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King George Whiting (*Sillaginodes punctatus*) Fishery

AJ Fowler, R McGarvey, J Carroll and JE Feenstra

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PO Box 120 Henley Beach SA 5022

September 2014

Fishery Assessment Report to PIRSA Fisheries and Aquaculture

PREMIUM FOOD AND WINE FROM OUR CLEAN ENVIRONMENT

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We wish to extend our gratitude to the numerous fish processors and fishers who gave us access to samples of King George whiting for the collection of data and biological material. In particular we wish to thank Adelaide's SAFCOL fish market for their on-going support of the catch sampling program. In all cases the data on population structure make a significant contribution to our stock assessment work.

The data on catch and effort from the commercial sector of the Marine Scalefish Fishery were provided to us by Angelo Tsolos of the Information Systems and Database Support Program of SARDI (Aquatic Sciences). The market sampling was undertaken by Bruce Jackson, Matt Lloyd and Mike Steer. The report was reviewed by Drs Ben Stobart and Crystal Beckman from SARDI Aquatic Sciences, and Michelle Besley of PIRSA Fisheries and Aquaculture whose comments helped to improve an earlier draft of the report. The report was also externally reviewed by Dr Tony Smith from CSIRO, whose comments led to considerable improvement to the presentation of the report, particularly with respect to inputs and outputs from the stock assessment model WhitEst. The contributions of all are acknowledged and greatly appreciated.

1. EXECUTIVE SUMMARY

This is the 9th in a series of stock assessment reports on South Australia's King George whiting fishery since 1997, and updates the most recent report from 2011. This assessment comes nearly 10 years after important changes were made to the management arrangements in response to a significant, broad-scale down-turn in the fishery from 1999 to 2002.

Three types of fishery performance indicators were considered at the State-wide scale and for the three stocks; West Coast (WC), Spencer Gulf (SG) and Gulf St. Vincent/ Kangaroo Island (GSV/KI). The first indicators were from the commercial fishery statistics from 1984 to 2013. The second indicators were the recent estimates of population size and age structures for numerous regions across the State. Finally, there were estimates of biological performance indicators from the fishery assessment model WhitEst for 1984 to 2013, including annual estimates of fishable biomass, exploitation rate and recruitment.

Emphasis was on statistics from the commercial handline sector as net fishing effort on King George whiting has declined to relatively low levels. At the State-wide scale, total catches and handline effort decreased between 1992 and 2013, partly relating to declining numbers of commercial fishers. State-wide estimates of handline CPUE were variable but increased after the low period of 1999 to 2002. However, trends in handline CPUE differed amongst stocks. For the WC, handline CPUE increased to a record level in 2013, whilst for both the SG and GSV/KI stocks, estimates of handline CPUE declined after 2007.

Size and age structures determined from market sampling done during 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 showed no obvious differences from the estimates from the 1990s and early 2000s. Thus, there is no evidence for population truncation relatable to the fishery.

The State-wide estimates of performance indicators from the stock assessment model WhitEst show strong increases in recruitment and fishable biomass since 2002, and declining exploitation rate since 1992. These largely reflect the influence of the WC which now contributes about 56% of the State-wide biomass of King George whiting. In contrast, model estimates of fishable biomass have declined marginally or

remained relatively flat for SG and GSV since 2009. For SG, this reflects relatively low recruitment but for GSV/KI reflects an increase in exploitation rate.

The general fishery performance indicators for 2013 were assessed against limit reference points from the time series back to 1984, at both the State-wide and stock-wide scales. Breaches of limit reference points differed amongst stocks. For the WC stock, there was a record level of handline CPUE in 2013. For both the SG and GSV/KI stocks they related to record low catches and effort.

The biological fishery performance indicators from 2013 included fishable biomass, recruitment and exploitation rates estimated by the WhitEst model at both the State-wide and stock-wide spatial scales. For the WC, estimates of fishable biomass and recruitment were above average, resulting in breaches of trigger reference points. For GSV, the high exploitation rate of 34% in 2013 also activated the trigger reference point.

The fourth biological performance indicator was population age structure. There was no evidence that any regional population age structure had changed significantly either over the last five years or over the long-term.

King George whiting remains the premium species in the Marine Scalefish Fishery. Its stock status for the WC fishery was determined as **sustainable**, based on increasing trends in CPUE, and estimated fishable biomass and recruitment from WhitEst. Alternatively, the SG stock was assigned the status of **transitional depleting** based on concomitant declining trends in commercial catch, effort and CPUE and estimated biomass from WhitEst. The stock status for GSV/KI was also classified as **transitional depleting**, due to similar declining trends in fishery statistics.

There are several uncertainties with respect to our assessment of stock status. These include the influence of increasing effective effort due to technology creep on handline CPUE, and the consequence of this for estimated biomass. A further uncertainty relates to the lack of time-series data on catch and effort from the recreational sector. The final uncertainty relates to the extent to which egg production may have been disrupted by targeted fishing on spawning aggregations.

2. GENERAL INTRODUCTION

2.1. Overview

Stock assessments have been produced regularly for South Australia's King George whiting fishery since 1997 with this being the ninth report since that time. This report has two aims; to summarise information about the fishery and biology of the species, and to synthesise this information into an assessment of the status of the stocks. The last stock assessment report was completed in July 2011, and summarised data that were available up to the end of 2010 (Fowler et al. 2011). This report incorporates a further three years of commercial catch and effort data, presenting data collected up to the end of 2013.

This introductory chapter establishes the context for the subsequent empirical and modelling-based chapters. It provides: a description of the fishery; summarises the management regulations; and provides a summary of the population biology and life history of the species based on research that has been done over the past 30 years across southern Australia. Chapter 3 summarises the commercial fishery statistics, which primarily involves the presentation of time series of estimates of catch, effort and catch rate at the State-wide, stock-wide and regional spatial scales.

Chapter 4 provides an analysis of the population size and age structures based on samples collected across the State by market sampling in 2011/12 and 2012/13. For comparison, these new data are provided along with those from 2006/07, 2008/09 and 2009/10 that were previously presented in Fowler et al. (2011). Since the population characteristics of King George whiting differ so much between regions and depend on life history processes, it is important that such data be collected every few years to consider possible size and age truncation and to update the computer fishery assessment model WhitEst.

Chapter 5 presents the results from WhitEst, the model that integrates all input data from the fishery to estimate biological indicators of stock status (Fowler and McGarvey 2000). The input data include: the time series of commercial catch and effort data; logbook data from charter boats; data on recreational catch from both the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) and the 2007/08 State survey (Jones 2009); and regional samples by month of age, sex, and length proportions in the commercial catch collected at various times between 1995 and

2013. Model outputs include time-series of estimates of recruitment, fishable biomass and exploitation rate at the State-wide and stock-wide scales, by month and year.

Chapter 6 addresses the second aim of the report of determining the status of the King George whiting fishery in South Australia. This is done by assessing the fishery performance indicators specified in the Management Plan for the commercial Marine Scalefish Fishery (PIRSA 2013), and by comparing the data available for King George whiting against prescribed limit reference points. A synthesis of the findings is presented in the General Discussion in Chapter 7, along with the conclusions about stock status.

2.2. Description of Fishery

In South Australia (SA), the fishery for King George whiting is geographically extensive, and includes all coastal waters from Gulf St. Vincent westwards to Denial Bay, throughout which it is intensively targeted by recreational and commercial Marine Scalefish fishers. SA's commercial fishery makes the highest contribution to the national catch of King George whiting, which is generally greater than twice the biomass harvested from Victoria and considerably more than the catch from Western Australia (ABARES 2010). In South Australia, King George whiting was historically the most valuable Marine Scalefish species, but since 2007/08 its total value has been below that of snapper (Knight and Tsolos 2012). Nevertheless, it remains the highest value species by unit weight.

Juvenile King George whiting move from shallow, protected nursery areas to adjacent deeper water. This is where they become vulnerable to fishing. The faster growing individuals in each annual cohort reach fishable size during the period of rapid growth in late summer and autumn when water temperatures are highest. Seasonal levels of exploitation in the commercial fishery for both handlines and hauling nets peak in late autumn and winter, when the new recruits are targeted. Monthly catches generally peak in July. In early summer, when fish reach about 3.5 years of age (based on a birth date of 1st May, Fowler and Short 1998), movement of young adult fish located in the two gulfs is directed southwards. In doing so, they encounter a gauntlet of fishing nets and lines that are used to target these young adults resulting in high levels of exploitation. The fish that reach the southern, deeper, offshore spawning areas at and near the mouths of the two gulfs replenish the populations of larger, older, mature fish (Fowler et al. 2000a, 2002; Fowler and Jones 2008).

The fisheries in Gulf St. Vincent, Northern Spencer Gulf and the West Coast bays predominantly take relatively small, young, immature fish of about 3 years of age that are quite close to the minimum legal size, while fish on the spawning grounds tend to be larger and older, with some up to 18 years of age (Fowler et al. 2000a). Analysis of the reproductive activity of adult fish during the time of spawning in different regions of the two gulfs indicated that King George whiting of comparable size and age showed no evidence of spawning activity in the northern regions, but nearly all those found in the southern aggregations, regardless of size, showed evidence of active spawning (Fowler et al. 1999, 2000a). This indicated that spawning in the gulfs is confined to southern areas, which means that the reproductive sustainability of such populations is determined by successful persistence and replenishment of resident populations in these spawning areas. These spawning sub-populations of larger, older fish are replenished annually by immigrants of 3-4 years of age that come from inshore fishing grounds and the upper gulfs (Fowler et al. 2000a, 2002). Historically, the exploitation of spawning aggregations was relatively low, which may have accounted for the stable recruitment of King George whiting over the years for which catch data were available (Fowler and McGarvey 2000, McGarvey et al. 2000). However, anecdotal reports suggest that now, with an established charter boat fishery and an expanded range offshore of the commercial and recreational sectors, it is likely that fishing pressure on the spawning aggregations has increased over the years.

For the commercial sector of the Marine Scalefish Fishery there are numerous endorsed gear types. Of these, the principal ones used to target King George whiting are handlines, hauling nets and gillnets. Recreational fishing for this species is by hook and line, principally from boats.

2.3. Management Regulations

Changes to the management regulations for the South Australian King George whiting fishery were implemented in October 2004. These included: (1) an increase in legal minimum length (LML) from 30 to 31 cm in all waters east of longitude 136°E; (2) the daily recreational bag limit was reduced from 20 to 12 legal-size fish per person, with the boat limit reduced from 60 to 36 fish per boat; (3) the existing licence amalgamation scheme was enhanced by reducing the number of points needed to acquire an amalgamated licence (from 26 to 24); and (4) if a non-licenced person was detected in possession of more than 75 King George whiting, which is considered a commercial quantity, then that person may be guilty of an offence. At that time,

consideration of appropriate management options was informed by management simulations that were undertaken using the simulation model WhitSim that tested a range of different strategies. The results of these were summarised in an earlier stock assessment report (McGarvey et al. 2003).

The principal means of effort control in the commercial sector is 'limited-entry'. Since 1994, a licence amalgamation scheme has operated to reduce effort in this sector and remove latent effort from the fishery. In association with other targeted licence buy-backs, the number of commercial Marine Scalefish licences has fallen from 701 in 1984 to 322 ('M'-class = 312; 'B'-class = 7) in June 2014. Also, the type of gear used by the commercial sector is strongly regulated by a complex suite of input and output controls. This includes hauling nets that must have a mesh size of 3.2 cm or greater, a maximum length of 600 m, a maximum drop of 5 m in the wings and 10 m in the bunt or pocket. Their use is restricted to coastal waters of less than 5 m depth, and is banned within half a nautical mile of any officially recognised artificial reef and within a radius of 100 m of any jetty, wharf or pier. Gillnets cannot be used in waters shallower than 5 m, the mesh size must be from 5 cm to 15 cm, with a maximum length of 600 m and a maximum drop of 5 m. Handlines are limited to 2 per person, with a limit of 3 hooks per line. There are limits on the number of agents who can fish from a licence, and the master of the licence must be an owner-operator. There are also many permanent and seasonal netting closures that have been introduced over the years for a variety of reasons including the protection of nursery areas and spawning grounds (Noell et al. 2006). A significant rationalisation of the net sector was undertaken in 2005 when a net licence buy-back scheme resulted in the reduction of 61 net licences and endorsements from 113 to 52 (24 full net licences were removed, and 37 net endorsements for hauling nets and gillnets were removed from licences). This resulted in the removal of approximately 45% of net fishing effort. At that time, further permanent spatial closures to the net fishery were implemented in large parts of the State's inshore waters.

Previous significant management changes include a reduction in the recreational bag limit from 30 to 20 fish.day^{-1} or from 90 to 60 fish.boatday^{-1} in September 1994. This was followed by an increase in the LML from 28 to 30 cm TL for both commercial and recreational sectors in September 1995 (Fowler and McGarvey 1997).

2.4. Population Biology and Life History

Although the general life cycle of King George whiting has been known for a number of years (Jones et al. 1990), understanding of it was enhanced through FRDC project 95/008 (Fowler and McGarvey 2000). That study provided: growth functions; estimates of population age structures; descriptions of adult movement patterns; understanding of annual reproductive cycles; spatial and temporal aspects of recruitment; as well as a study of genetic structure. The findings were used to develop a comprehensive understanding of the demography, life history and stock structure of the species in South Australia.

The nursery areas for recruitment of King George whiting are shallow, protected bays where the post-larvae arrive during each winter and spring. They occur in the northern gulfs and bays of the west coast of Eyre Peninsula and Kangaroo Island. Juveniles reside in such nursery areas for a year or two before they move out into gulf waters or deeper areas outside the bays, which are characterised by broken, low-profile reef and stands of seagrass (e.g. *Posidonia* spp.) (Jones et al. 1990).

When the fish reach 3-4 years of age they are capable of moving up to several hundred kilometres within a few months (Fowler and McGarvey 1997, Fowler and March 2000, Fowler and McGarvey 2000, McGarvey and Feenstra 2002, Fowler et al. 2002, Fowler and Jones 2008). They migrate from nursery areas to spawning grounds, whilst there are also less directed movements among coastal areas, mostly along the coast. Fish from Gulf St. Vincent and northern Spencer Gulf move the greatest distances, generally in a net southerly direction. Some fish tagged in Gulf St. Vincent were recaptured along the north coast of Kangaroo Island; some from northern Spencer Gulf were recaptured principally in Hardwicke Bay in the southeast, whilst some were found around the islands of the southwest of the gulf; those from West Coast bays have rarely been recaptured, but are thought to end up around offshore shoals and islands. In contrast, fish tagged near Kangaroo Island and southern Spencer Gulf did not move far and showed no systematic directional displacement (Fowler and McGarvey 1997, 1999; Fowler and March 2000; Fowler et al. 2002). These different movement patterns influence population structure. In those source areas from where fish move and where fishing is concentrated, population structure is generally truncated, involving small fish from a few young age classes. By contrast, at destination locations, older fish can be well represented with some up to 18 years of age (Fowler et al. 1999, 2000a).

Spawning occurs at the offshore grounds to which fish migrate, including: Investigator Strait along the north coast of Kangaroo Island; south-eastern tip of Yorke Peninsula in Gulf St. Vincent (Tapley Shoal); and south-eastern Spencer Gulf around Corny Point and Wardang Island. Spawning typically occurs between March and May (Fowler et al. 1999, 2000a). Patterns of larval distribution that were determined by plankton sampling during the 1980s (Bruce 1989), provided further evidence that spawning occurs in the southern locations and that larvae are advected northwards into and throughout the gulfs (B. Bruce unpublished data). To date, the spawning areas responsible for replenishing the bays of the west coast have not been determined. Commercially-harvested fish from these bays display minimal gonad maturation suggesting that spawning may occur offshore from these fishing grounds.

