yearly time step, with each half-yearly time increment, a new slice, as the fish of length newly grown above LML (for illustration assumed here as 230 mm TL), numbered s=1, 2, etc., is created as shown. See Steps 1 and 2 above.

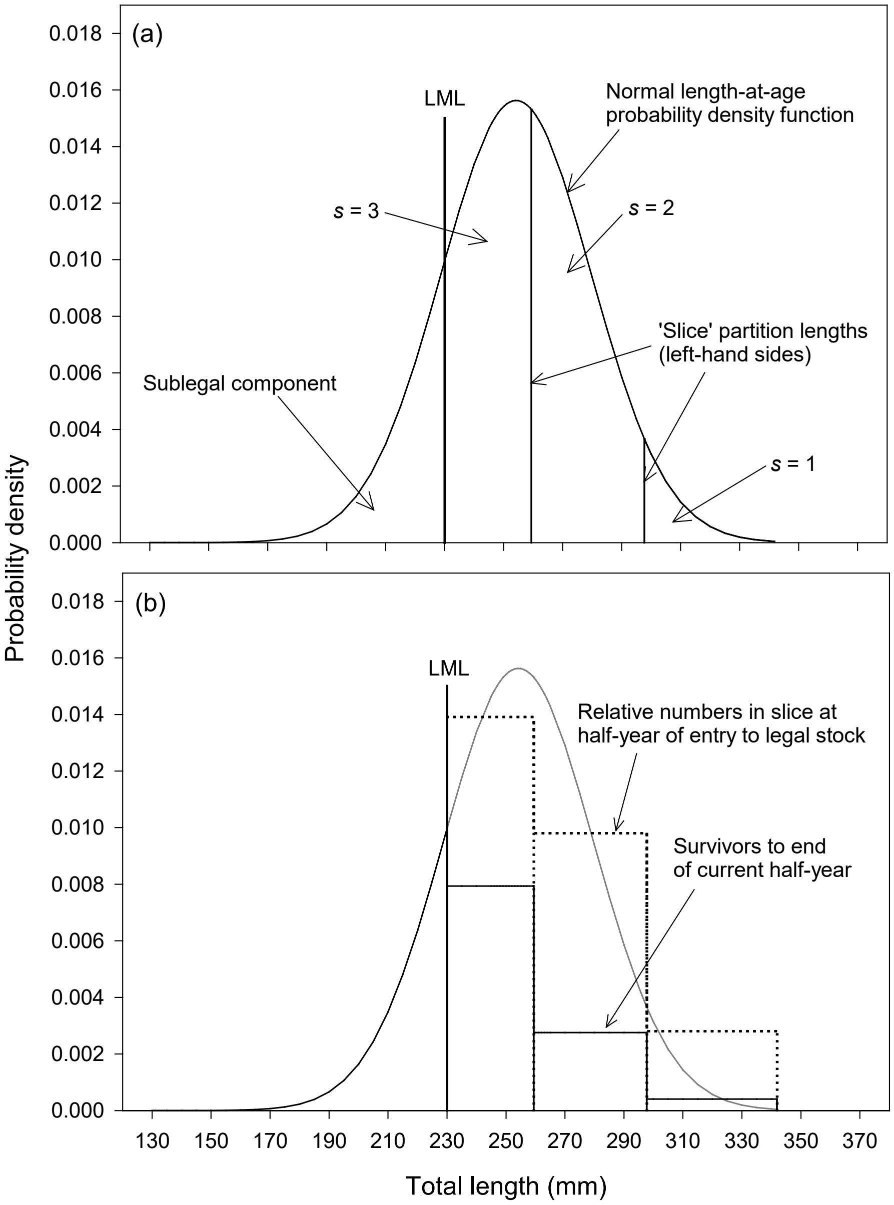

Figure 6-6. (a) The transfer of Garfish from sublegal sizes (left of LML, for illustration assumed here as 230 mm TL) to each newly created slice, is done using Step 3. (b) Subsequently, the proportional reductions in the population number in each slice differ depending on how long it has been exposed to fishing mortality, and on the length selectivity applying to each slice, in each (here, half-yearly) 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.

6.4. Appendix 4. Garfish Stock Assessment Model

The starting point and basis of the slice method for partitioning fish cohorts by length is the normal length-at-age growth submodel, specified by the mean length and standard deviation at the start of each quarterly age. This represents the length distribution of fish in each cohort age that would be observed in the absence of length-asymmetric mortality. Changes in the numbers by length, notably fewer faster growing Garfish that result from length-selective capture mortality, will subsequently be imposed on these model cohorts, after they are partitioned into slices. To model mean fish length $\overline{l}$, the mean of the normal length-at-age pdf, as well as spread about this mean length, for any quarterly cohort age, a, we employed a 7-parameter seasonal von Bertalanffy curve for mean length-at-age (McGarvey and Fowler 2002)

$$\overline{l}\,(a) = L_\infty \left\{ 1 - \exp\left[-K\left(\frac{a-t_0}{4}\right) + \frac{u}{2\pi}\cdot\left\langle \cos\left(2\pi\cdot\left(\frac{a-w}{4}\right)\right) - \cos\left(2\pi\cdot\left(\frac{t_0-w}{4}\right)\right)\right\rangle \right]\right\}$$

with the spread modelled via dependence on the length-at-age standard deviation $\sigma(a)$ as modelled by an allometric function of mean length: $\sigma(a) = \sigma_0 \cdot \left(\overline{l}\,(a)\right)^{\sigma_1}$.

The growth parameters $\{L_\infty, K, t_0, u, w, \sigma_0, \sigma_1\}$ can be estimated by fitting to length-at-age samples either (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 estimates for all growth parameters. The likelihood probability of observing a given length-at-age is truncated at LML to make explicit the absence of sublegal Garfish in catch samples (McGarvey and Fowler 2002). A second growth estimation was integrated into the GarEst stock assessment likelihood, re-estimating the two parameters that most directly determine the mean rate of growth, von Bertalanffy K, and the spread of lengths at each age, the normal length-at-age standard deviation coefficient σ_0.

Accounting for seasonality in growth was made possible by improved temporal model resolution (quarterly rather than half-yearly). The phase parameter that determines the time of peak growth, w, was also estimated in the second integrated stage of estimating growth. The seasonality amplitude, u = 0.9 fixed.

Starting from this growth submodel, an algorithm (described in Appendix 3) was devised to effectively ‘slice off’ in each model time step the cohort’s length portion that has grown past a specified slice partition length. This partition threshold length is fixed at 210 mm TL for all years in order to obtain a definition of biomass to complement reporting (‘adult biomass’) that is consistent over all model time. The increases in LML to 230 mm TL and above during 2001-2022 mean that a proportion of the fishery’s sublegal population is modelled by slices indexed by values greater than zero for years 2001-2022. Each time step, a hived-off population segment is assigned to a newly created slice bin sized above 210 mm TL by transferring these fish from the population sized below 210 mm TL, after which there is no subsequent further exchange of fish between length bins (between slices). Fish within slices incur only mortality. In a slice partition model, growth is quantified as the increasing length range with age of each slice subinterval, and no computation is needed to shift fish among bins.

6.4.1. Recruitment

Recruitment is defined as the creation of the (normal) length-at-age cohort at age a_b = 5 quarters (at age 1 year), which is when the fastest growing fish may first reach 210 mm TL in length. The total number of fish in each cohort at the birth age, a_b, is the model estimate of yearly recruitment. Each cohort's yearly recruit number is a freely estimated model parameter, which is multiplied by an estimated proportion per sex. The numbers of Garfish above 210 mm TL in length at age a_b (in the upper tail of the length at age pdf) are computed (Appendix 3) and defined as the first newly created slice (s = 1). In subsequent model time steps, new slices of length above 210 mm TL are created, thereby modelling the gradual recruitment of each cohort to above 210 mm TL over the number of model time steps required, as determined by the growth submodel (Appendix 3).

6.4.2. Model Population Array

The model Garfish population array $N\left(t,r,x,c,s\right)$ is 5-dimensional, fish numbers broken down by (1) quarterly 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.

The variable subscript that indicates the season (t_{season}) for a quarterly time step, is either 'SUM1' (first summer quarter of October-December), 'SUM2' (second summer quarter of January-March), 'WIN1' (first winter quarter of April-June), or 'WIN2' (second winter quarter of July-September). Each model year index commences in 'SUM1'; for example, year 1983 commences as October-December 1983 which indexes the first model year as 1983. Cohort age in quarters (a), were calculated as functions of model time step, t, and cohort year, c. Ages ran from 5 to 24+ quarters, the oldest age being a 'plus' group. Please see Appendix 9 for the association between GarEst model time step t and quarterly time periods.

6.4.3. 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 the slice partition length (210 mm TL for all model time steps), gear-specific length selectivity is modelled for legal size Garfish. For all years the full population of Garfish incur natural mortality, while a portion of the population above 210 mm TL incur also fishing mortality.

In particular, from 2001 onwards ($t > 71$) when an LML increase occurred from 210 to 230 mm TL, sublegal Garfish in the size range 210-230 mm TL are modelled using slices indexed greater than zero. These experience only natural mortality, which is implemented by introducing a cut-off size into length selectivity of 230 mm TL below which selectivity is set to 0 for any slice whose midpoint falls below 230 mm TL. Similarly, the LML increase specific to the commercial sector that occurred in 2015 ($t > 126$), from 230 to 250 mm TL, is implemented by setting to 0 commercial length selectivity for population length slices with midpoints below 250 mm TL. In 2021 ($t > 151$) the commercial LML dropped back to 230 mm TL and length selectivity was set to that applied for years 2001-2014. In this way, the exclusion of sublegal Garfish from model catches over time is accounted for in fits to the data catches.

Southern Garfish catch and effort, for data and model, were divided into five ordered effort types, i_E: (1) haul nets targeting Garfish, (2) haul nets not targeting Garfish, (3) dab nets and minor gears, (4) charter boat, and (5) recreational. Section '2.4. Stock assessment model – 'GarEst'' in this report describes refinements to these effort types. The two commercial gears, g, each with separate fixed length selectivity, are haul net (gear type 1) and dab net (gear type 2), with charter boats and recreationals sharing dab net selectivity. Reported data on effort by time step, region, and effort type, is denoted as $\tilde{E}$.

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

$$F(t,r,x,c,s,i_E) = q(r,\ t_{season},\ x,\ i_E)\ \cdot \tilde{E}(t,r,i_E)\ \cdot s_{len}(t,i_E,g(i_E),s)\,. \tag{6.1}$$

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, $\bar{l}(s)$, above 210 mm TL (s>0).

$$s_{len}(t,i_E,g(i_E),s)=\begin{cases}0,\ \ t>71\ \&\ t<127\ \&\ \bar{l}(s)<230\ (\mathit{commercial\ and\ recreational})\\0,\ \ t>126\ \&\ t<152\ \&\ \bar{l}(s)<250\ \&\ i_E<4\ (\mathit{commercial})\\0,\ \ t>126\ \&\ t<152\ \&\ \bar{l}(s)<230\ \&\ i_E>3\ (\mathit{recreational})\\0,\ \ t>151\ \ \&\ \bar{l}(s)<230\ (\mathit{commercial\ and\ recreational})\\1,\ \ t<72\ \ \&\ i_E<3\ (\mathit{commercial\ hauling\ net})\\1,\ \ t>71\ \&\ t<119\ \&\ \bar{l}(s)>=230\ \&\ i_E<3\ (\mathit{commercial\ hauling\ net})\\1\Big/\left\{1+\exp\left[-r_{sel}\left(g(i_E)\right)\cdot\left(\bar{l}(s)-l_{50}\left(g(i_E)\right)\right)\right]\right\},\ \ \mathit{otherwise}\end{cases}\tag{6.2}$$

.

For haul net the logistic length selectivity is varied in time to model regulated increases in pocket mesh size from 30 to 32 mm implemented in winter 2013 (1 April 2013) to reduce capture rates of undersize Garfish. Prior to winter 2013 (April-June 2013), haul 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 haul net gear is given by regression equations relating mesh size to l_{50} derived from a series of mesh selectivity experiments undertaken by SARDI and industry:

$$l_{50}\left(g(i_E=1\ \&\ 2)\right)=\begin{cases}7.9684\cdot \mathit{meshsize}-29.203 & (\mathit{summer\ quarters})\\6.4785\cdot \mathit{meshsize}+32.246 & (\mathit{winter\ quarters})\end{cases}.\tag{6.3}$$

On 1 April 2015 the mesh size was increased to 34 mm, on 1 April 2016 to 35 mm, and on 1 January 2019 to 36 mm. Figure 6-7 illustrates the length selectivity ogives prior to filtering by the LML thresholds.

For commercial effort types, the catchability was written:

$$q(r,t_{season},x,i_E)=\begin{cases}q_{CSE}(r,t_{season},i_E)\cdot\ s_{SS}(t_{season},x)\cdot\left(1+q'\cdot(t-t_{mid})\right) & (t<71)\\q_{CSE}(r,t_{season},i_E)\cdot\ s_{SS}(t_{season},x)\cdot\left(1+q'\cdot(71-t_{mid})\right) & (t>70)\end{cases}\tag{6.4}$$

with q_{CSE} being the absolute catchability given as function of region, season (SUM1 and SUM2 combined, WIN1 and WIN2 combined), and effort type, and $s_{SS}(t_{season},x)$ representing a relative selectivity coefficient for sex-dependent seasonality of catchability (SUM1 females fixed at 1) allowing for modelling of 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 model year 2000 (April-June-2001, *t* = 71) is implemented as an increase, $q'\cdot(t-t_{mid})$, the rate of catchability change relative to the time step t_{mid} = 44 quarters; q' is fixed at 0.00678012 or 0.68% increase per annum applied quarterly. Parameter $q_{CSE}(r,t_{season},i_E)$ was replaced for a few limited time periods with additional catchability parameters, namely for GSV i_E 1 period April-

June-98 to July-September-02 (winter quarters only), i_E 2 period April-June-05 to July-September-05, i_E 1 period April-June-06 to July-September-06, and for Spencer Gulf i_E 2 period April-June-02 to July-September-02 and April-June-04 to July-September-04. Furthermore, a separate parameter for $q_{CSE}(r, t_{season}, i_E)$ was estimated for haul net (i_E 1 and 2) over period ≥ 2005 (*t* ≥ 89). For charter and recreational effort types the catchability is not modelled with a linear time trend, and no separate parameters are estimated for the period before and after 2005.

The estimate of adult biomass is computed in any given time step by summing over all of the length slices to include only fish above 210 mm TL (slice index > 0). In this way the biomass estimate is not altered by changes in LML. Adult biomass is calculated as follows

$$(6.5)\qquad B_{adult}(t,r) = \sum_{\bar{l}(s)\geq 210} \sum_{a=a_b}^{24+} \sum_{x=0}^{1} N(t,r,x,c,s)\cdot w(a(t,c),s)$$

where the fish weights by age and slice $w(a(t,c),s)$ are derived in Appendix 3. Corresponding harvest fractions are then calculated per time step *t* as model-predicted catch divided by $B_{adult}(t,r)$. The estimate of fishable biomass used in this report incorporates only all animals above the regulated LML that applies for a given time step, that is

$$(6.6)\qquad B_{fish}(t,r) = \sum_{\bar{l}(s)\geq LML} \sum_{a=a_b}^{24+} \sum_{x=0}^{1} N(t,r,x,c,s)\cdot w(a(t,c),s)\,.$$

Changes in $B_{adult}(t,r)$ are not influenced by changes LML, however it is less suitable for use in harvest rates because catch is impacted by LML and thus trend in such rates may mask or confound changes in fishing mortality. Note that $B_{fish}(t,r)$ includes all animals above LML and it incorporates neither a length selectivity ogive nor relative sex selectivity as factors, and so it may be greater than the biomass that is potentially accessible by the fishery.