The long pre-settlement duration of 80 to >120 days of larval King George whiting (Fowler and Short 1996, Fowler and Jones 2008) provides ample opportunity for advection over long distances by hydrodynamic processes, as is the case for Victorian populations (Jenkins et al. 2000). In Port Phillip Bay, Victoria, the inter-annual variation in post-larval abundance is strongly correlated with the strength of the zonal westerly winds that influence the rate of transport of the larvae. This influences recruitment success and productivity to the fishery several years later (Jenkins 2005). Because of this, it is possible that spawning by King George whiting in South Australian waters replenish the fished populations in Port Phillip Bay, Western Port and Corner Inlet in Victoria. In contrast, however, hydrodynamic modelling for coastal areas around South Australia suggests that King George whiting larvae are advected over relatively short distances and that there exist relationships between particular spawning locations and nursery areas separated only by 100-200 km (Fowler et al. 2000b). This suggests that the South Australian populations are sustained by relatively local spawning. Furthermore, the combination of hydrodynamic modelling, sampled larval distributions, and adult movement patterns suggest that the two gulfs are largely-distinct, self-sustaining populations. Nevertheless, analysis of stock structure based on mitochondrial DNA and microsatellite primers found no significant phylogeographic structure across the distribution of King George whiting (Haigh and Donnellan 2000). This is consistent with the long pre-settlement duration, and does not counter the above-mentioned sub-population model since only a minimal but consistent exchange of two or three individuals per year between subpopulations is sufficient to maintain them as genetically homogeneous (Taylor and Dizon 1996).

South Australia's King George whiting population is genetically homogeneous (Haigh and Donnellan 2000). Nevertheless, several stocks are recognised based on our understanding of the spatial aspects of the life history that were described above. These include the interactions between: the adult movement patterns as determined by tag/recapture studies; reproductive biology with respect to the locations of spawning grounds and nursery areas; and advection of larvae, based on determination of early life history characteristics and hydrodynamic modelling (Fowler et al. 1999, 2000b, 2002). For management and stock assessment purposes the King George whiting population is divided into three adjacent stocks: west coast of Eyre Peninsula; Spencer Gulf; and Gulf St. Vincent / Kangaroo Island (Fowler and McGarvey 2000).

3. TRENDS IN COMMERCIAL CATCH, EFFORT AND CPUE

3.1. Introduction

Since 1984, commercial fishers in South Australia's Marine Scalefish Fishery have been required to submit, on a monthly basis, a catch return that relates their catch and effort data for the preceding month. This data time-series constitutes the most fundamental dataset for indicating the status of the fishery. These commercial statistics are considered here at several spatial scales, i.e. State-wide, stock and regional levels. The regional catch and effort data reported are also used in the fishery assessment model 'WhitEst', to calculate time-series of output parameters that relate to population processes and fishery status (Chapter 5). These output parameters are assessed against target reference points to indicate the status of the fishery. Also, in Chapter 6, the commercial statistics at the State-wide and stock levels are used to calculate general fishery performance indicators for comparison against trigger reference points.

3.2. Methods

The South Australian King George whiting fishery involves three stocks: West Coast of Eyre Peninsula (WC); Spencer Gulf (SG); and Gulf St. Vincent/Kangaroo Island (GSV/KI). Each stock involves at least two regional fisheries that consist of numerous adjacent Marine Fishing Areas (MFAs) (Fig. 3.1, Table 3.1). The WC stock includes the Far West Coast (FWC), Mid West Coast (MWC) and Coffin Bay (CB) (Fig. 3.1). The SG stock incorporates the regions of Northern Spencer Gulf (NSG) and Southern Spencer Gulf (SSG) (Fig. 3.1). The GSV/KI stock includes the waters inside Gulf St. Vincent (GSV), and those surrounding Kangaroo Island including Investigator Strait (Fig. 3.1). For this stock assessment, the fishery statistics for King George whiting were aggregated to provide annual totals at the regional, stock and State-wide levels. Annual totals of catch and effort by gear type were used to calculate annual estimates of catch per unit effort (CPUE) at the various spatial scales. The data for the three main gear types, i.e. handlines, hauling nets and gillnets were considered. Nevertheless, the focus in this report is on the handline sector as handline effort and CPUE are recognised as primary fishery performance indicators (PIRSA 2013). This is because the declining effort in the net sector has reduced the value of the data from this sector as fishery performance indicators. Furthermore, for some regions the presentation of data for this sector was limited by constraints of confidentiality, i.e. could not be presented if from <5 fishers. Consequently, detailed data for the net

sector are presented only at the regional level for the two northern gulfs, i.e. NSG and GSV, where most net fishing effort remains.

With respect to fishing effort, data are reported as fisherdays, which relate to the number of days fished and number of personnel involved, i.e. if there were two fishers on board a vessel for a day of fishing then this counted as two fisherdays. There are two components of fishing effort for each gear type, i.e. targeted and untargeted effort. The former relates to when the fishers intentionally try to catch King George whiting, whilst the latter refers to effort directed at other species that produces catches of King George whiting. For handlines and gillnets, total effort was estimated from targeted effort that was scaled upwards by the proportional additional catch that was taken by untargeted effort. Thus, for handlines and gillnets it was possible to provide annual estimates of total catch and effort and associated estimates of CPUE. However, for hauling nets the situation is more complex because fishers may catch substantial numbers of King George whiting whilst targeting other species, or when not targeting any species in particular. Under such circumstances it is not possible to determine the targeted effort directed specifically at King George whiting, making it impossible to provide a direct estimate of targeted CPUE. Consequently, for hauling nets, estimates of catch, effort and CPUE are reported for three different fishing effort categories: targeted effort; effort targeted at other species; and effort not directed at any particular species.

Table 3.1 Fishery stocks considered for the King George whiting fishery and the regions and the MFAs that comprise them (refer Fig. 3.1).

Stock	Region name	Marine Fishing Areas
West Coast	Far West Coast (FWC)	07, 08, 09, 10
	Mid West Coast (MWC)	15, 16, 17, 18
	Coffin Bay (CB)	27, 28
Spencer Gulf	Southern Spencer Gulf (SSG)	29, 30, 31, 32, 33
	Northern Spencer Gulf (NSG)	11, 19, 20, 21, 22, 23
Gulf St. Vincent /	Gulf St. Vincent (GSV)	34, 35, 36, 40, 43
Kangaroo island	Kangaroo Island (KI)	39, 41, 42, 44, 48, 49

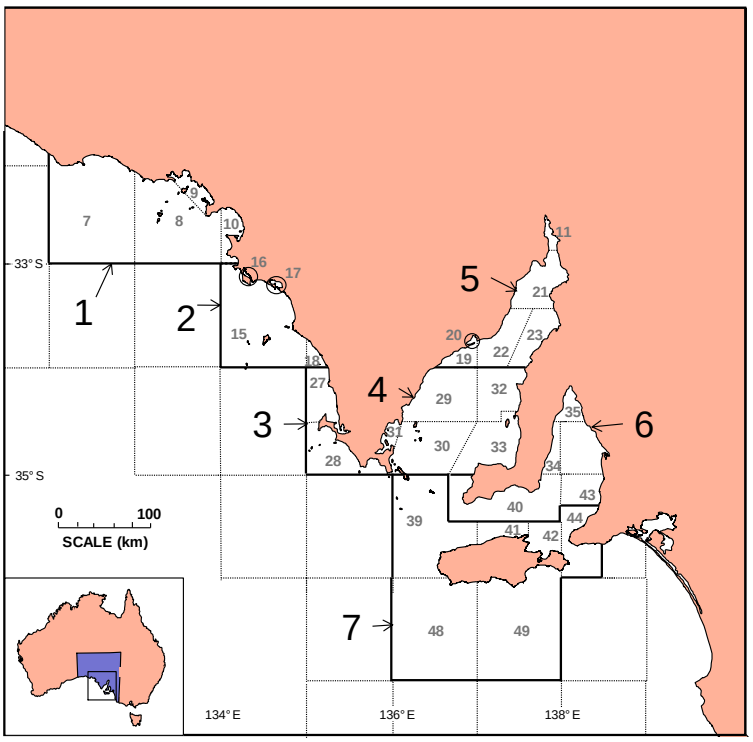

Fig. 3.1. Map of marine waters of South Australia identifying the seven fishery regions involved in the three stocks: WC (1 = Far West Coast, 2 = Mid West Coast, 3 = Coffin Bay); SG (4 = Southern Spencer Gulf, 5 = Northern Spencer Gulf); GSV/KI (6 = Gulf St. Vincent, 7 = Kangaroo Island).

3.3. Results

State-wide analysis of commercial fishery statistics

The time-series of State-wide estimates of commercial catch and effort for King George whiting extend from 1984 to 2013. The most notable feature of these long-term data is declining trends over time (Fig. 3.2a, b). The annual estimates of catch have decreased substantially since 1984, particularly since the record catch of 776 t was recorded in 1992. The most substantial annual decline in catch occurred in 2000, which involved a drop of 161 t. Since then, there has been further gradual decline to 2013 when the lowest annual catch of 293 t was recorded. The value of the annual commercial catch of King George whiting has varied considerably over time (Fig. 3.2a). It increased from its lowest value in 1984 to its highest in 1995 and has since varied between $3.9 and $5.2 million, with no long-term trend. Over the last four years to 2013, the estimated value has declined to $4.4 million.

Since 1984, handlines have been the dominant gear type in the commercial fishery (Fig. 3.2a). Between 1984 and 1999, handline catch varied around 400 t.yr^{-1}.

Subsequently, handline catch has dropped by 41% from 428 t in 1999 to 253 t in 2013. The catch of King George whiting by hauling nets has also fallen considerably since the record net catch taken in 1992. The hauling net catch of 22 t in 2013 was the lowest for this gear type, representing a decline by 92% since 1992. Even though the total State-wide gillnet catch has always been less than 50 $t.year^{-1}$, it has declined over the years and fell to only 9 t in 2013 (Fig. 3.2a).

Handline effort on King George whiting has declined from 30,709 fisherdays in 1992 to 12,078 fisherdays in 2013, i.e. a reduction of 60.7% over this 21 year period (Fig. 3.2b). Gillnet effort has declined by 88.6% from 2,256 to only 257 fisherdays over the same period. Such falling fishing effort relates at least partly to the decrease in number of licence holders in the commercial fishery (Fig. 3.2d). This decline accelerated after 1994 when the licence amalgamation scheme was introduced and again in 2005 through the net buyback. Consequently, over the years, there has been a considerable decline in number of commercial fishers who targeted and/or caught King George whiting (Fig. 3.2d).

The estimates of State-wide CPUE for handlines and gillnets have been variable, but have trended upward over time (Fig. 3.2c). The trend for handlines is divisible into two time periods. It increased relatively consistently from 1984 to 1999, but then dropped noticeably in 2000 and then again in 2002. Since then, CPUE has gradually increased although with declines in both 2008 and 2010. This increase has culminated in the highest average handline CPUE of 20.9 kg. $fisherday^{-1}$ being recorded in 2013. Since the early 2000s, CPUE has increased substantially in the gillnet fishery, but these estimates are based on very low levels of catch and effort and so are unlikely to provide a good indication of fishable biomass.

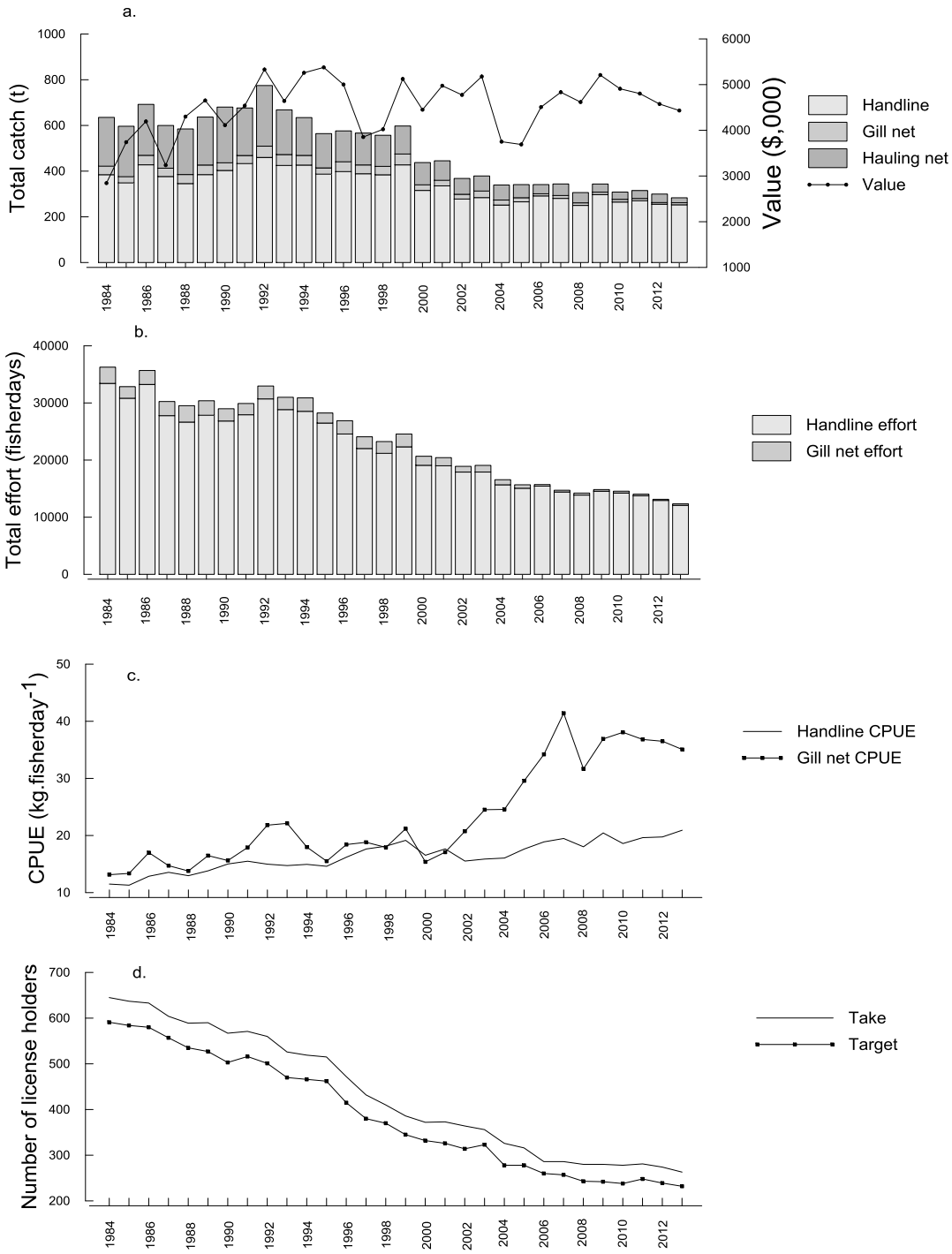

Fig. 3.2. State-wide fishery statistics. a. total annual catches by gear type and annual commercial value. b. total effort for handline and gill net sectors. c. annual State-wide estimates of CPUE for handline and gill net sectors. d. Annual estimates of number of commercial licence holders who reported taking and targeting King George whiting.

Stock-wide analysis of commercial fishery statistics

West Coast stock

The estimates of total catch for this stock have varied through several time periods. There was a general increase from 1984 to a maximum of 283 t in 1992 (Fig. 3.3a). From then, the catch gradually declined by 53% to the lowest level of 134 t in 2002. Subsequently there has been a gradual increase in catch to 170 t in 2013. In all years, handlines dominated the catches from this stock, ranging from a low of 129 t in 2008 to the record high level of 218 t in 1999. The drop in hauling net and gill net catches account for a significant proportion of the decline in total catch.