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:

$$(6.7)\qquad F(t,r,x,c,s) = \sum_{i_E=1}^{n_E} F(t,r,x,c,s,i_E)\,.$$

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

$$(6.8)\qquad N(t+1,r,x,c,s) = N(t,r,x,c,s)\cdot \exp\left[-\left(M + F(t,r,x,c,s)\right)\cdot p_{yr}(t)\right]$$

where $p_{yr}(t)$ quantifies the proportion of a year spanned by the days in each quarterly time step. Instantaneous natural mortality rate was taken as constant, M = 0.4 yr^{-1} (Jones 1990).

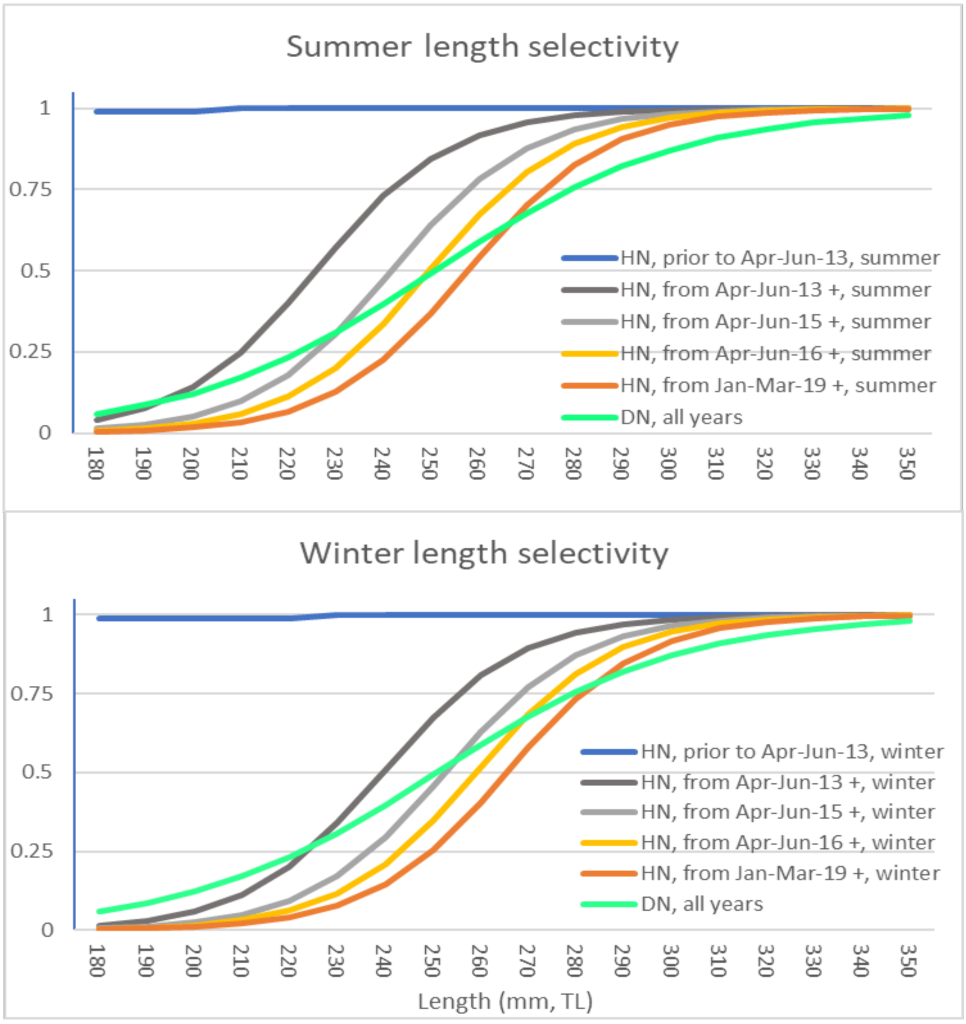

Figure 6-7. Fixed length selectivity, prior to application of LML thresholds.

6.4.4. Estimation: Parameters and Model Likelihood

The model likelihood (Fournier and Archibald 1982) is fitted to (1) quarterly catch totals by weight, (2) SAFCOL market sample catch proportions by age and sex, (3) market sample catch moment properties of fish length for each age and sex, and (4) recent FRDC fishery-independent sample catch proportions by age and sex for Gulf St Vincent. The negative log-likelihood components for the fitting to age and length data respectively were down-weighted by factors of 0.2 and 0.025, while the recreational catch component was also down-weighted by a factor of 0.05. See appendices 1 and 2 and chapter 2 for more information on the data.

6.4.5. Parameters

Estimated parameters for the model fall into six categories: (1) yearly recruit numbers by region, (2) recruitment sex proportion by region, (3) catchabilities by effort type, region and summer-winter, (4) relative selectivities by sex and season, (5) growth by sex and region, and (6) likelihood standard deviations by gear, region and season of fits to quarterly catch totals. The following parameters were fixed: a) initial steady-state fishing mortality, b) length selectivity parameters, c) and all growth parameters except K, σ_0, and W, and d) the sigma parameter belonging to the likelihood for the fit to the age-sex proportion data from the fishery-independent sampling project (FRDC 2015/018).

6.4.6. Likelihood for Catch Totals by Weight

Model-predicted catch totals in weight (kg) are fitted to commercial and charter boat data, and model-predicted catch totals in number are fitted to recreational catch survey data, using a normal likelihood. The catch in weight is calculated using the standard Baranov formula as:

$$\begin{aligned}\hat{C}(t,r,x,c,s,i_E) &= N(t,r,x,c,s)\cdot w(a(t,c),s)\cdot \\ &\quad \frac{F(t,r,x,c,s,i_E)}{M+F(t,r,x,c,s)}\cdot\left\{1-\exp\left[-\left(M+F(t,r,x,c,s)\right)\cdot p_{yr}(t)\right]\right\}\end{aligned} \tag{6.9}$$

The normal likelihood factor is written as:

$$L_C=\prod_{t=1}^{n_t}\prod_{i_E=1}^{n_E-1}\prod_{r=1}^{n_r}\frac{1}{\sqrt{2\pi}\cdot\sigma_C(t_{season},r,g(i_E))}\exp\left[-\frac{1}{2}\left(\frac{\hat{C}(t,r,i_E)-\tilde{C}(t,r,i_E)}{\sigma_C(t_{season},r,g(i_E))}\right)^2\right] \tag{6.10}$$

where

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

$\hat{C}(t,r,i_E)$ = model-predicted catch in weight (number) for each t, r, and i_E;

$\sigma_C(t_{season},r,g(i_E))$ = an estimated standard deviation parameter, one per season, region r, and gear.

Charter boat data is ($i_E = n_E - 1$) is fit from April-September-07 onwards, and for each of charter boat and recreational survey ($i_E = n_E$) the estimated standard deviation varies only by region. Details of these data can be found in Appendices 1 and 2.

6.4.7. 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 distinct attributes of a single catch sample data set. The fitted data, from the principal gear, haul nets, in the four time steps and regions where catch was monitored, consists of the counts of sampled fish falling into each possible combination of sex and quarterly age, $\tilde{n}(a, x;\ t, r)$. But the data fitted consisted of the observed counts multiplied by a factor that depends on the relative discrepancy ratio of each age sampled length value compared to that length in the full market samples of lengths (including fish not aged), the latter samples taken as being more length-representative of the population than the aged samples (see the FRDC report, McGarvey and Feenstra (2004)). Finally, each such corrected count at age-length was multiplied by a scaling factor so that the total raw sample size is preserved at the level of region, time step, and gear. The multinomial likelihood factor is written:

$$(6.11)\quad L_{AX} = \prod_{i_{AX}=1}^{n_{AX}} \prod_{a=a_b}^{24+} \prod_{x=0}^{1} \hat{p}(a, x;\ i_{AX})^{\tilde{n}(a, x;\ i_{AX})}$$

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 quarter 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} .

The data on proportions by age and sex from the FRDC fishery-independent sampling project are fitted in an analogous manner to above, except these data are available only for Gulf St Vincent and the model-predicted proportions are formed using the population quantities of slices (fish > 210 mm TL), rather than the catch, assuming that these samples are representative of the age-sex population structure of Garfish in Gulf St Vincent. Thus, also no relative discrepancy ratios are applied in the likelihood.

6.4.8. 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:

$$L_{mp} = \prod_{i_{AX}=1}^{n_{AX}(i_{mp})} \prod_{i_{mp}=1}^{4} \prod_{sex=0}^{1} \prod_{a=a_b}^{24+} \prod_{g=1}^{2} \left\{ \frac{\exp\left[-\frac{1}{2} \left(\frac{\left\{ \begin{array}{l} \tilde{b}(i_{mp},x,a,g;i_{AX}) - \\ \hat{b}(i_{mp},x,a,g;i_{AX}) \end{array} \right\}}{\sigma_{mp}(g)} \right)^{2} \right]}{\sqrt{2\pi} \cdot \sigma_{mp}(g)} \right\}^{\tilde{n}_a(x,a,g;\,i_{AX})} . \tag{6.12}$$

Where

σ_{mp} = is the estimated moment-likelihood standard deviation parameter, separately per the two commercial gears but shared among the four moments.

$\tilde{b}(i_{mp},...)$ = observed moment, indexed by i_{mp}, per sample and quarterly age-sex.

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

The observed moments were not calculated using the raw counts of fish per age and length category, but instead were based on length counts from the aged fish that were corrected for representative length sampling as noted further above (see the FRDC report, McGarvey and Feenstra (2004)). We weighted each factor in the log-likelihood by the uncorrected sample size ($\tilde{n}_a(x,a,g;\,i_{AX})$), 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 4 aged fish for kurtosis, 3 for skewness, 2 for standard deviation, and 1 for fitting to mean length. Similarly, we required 4 model slices for kurtosis, 3 for skewness, 2 for standard deviation, and 1 for fitting mean length.

6.5. Appendix 5. Model Fits to Data

Parameters and thus stock performance indicators in the GarEst model are estimated by fitting to data for commercial catch totals in weight, charter boat catches in number, interpolated recreational catches in number, commercial market catch proportions by age and sex, commercial market catch moments of length-at-age, and to fishery-independent sampling proportions by age and sex, in each quarterly time step when sampling occurred. In this Appendix, graphs comparing fitted model and data are presented (Figures 6-8 to 6-16).

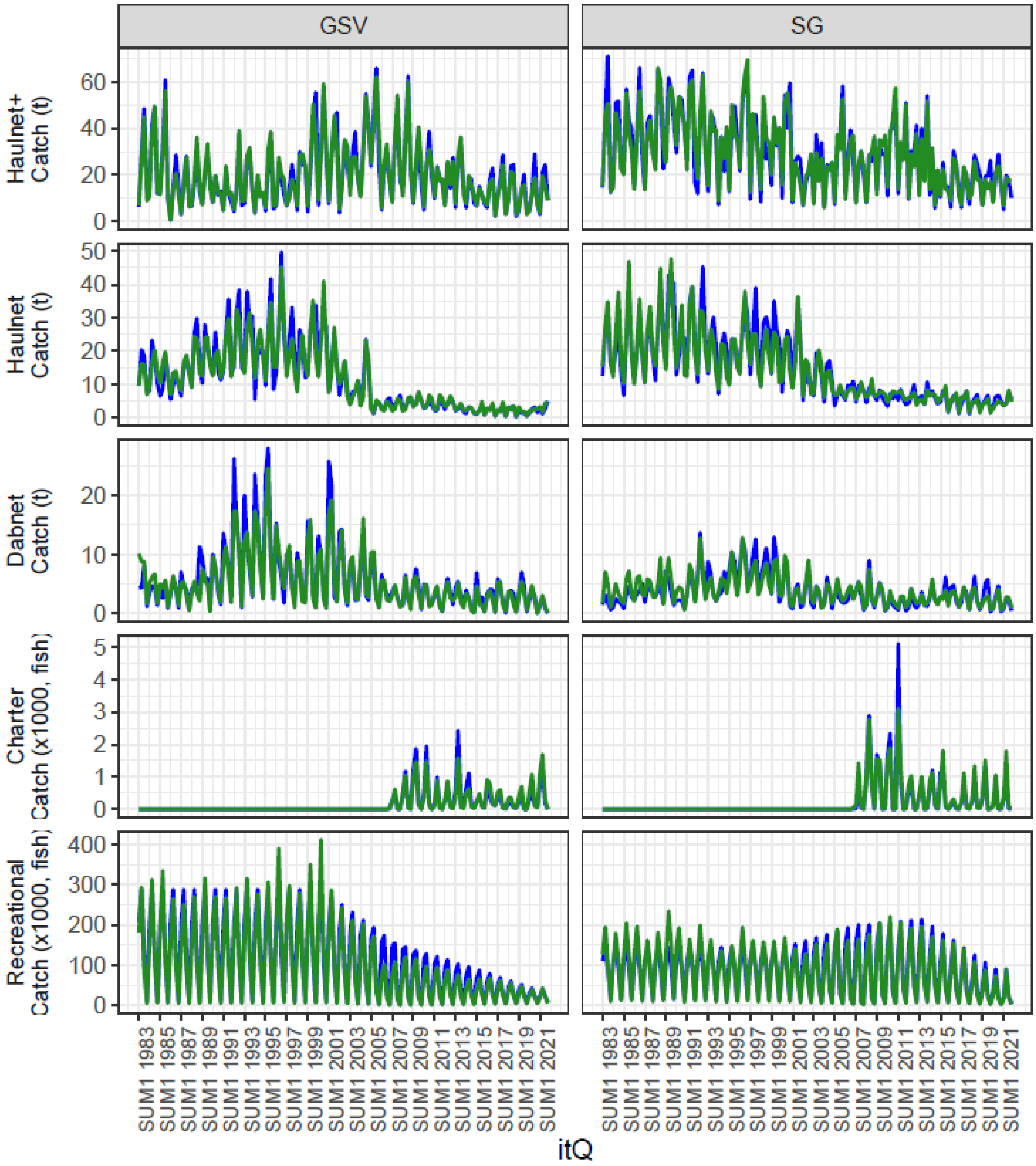

Figure 6-8. Fits of Spencer Gulf and Gulf St Vincent models to data quarterly catch totals (blue) for the five effort types. Green lines indicate the model estimate.