There was a step-wise decline in commercial handline effort between the maximum of 15,737 fisherdays in 1984 to 7,192 fisherdays in 2007 (Fig. 3.3b). Subsequently, the rate of decline slowed and was at 6,729 fisherdays in 2013. Handline CPUE has increased considerably in three multi-year steps since 1984 (Fig. 3.3b). It increased from 1987 to 1992 then declined considerably to 1995. It increased again to 1999 after which it fell from 20.8 to 15.6 kg.fisherday^{-1} in 2002. Subsequently, CPUE has increased by 61.8%, attaining the highest ever recorded value of 25.2 kg.fisherday^{-1} in 2013.

The number of fishers taking and targeting King George whiting for this stock have both declined considerably between 1984 and 2013 (Fig. 3.3c). The steepest rates of decline occurred between 1984 and 1997. Subsequently the declines have slowed, and in fact since 2007 there have been marginal increases in the numbers of fishers. From 1984 to 2013, the declines were from 211 to 97 in fishers who reported taking catches and 203 to 95 in numbers who targeted King George whiting.

Spencer Gulf stock

Total catch from this stock was variable from 1984 to 1997, but showed no long-term trend (Fig. 3.4a). It then declined by 57.1% between 1997 and 2004. Then from 2007 to 2013, total catch declined by a further 44.8% to the lowest ever recorded value of 68.6 t. This reflects declining catch by each of the major gear types but is particularly evident for the hauling net sector.

Handline fishing effort was variable between 1984 and 1992 (Fig. 3.4b). However, it then declined almost from year-to-year until 2004, giving a total decline of 60%.

Handline effort was then relatively stable for a number of years, but by 2013 had decreased by a further 28.3% to the lowest ever recorded level of 3,270 fisherdays. Handline CPUE increased considerably from 11.7 kg.fisherday^{-1} in 1984 to a high level of 19.6 kg.fisherday^{-1} in 1997 (Fig. 3.4b). It then declined by 20.7% to only 15.6 kg.fisherday^{-1} in 2003. After this, there was a considerable rise to 20.6 kg.fisherday^{-1} in 2007. However, from 2007 to 2013, handline CPUE declined almost annually by 17.4%. Apart from the low values recorded between 2002 and 2004, this is the lowest recorded level since 1996.

The number of licence holders taking and targeting this stock of King George whiting has declined considerably over the years. Those taking this species declined from 325 in 1984 to 136 in 2013. The decline in fishers targeting this species was from 295 to 119.

Gulf St. Vincent/Kangaroo Island stock

The total catch from this stock has generally been consistently lower than for the other two stocks and has varied through a number of different periods (Fig. 3.5a). First, it declined between 1984 and 1988 before increasing to the record level of 146.4 t in 1992. Subsequently, it has declined to the lowest annual catch of 45 t in 2013. Each of the three major gear types contributed to these catches over time, with the catch from each having declined. Handline catches were relatively stable from 2000 to 2006, but subsequently declined by a further 43.3% to 27.3 t.

Handline fishing effort on this stock reached its highest level of 7,649 fisherdays in 1992 (Fig. 3.5b). It subsequently declined by 54.9% to 3,449 fisherdays in 2000. It then remained relatively flat to 2009, after which there was further decline to 2,092 fisherdays in 2013. Although variable amongst years, handline CPUE increased by 57.7% between 1984 and 2000 (Fig. 3.5b). It then declined for a few years before increasing between 2003 and 2007. Subsequently, CPUE has declined by 19.3% from 16.2 to 13.1 kg.fisherday^{-1} in 2013.

The number of licence holders who captured or targeted King George whiting showed no consistent trend between 1984 and 1992 (Fig. 3.5c). However, subsequently the numbers have declined considerably. In 1984, a total of 187 fishers took King George whiting, which fell to 69 in 2013. Furthermore, the number of fishers who targeted this species declined from 160 to 51 over the same time period.

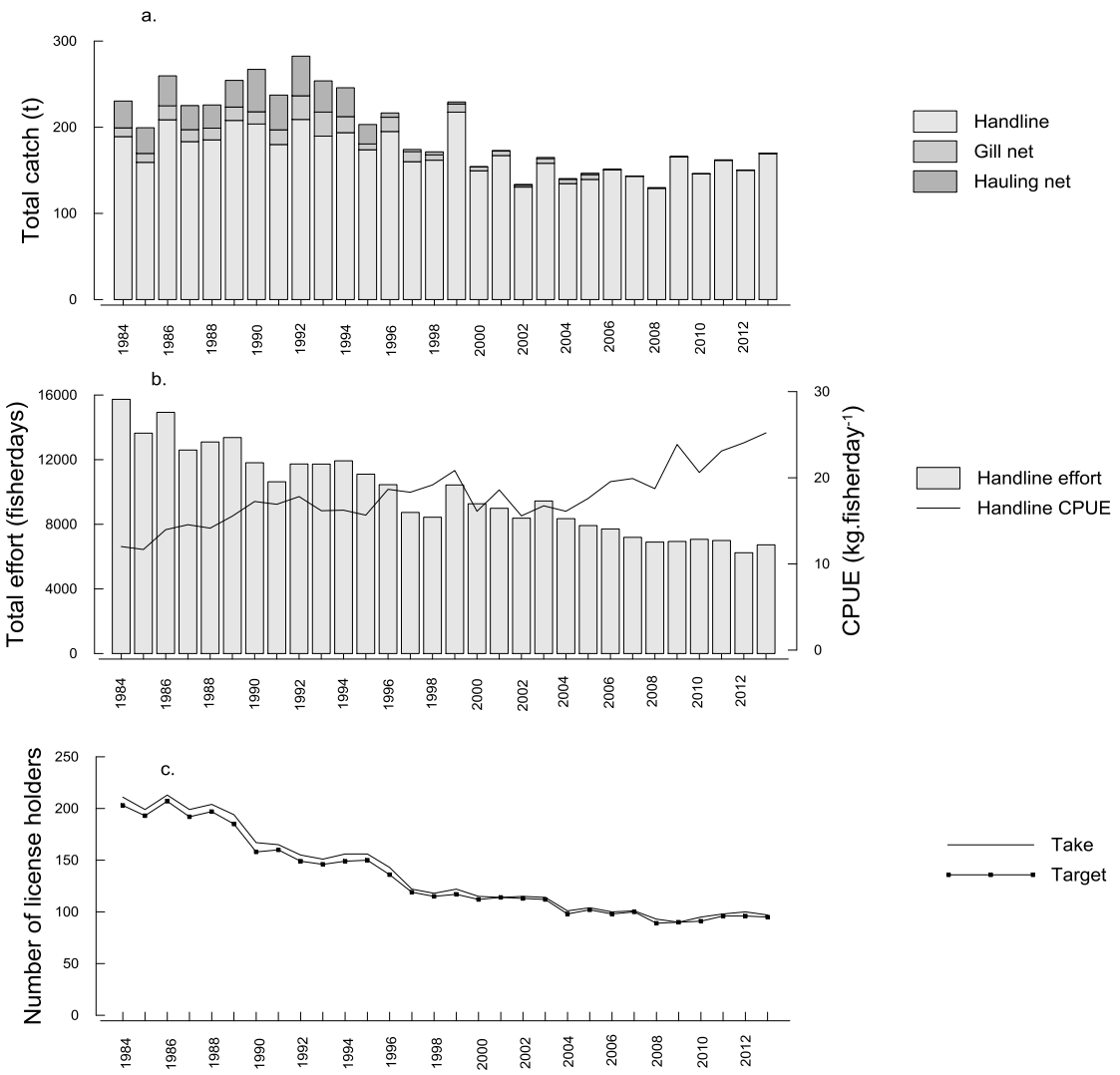

Fig. 3.3. Fishery statistics for West Coast stock. a. total annual catches by gear type. b. total effort and CPUE for handlines. c. annual estimates of numbers of commercial licence holders who reported taking and targeting King George whiting.

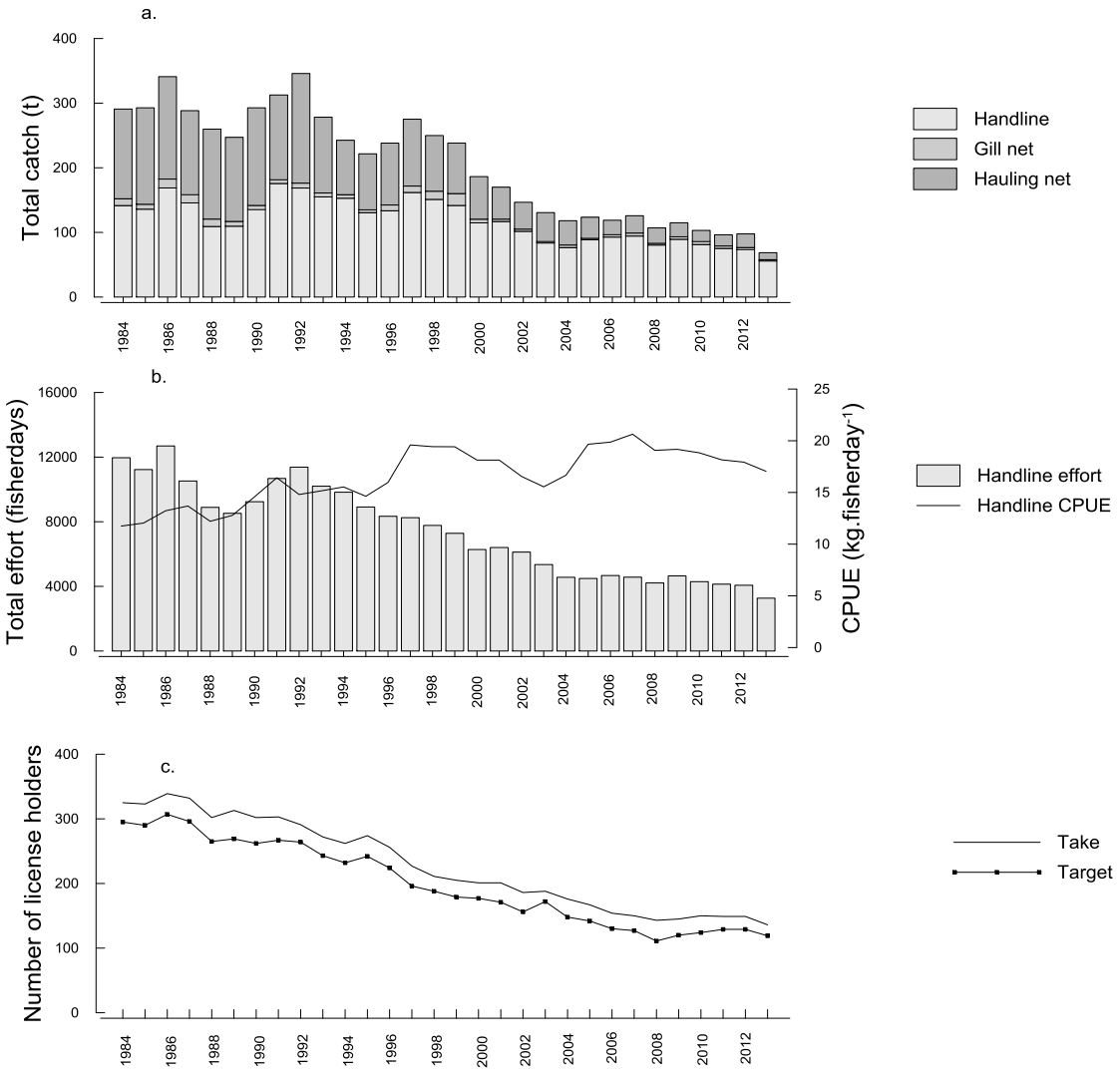

Fig. 3.4. Fishery statistics for Spencer Gulf stock. a. total annual catches by gear type. b. total effort and CPUE for handlines. c. annual estimates of numbers of commercial licence holders who reported taking and targeting King George whiting.

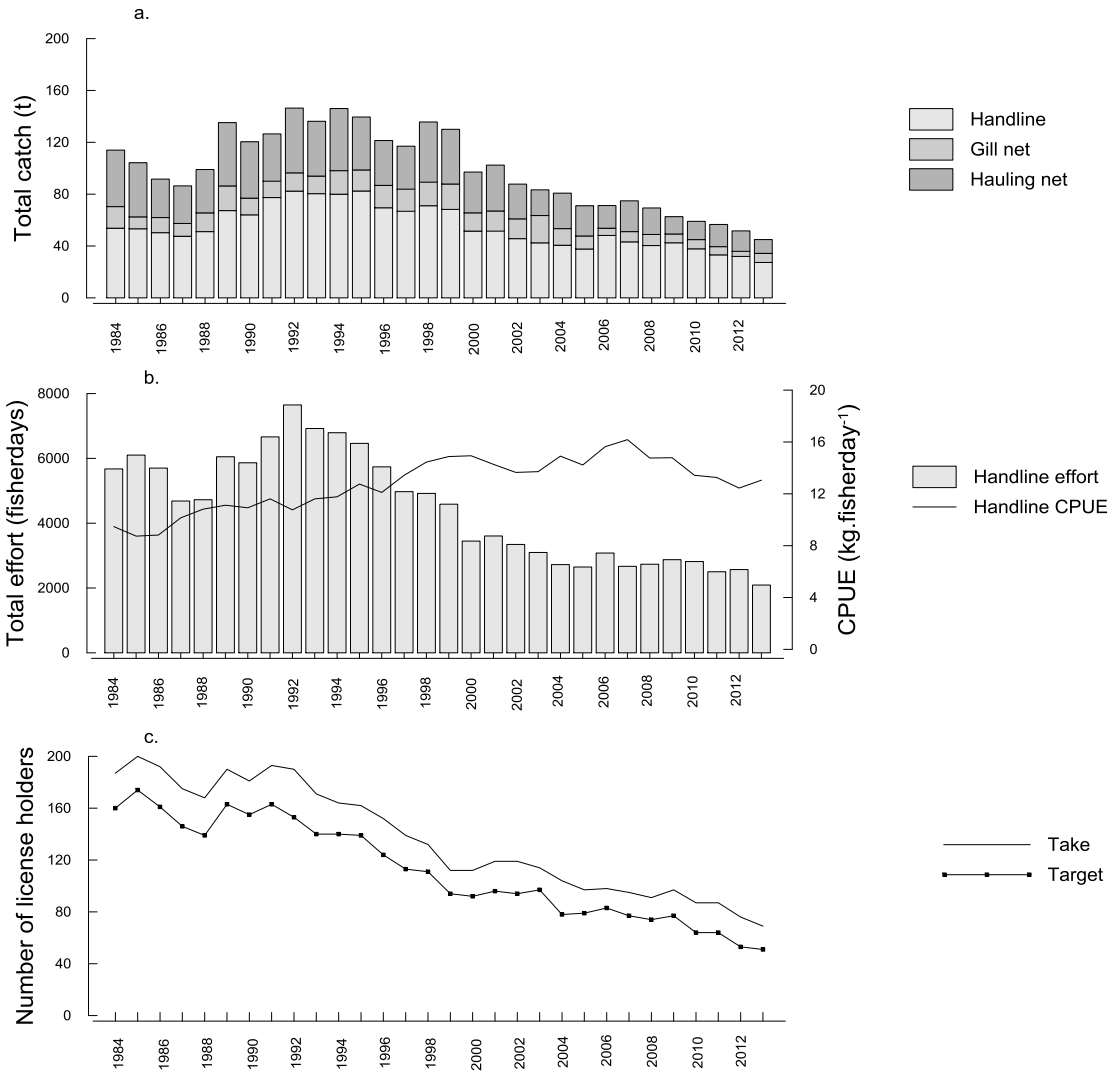

Fig. 3.5. Fishery statistics for Gulf St. Vincent / Kangaroo Island stock. a. total annual catches by gear type. b. total effort and CPUE for handlines. c. annual estimates of numbers of commercial licence holders who reported taking and targeting King George whiting.

Regional analysis of commercial fishery statistics

The fishery statistics were considered in further detail to assess for consistency in trends amongst the different regions of the three stocks. The time series of total annual catches across all gear types for the seven regions demonstrated some consistent changes over time. The FWC has generally been the most consistent contributor amongst all regions (Fig. 3.6). The catches from the MWC and CB have generally been lower and more variable than those of the FWC. The catches from SSG were generally higher and more consistent than those of NSG, which demonstrated the most consistent decline amongst all regions. The total catches from GSV and KI have been relatively low, whilst those from GSV declined from the early 1990s and those from KI declined considerably over the past five years.

When considered at the spatial scale of MFA, there has been a gradual contraction in fishery catches over time towards several MFAs (Fig. 3.7). MFA 9, located on the WC, has been the most productive block throughout the entire time period, whilst MFAs 10 and 27 have also been consistently significant for the WC stock. For the SG stock, catches were historically widespread but have eventually contracted back to those from MFA 23 in NSG and MFAs 30 and 33 in SSG. For the GSV/KI stock, catches have been most consistent from MFA 35 in NGSV and MFA 42 for KI.

The remainder of this chapter examines the trends in annual catch, effort and CPUE for the seven different regions. For each region, annual estimates of handline catch, effort and CPUE are presented. Furthermore, for both NSG and GSV, where hauling nets remain a significant gear type, a separate figure is also presented that relates the region-specific estimates of hauling net catch, effort and CPUE with effort divided into the categories of ‘targeted’, ‘no specific species targeted’ and ‘other species targeted’.

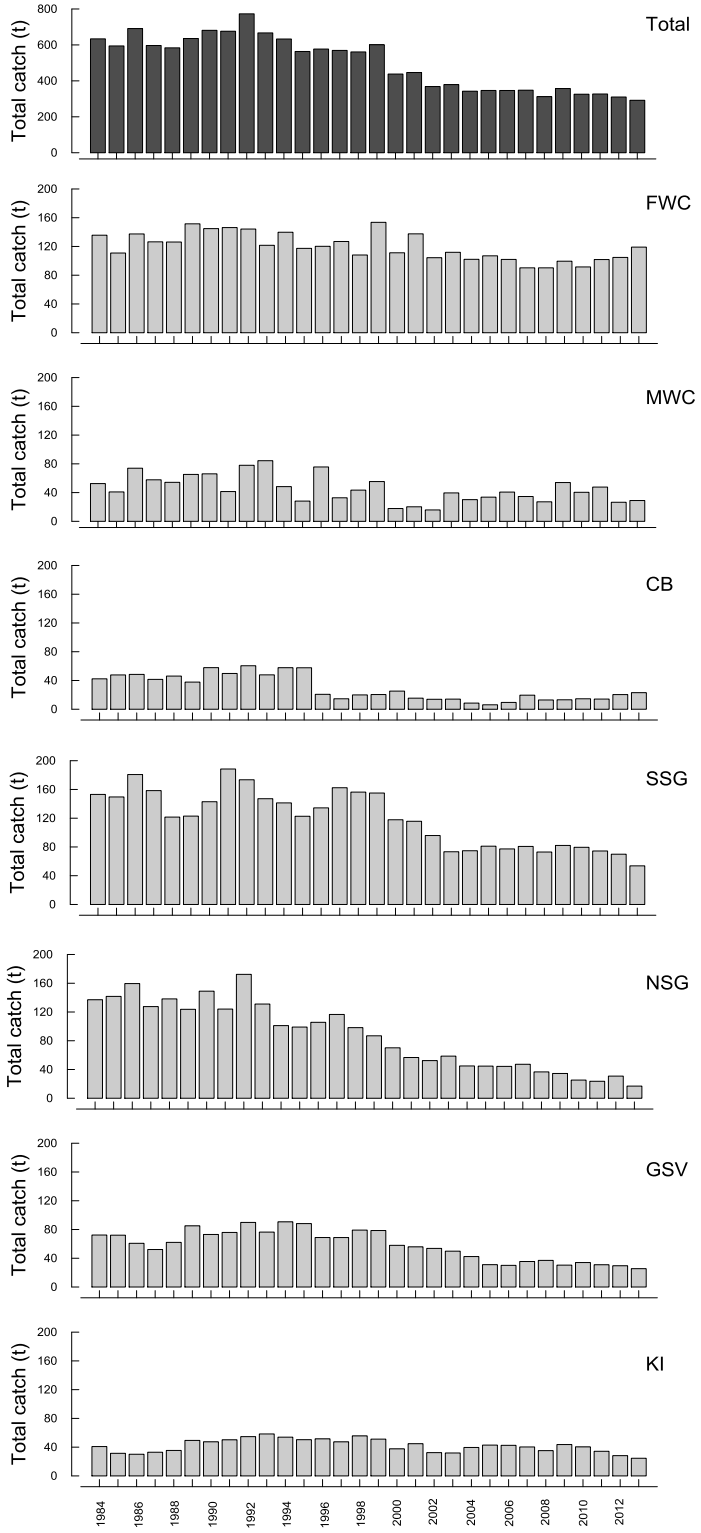

Fig. 3.6. Summary of annual commercial catches of King George whiting at the State-wide and regional scales from 1984 to 2013.

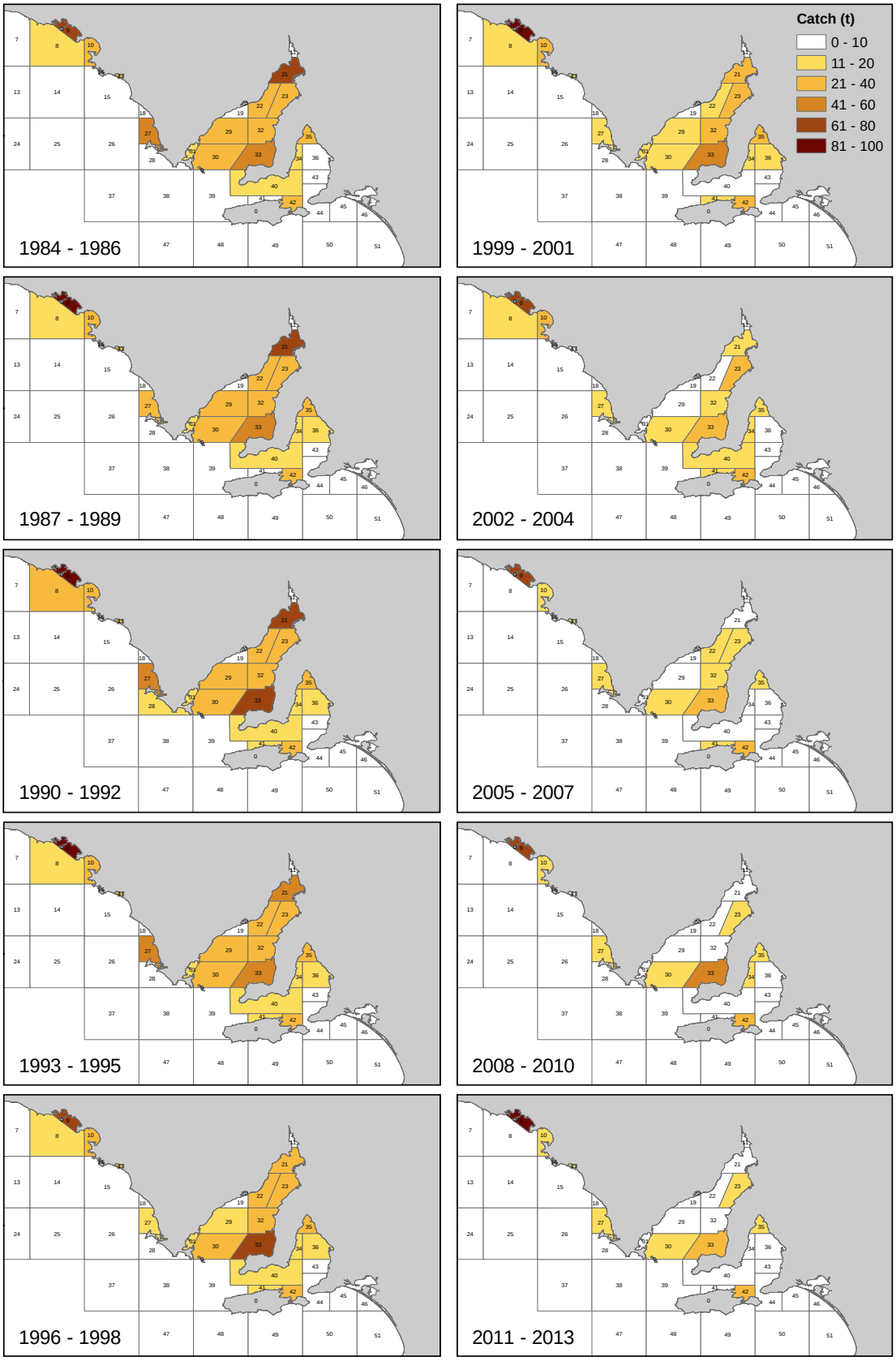

Fig. 3.7. Maps of South Australian coastal waters showing the average annual catch in each Marine Fishing Area for the three-year periods indicated.

Far West Coast (Denial and Streaky Bays)

The annual catches from the bays of the Far West Coast have been relatively high and consistent over time and dominated by the handline sector since the implementation of a netting ban in 1958 (Fig. 3.8a). Up to 2001, the handline catches varied around an average of 130 t.yr^{-1}. From 2002, the catches have been generally lower although the catch of 118.7 t recorded in 2013 was the highest recorded for 12 years. Between 1984 and 1998, handline effort declined by 40% to approximately 6,000 fisherdays.year^{-1} (Fig. 3.8b). It then increased through the period of 1999 to 2005 before gradually declining again. It declined by 24.4% from 6,384 fisherdays in 2004 to 4,824 fisherdays in 2013.

Handline CPUE showed a long-term increasing trend from 1984 to 1999 (Fig. 3.8b). Through this time there were several periods of higher catch rates, one from 1989 to 1992 and the second from 1996 to 1999. It then declined considerably through the period of 1999 to 2002. However, from 2004, handline CPUE has gradually recovered and in 2013 attained the highest level ever recorded of 24.6 kg.fisherday^{-1}.

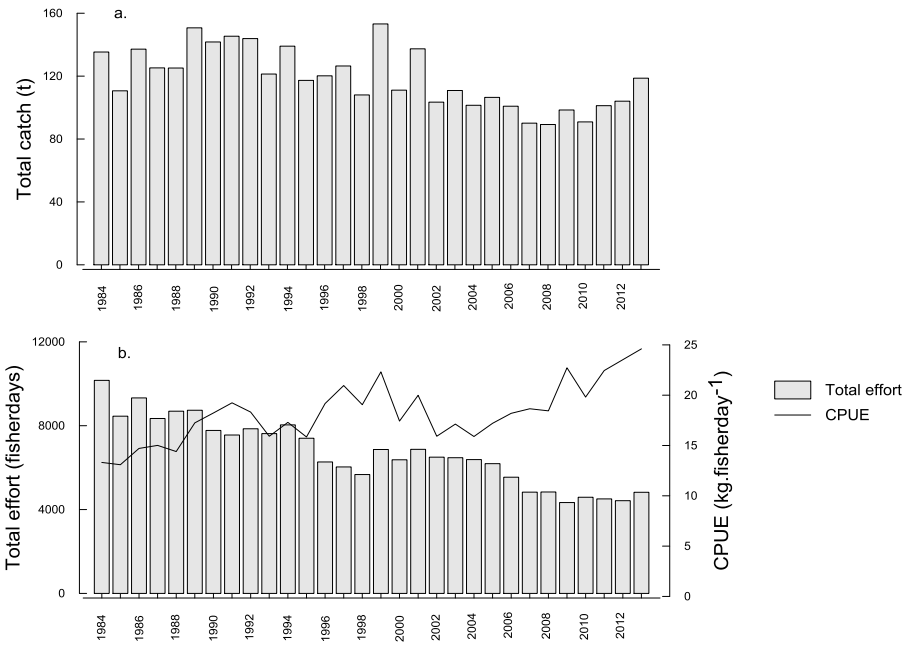

Fig. 3.8. Far West Coast. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines. b. total effort and CPUE for handlines.

Mid West Coast (Baird and Venus Bays)

Between 1958 and 2005, the bays of the Mid West Coast were closed to net fishing through a number of management measures. As such, only handline fishery statistics are considered below for this region.

The annual handline catches from the bays of the Mid West Coast have been highly variable from year-to-year (Fig. 3.9a). From 1984 to 1999, annual catches showed no long term trend. In 2000, the catch dropped to the lowest recorded level of 13.1 t and remained low in both 2001 and 2002. From 2003 to 2011, it increased before declining again to 26.5 and 28.9 t in 2012 and 2013, respectively. These recent catches were higher than the low catches at the start of the decade. Handline effort has also been highly variable from year-to-year but has demonstrated a long-term decline, particularly from 1999 to 2002, culminating in the lowest recorded fishing effort in 2002 of 1,065 fisherdays (Fig. 3.9b). Subsequently, handline fishing effort was also relatively low in 2012 and 2013. Between 1984 and 2000, handline CPUE was variable but showed no long-term trend (Fig. 3.9b). However, since 2000, it has risen from a low level of 7.8 kg.fisherday^{-1} to a maximum of 26.1 kg.fisherday^{-1} in 2009, before falling back to 24.5 kg.fisheryday^{-1} in 2013.

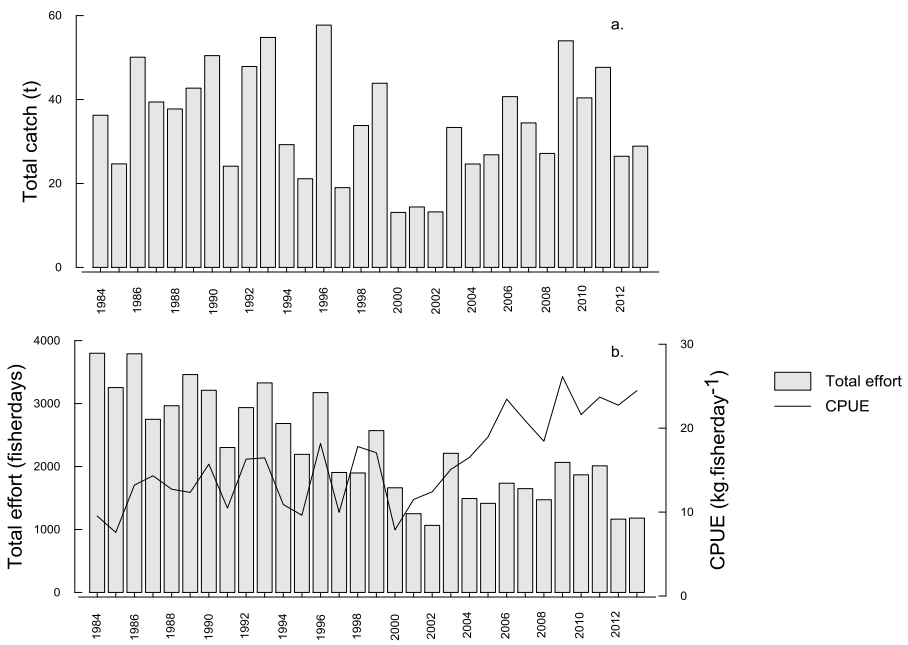

Fig. 3.9. Mid West Coast. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines. b. total effort and CPUE for handlines.

Coffin Bay

As a consequence of a review of the net fishery in 1995 and 1996, Coffin Bay was closed to net fishing in 1996. Since then, the region has supported only a line fishery. As such, only line-based statistics are presented here.