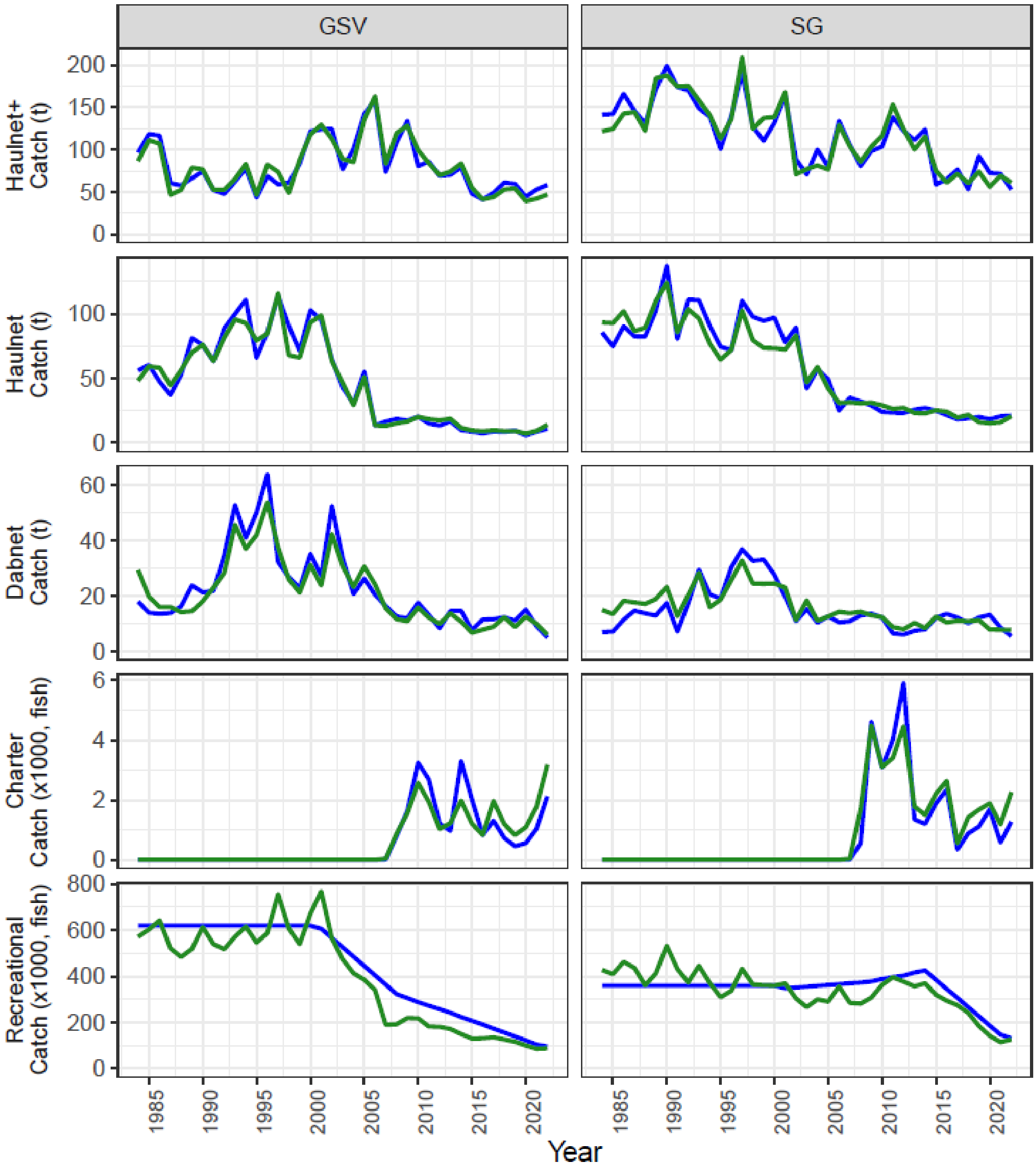

Figure 6-9. Comparisons of Gulf St Vincent (GSV, left) and Spencer Gulf (SG, right) model estimated yearly catch totals (green) to observed annual catch totals (blue) for the five effort types. Years begin with “1984” spanning 1 Oct 1983 to 30 Sep 1984.

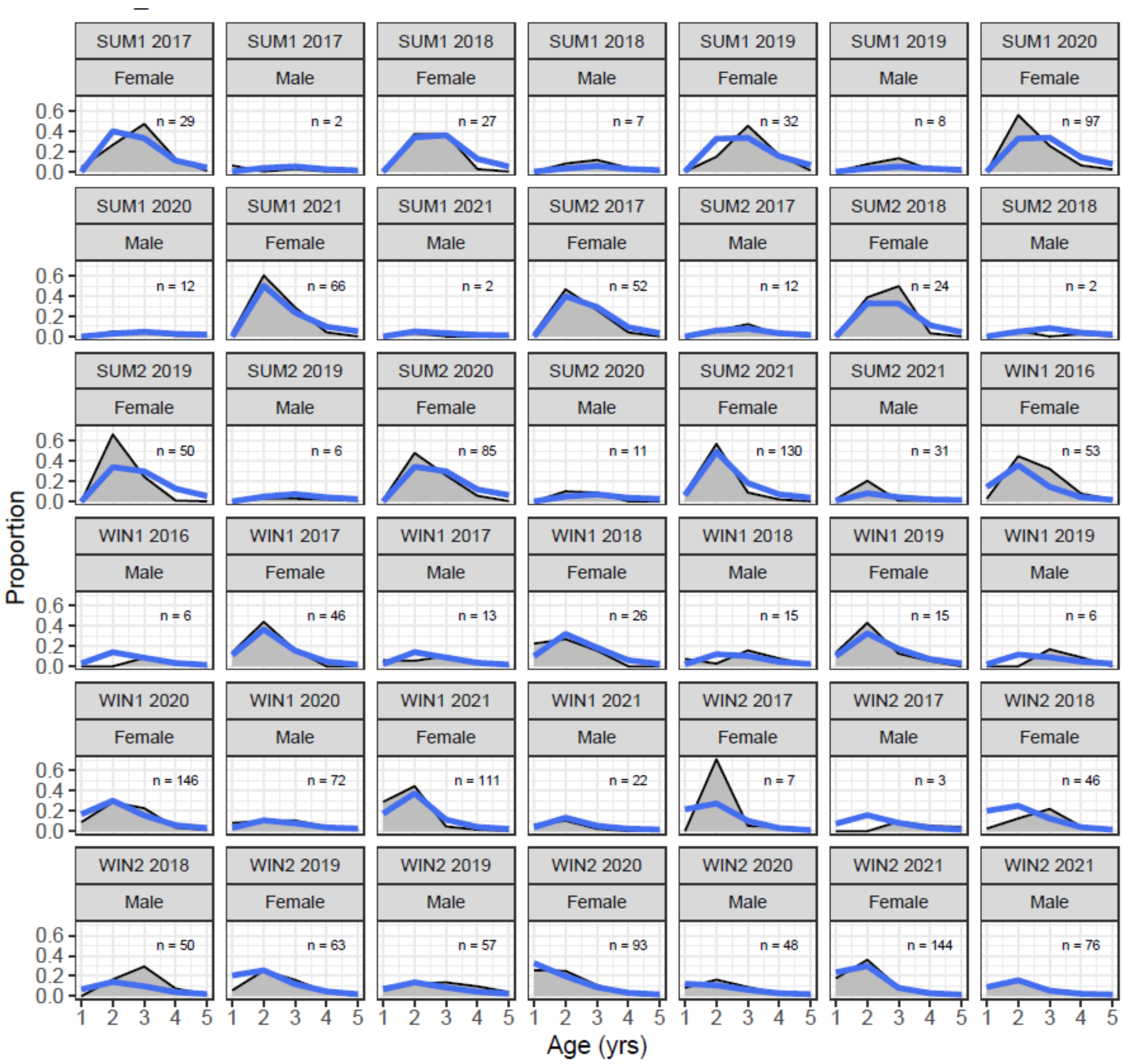

Figure 6-10. Model fits to age-sex proportions from SAFCOL market haul net catch samples. The 42 most recent Spencer Gulf data sets are shown by sex and quarterly model time step. Blue lines indicate the model estimate.

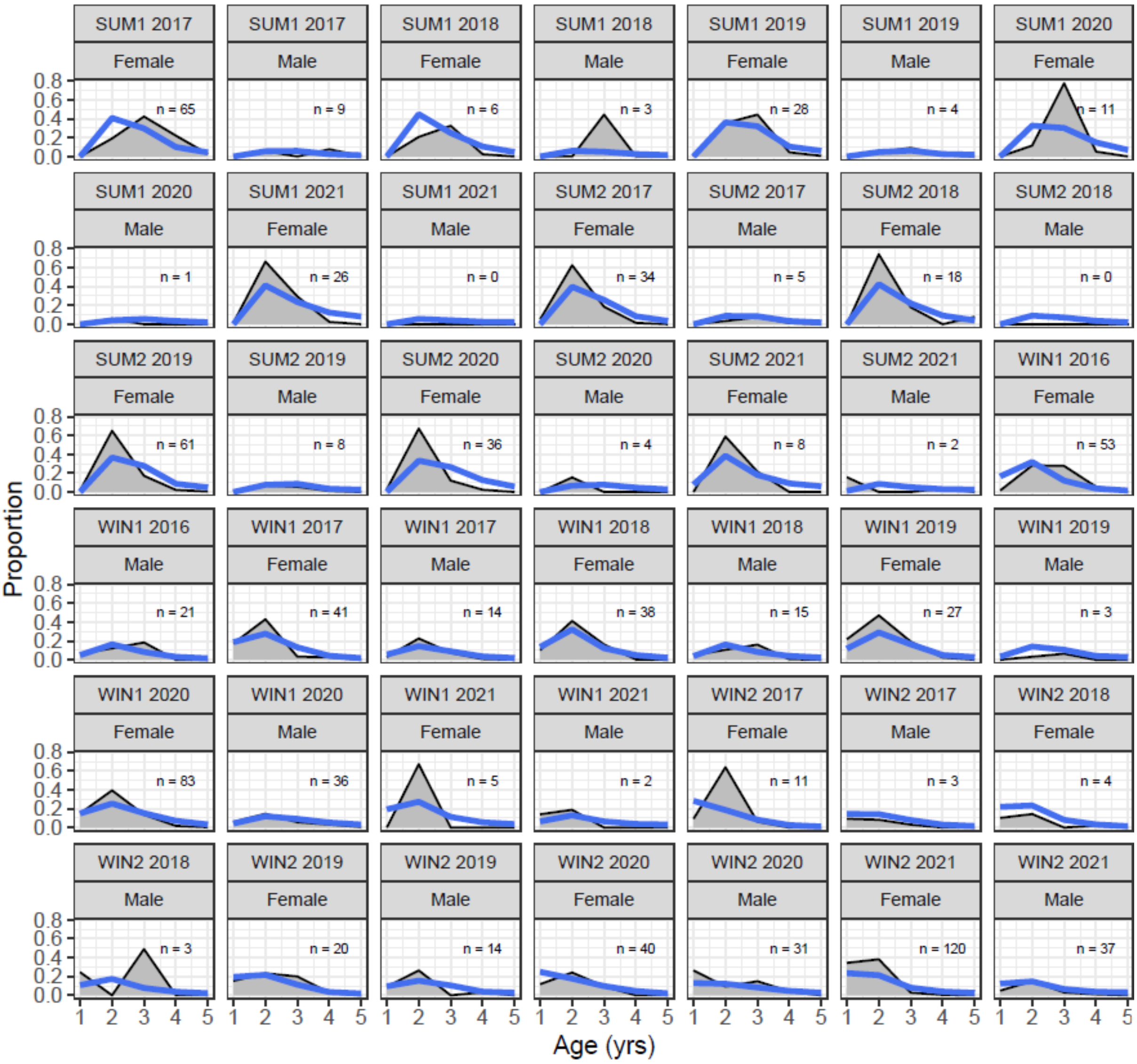

Figure 6-11. Model fits to age-sex proportions from SAFCOL market haul net catch samples. The 42 most recent Gulf St Vincent data sets are shown by sex and quarterly model time step. Blue lines indicate the model estimate.

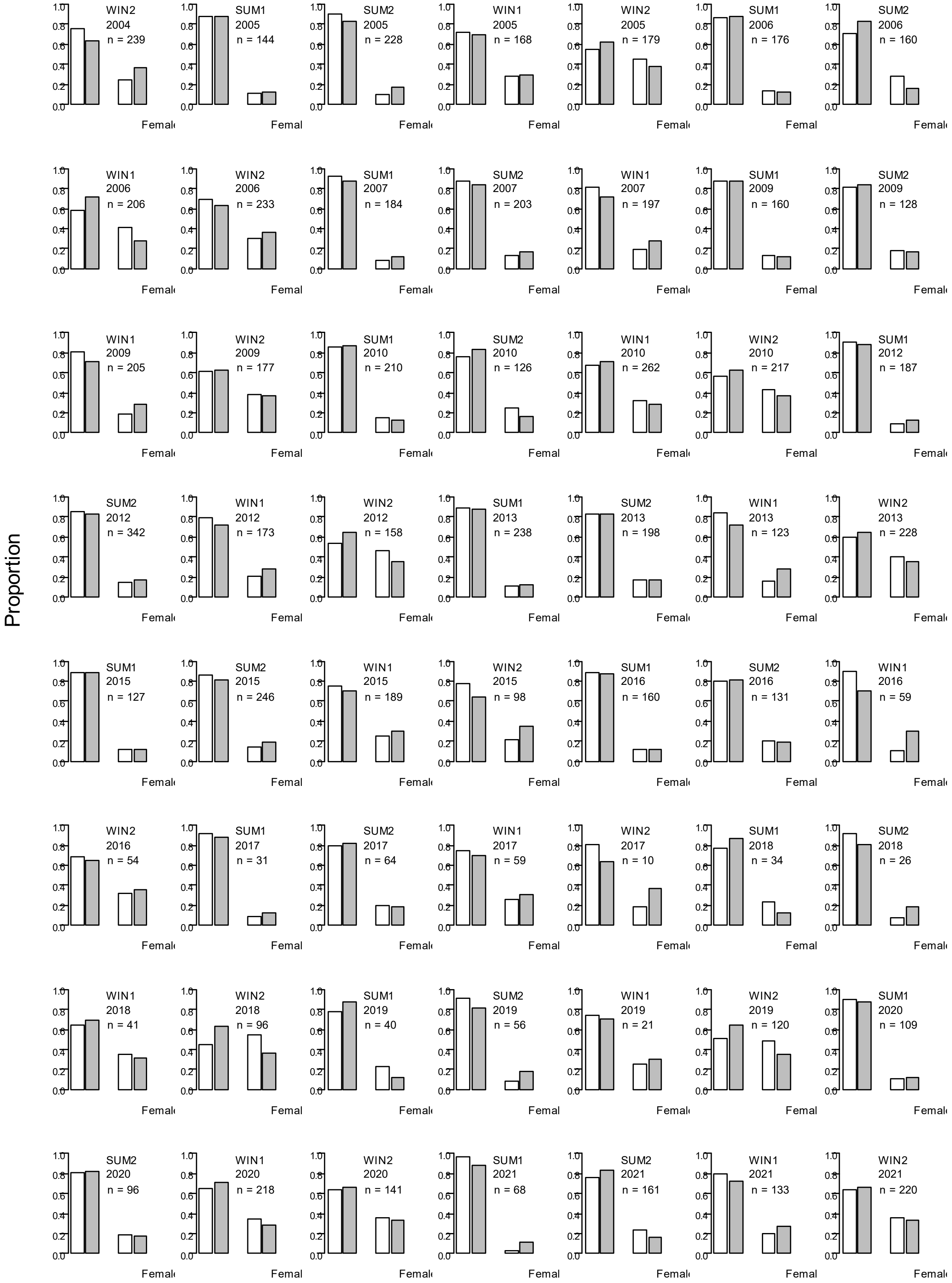

Figure 6-12. Model predicted and data sex ratios from SAFCOL market haul net catch samples for Spencer Gulf are shown by quarterly model time step. Shaded bars indicate the model estimate.