From 1984 to 2000, the handline catch of King George whiting was highly variable but showed no long-term trend (Fig. 3.10a). From 2000 to 2005, it declined to 6 t, but has since recovered to 22 t in 2013. The temporal variation in fishery catches is also reflected in the trends in effort (Fig. 3.10b). There was a considerable decline to 316 fisherdays in 2005, after which it increased to 723 fisherdays in 2013. Handline CPUE has been variable but nevertheless generally increased over time (Fig. 3.10b). However, handline CPUE declined by 25.8% between 1998 and 2002 from 22.9 to 17.0 kg.fisherday^{-1}. It has subsequently increased to >20.0 kg.fisherday^{-1} in 2006, and to >30.0 kg.fisherday^{-1} in 2012 and 2013.

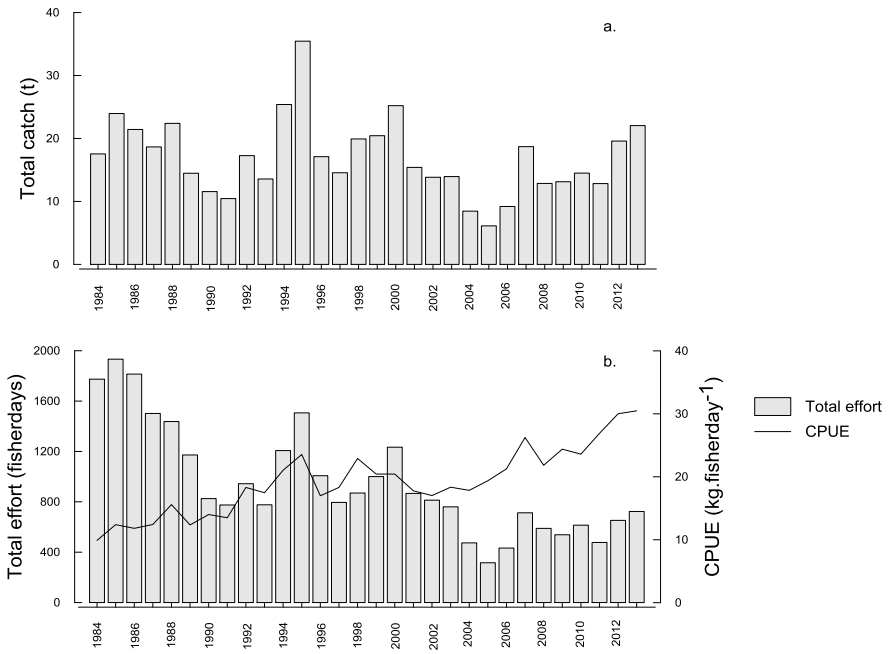

Fig. 3.10. Coffin Bay. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines. b. total effort and CPUE for handlines.

Southern Spencer Gulf

Handlines have always been the dominant gear type in this region followed by hauling nets and gillnets. The gillnet catches fell considerably in 2000 and have remained low, contributing only a few tonnes per year. The hauling net catch was always higher than the gillnet catch before dropping to only a few hundred kg per year as a consequence of the netting closures that were implemented in 2005. Consequently, now only the statistics associated with the handline fishery provide a reasonable indication of the stock status.

Handline catch has been variable over the years with three obvious peaks, one in 1986, the next in 1991 and the third in 1997 (Fig. 3.11a). After that, catches have declined regularly from 131 t to only 57.4 t in 2004, followed by an increase to 76.6 t in 2009. Since then, catch has declined to 48.5 t in 2013. Handline effort was particularly variable in this region between 1984 and 1993 (Fig. 3.11b). From then until 2004, handline effort fell systematically by approximately one half from 7,716 to 3,583 fisherdays. It was then relatively stable from 2004 to 2012, before falling by 20% to 2,761 fisherdays in 2013.

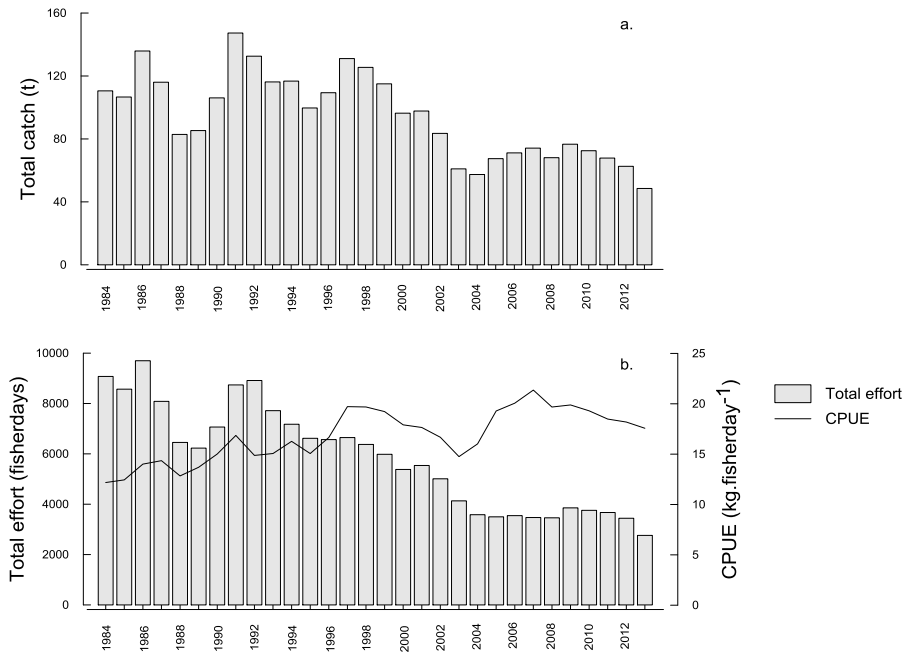

Fig. 3.11. Southern Spencer Gulf. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines. b. total effort and CPUE for handlines.

The estimates of CPUE for handlines between 1984 and 2010 have been highly variable (Fig. 3.11b). Through the period from 1984 to 1997 they increased from 12.2 to 19.7 kg.fisherday^{-1}, but over the following six years declined to 14.8 kg.fisherday^{-1}. Handline CPUE rose again to 21.4 kg.fisherday^{-1} in 2007, but has subsequently declined by 17.8% to 17.6 kg.fisherday^{-1} in 2013.

Northern Spencer Gulf

Hauling nets have consistently been the dominant gear type for catching King George whiting in this region (Fig. 3.12a). Hauling net catch was relatively high and variable until 1997 after which there was a downward trend to 2013, when the catch fell to 9.7 t. Handline catch has also declined considerably since the relatively high catches of the early 1990s, producing the lowest catches from 2010 onwards with the lowest catch on record of 7.2 t in 2013. The decline in handline catch from 1993 onwards is consistent with declining fishing effort, particularly between 1994 and 2001, but also from 2007 to 2011 (Fig. 3.12b). Gillnet catches have declined to minimal levels since 2000 and involved less than five fishers (not presented on Fig. 3.12a).

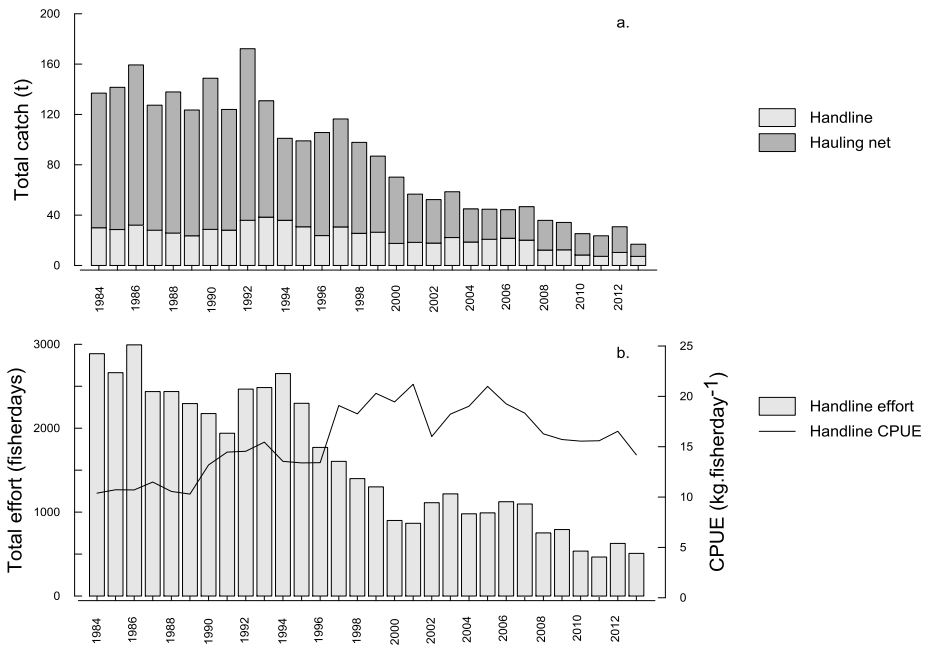

Fig. 3.12. Northern Spencer Gulf. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines and gill nets. b. total effort and CPUE for handlines.

Between 1984 and 2005, CPUE in the handline sector varied in several phases, but nevertheless demonstrated a long-term increasing trend (Fig. 3.12b). CPUE in 1984 was 10.4 kg.fisherday^{-1} and gradually increased to 21.0 kg.fisherday^{-1} in 2005. Since then it has fallen by 32.4% to 14.2 kg.fisherday^{-1} in 2013, the lowest value recorded since 1996.

Both targeted and non-targeted hauling net catches have declined since 1992 (Fig. 3.13a). There have also been continual declines in both targeted and non-targeted effort since 1988 (Fig. 3.13b). Whilst CPUE of targeted effort has slowly declined since 1990, the estimates from the non-targeted categories have been variable but show no long-term trends (Fig. 3.13c).

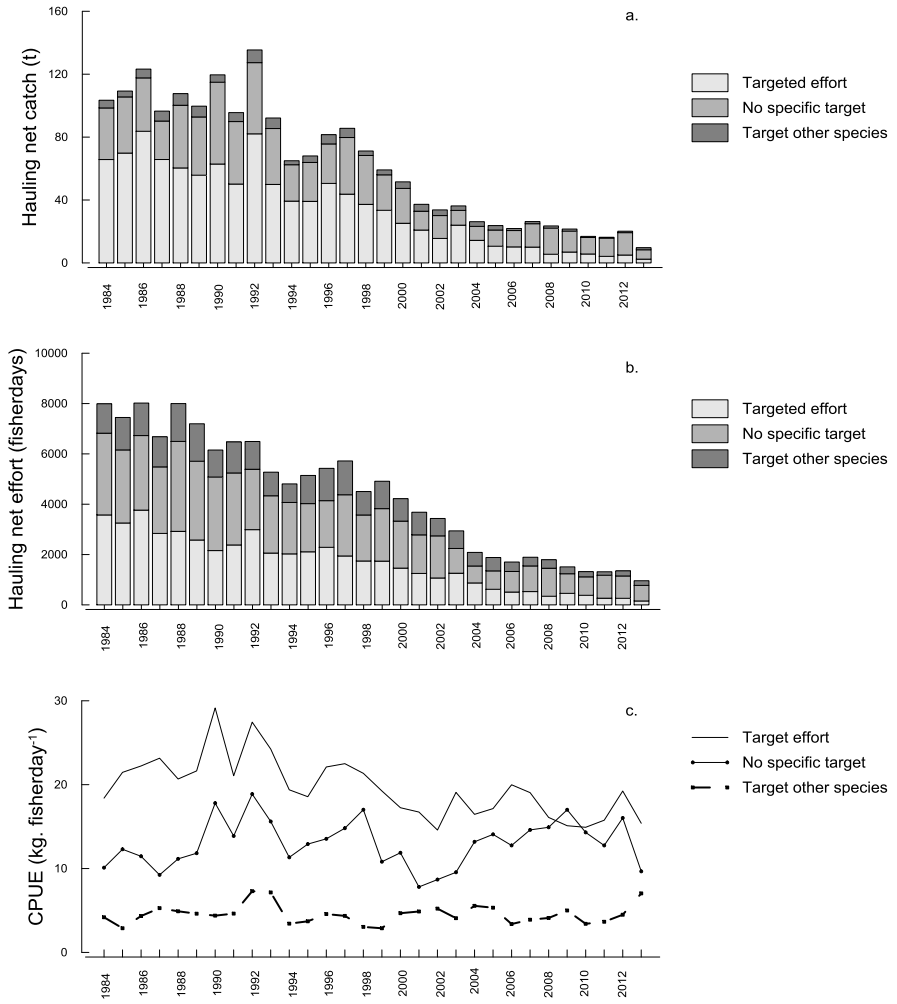

Fig. 3.13. Northern Spencer Gulf. Historical trends in commercial hauling net fishery statistics for King George whiting. a. hauling net catch by effort category. b. hauling net effort by effort category. c.CPUE by effort category.

Gulf St. Vincent

Hauling nets, handlines and gillnets have each contributed substantially to the fishery for King George whiting in Gulf St. Vincent over the years (Fig. 3.14a). Hauling net catch was quite variable from 1984, reached a peak of 37.8 t in 1998. Since then it has declined to only 7.0 t in 2013. Handline catches were highest through the early and mid 1990's but since then demonstrated a long-term systematic decline from 39.2 t to only 9.4 t in 2005. Since then they have recovered marginally to 13 t in 2013. The gillnet catches were also relatively low through 2000-2002, increased in 2003, but then decreased to a minimum level of 2.0 t in 2006. Since then, gillnet catches have remained less than 6 t.yr^{-1}.

Handline effort was quite variable from 1984 until it peaked in 1992, after which it declined to 2005 (Fig. 3.14b). It has remained relatively stable up to 2013. The peak in effort in 1992 was 3,789 fisherdays, decreasing to the minimum of 789 fisherdays in 2005. Gillnet effort has also declined over the same period, particularly between 2001 and 2006, and has remained less than 200 fisherdays.yr^{-1}.

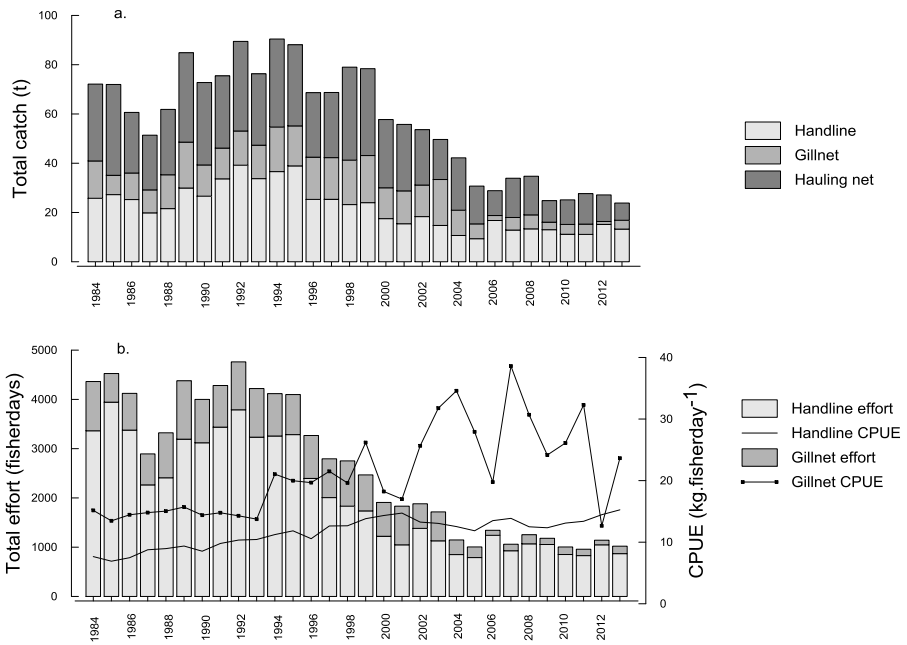

Fig. 3.14. Gulf St. Vincent. Historical trends in commercial fishery statistics for King George whiting. a. total catch by gear type. b. total effort and CPUE for handlines and gill nets.