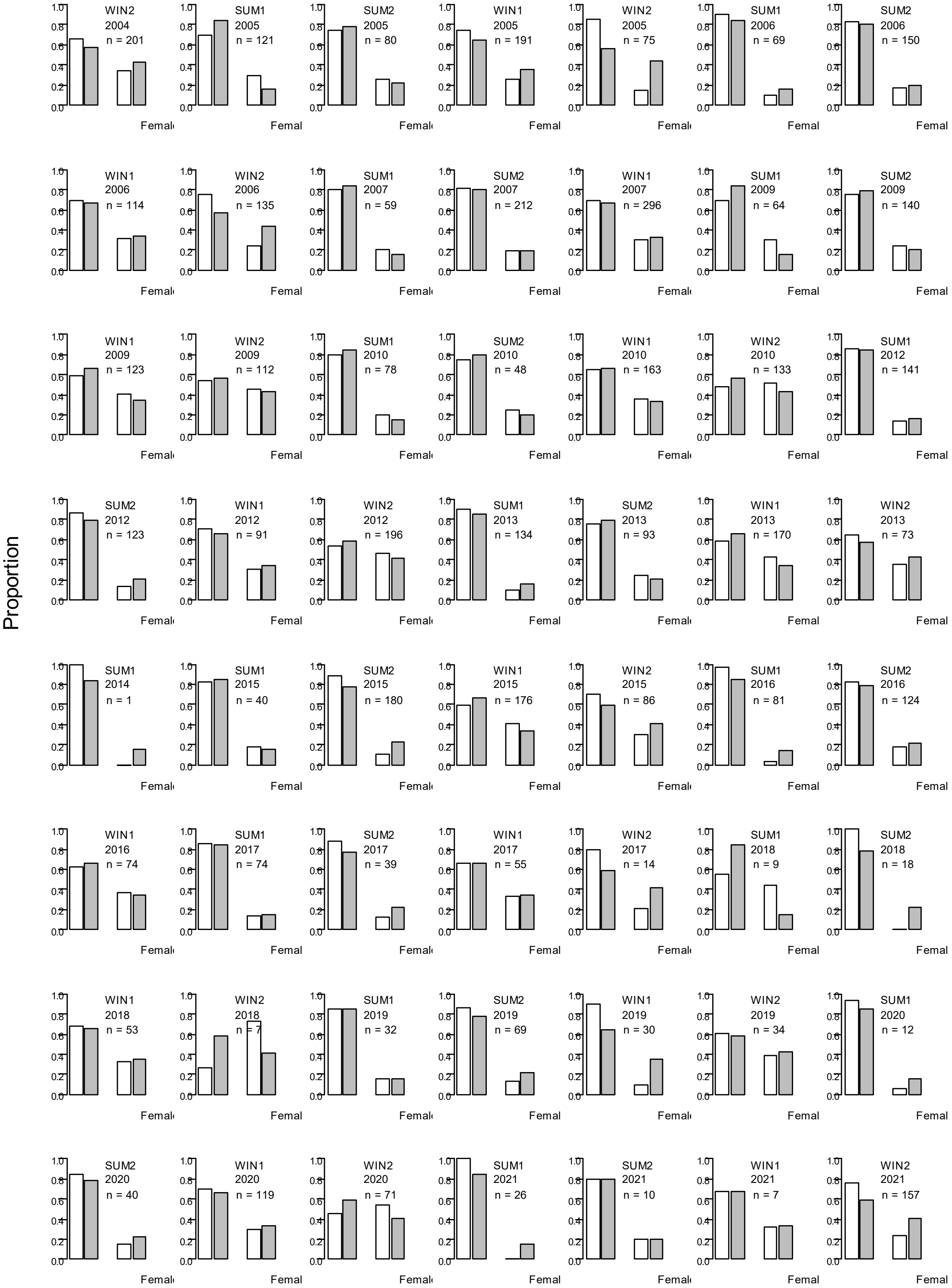

Figure 6-13. Model predicted and data sex ratios from SAFCOL market haul net catch samples for Gulf St Vincent are shown by quarterly model time step. Shaded bars indicate the model estimate.

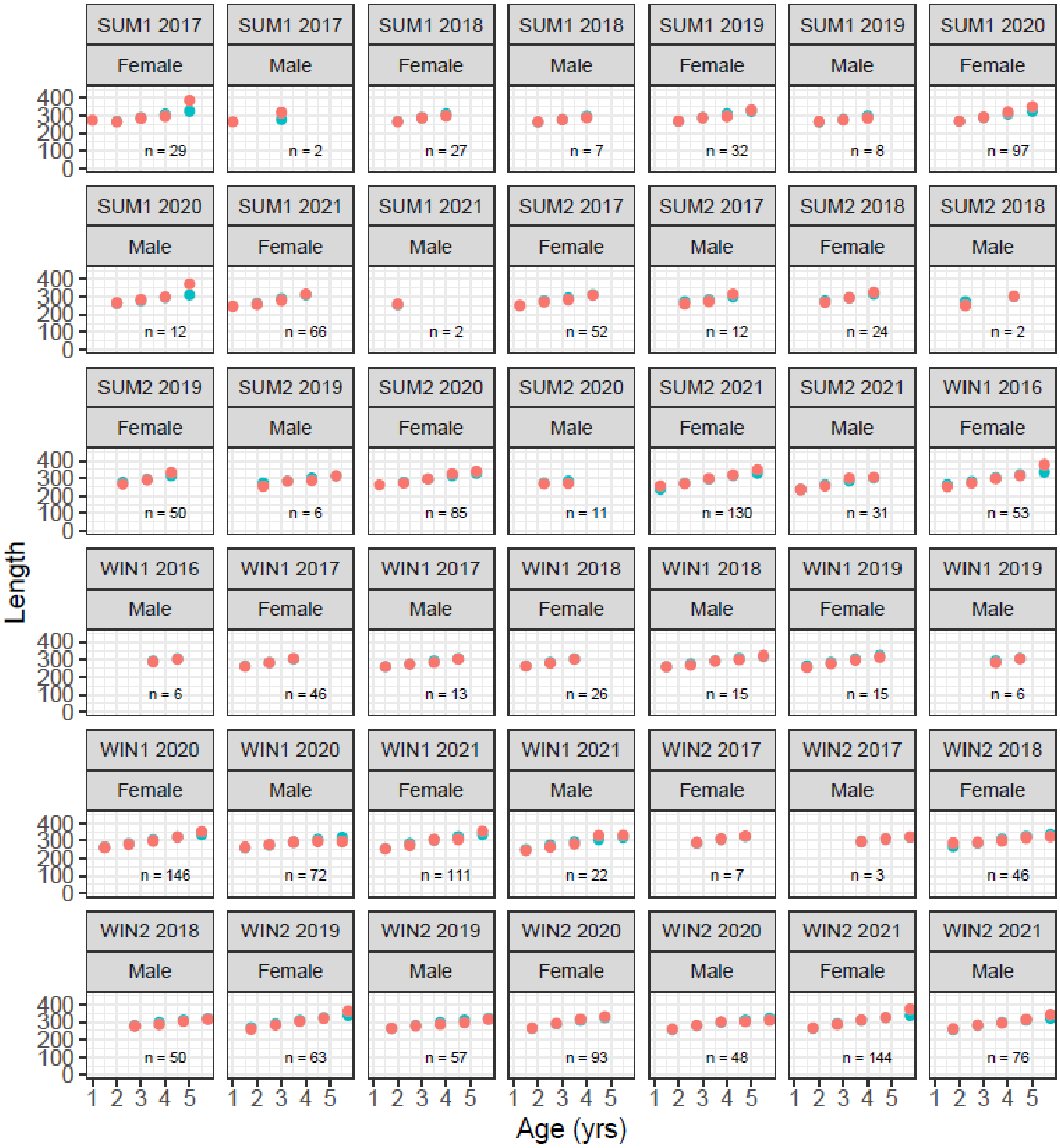

Figure 6-14. Model fits to catch mean lengths of modelled cohorts from SAFCOL market haul net catch samples. The 42 most recent Spencer Gulf data sets are shown by sex and quarterly model time step. Green circles indicate the model estimate. Blue-green dots indicate the model estimate.

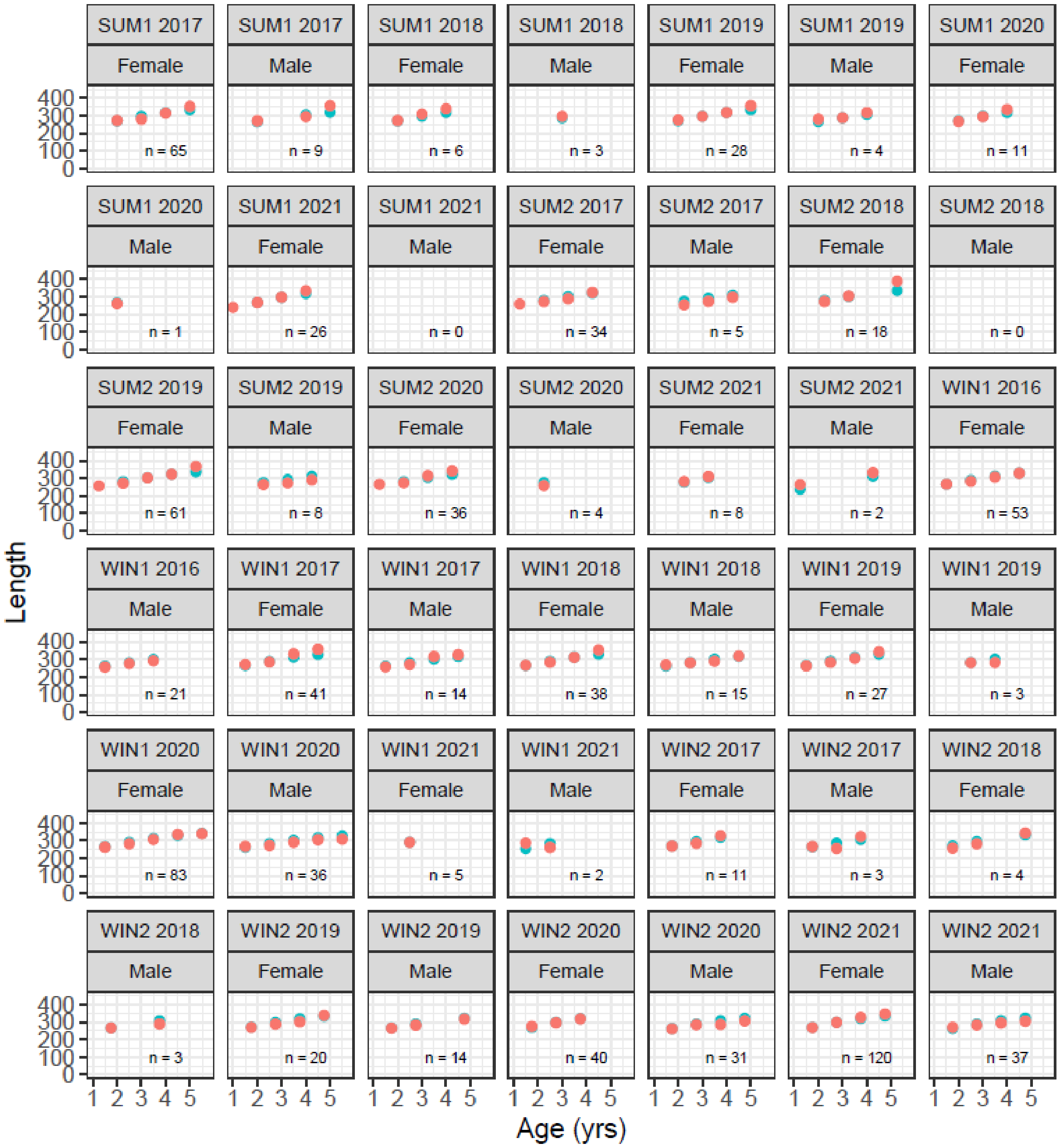

Figure 6-15. Model fits to catch mean lengths of modelled cohorts from SAFCOL market haul net catch samples. The 42 most recent Gulf St Vincent data sets are shown by sex and quarterly model time step. Green circles indicate the model estimate. Blue-green dots indicate the model estimate.

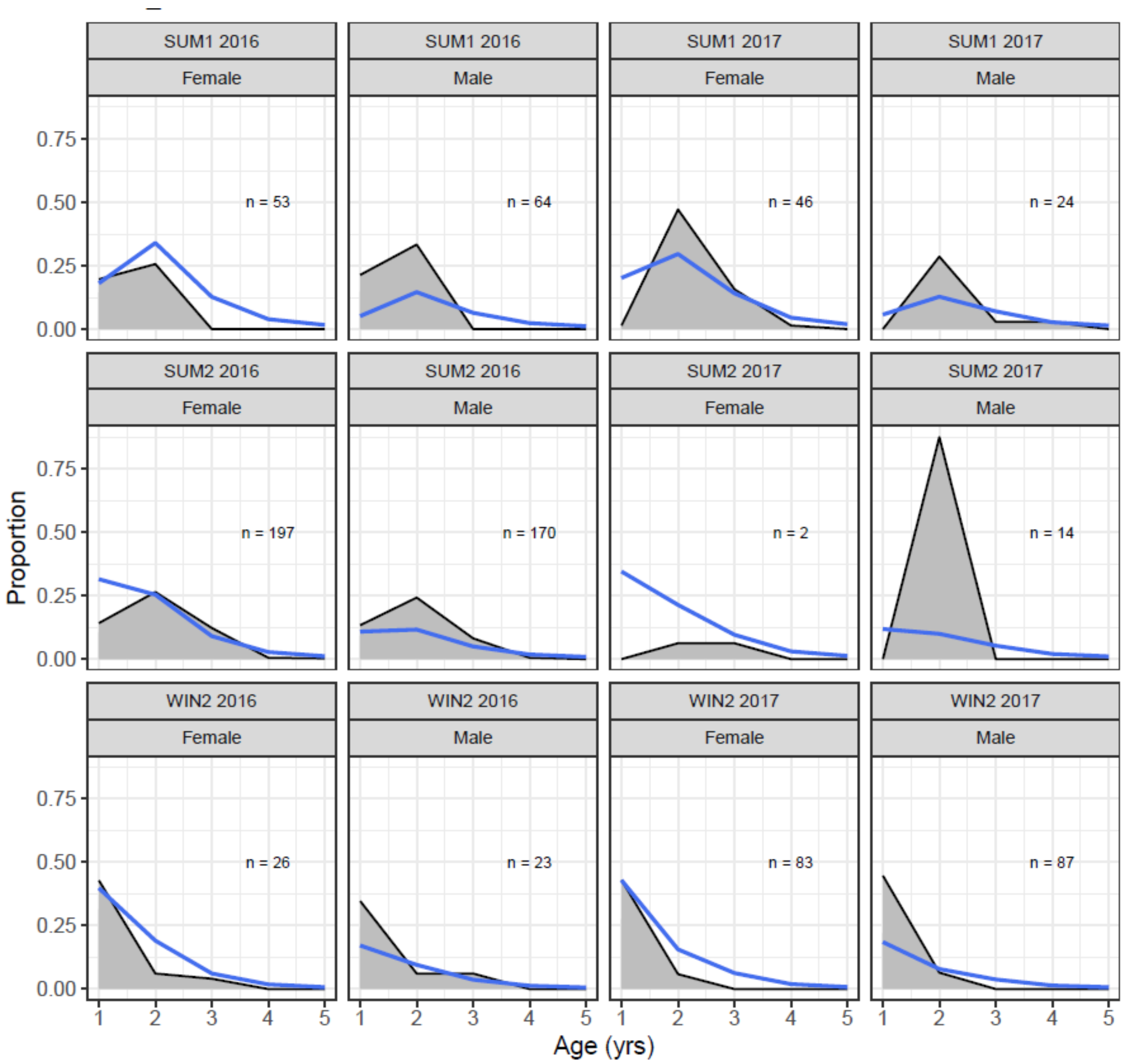

Figure 6-16. Model fits to age-sex proportions from FRDC fishery-independent samples of Gulf St Vincent, by sex and quarterly model time step (October-December-2016 to July-September-2018). Blue lines indicate the model estimate.

6.6. Appendix 6. GarEst model sensitivity analyses

6.6.1. Introduction

In this Appendix, the following types of GarEst model sensitivity testing were conducted: (1) alternative standardised effort type 1 effort data input; (2) removal of separate haul net gear (effort type 1 and 2) catchability parameters for pre- and post-2005 periods; and (3) removal of fitting to the FRDC fishery-independent sampling project data. The sensitivity model runs are variations from the 'baseline', with the latter being the GarEst model run the results of which are used to inform the indicator values reported in the main sections of this assessment's report.

Time series of fishable biomass (as defined in Appendix 4) are compared between baseline and sensitivity model runs. But note that last assessment adult biomass (Appendix 4) was used. This difference in definition of biomass has a substantial effect as illustrated below in Figure 6-17, indicating that since 2001 (when the first LML change occurred) the fishable biomass level can be over 30% below adult biomass, the effect being most significant over periods of maximum difference in LML compared to 210+ mm TL. Also, note that adult biomass for period 2001+ estimated by GarEst baseline this assessment is lower than that estimated last assessment, most of which may be explained (see further below) by the present baseline model having the freedom to estimate separate haul net catchability parameters for periods before and after 2005 together with being conditioned on differently standardised effort data.

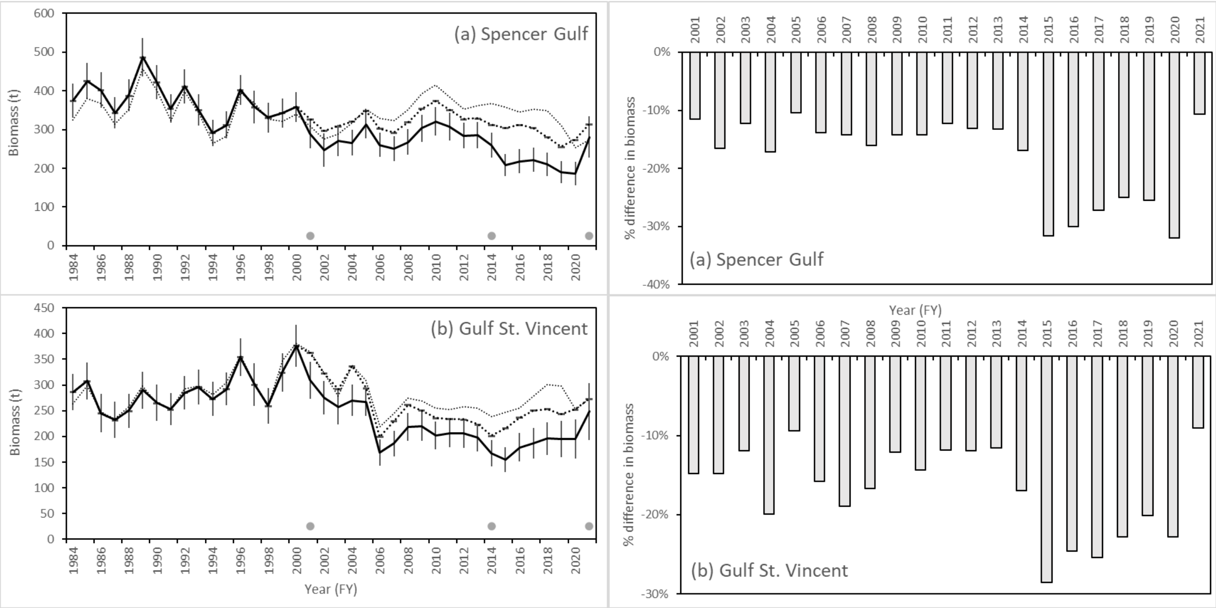

Figure 6-17. Left column: Comparison of fishable and adult biomass estimates from this assessment's baseline run, by financial year (FY). Filled circles just above x-axis indicate years of LML change. Solid line signifies fishable biomass from the current assessment's baseline GarEst model run, vertical lines = 95% confidence intervals (CI), and dash-dot is corresponding adult biomass, and dash-dash line is adult biomass from last assessment. Right column: Corresponding change in reported biomass estimate when using fishable biomass compared with adult biomass (100*(fishable – adult)/adult).

6.6.2. Method

Alternative Effort type 1 data

The choice of method for the GLM function (externally estimated) that is used to provide the Effort type 1 (haul net, targeted) effort data input to GarEst potentially impacts the time trend information for this effort data source. Thus, because the catch data is not changed, this means that the aforementioned choice of GLM method also impacts the corresponding trend in implied catch rates, and this in turns influences trend in estimated biomass. The following three alternative forms of effort type 1 effort data are considered: (1) GLM gamma with inverse link; used in last assessment's baseline. (2) GLM gamma with identity link. (3) No GLM method applied, ('raw' data). Note that the baseline run uses standardised data produced from a GLM gamma with logarithm link (Appendix 1, Stage 1).

Same absolute catchability parameter for haul net gear pre and post 2005

In the baseline model a separate set of absolute catchability parameters is estimated for each of effort types 1 and 2 for the period before 2005 and for period 2005+; coefficient q_{CSE} is described in Appendices 1 (Stage 2) and 4. For this sensitivity run the same set of estimated catchability parameters are used for both before 2005 and for 2005+, which was the specification of last assessment's baseline. The choice of catchability parameterisation can allow for better modelling of trend in biomass because, when fishery influences exist (e.g., fishing fleet reduction and spatial closures in 2005, Table 1-1) that may alter trend in reported catch rates over time unrelated to Garfish abundance, such influences may appropriately express themselves in heterogeneous catchability rather than biomass.

FRDC fishery-independent sampling project data not fit

For this sensitivity run the fishery-independent data source of catch at age-sex, available for Gulf St. Vincent 2016-2018, is not fit. This is achieved by setting the value for the corresponding model log-likelihood weighting component to 0.

6.6.3. Results

Alternative effort type 1 data

From Figure 6-18, the sensitivity run using effort type 1 effort data standardised from a GLM gamma with inverse link had very minor effect for Spencer Gulf, while for Gulf St. Vincent it was somewhat stronger with biomass rising on average by 4% for period prior to 2005 and declining by 5% for period from 2005 onwards. The trend for GSV biomass for the sensitivity was consequently moderately more pessimistic.

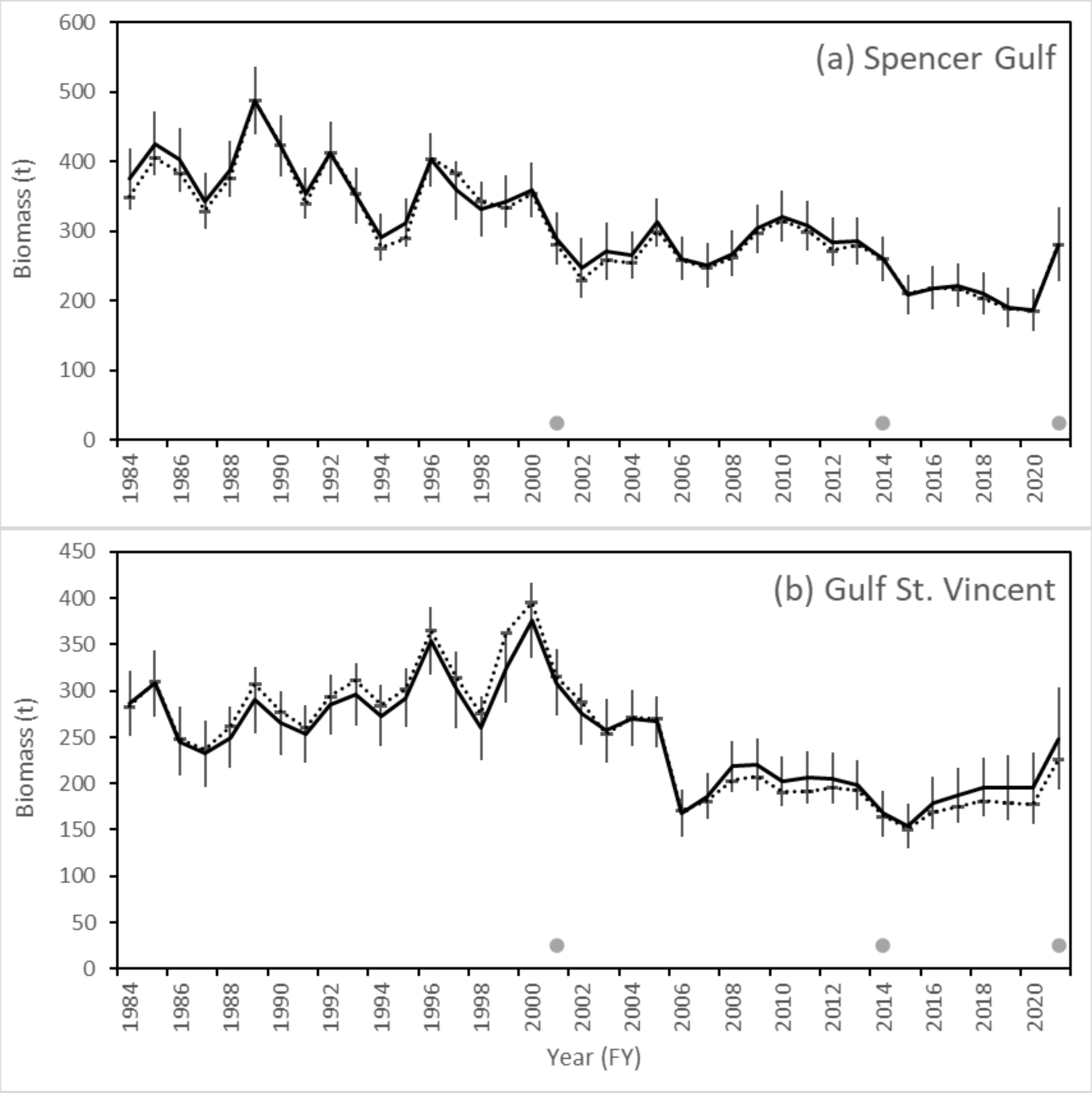

Figure 6-18. Comparison of fishable biomass estimates from GarEst baseline (solid line) run and a sensitivity run with effort type 1 effort data standardised using a GLM gamma with inverse link (dashed line), by financial year (FY). Filled circles just above x-axis indicate years of LML change. Vertical lines are 95% CI.

The sensitivity run using effort type 1 effort data standardised from a GLM gamma with identity link had very minor effect for Spencer Gulf (Figure 6-19), and mainly for the first five years for which biomass rose by an average of 6%. For Gulf St. Vincent the impact was more significant, biomass on average rising by 6% for the period prior to 2005 and 10% for period from 2005 onwards, but although absolute levels increased overall, the pre-post 2005 trend is less changed with a relatively more moderate optimistic outcome for the period 2005 onwards.

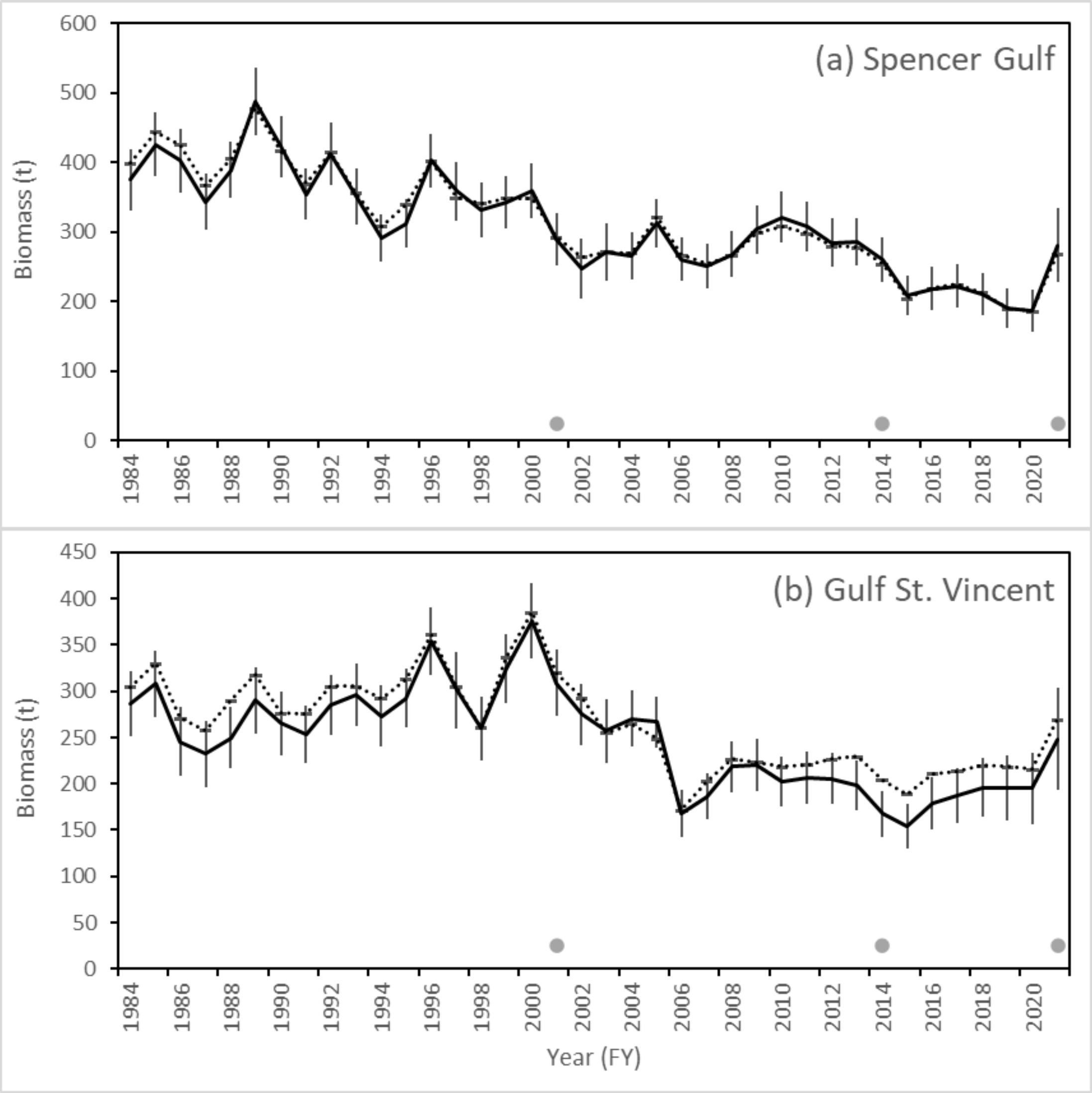

Figure 6-19. Comparison of fishable biomass estimates from GarEst baseline (solid line) run and a sensitivity run with effort type 1 effort data standardised using a GLM gamma with identity link (dashed line), by financial year (FY). Filled circles just above x-axis indicate years of LML change. Vertical lines are 95% CI.

The sensitivity run using raw (i.e., not standardised) effort type 1 effort data was reasonably impactful for both regions in terms of biomass trend with these being more optimistic (Figure 6-20). For Spencer Gulf, pre 2005 biomass declined by an average of 12% and rose for 2005 and onwards by 6%, while for Gulf St. Vincent these average levels declined by 2% and rose 8% respectively.