CPUE in the handline fishery increased consistently from 1984, attained a maximum of 14.7 kg.fisherday^{-1} in 2001 before decreasing annually between 2001 and 2005 (Fig. 3.14b). It has subsequently varied between 12 and 14 kg.fisherday^{-1}. From

2009 onwards, handline CPUE has increased annually to 15.3 kg.fisherday^{-1} in 2013. CPUE for gillnets increased to 26.2 kg.fisherday^{-1} in 1999, but then became highly variable due to the low levels of catch and effort.

Hauling net catch has decreased considerably since 1998 (Figs. 3.14a, 3.15a), primarily reflecting a significant decline in effort directed at 'no specific targeted species' (Fig. 3.15b). The different categories of CPUE in the hauling net sector have generally increased over time, particularly from 2003 to 2007 (Fig. 3.15c). However, estimates of CPUE for the three effort categories have declined over the recent three years.

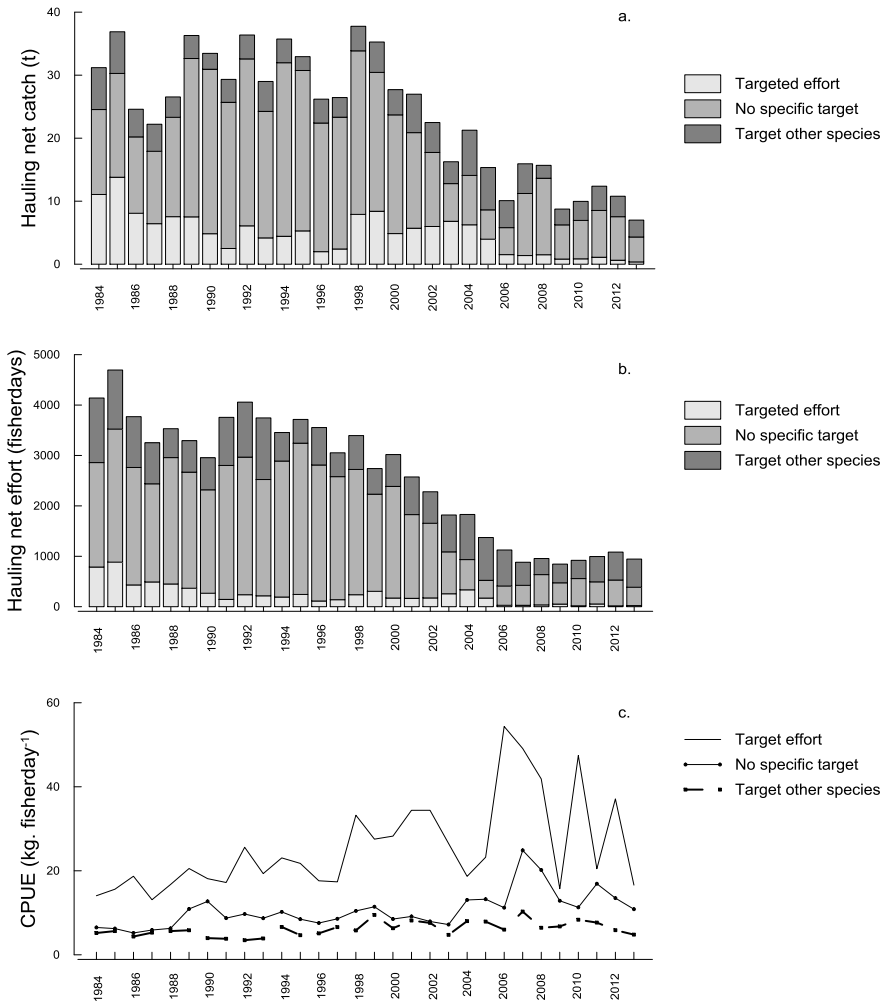

Fig. 3.15. Gulf St. Vincent. Historical trends in commercial hauling net fishery statistics for King George whiting. a. hauling net catch by effort category. b. hauling net effort by effort category. c.CPUE by effort category.

Kangaroo Island

Handlines have been the main gear type in this region since 1984. Handline catches increased from 25.0 t in 1986 to a peak of 47.9 t in 1998, before declining substantially to 27.3 t in 2002 (Fig. 3.16a). After that, the annual catches were relatively consistent until 2010. Through 2011, 2012 and 2013, they have declined annually to the lowest recorded level of 14.1 t in 2013.

Handline effort increased substantially between 1988 and 1992 (Fig. 3.16b). From 1992 to 2002, handline effort fell from 3,861 fisherdays to 1,963 fisherdays. It then remained relatively consistent to 2010, after which it has declined systematically to 1,223 fisherdays in 2013.

CPUE in the handline sector increased moderately through the years to a maximum of 15.5 kg.fisherday^{-1} in 1998 (Fig. 3.16b). After that, it slowly declined to 13.9 kg.fisherday^{-1} in 2002, but subsequently increased to 17.4 kg.fisherday^{-1} in 2007, the highest ever recorded. From then, CPUE decreased by 36.2% to the low level of 11.1 kg.fisherday^{-1} in 2012 before recovering marginally to 11.5 kg.fisherday^{-1} in 2013.

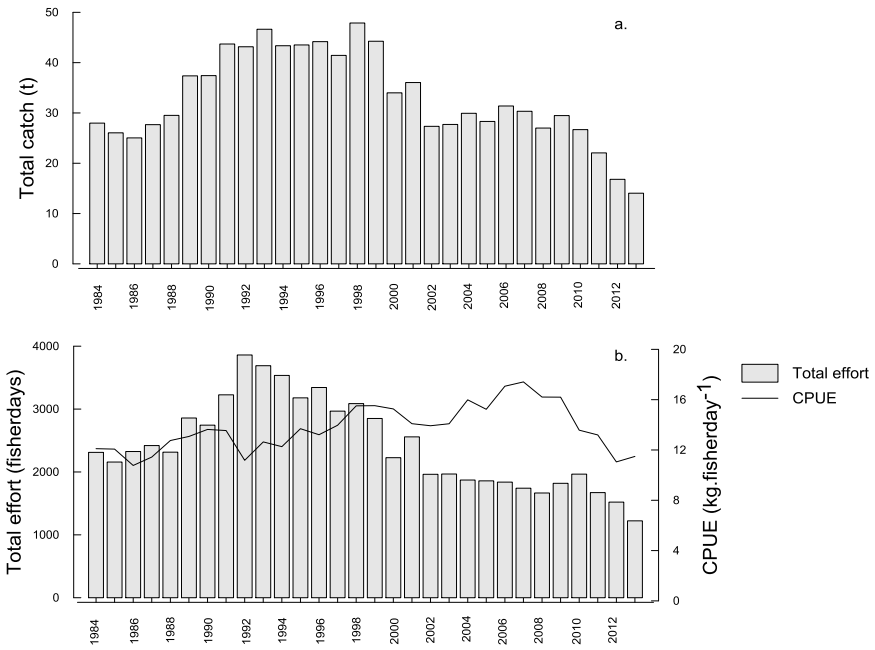

Fig. 3.16 Kangaroo Island. Historical trends in commercial fishery statistics for King George whiting. a. total catch by handlines. b. total effort and CPUE for handlines.

3.4. Discussion

The commercial fishery statistics for King George whiting were considered here at three spatial scales, i.e. State-wide, stock and regional scales. At the former scale, the statistics demonstrated some strong temporal trends that largely reflected significant changes in the structure of the fishery. Since 1984, the State-wide catch of King George whiting has dropped considerably. This reflects a gradual decline from 1992 to 1999, a significant drop in 2000, followed by further gradual decline to 2013. These reflected substantial reductions in handline and gillnet catches since 1999 and a gradual decline in hauling net catch since 1992. Such reductions reflect substantial declines in commercial fishing effort. Both targeted handline and gillnet fishing effort have fallen considerably since 1992. It is more problematic to determine levels of targeted hauling net effort, nevertheless since 1984 there has been a substantial reduction in the number of net endorsements that has culminated in a decline in the total number of hauling net fishing days (Fowler 2005), suggesting the likelihood that targeted hauling net fishing effort on King George whiting has also declined. The State-wide estimates of CPUE for handlines and gillnets have generally increased since 1984 but nevertheless demonstrated considerable declines during the early 2000s. Since 2002, the State-wide estimates of handline and gillnet CPUE have increased. The recovery for handline CPUE was quite slow but increased to the highest on record in 2013.

The analysis of commercial fishery statistics at the scale of the three stocks identified some consistencies and some differences amongst them. The dominant consistency was the decline in handline fishing effort over time. There was some variation amongst stocks in the timing and extent of these declines. For the two gulfs the declines were most dramatic between 1992 and the early 2000s, whilst for the West Coast the decline was from 1984 onwards. In each case, they reflect declining trends in the numbers of fishers taking and targeting King George whiting. For each stock, there were also associated declining catches over time, although the reductions were proportionally greater for the gulf stocks than for the WC stock. The trends in CPUE were also similar amongst stocks, at least until relatively recently. Each stock shows a long-term increasing trend that is interrupted, to some extent, by reductions in the rates of increase through the early to mid 1990s and again from around 1999 to 2002. However, these stock-wide trends in CPUE then diverged from 2007 onwards. Whilst that for the WC stock continued to increase attaining a record level by 2013, those

from SG and GSV/KI declined from 2007 onwards. These different trends imply different trajectories for the fishable biomass of the different stocks.

The analysis of trends in fishery statistics at the regional scale provided opportunity to assess for spatial consistency within each of the three stocks. Of the three regions of the WC, the MWC and CB experienced proportionally more variable fishing effort than did the FWC that resulted in more variable catches. Nevertheless, the three regions displayed similar trends in CPUE, particularly with respect to the record high levels attained in recent years. Such results are consistent with relatively high levels of fishable biomass in these recent years. For the SG stock, both SSG and NSG have experienced declining handline catches and catch rates since at least 2007. These consistent recent trends between NSG and SSG suggest declining levels of biomass in the two regions. There was less similarity in the recent trends between GSV and KI. For KI, handline catch and CPUE declined significantly between 2007 and 2013, providing a strong indicator of fishery status. For GSV, handline catch has been relatively stable since 2009, whilst handline CPUE has increased marginally over the same time period. In contrast, both the hauling net catch and CPUE for GSV have declined over the same period. The latter trends provide ambiguous temporal trends in fishable biomass for the GSV regional population.

4. POPULATION STRUCTURE

4.1. Introduction

Populations of fish that are subjected to fishing pressure normally experience some degree of truncation of their age and size distributions as a consequence of the removal of the larger, older individuals by the fishery. This can have considerable population-level effects by influencing egg production, and ultimately recruitment success (Longhurst 1998, Francis 2003, Berkeley et al. 2004). As such, population structure can be an important indicator of the status of a fishery. Nevertheless, its assessment as an indicator depends on having a good understanding of how the population structure naturally varies amongst different places, as a consequence of the life history of the species.

The characteristics of the populations of King George whiting throughout South Australia's coastal waters have been determined at different times, revealing a complex interaction between population structure and life history. King George whiting are not distributed evenly with respect to size and age (Fowler 1998, Fowler et al. 2000a, Fowler and McGarvey 2000). Catches from throughout Gulf St. Vincent, northern Spencer Gulf and bays of the west coast of Eyre Peninsula generally involve relatively small fish from the 3+ age class. Alternatively, fish sampled from Investigator Strait along the northern coast of Kangaroo Island and from south eastern Spencer Gulf involve much broader size and age ranges that consist of multiple year classes of fish that are up to 20 years of age. These latter populations occur in deeper waters in more exposed places.

Tag/recapture studies have revealed that the populations on the spawning grounds that involve the larger, older King George whiting are replenished by migration from the northern gulfs (Fowler et al. 2002, Fowler and Jones 2008). Thus, fish movement constitutes an important obligative process that closes the life history cycle between the nursery areas and spawning grounds. The older, larger fish found in the deeper, offshore places constitute the spawning populations (Fowler et al. 1999). As such, spawning by this species does not occur generally throughout all of South Australia's coastal waters, but rather is restricted to particular locations or spawning grounds. Given that there is an obvious geographic separation between the spawning grounds and nursery areas, the eggs and larvae must be advected to the nursery areas. As such, it is likely that the larger, older fish in the spawning populations make substantial

contributions to egg production. Therefore, the age structures of these populations may be important indicators of egg production.

The studies on population structure of King George whiting that were done between 1995 and 1998 identified both the spatial dispersion patterns with respect to size and age, as well as the locations of the spawning grounds (Fowler et al. 1999, Fowler and McGarvey 2000, Fowler et al. 2002). Sampling done between 2001 and 2004 focussed on the age structures of the populations on the spawning grounds, which may have been important indicators of egg production. In each case, these two historic sampling programs depended on samples that were accessed from both the commercial and recreational fishing sectors. In 2006, a new sampling protocol for King George whiting was initiated, which was based on sampling the commercial catches. So far this focussed market-sampling has been done for King George whiting throughout five financial years, i.e. 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13. The aim of this chapter is to present the results from this sampling and provide a qualitative comparison with data collected from similar regions in the past that have been published elsewhere (Fowler and McGarvey 2000, Fowler et al. 2000a).

4.2. Methods

The market sampling was primarily done at the SAFCOL fish market in Adelaide, which receives commercial catches of King George whiting from the regional areas. Generally once per week a team of three researchers processed samples of King George whiting prior to the morning auction at this wholesale market. Catches were selected from those available on the market floor to ensure as broad a geographic coverage as possible. This regular sampling was augmented by occasional sampling trips to Kangaroo Island and the west coast of Eyre Peninsula to access local catches. A two-stage sampling protocol was used in processing the individual catches. First, a relatively large number of fish were measured to obtain size information for the catch, from which a random sub-sample of fish was taken for further biological analysis. Back in the laboratory, the latter fish were measured for total length (TL) and weighed individually, sexed and stage of reproductive development determined. They were then dissected for the removal of the sagittae, i.e. the largest pair of otoliths, for ageing. 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 glass microscope slide and its structure was interpreted using low power microscopy by counting the opaque zones. Each count was then interpreted to provide an

estimate of fish age (Fowler and Short 1998). For each region, an age/length key was developed to convert the sample proportions by length into proportions by age. In this way, population size and age structures were produced for each region. For this work, the State's coastal waters were divided into a number of regions for which the data on population structure were presented. In general, these regions corresponded to those that were considered for the analysis of both the commercial and recreational fishery statistics (Figs. 3.1), with the primary difference being the division of the waters of Gulf St. Vincent, Investigator Strait and Kangaroo Island. Throughout this broad region, the data were grouped and presented for three areas: Northern Gulf St. Vincent (MPAs 34, 35, 36); Kangaroo Island bays (MFA 42); and the remaining waters of Investigator Strait and Kangaroo Island (MFAs 39, 40, 41, 44, 48, 49).

4.3. Results

Far West Coast (MFAs 7, 8, 9, 10)

Across the five years, >10,000 fish captured from the bays of the Far West Coast (FWC) were measured (Fig. 4.1). The resulting size distributions were characterised by medium-sized fish that were generally <40 cm TL, although with a few large fish between 40 and 52 cm TL. The modal sizes were 32 – 34 cm TL. The age structures consisted of the 2+ to 5+ age classes. They were dominated by the 3+ age class in 2006/07, 2009/10 and 2012/13, whilst the 2+ age class was most apparent in 2008/09 and 2011/12. The sampling trips in these latter years were done largely in March and April, prior to the nominated birthday of 1st May. As such, it is unlikely that the nominal differences in age structures between years reflected population truncation.

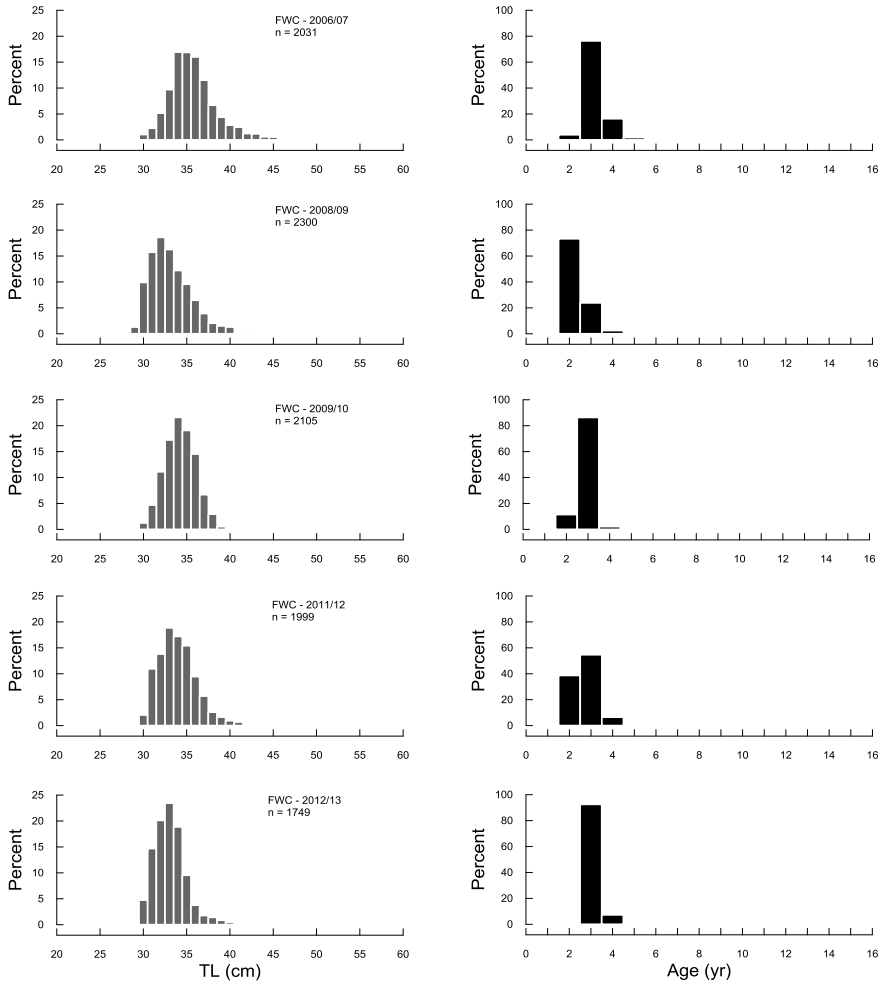

Fig. 4.1 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from Far West Coast of Eyre Peninsula.

Mid West Coast (MFAs 15, 16, 17, 18)

The sizes of King George whiting captured from the bays of the Mid West Coast (MWC) have always generally been relatively small, i.e. <34 cm TL (Fowler and McGarvey 2000). This was the case for the five years sampled between 2006/07 to 2012/13 during which the modal sizes were from 30 to 32 cm TL (Fig. 4.2). There were also occasional incidental catches of big fish of up to 58 cm TL taken from these bays in some years. The age structures generally involved the 2+ to 4+ age classes and were dominated by the 3+ age class that accounted for 90% or more of the catches. The exceptions were in 2008/09 and 2011/12 when the 2+ age class dominated, which reflected the timing of the sampling trips to this region.

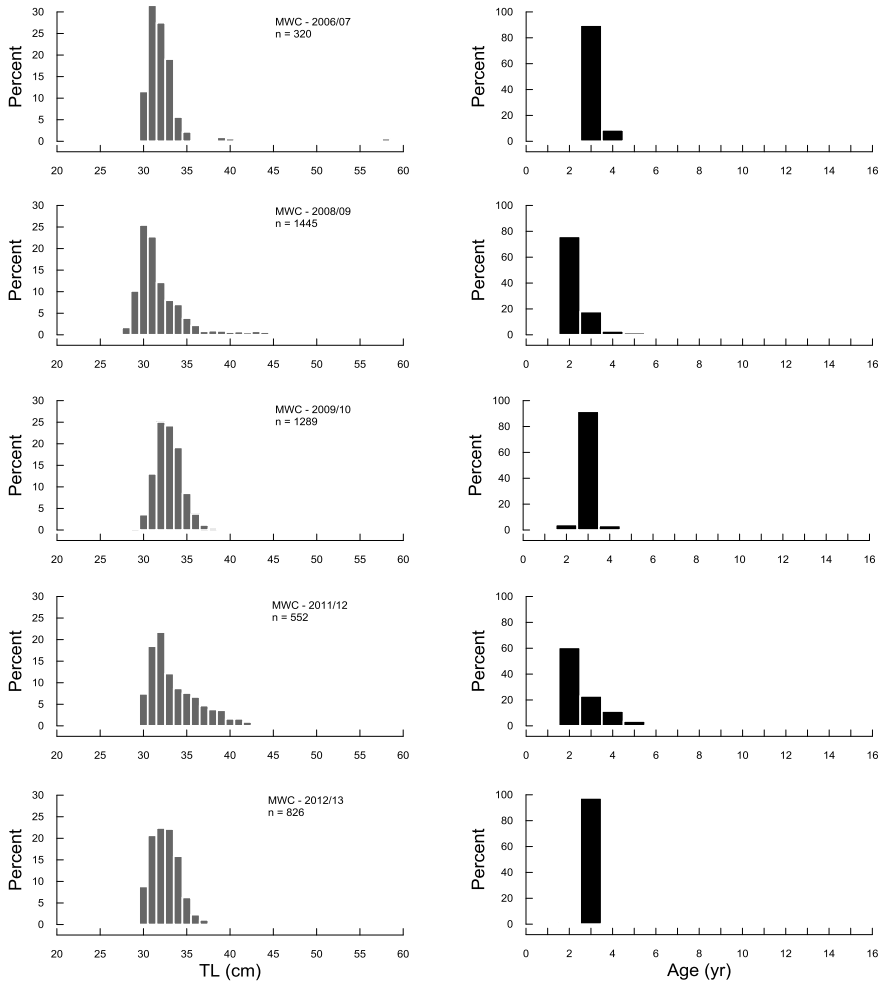

Fig. 4.2 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from the Mid West Coast of Eyre Peninsula.

Coffin Bay (MFA 27, 28)

More than 5,000 fish captured in Coffin Bay (CB) between 2006/07 and 2012/13 were measured for development of size structures. The size structures were relatively consistent between years, being skewed to the right as they were dominated by small fish with relatively low numbers of larger fish (Fig. 4.3). Only a few fish >40 cm TL were measured from this region in each year. The age distributions also were consistent from year to year being dominated by the 3+ age class that generally accounted for >60% of the fish aged in each year. The 4+ age class accounted for the majority of the remaining fish with occasional fish captured from the 2+ and 5+ age classes.

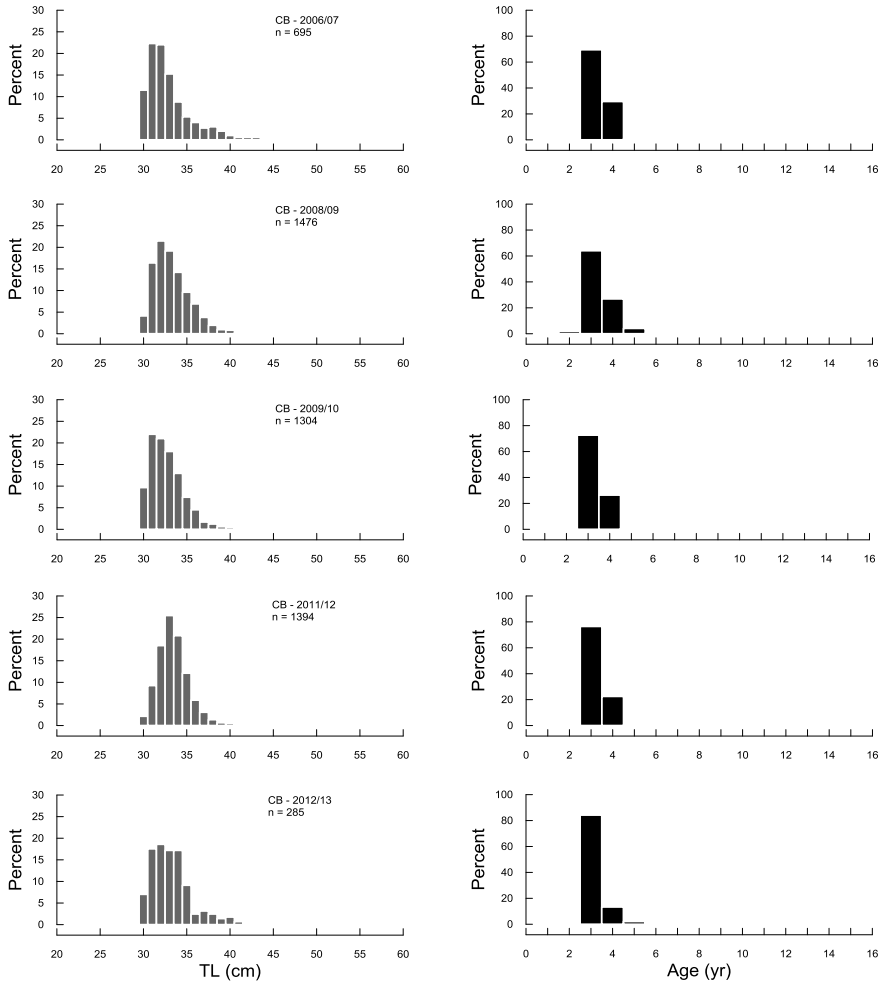

Fig. 4.3 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from Coffin Bay, southern Eyre Peninsula.

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

Approximately 20,000 fish captured from Northern Spencer Gulf (NSG) between 2006/07 and 2012/13 were measured for development of size structures. The resulting size structures were consistent between years, being skewed to the right as they were dominated by small fish with decreasing numbers of larger fish (Fig. 4.4). Relatively few fish >40 cm TL were captured from this region. The modal size classes were generally 33 or 34 cm TL. The age distributions also were consistent from year to year being dominated by the 3+ age class that generally accounted for >70% of the fish aged in each year. The 2+ and 4+ age classes accounted for the majority of the remainder with a few fish from the 5+ and 6+ age classes also captured.

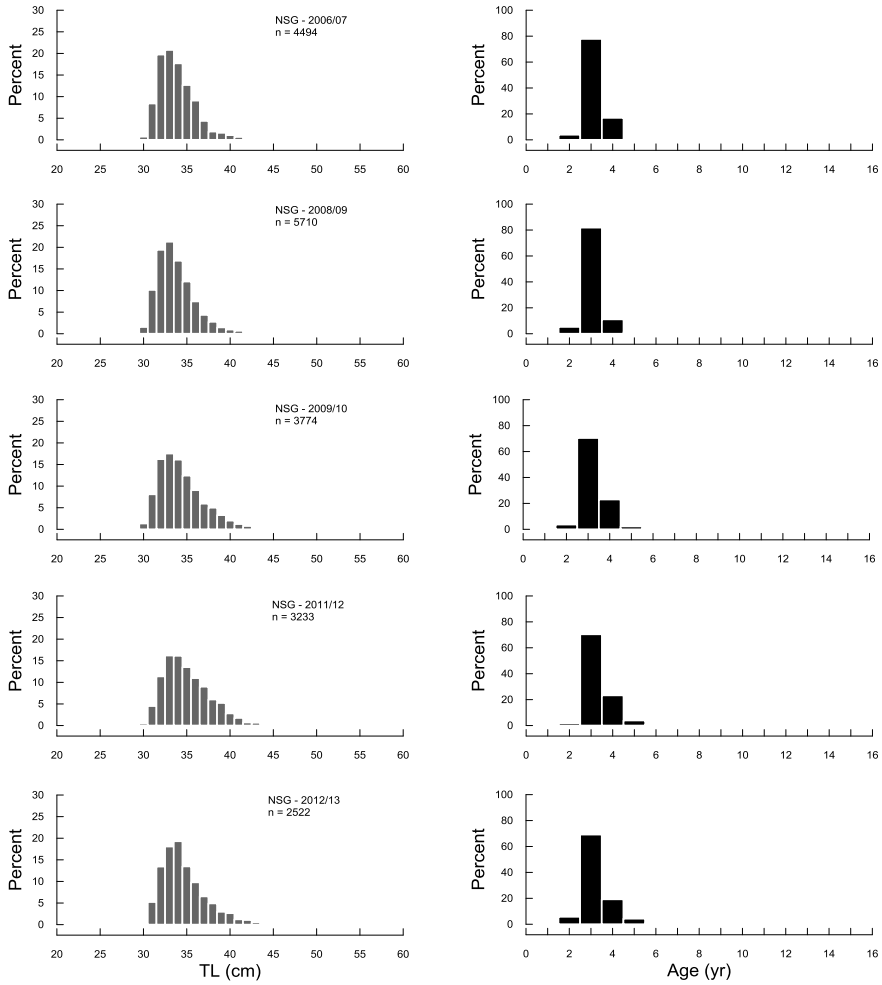

Fig. 4.4 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from Northern Spencer Gulf.

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

Greater than 14,000 fish captured from Southern Spencer Gulf were measured. Although the size distributions were skewed to the right, due to the small and decreasing numbers in the larger size classes of up to 52 cm TL, the fish were generally larger than those captured in NSG (Fig. 4.5). The modal sizes were between 35 and 37 cm TL in the five sample years. Up to 20% of the fish measured in every year were 40 cm or larger. The age distributions were consistent between years and dominated by the 3+ and 4+ age classes, whilst the older age classes of 5+ to 15+ age classes were more numerous than in the other regions. The oldest fish aged in each year was 10+ years or more, with the oldest of 15+ years in 2011/12.

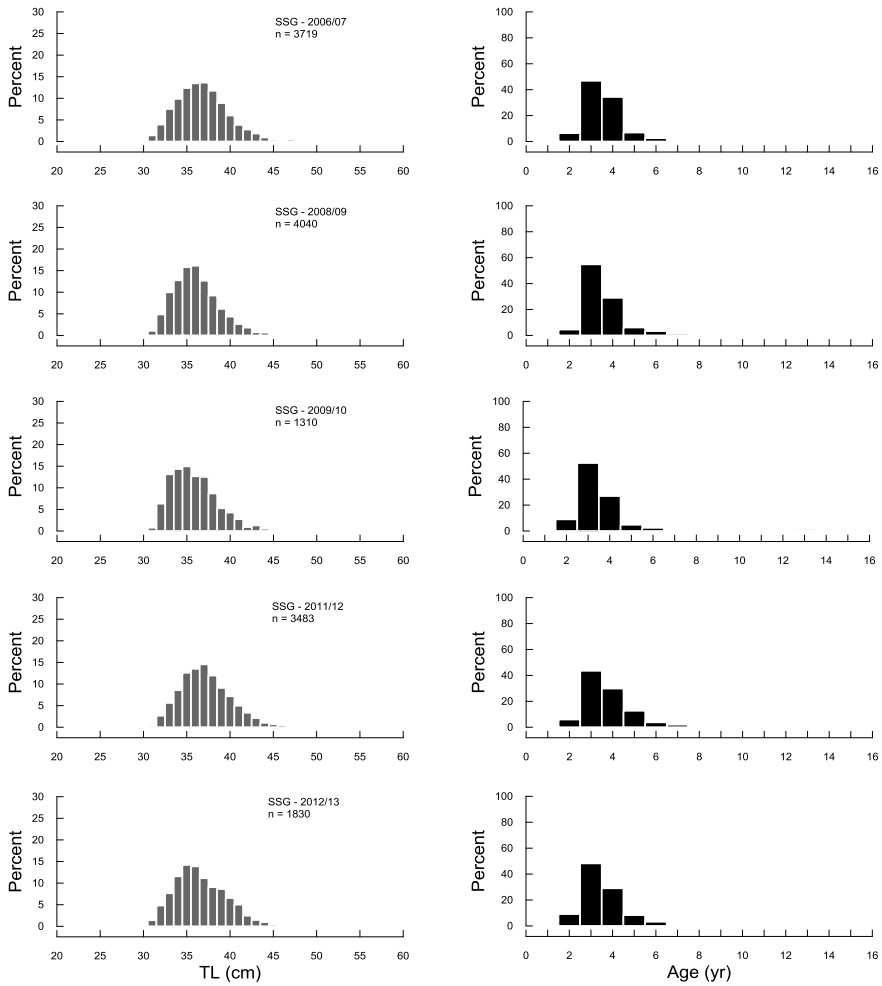

Fig. 4.5 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from Southern Spencer Gulf.