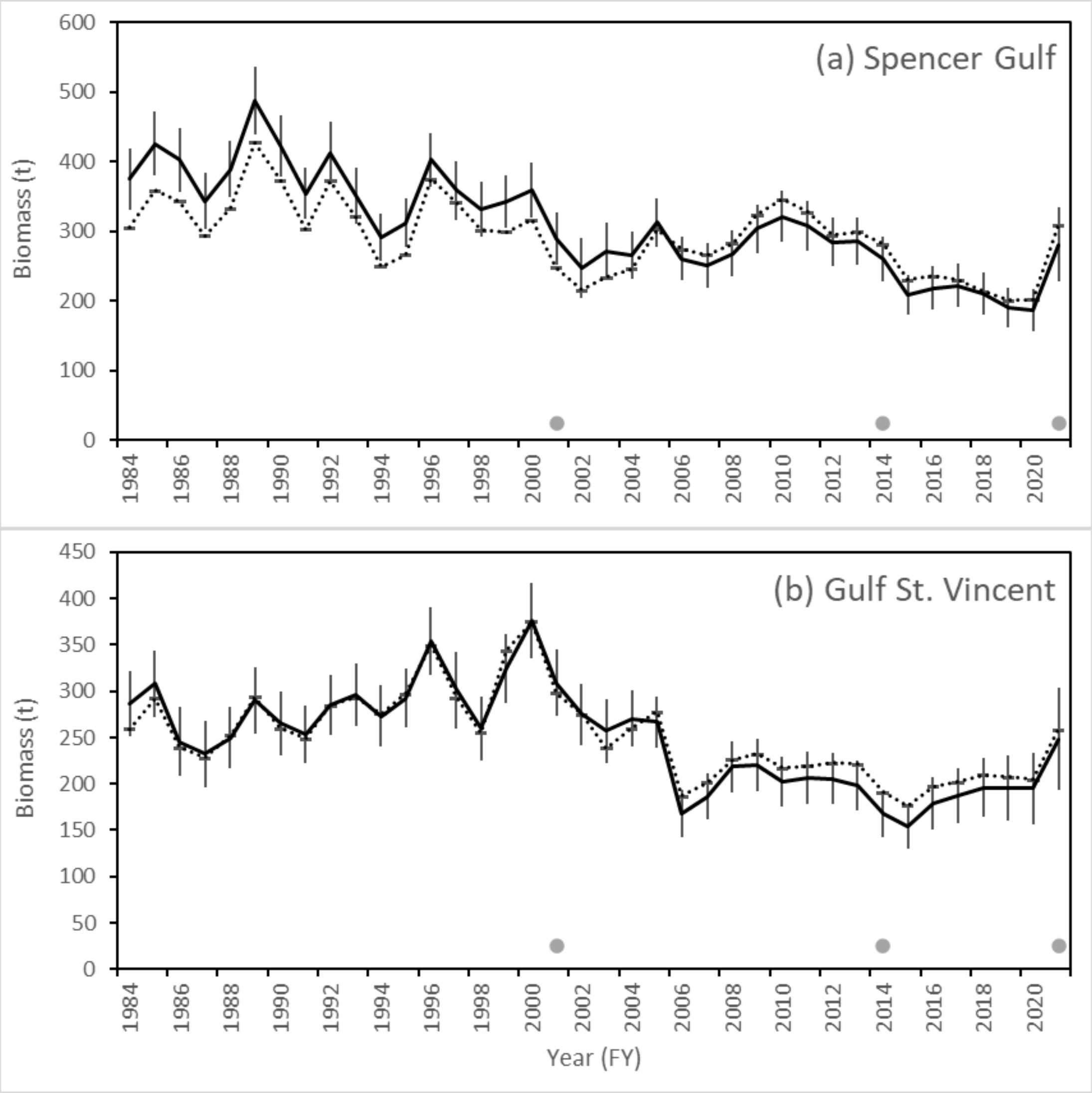

Figure 6-20. Comparison of fishable biomass estimates from GarEst baseline (solid line) run and a sensitivity run with effort type 1 effort data not having been standardised by any method (i.e., raw) (dashed line), by financial year (FY). Filled circles just above x-axis indicate years of LML change. Vertical lines are 95% CI.

Same absolute catchability parameter for haul net gear pre and post 2005

The sensitivity run using the same catchability parameters for haul net gear pre- and post-2005 was significant for both regions in terms of biomass trend with these being more optimistic (Figure 6-21). For Spencer Gulf, pre-2005 biomass declined by an average of 11% and rose for 2005 and onwards by 13%, while for Gulf St. Vincent these average levels declined by 6% and rose 15% respectively.

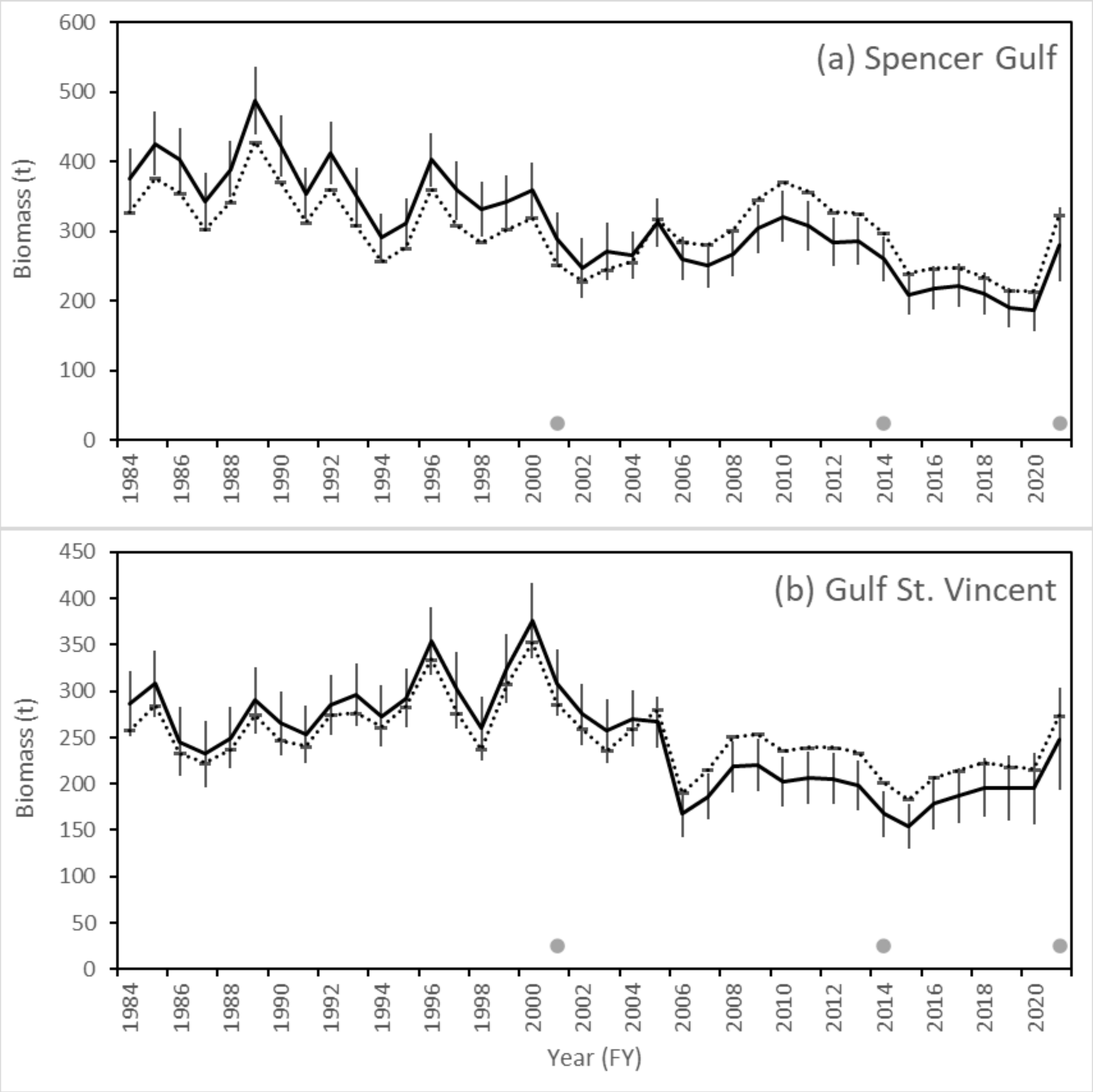

Figure 6-21. Comparison of fishable biomass estimates from GarEst baseline (solid line) run and a sensitivity run with haul net catchability parameters shared across all years (i.e., no separate pre-post 2005 parameters) (dashed line), by financial year (FY). Filled circles just above x-axis indicate years of LML change. Vertical lines are 95% CI.

FRDC fishery-independent sampling project data not fit

The sensitivity run that does not fit to the GSV 2016-2018 fishery-independent sampling data had a very minor effect (Figure 6-22), with biomass rising only 3% over the period of 2005 and onwards. Pre-2005 the biomass also increased, on average, by 2%, and therefore the trend in biomass was barely impacted. Post-2005 increases in modelled biomass were period specific, namely by 4% for 2006–2012, 6% for 2013–2015, 2% for 2016–2017, and 0% 2018–2021.

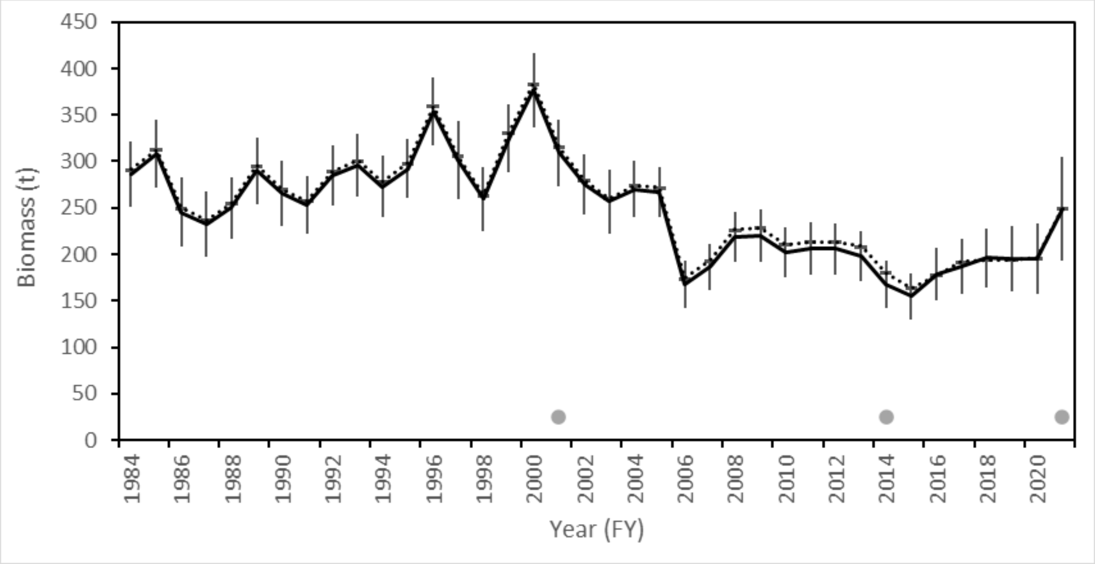

Figure 6-22. Comparison of fishable biomass estimates from GarEst baseline (solid line) run and a sensitivity run with data not fit to FRDC fishery-independent sampling project data for GSV 2016-2018 (dashed line), by financial year (FY). Filled circles just above x-axis indicate years of LML change. Vertical lines are 95% CI.

Over 1983-2000, all GarEst runs considered a linear increase in commercial sector catchability (Appendix 4), resulting in a total increase of 67% over that period. Over 2001-2004 there were no further linear increases modelled. Hence the changes in haul net catchability provided in Table 6-1 for period 2005-2022 effectively multiply the change for 1983-2000 when considering change in catchability for 2005-2022 relative to 1983 (i.e., Eq. 6.4 for $t > 89$ divided by Eq. 6.4 for $t = 1$).

Table 6-1. Comparison of haul net catchability estimated for period 2005-2022 relative to that of 2001-2004 (% change = 100 * (2005–2022 / 2001–2004) – 1), for each indicated GarEst run. Steps1and2 = SUM1 & SUM2 combined, Steps3and4 = WIN1 & WIN2 combined, HN+ = effort type 1, HNOther = effort type 2, SG = Spencer Gulf, and GSV = Gulf St. Vincent.

	HN+	HNOther	HN+	HNOther
	SG		GSV	
	Baseline			
Steps1and2	50%	18%	49%	1%
Steps3and4	32%	41%	24%	-3%
	Alternative HN+ effort data: gamma, inverse			
Steps1and2	66%	18%	46%	11%
Steps3and4	14%	38%	12%	6%
	Alternative HN+ effort data: gamma, identity			
Steps1and2	23%	10%	43%	-2%
Steps3and4	33%	45%	29%	-7%
	Alternative HN+ effort data: raw			
Steps1and2	84%	16%	55%	6%
Steps3and4	90%	35%	32%	-2%
	Same HN catchability before and after 2005			
Steps1and2	0%	0%	0%	0%
Steps3and4	0%	0%	0%	0%
	Fishery-independent sampling data not fit			
Steps1and2	50%	18%	46%	0%
Steps3and4	32%	40%	21%	-7%

6.6.4. Discussion

Alternative effort type 1 data

Comparing the baseline run with each of the three runs applying alternative effort type 1 (HN+) data inputs, this does not particularly suggest an inverse relationship between changes in catchability and biomass, due to the conditioned-upon data (effort) being different in each of the runs. Yet, considering a given run, higher values for percentage change in the HN+ column of Table 6-1 may imply less influence on biomass trend attributable to the standardisation process (Appendix 1, stage 1) given that catch data is the same between runs. For example, the run with raw effort data as input has higher values for percentage change in catchability (post 2005 / pre 2005) than any of the alternative standardisation runs including the baseline run, especially evident for Spencer Gulf.

However, the HN+ effort data standardisations appear to have removed at least some of the potential catchability influences (given the covariates) not captured by GarEst's heterogeneous catchability, such as accounting for gradual removal of less efficient fishers since 2005. This may explain differences in estimated biomass observed between that from the baseline and the run with raw data input (Figure 6-20). Differences in absolute levels of estimated biomass between the baseline and the two alternative HN+ effort data runs (Figures 6-18 and 6-19) are evident for Gulf St. Vincent but not so much for Spencer Gulf, the reason for which is unclear. However, the difference in biomass trend between those three runs is relatively minor compared to the difference in trends between baseline and the raw effort data run. As noted in Appendix 1, stage 1, the form of standardisation that informs data input to the baseline, namely GLM gamma log link, was deemed most appropriate.

Same absolute catchability parameter for haul net gear pre- and post-2005

The change in catchability compared with baseline GarEst (Table 6-1), as expected, is qualitatively inverse to the corresponding change in biomass (Figure 6-21), with biomass trend becoming more optimistic (i.e., rises) when the absolute catchability parameter does change past 2005. Comparing Figures 6-21 and 6-20 suggests that GarEst's separation of catchability about 2005 may be more influential than the form of effort data standardisation. Note that the extra catchability parameters which the baseline run possesses was well supported parameter parsimony wise, with the AIC value having decreased by more than 10 units.

The extent of the aforementioned inverse relationship varies because biomass is also influenced by catchability effects other than that from fits to haul net catch totals data, such as from dab net and recreational catch; although the haul net catches form the major source of catch. The data on catch proportions by age and sex also influences estimation, and such data is sparse for the period prior to 2005 compared with 2005-2022.

FRDC fishery-independent sampling project data not fit

The influence of this data is shown to be minimal in terms of long-term biomass trend (Figure 6-22). This may be because this data was collected and fit only over a limited period, namely 2016-2018, and consequently biomass was most strongly impacted over 2013-2015. The latter is explained noting that age data in a given year is expected to influence Garfish cohorts at lags 1 year and older. The predicted proportions at age were computed directly in terms of population estimates and did not incorporate catchability parameters, which may limit the influence on long-term biomass trend, as those parameters are factors in predicted catch in many years of fishery data.

6.7. Appendix 7. Quarterly catch totals and harvest rates for SG fishing zone

Quarter time-step	itQ	SG Catch: in weight			Catch: in number		Harvest fraction
		COM, Model	COM, Data	CB+REC, Model	CB+REC, Model	CB+REC, Data	
Oct-Dec-83	1	33,000	29,000	11,000	130,000	110,000	11%
Jan-Mar-84	2	77,000	72,000	17,000	190,000	140,000	23%
Apr-Jun-84	3	90,000	100,000	8,700	98,000	91,000	24%
Jul-Sep-84	4	30,000	29,000	890	9,600	14,000	10%
Oct-Dec-84	5	29,000	32,000	8,700	100,000	110,000	12%
Jan-Mar-85	6	76,000	74,000	14,000	180,000	140,000	23%
Apr-Jun-85	7	82,000	80,000	9,100	120,000	91,000	20%
Jul-Sep-85	8	43,000	39,000	1,000	12,000	14,000	11%
Oct-Dec-85	9	32,000	33,000	9,700	120,000	110,000	11%
Jan-Mar-86	10	87,000	84,000	16,000	200,000	140,000	23%
Apr-Jun-86	11	91,000	87,000	9,700	120,000	91,000	21%
Jul-Sep-86	12	52,000	63,000	1,000	12,000	14,000	13%
Oct-Dec-86	13	26,000	30,000	9,900	120,000	110,000	10%
Jan-Mar-87	14	64,000	59,000	16,000	200,000	140,000	20%
Apr-Jun-87	15	98,000	100,000	9,000	110,000	91,000	24%
Jul-Sep-87	16	60,000	52,000	870	10,000	14,000	18%
Oct-Dec-87	17	27,000	26,000	8,200	99,000	110,000	12%
Jan-Mar-88	18	69,000	72,000	13,000	160,000	140,000	23%
Apr-Jun-88	19	82,000	78,000	7,400	92,000	91,000	23%
Jul-Sep-88	20	50,000	51,000	760	9,000	14,000	17%
Oct-Dec-88	21	41,000	39,000	7,600	99,000	110,000	15%
Jan-Mar-89	22	98,000	95,000	13,000	180,000	140,000	26%
Apr-Jun-89	23	120,000	100,000	8,700	120,000	91,000	25%
Jul-Sep-89	24	59,000	48,000	930	12,000	14,000	15%
Oct-Dec-89	25	46,000	65,000	9,400	130,000	110,000	13%
Jan-Mar-90	26	100,000	110,000	16,000	230,000	140,000	22%
Apr-Jun-90	27	110,000	94,000	11,000	150,000	91,000	20%
Jul-Sep-90	28	78,000	84,000	1,200	16,000	14,000	15%
Oct-Dec-90	29	51,000	45,000	11,000	140,000	110,000	15%
Jan-Mar-91	30	82,000	75,000	16,000	190,000	140,000	25%
Apr-Jun-91	31	84,000	79,000	8,000	90,000	91,000	26%
Jul-Sep-91	32	55,000	63,000	730	7,800	14,000	22%
Oct-Dec-91	33	38,000	44,000	6,900	85,000	110,000	16%
Jan-Mar-92	34	99,000	100,000	12,000	160,000	140,000	28%
Apr-Jun-92	35	110,000	110,000	8,000	110,000	91,000	24%
Jul-Sep-92	36	56,000	42,000	880	12,000	14,000	15%
Oct-Dec-92	37	37,000	29,000	8,700	120,000	110,000	12%
Jan-Mar-93	38	92,000	85,000	14,000	200,000	140,000	25%
Apr-Jun-93	39	100,000	120,000	8,900	120,000	91,000	24%
Jul-Sep-93	40	52,000	59,000	920	11,000	14,000	15%
Oct-Dec-93	41	34,000	35,000	8,500	110,000	110,000	13%
Jan-Mar-94	42	80,000	78,000	13,000	160,000	140,000	26%
Apr-Jun-94	43	65,000	77,000	7,500	91,000	91,000	20%
Jul-Sep-94	44	55,000	60,000	750	8,700	14,000	19%
Oct-Dec-94	45	21,000	17,000	6,900	84,000	110,000	11%
Jan-Mar-95	46	64,000	61,000	11,000	140,000	140,000	25%
Apr-Jun-95	47	54,000	54,000	6,600	81,000	91,000	19%
Jul-Sep-95	48	56,000	62,000	650	7,700	14,000	22%
Oct-Dec-95	49	29,000	30,000	6,300	82,000	110,000	14%
Jan-Mar-96	50	84,000	75,000	11,000	150,000	140,000	28%
Apr-Jun-96	51	68,000	82,000	7,000	96,000	91,000	19%
Jul-Sep-96	52	53,000	55,000	770	9,800	14,000	16%
Oct-Dec-96	53	43,000	48,000	7,700	110,000	110,000	15%
Jan-Mar-97	54	95,000	88,000	13,000	190,000	140,000	25%
Apr-Jun-97	55	110,000	110,000	8,800	120,000	91,000	24%
Jul-Sep-97	56	96,000	92,000	910	12,000	14,000	24%
Oct-Dec-97	57	34,000	28,000	8,100	110,000	110,000	13%
Jan-Mar-98	58	79,000	80,000	12,000	160,000	140,000	26%
Apr-Jun-98	59	72,000	98,000	7,200	89,000	91,000	22%
Jul-Sep-98	60	44,000	52,000	730	8,600	14,000	16%
Oct-Dec-98	61	27,000	24,000	7,200	91,000	110,000	12%
Jan-Mar-99	62	80,000	83,000	12,000	160,000	140,000	26%
Apr-Jun-99	63	71,000	68,000	7,700	100,000	91,000	20%
Jul-Sep-99	64	57,000	64,000	820	10,000	14,000	17%
Oct-Dec-99	65	37,000	32,000	7,500	97,000	110,000	14%
Jan-Mar-00	66	79,000	92,000	12,000	160,000	140,000	26%
Apr-Jun-00	67	67,000	68,000	7,300	94,000	91,000	20%
Jul-Sep-00	68	54,000	64,000	780	9,400	14,000	18%
Oct-Dec-00	69	30,000	21,000	7,500	97,000	110,000	12%
Jan-Mar-01	70	85,000	83,000	12,000	170,000	140,000	25%
Apr-Jun-01	71	88,000	73,000	7,000	94,000	81,000	22%
Jul-Sep-01	72	61,000	84,000	750	9,300	12,000	18%
Oct-Dec-01	73	19,000	19,000	8,000	97,000	120,000	11%
Jan-Mar-02	74	45,000	50,000	12,000	140,000	150,000	22%
Apr-Jun-02	75	62,000	69,000	5,200	59,000	70,000	23%
Jul-Sep-02	76	39,000	50,000	590	6,700	11,000	15%
Oct-Dec-02	77	16,000	13,000	7,300	82,000	120,000	11%
Jan-Mar-03	78	42,000	37,000	11,000	130,000	160,000	23%
Apr-Jun-03	79	46,000	39,000	4,300	50,000	60,000	18%
Jul-Sep-03	80	39,000	38,000	580	6,900	9,800	13%
Oct-Dec-03	81	17,000	16,000	8,700	100,000	130,000	10%
Jan-Mar-04	82	49,000	61,000	13,000	150,000	170,000	24%
Apr-Jun-04	83	42,000	43,000	3,600	41,000	50,000	16%
Jul-Sep-04	84	44,000	47,000	460	5,300	8,500	16%
Oct-Dec-04	85	14,000	13,000	8,500	95,000	140,000	10%
Jan-Mar-05	86	42,000	47,000	13,000	150,000	180,000	22%
Apr-Jun-05	87	40,000	44,000	3,200	37,000	40,000	14%
Jul-Sep-05	88	35,000	37,000	480	5,800	7,100	10%
Oct-Dec-05	89	18,000	14,000	12,000	140,000	150,000	10%
Jan-Mar-06	90	50,000	42,000	16,000	190,000	180,000	23%
Apr-Jun-06	91	44,000	47,000	2,500	28,000	29,000	15%
Jul-Sep-06	92	62,000	66,000	350	3,900	5,800	20%
Oct-Dec-06	93	18,000	19,000	9,700	110,000	150,000	13%
Jan-Mar-07	94	34,000	39,000	14,000	160,000	190,000	21%
Apr-Jun-07	95	48,000	53,000	1,400	16,000	19,000	18%
Jul-Sep-07	96	48,000	41,000	250	2,900	4,500	17%
Oct-Dec-07	97	17,000	17,000	9,600	110,000	160,000	12%
Jan-Mar-08	98	36,000	37,000	14,000	160,000	200,000	22%
Apr-Jun-08	99	46,000	43,000	640	7,300	9,000	17%
Jul-Sep-08	100	32,000	28,000	180	2,100	3,200	11%
Oct-Dec-08	101	17,000	14,000	9,800	110,000	160,000	12%
Jan-Mar-09	102	42,000	47,000	15,000	180,000	200,000	23%
Apr-Jun-09	103	44,000	37,000	1,400	17,000	17,000	15%
Jul-Sep-09	104	44,000	43,000	280	3,400	4,400	13%
Oct-Dec-09	105	21,000	22,000	11,000	130,000	150,000	12%
Jan-Mar-10	106	48,000	46,000	18,000	210,000	210,000	23%
Apr-Jun-10	107	44,000	38,000	2,200	25,000	26,000	14%
Jul-Sep-10	108	45,000	34,000	380	4,500	5,500	13%
Oct-Dec-10	109	21,000	15,000	12,000	140,000	150,000	12%
Jan-Mar-11	110	47,000	49,000	19,000	220,000	210,000	22%
Apr-Jun-11	111	54,000	47,000	3,100	35,000	34,000	16%
Jul-Sep-11	112	66,000	57,000	460	5,300	6,700	18%
Oct-Dec-11	113	23,000	18,000	11,000	130,000	150,000	12%
Jan-Mar-12	114	45,000	42,000	18,000	210,000	210,000	23%
Apr-Jun-12	115	35,000	36,000	3,600	40,000	43,000	13%
Jul-Sep-12	116	56,000	55,000	500	5,700	7,800	17%
Oct-Dec-12	117	18,000	15,000	10,000	110,000	140,000	11%
Jan-Mar-13	118	39,000	41,000	17,000	190,000	210,000	21%
Apr-Jun-13	119	34,000	41,000	4,000	45,000	51,000	13%
Jul-Sep-13	120	43,000	47,000	570	6,500	9,000	14%
Oct-Dec-13	121	18,000	19,000	9,900	110,000	140,000	11%
Jan-Mar-14	122	44,000	50,000	17,000	200,000	220,000	23%
Apr-Jun-14	123	23,000	23,000	4,800	55,000	59,000	9%
Jul-Sep-14	124	62,000	66,000	650	7,600	10,000	18%
Oct-Dec-14	125	23,000	21,000	8,700	99,000	130,000	13%
Jan-Mar-15	126	45,000	41,000	15,000	170,000	200,000	24%
Apr-Jun-15	127	16,000	14,000	4,000	45,000	54,000	10%
Jul-Sep-15	128	28,000	20,000	560	6,400	9,200	12%
Oct-Dec-15	129	20,000	18,000	7,600	86,000	110,000	14%
Jan-Mar-16	130	32,000	36,000	14,000	160,000	180,000	27%
Apr-Jun-16	131	28,000	27,000	3,700	41,000	48,000	14%
Jul-Sep-16	132	16,000	18,000	520	5,900	8,200	7%
Oct-Dec-16	133	18,000	15,000	6,900	78,000	95,000	12%
Jan-Mar-17	134	36,000	42,000	14,000	150,000	160,000	27%
Apr-Jun-17	135	35,000	32,000	3,400	38,000	43,000	17%
Jul-Sep-17	136	13,000	18,000	470	5,300	7,300	6%
Oct-Dec-17	137	16,000	12,000	6,000	67,000	80,000	10%
Jan-Mar-18	138	34,000	34,000	12,000	140,000	140,000	24%
Apr-Jun-18	139	31,000	28,000	3,000	32,000	37,000	15%
Jul-Sep-18	140	12,000	9,100	390	4,300	6,400	5%
Oct-Dec-18	141	21,000	26,000	4,500	48,000	64,000	12%
Jan-Mar-19	142	35,000	40,000	10,000	110,000	130,000	25%
Apr-Jun-19	143	25,000	34,000	2,300	25,000	31,000	13%
Jul-Sep-19	144	20,000	24,000	300	3,300	5,400	9%
Oct-Dec-19	145	12,000	13,000	3,100	34,000	49,000	9%
Jan-Mar-20	146	25,000	30,000	8,200	88,000	110,000	20%
Apr-Jun-20	147	23,000	32,000	1,800	19,000	26,000	12%
Jul-Sep-20	148	19,000	29,000	240	2,600	4,500	9%
Oct-Dec-20	149	12,000	12,000	2,000	22,000	33,000	8%
Jan-Mar-21	150	28,000	28,000	6,700	74,000	91,000	22%
Apr-Jun-21	151	32,000	40,000	1,500	17,000	20,000	16%
Jul-Sep-21	152	21,000	20,000	210	2,500	3,600	7%
Oct-Dec-21	153	12,000	9,800	1,300	15,000	17,000	5%
Jan-Mar-22	154	25,000	26,000	8,100	91,000	91,000	13%
Apr-Jun-22	155	29,000	28,000	1,800	19,000	20,000	10%
Jul-Sep-22	156	23,000	16,000	260	2,800	3,600	7%

6.8. Appendix 8. Quarterly catch totals and harvest rates for GSV/KI fishing zone

Quarter time-step	itQ	GSV/KI catch: in weight			Catch: in number		Harvest fraction
		COM, Model	COM, Data	CB+REC, Model	CB+REC, Model	CB+REC, Data	
Oct-Dec-83	1	27,000	20,000	17,000	180,000	210,000	15%
Jan-Mar-84	2	51,000	54,000	27,000	290,000	290,000	26%
Apr-Jun-84	3	69,000	75,000	8,700	92,000	120,000	29%
Jul-Sep-84	4	17,000	22,000	430	4,400	8,800	10%
Oct-Dec-84	5	25,000	26,000	13,000	150,000	210,000	15%
Jan-Mar-85	6	60,000	70,000	23,000	310,000	290,000	25%
Apr-Jun-85	7	76,000	73,000	10,000	130,000	120,000	24%
Jul-Sep-85	8	28,000	24,000	560	6,600	8,800	10%
Oct-Dec-85	9	27,000	24,000	15,000	190,000	210,000	14%
Jan-Mar-86	10	50,000	44,000	27,000	330,000	290,000	23%
Apr-Jun-86	11	81,000	85,000	9,900	110,000	120,000	28%
Jul-Sep-86	12	23,000	24,000	510	5,600	8,800	10%
Oct-Dec-86	13	12,000	9,500	14,000	160,000	210,000	11%
Jan-Mar-87	14	34,000	31,000	22,000	260,000	290,000	22%
Apr-Jun-87	15	39,000	45,000	8,500	95,000	120,000	19%
Jul-Sep-87	16	22,000	26,000	460	4,800	8,800	11%
Oct-Dec-87	17	17,000	16,000	12,000	140,000	210,000	13%
Jan-Mar-88	18	37,000	36,000	21,000	250,000	290,000	23%
Apr-Jun-88	19	49,000	50,000	8,000	92,000	120,000	23%
Jul-Sep-88	20	20,000	24,000	420	4,600	8,800	10%
Oct-Dec-88	21	20,000	20,000	12,000	140,000	210,000	14%
Jan-Mar-89	22	49,000	46,000	21,000	270,000	290,000	25%
Apr-Jun-89	23	63,000	65,000	8,400	100,000	120,000	25%
Jul-Sep-89	24	31,000	41,000	450	5,000	8,800	15%
Oct-Dec-89	25	27,000	28,000	13,000	160,000	210,000	15%
Jan-Mar-90	26	51,000	54,000	23,000	320,000	290,000	23%
Apr-Jun-90	27	62,000	55,000	10,000	130,000	120,000	21%
Jul-Sep-90	28	30,000	35,000	580	6,700	8,800	11%
Oct-Dec-90	29	31,000	31,000	15,000	170,000	210,000	17%
Jan-Mar-91	30	46,000	52,000	23,000	270,000	290,000	26%
Apr-Jun-91	31	37,000	28,000	8,300	92,000	120,000	19%
Jul-Sep-91	32	26,000	26,000	430	4,500	8,800	13%
Oct-Dec-91	33	28,000	32,000	12,000	140,000	210,000	17%
Jan-Mar-92	34	60,000	58,000	20,000	270,000	290,000	28%
Apr-Jun-92	35	48,000	55,000	8,500	100,000	120,000	19%
Jul-Sep-92	36	27,000	26,000	490	5,600	8,800	11%
Oct-Dec-92	37	40,000	46,000	13,000	160,000	210,000	19%
Jan-Mar-93	38	62,000	60,000	22,000	290,000	290,000	27%
Apr-Jun-93	39	78,000	86,000	8,900	110,000	120,000	28%
Jul-Sep-93	40	27,000	23,000	470	5,400	8,800	12%
Oct-Dec-93	41	34,000	42,000	13,000	170,000	210,000	17%
Jan-Mar-94	42	69,000	78,000	23,000	320,000	290,000	27%
Apr-Jun-94	43	71,000	63,000	9,800	120,000	120,000	24%
Jul-Sep-94	44	37,000	46,000	530	6,200	8,800	14%
Oct-Dec-94	45	33,000	33,000	13,000	160,000	210,000	17%
Jan-Mar-95	46	57,000	53,000	22,000	280,000	290,000	27%
Apr-Jun-95	47	45,000	39,000	8,600	100,000	120,000	19%
Jul-Sep-95	48	33,000	34,000	460	5,100	8,800	15%
Oct-Dec-95	49	34,000	38,000	13,000	160,000	210,000	17%
Jan-Mar-96	50	79,000	78,000	22,000	310,000	290,000	30%
Apr-Jun-96	51	83,000	87,000	9,000	110,000	120,000	27%
Jul-Sep-96	52	25,000	16,000	500	5,900	8,800	10%
Oct-Dec-96	53	38,000	36,000	15,000	200,000	210,000	16%
Jan-Mar-97	54	65,000	58,000	28,000	390,000	290,000	23%
Apr-Jun-97	55	73,000	74,000	13,000	160,000	120,000	20%
Jul-Sep-97	56	51,000	37,000	720	8,400	8,800	15%
Oct-Dec-97	57	29,000	32,000	17,000	210,000	210,000	15%
Jan-Mar-98	58	40,000	48,000	26,000	300,000	290,000	23%
Apr-Jun-98	59	46,000	62,000	9,400	99,000	120,000	22%
Jul-Sep-98	60	28,000	37,000	470	4,700	8,800	15%
Oct-Dec-98	61	23,000	26,000	12,000	140,000	210,000	15%
Jan-Mar-99	62	55,000	65,000	22,000	280,000	290,000	26%
Apr-Jun-99	63	56,000	49,000	9,200	110,000	120,000	21%
Jul-Sep-99	64	41,000	38,000	490	5,500	8,800	17%
Oct-Dec-99	65	31,000	33,000	14,000	180,000	210,000	15%
Jan-Mar-00	66	67,000	62,000	25,000	350,000	290,000	25%
Apr-Jun-00	67	88,000	73,000	11,000	140,000	120,000	25%
Jul-Sep-00	68	56,000	91,000	550	6,400	8,800	19%
Oct-Dec-00	69	31,000	33,000	16,000	210,000	210,000	14%
Jan-Mar-01	70	62,000	68,000	30,000	410,000	290,000	22%
Apr-Jun-01	71	100,000	89,000	11,000	140,000	100,000	25%
Jul-Sep-01	72	56,000	56,000	600	7,000	7,700	17%
Oct-Dec-01	73	33,000	42,000	15,000	170,000	200,000	18%
Jan-Mar-02	74	60,000	66,000	24,000	290,000	270,000	29%
Apr-Jun-02	75	77,000	70,000	8,600	98,000	91,000	26%
Jul-Sep-02	76	47,000	65,000	460	5,200	6,700	16%
Oct-Dec-02	77	26,000	24,000	13,000	140,000	190,000	17%
Jan-Mar-03	78	43,000	41,000	21,000	240,000	250,000	24%
Apr-Jun-03	79	57,000	55,000	7,200	82,000	79,000	21%
Jul-Sep-03	80	40,000	33,000	400	4,400	5,700	14%
Oct-Dec-03	81	24,000	27,000	13,000	140,000	180,000	16%
Jan-Mar-04	82	43,000	46,000	19,000	210,000	230,000	25%
Apr-Jun-04	83	39,000	48,000	5,500	60,000	67,000	17%
Jul-Sep-04	84	33,000	31,000	300	3,200	4,700	13%
Oct-Dec-04	85	22,000	25,000	11,000	120,000	170,000	17%
Jan-Mar-05	86	53,000	56,000	17,000	200,000	210,000	26%
Apr-Jun-05	87	80,000	82,000	5,300	62,000	54,000	24%
Jul-Sep-05	88	62,000	61,000	270	3,200	3,700	18%
Oct-Dec-05	89	38,000	36,000	12,000	140,000	170,000	20%
Jan-Mar-06	90	52,000	56,000	15,000	170,000	190,000	28%
Apr-Jun-06	91	69,000	73,000	2,900	32,000	42,000	30%
Jul-Sep-06	92	42,000	29,000	120	1,300	2,700	22%
Oct-Dec-06	93	14,000	14,000	6,600	69,000	160,000	15%
Jan-Mar-07	94	32,000	29,000	9,000	100,000	170,000	26%
Apr-Jun-07	95	40,000	37,000	1,600	19,000	30,000	22%
Jul-Sep-07	96	26,000	26,000	73	820	1,700	14%
Oct-Dec-07	97	13,000	16,000	6,500	71,000	150,000	14%
Jan-Mar-08	98	42,000	44,000	9,000	110,000	160,000	27%
Apr-Jun-08	99	62,000	54,000	1,100	13,000	18,000	27%
Jul-Sep-08	100	29,000	25,000	32	370	670	13%
Oct-Dec-08	101	15,000	19,000	7,300	82,000	140,000	13%
Jan-Mar-09	102	42,000	46,000	10,000	120,000	150,000	24%
Apr-Jun-09	103	68,000	70,000	1,500	18,000	21,000	26%
Jul-Sep-09	104	30,000	28,000	65	740	1,200	13%
Oct-Dec-09	105	17,000	16,000	7,700	85,000	130,000	13%
Jan-Mar-10	106	36,000	33,000	10,000	120,000	140,000	22%
Apr-Jun-10	107	51,000	48,000	1,700	19,000	23,000	22%
Jul-Sep-10	108	31,000	21,000	86	930	1,600	15%
Oct-Dec-10	109	14,000	13,000	6,100	65,000	120,000	12%
Jan-Mar-11	110	32,000	32,000	8,800	97,000	130,000	21%
Apr-Jun-11	111	39,000	45,000	1,900	20,000	26,000	17%
Jul-Sep-11	112	30,000	24,000	120	1,300	2,100	13%
Oct-Dec-11	113	17,000	15,000	6,000	64,000	100,000	13%
Jan-Mar-12	114	31,000	30,000	8,700	94,000	120,000	20%
Apr-Jun-12	115	26,000	25,000	2,000	22,000	29,000	12%
Jul-Sep-12	116	24,000	21,000	150	1,500	2,600	11%
Oct-Dec-12	117	14,000	13,000	5,700	59,000	94,000	11%
Jan-Mar-13	118	35,000	32,000	8,200	88,000	110,000	21%
Apr-Jun-13	119	25,000	22,000	2,300	24,000	31,000	12%
Jul-Sep-13	120	33,000	34,000	170	1,800	3,100	15%
Oct-Dec-13	121	13,000	12,000	4,700	49,000	83,000	10%
Jan-Mar-14	122	36,000	35,000	7,200	77,000	110,000	23%
Apr-Jun-14	123	42,000	38,000	2,200	23,000	34,000	21%
Jul-Sep-14	124	14,000	18,000	180	1,900	3,600	8%
Oct-Dec-14	125	13,000	11,000	3,900	41,000	75,000	11%
Jan-Mar-15	126	25,000	22,000	6,000	65,000	97,000	18%
Apr-Jun-15	127	19,000	22,000	2,100	22,000	33,000	14%
Jul-Sep-15	128	13,000	9,600	220	2,300	4,100	8%
Oct-Dec-15	129	13,000	15,000	3,700	39,000	68,000	11%
Jan-Mar-16	130	18,000	19,000	6,100	65,000	88,000	19%
Apr-Jun-16	131	18,000	18,000	2,300	24,000	31,000	12%
Jul-Sep-16	132	9,500	8,700	280	2,900	4,600	5%
Oct-Dec-16	133	13,000	12,000	4,000	41,000	60,000	10%
Jan-Mar-17	134	22,000	24,000	6,500	68,000	79,000	19%
Apr-Jun-17	135	25,000	30,000	2,400	24,000	30,000	14%
Jul-Sep-17	136	3,000	3,000	330	3,400	5,100	2%
Oct-Dec-17	137	18,000	19,000	3,700	37,000	53,000	12%
Jan-Mar-18	138	22,000	25,000	6,000	62,000	70,000	18%
Apr-Jun-18	139	30,000	34,000	2,300	24,000	28,000	16%
Jul-Sep-18	140	3,900	3,800	380	3,800	5,600	2%
Oct-Dec-18	141	16,000	15,000	3,400	34,000	46,000	10%
Jan-Mar-19	142	27,000	31,000	5,400	55,000	61,000	19%
Apr-Jun-19	143	25,000	31,000	2,300	23,000	26,000	13%
Jul-Sep-19	144	3,500	2,500	410	4,100	6,100	2%
Oct-Dec-19	145	13,000	11,000	2,900	28,000	38,000	8%
Jan-Mar-20	146	21,000	22,000	4,800	48,000	52,000	15%
Apr-Jun-20	147	21,000	26,000	2,100	20,000	25,000	11%
Jul-Sep-20	148	4,100	5,700	440	4,200	6,600	2%
Oct-Dec-20	149	9,600	7,900	2,400	22,000	31,000	6%
Jan-Mar-21	150	18,000	19,000	4,000	39,000	43,000	13%
Apr-Jun-21	151	23,000	35,000	2,100	21,000	23,000	12%
Jul-Sep-21	152	10,000	8,800	500	4,900	7,100	4%
Oct-Dec-21	153	8,800	6,500	2,000	19,000	24,000	5%
Jan-Mar-22	154	24,000	26,000	4,400	43,000	43,000	12%
Apr-Jun-22	155	20,000	28,000	2,300	23,000	23,000	8%
Jul-Sep-22	156	14,000	14,000	530	5,200	7,100	5%

6.9. Appendix 9. Conversions between GarEst model time-steps (t) and quarterly time periods.

Time period	Model time step *t*
Oct-Dec-83	1
Jan-Mar-84	2
Apr-Jun-84	3
Jul-Sep-84	4
Oct-Dec-84	5
Jan-Mar-85	6
Apr-Jun-85	7
Jul-Sep-85	8
Oct-Dec-85	9
Jan-Mar-86	10
Apr-Jun-86	11
Jul-Sep-86	12
Oct-Dec-86	13
Jan-Mar-87	14
Apr-Jun-87	15
Jul-Sep-87	16
Oct-Dec-87	17
Jan-Mar-88	18
Apr-Jun-88	19
Jul-Sep-88	20
Oct-Dec-88	21
Jan-Mar-89	22
Apr-Jun-89	23
Jul-Sep-89	24
Oct-Dec-89	25
Jan-Mar-90	26
Apr-Jun-90	27
Jul-Sep-90	28
Oct-Dec-90	29
Jan-Mar-91	30
Apr-Jun-91	31
Jul-Sep-91	32
Oct-Dec-91	33
Jan-Mar-92	34
Apr-Jun-92	35
Jul-Sep-92	36
Oct-Dec-92	37
Jan-Mar-93	38
Apr-Jun-93	39
Jul-Sep-93	40
Oct-Dec-93	41
Jan-Mar-94	42
Apr-Jun-94	43
Jul-Sep-94	44
Oct-Dec-94	45
Jan-Mar-95	46
Apr-Jun-95	47
Jul-Sep-95	48
Oct-Dec-95	49
Jan-Mar-96	50
Apr-Jun-96	51
Jul-Sep-96	52
Oct-Dec-96	53
Jan-Mar-97	54
Apr-Jun-97	55
Jul-Sep-97	56
Oct-Dec-97	57
Jan-Mar-98	58
Apr-Jun-98	59
Jul-Sep-98	60
Oct-Dec-98	61
Jan-Mar-99	62
Apr-Jun-99	63
Jul-Sep-99	64
Oct-Dec-99	65
Jan-Mar-00	66
Apr-Jun-00	67
Jul-Sep-00	68
Oct-Dec-00	69
Jan-Mar-01	70
Apr-Jun-01	71
Jul-Sep-01	72
Oct-Dec-01	73
Jan-Mar-02	74
Apr-Jun-02	75
Jul-Sep-02	76
Oct-Dec-02	77
Jan-Mar-03	78
Apr-Jun-03	79
Jul-Sep-03	80
Oct-Dec-03	81
Jan-Mar-04	82
Apr-Jun-04	83
Jul-Sep-04	84
Oct-Dec-04	85
Jan-Mar-05	86
Apr-Jun-05	87
Jul-Sep-05	88
Oct-Dec-05	89
Jan-Mar-06	90
Apr-Jun-06	91
Jul-Sep-06	92
Oct-Dec-06	93
Jan-Mar-07	94
Apr-Jun-07	95
Jul-Sep-07	96
Oct-Dec-07	97
Jan-Mar-08	98
Apr-Jun-08	99
Jul-Sep-08	100
Oct-Dec-08	101
Jan-Mar-09	102
Apr-Jun-09	103
Jul-Sep-09	104
Oct-Dec-09	105
Jan-Mar-10	106
Apr-Jun-10	107
Jul-Sep-10	108
Oct-Dec-10	109
Jan-Mar-11	110
Apr-Jun-11	111
Jul-Sep-11	112
Oct-Dec-11	113
Jan-Mar-12	114
Apr-Jun-12	115
Jul-Sep-12	116
Oct-Dec-12	117
Jan-Mar-13	118
Apr-Jun-13	119
Jul-Sep-13	120
Oct-Dec-13	121
Jan-Mar-14	122
Apr-Jun-14	123
Jul-Sep-14	124
Oct-Dec-14	125
Jan-Mar-15	126
Apr-Jun-15	127
Jul-Sep-15	128
Oct-Dec-15	129
Jan-Mar-16	130
Apr-Jun-16	131
Jul-Sep-16	132
Oct-Dec-16	133
Jan-Mar-17	134
Apr-Jun-17	135
Jul-Sep-17	136
Oct-Dec-17	137
Jan-Mar-18	138
Apr-Jun-18	139
Jul-Sep-18	140
Oct-Dec-18	141
Jan-Mar-19	142
Apr-Jun-19	143
Jul-Sep-19	144
Oct-Dec-19	145
Jan-Mar-20	146
Apr-Jun-20	147
Jul-Sep-20	148
Oct-Dec-20	149
Jan-Mar-21	150
Apr-Jun-21	151
Jul-Sep-21	152
Oct-Dec-21	153
Jan-Mar-22	154
Apr-Jun-22	155
Jul-Sep-22	156