Gulf St Vincent (MFAs 34, 35, 36)

Nearly 10,000 fish were sampled from northern Gulf St. Vincent, primarily from MFAs 34 and 35. The resulting annual size distributions were dominated by small-medium fish, i.e. <40 cm TL, with a small number of fish up to 52 cm TL also captured (Fig. 4.6). The modal sizes varied between 32 and 35 cm TL across the three years. The age structures were consistently dominated by the 3+ age class whilst the remaining fish were largely from the 2+ and 4+ age classes, although with occasional representation from the 5+ to 10+ age classes.

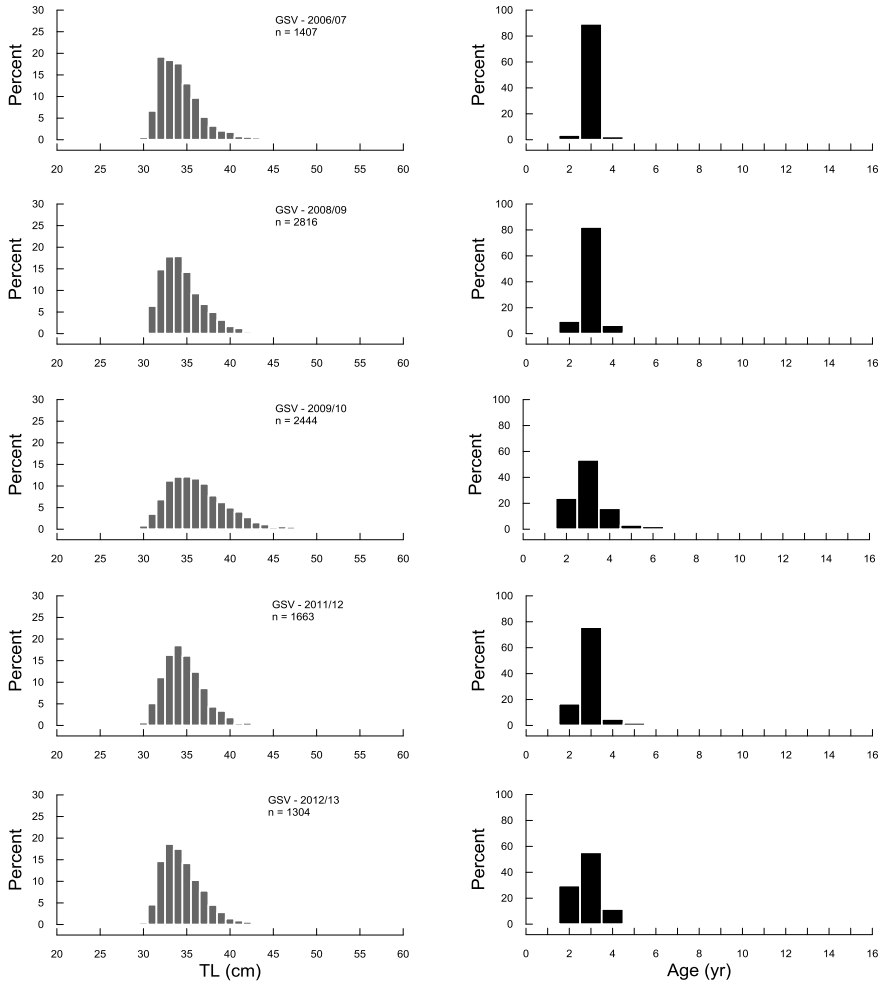

Fig. 4.6 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09 and 2009/10 from Gulf St. Vincent.

Kangaroo Island (MFA 42)

MFA 42 (refer Fig. 3.1) was considered independently from the other MFAs in this region because it includes the inshore, shallow bays of Kangaroo Island, which have traditionally provided large numbers of relatively small King George whiting to the local fishery, probably reflecting that its coastal margins constitute an important nursery area. Nevertheless, the fish sampled from this MFA between 2006/07 and 2009/10 reflected relatively complex size structures (Fig. 4.7). Those for 2006/07 and 2008/09 reflected the influence of several modes of small and relatively large fish. This probably relates to the small fish being captured in the bays in relatively shallow water whilst the larger ones were captured further offshore. Each size distribution is skewed to the right and includes relatively high contributions from fish in the high 30s and 40s cm TL. The age structures were also relatively complex. Although dominated by the 3+ age class they also involved considerable numbers of 4+ and 5+ fish, and small contributions from the 6+ to 14+ age classes.

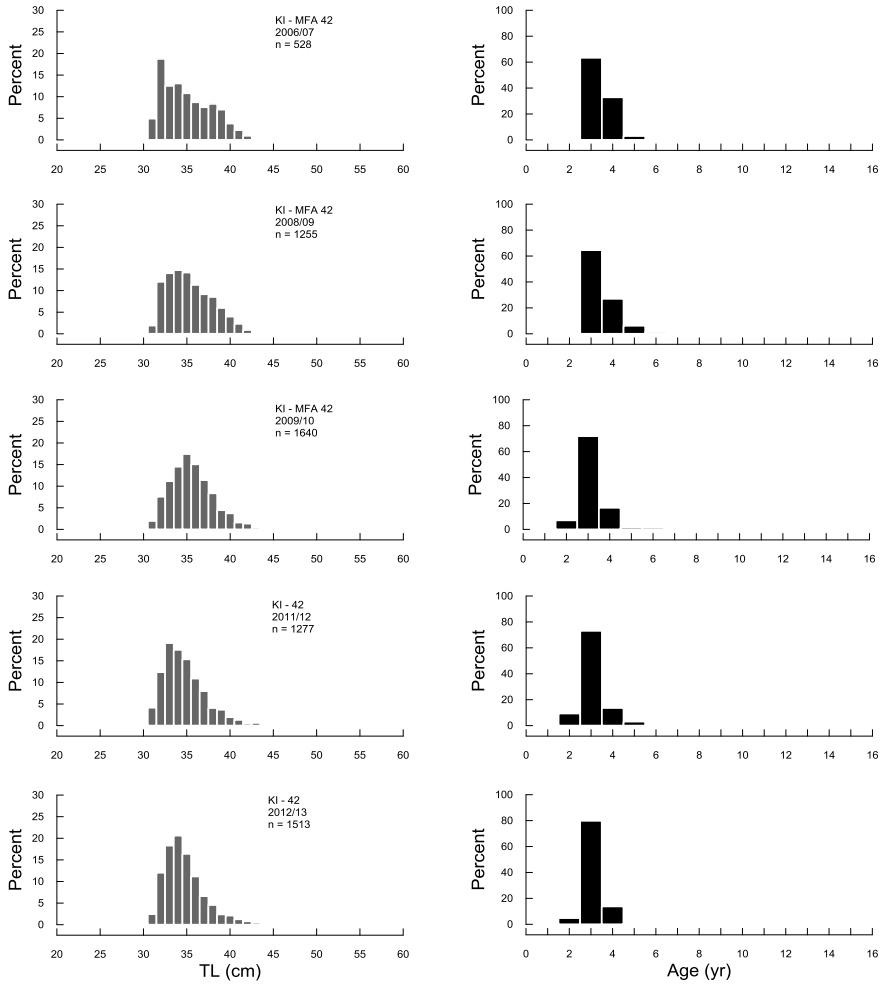

Fig. 4.7 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from MFA 42 in Investigator Strait.

Kangaroo Island / Investigator Strait (MFAs 39, 40, 41, 43, 44, 48, 49)

Although the remaining area of southern Gulf St. Vincent, Investigator Strait and Kangaroo Island included numerous MFAs, the samples considered for this region primarily came from MFAs 40 and 41 (Fig. 3.1). Approximately 2,000 fish were measured from across the five years, from which size structures were developed. The annual size distributions were broader than for the other regions as 19 to 29% of fish measured were in the 40 – 50 cm TL size classes (Fig. 4.8), with the modal sizes of 35 to 37 cm TL in each year. Whilst the 3+ and 4+ age classes dominated numerically, the age structures were complicated and skewed to the right. The oldest fish aged in each year was at least 10+ years, with a 17+ age class fish captured in 2011/12.

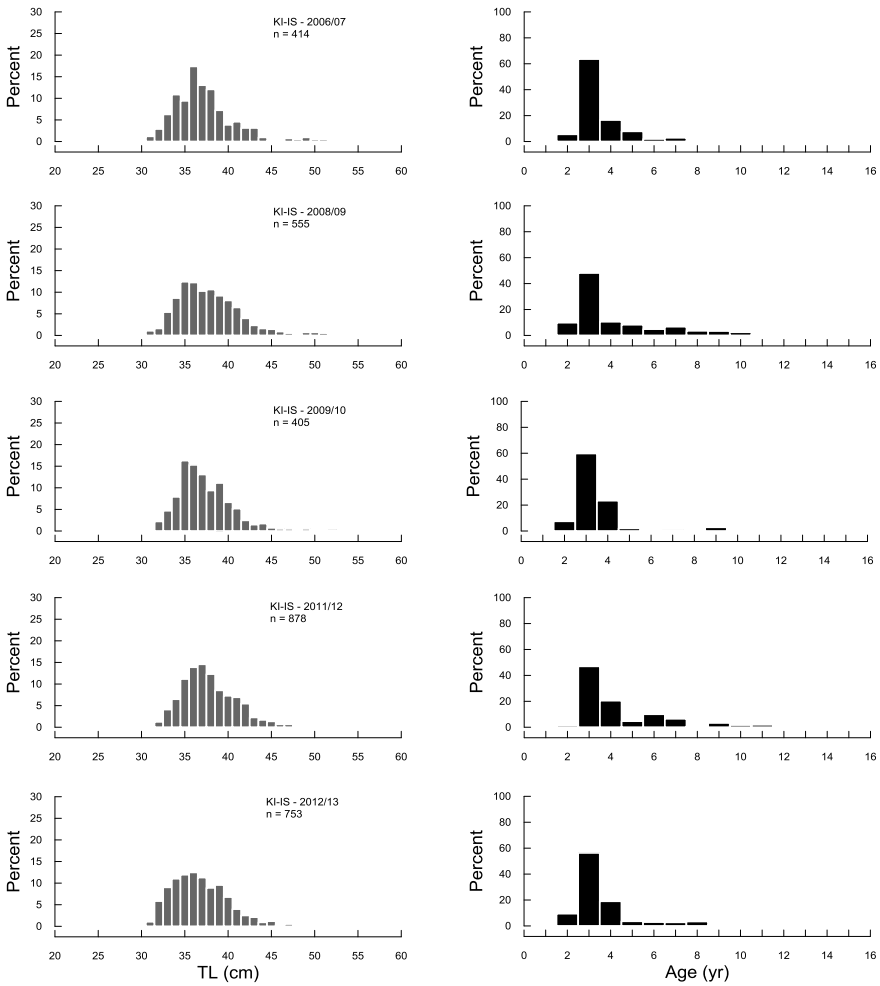

Fig. 4.8 Age and size structures of samples of King George whiting collected in 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 from Kangaroo Island / Investigator Strait.

4.4. Discussion

Earlier sampling-based studies have documented the size and age structures of populations of King George whiting captured from throughout South Australia's coastal waters and have consistently demonstrated that there are considerable differences in population structure at different locations (Fowler and McGarvey 2000, Fowler et al. 2000a). Furthermore, these differences relate to the reproductive biology of the species that result in a complex relationship between habitat, population structure and reproductive maturity and activity (Fowler et al. 2000a). Fish located in shallow, inshore areas adjacent to nursery areas tend to be relatively small, young and immature. Alternatively, fish located in deeper water associated with off-shore reefs, shoals or large mounds in exposed locations that experience medium to high wave energy tend to support populations with broader size and age structures. Furthermore, these are the places where reproductive maturation takes place, and thereby represent the spawning grounds. Such populations can involve fish up to approximately 20 years of age, which means that in any year there are numerous age classes in the populations.

One intention of considering population age structures in a fishery context is to determine whether there is evidence of a reduction in the number of age or size classes in the population as a consequence of the fishing activity. This occurs because fishing tends to remove the largest, oldest individuals from fish populations and thereby reduces the number of age classes in such populations (Berkeley et al. 2004).

Since age-based sampling commenced in the 1990s in a number of the regions considered here (FWC, MWC, NSG and GSV), the populations have been characterised by relatively small, young fish that have been primarily dominated by the 3+ year class (Fowler and McGarvey 2000, Fowler et al. 2000a, 2005). Such fish recruit to the fishery as fast-growing 2+ or later as 3+ fish. They are fished relatively heavily in this gauntlet fishery, whilst their numbers are also depleted as the fish emigrate southwards in the gulfs or leave the bays of the west coast (Fowler et al. 2002). Since these populations primarily consist of a single year class, it would be difficult to detect truncation of their age structures. In fact, in contrast, there are some indications that older fish in the 5+ and 6+ age classes are now more evident in these northern regions.

The fish that emigrate as 3+ individuals from the northern gulfs move to the spawning populations that are located in the deeper waters of SGSV, SSG or Investigator Strait that support multiple age classes of up to 20 years of age (Fowler et al. 2002). So far, the size and age structures of these populations have been monitored through several research programs from 1996 to 1998, from 2001 to 2004 and most recently from 2006/07 to 2012/13. By comparing the results between sampling regimes during these periods for the different regions, it is apparent that the age structures still support relatively old fish. The 6+ to 10+ age classes have been relatively abundant in SSG and Investigator Strait over time, whilst in 2011/12, SSG still had some fish that were in the 15+ age class whilst Investigator Strait supported fish that were in the 17+ age class. Overall, these results provide no evidence that any obvious truncation of population size and age structures has occurred either between 2006/07 and 2012/13 or over the longer term between the 1990s and 2000s, as a consequence of fishing activity.

5. MODEL ESTIMATION OF BIOLOGICAL PERFORMANCE INDICATORS

5.1. Introduction

For King George whiting in South Australia the primary management objective remains to ensure sustainability of the fishery. To facilitate this, a fishery stock assessment model, WhitEst, was developed in an FRDC-funded project (Fowler and McGarvey 2000). This is a dynamic, spatial, age- and length-structured model that integrates data from 1984 to the most recent complete calendar year of 2013 to provide estimates of biological performance indicators of the status of the fishery.

A spatial breakdown with a monthly time step allows the model to account for seasonal movement and exploitation levels that vary seasonally and in space. The model divides the fishery into six spatial cells, five of which contribute most of the catch, i.e. the West Coast, and northern and southern regions of the two gulfs. Negligible King George whiting catch is reported from the sixth cell which is located offshore (Fig. 5.1). The model takes into account annual summer migration rates from inshore nursery areas in the northern gulfs to the spawning regions in the southern gulfs and to offshore WC grounds. Exploitation rates are higher in the upper gulfs and inshore waters where King George whiting typically mature and reach legal size prior to migration.

5.2. Methods

The data sources that inform the maximum likelihood estimation of model parameters in WhitEst are: (1) monthly totals for catch (kg) and effort (fisherdays); (2) market samples of the commercial catch giving proportions by age and sex in different spatial cells for most months through the four sampling periods of September 1994 to June 1997, July 2004 to June 2007, July 2008 to December 2010, and October 2011 to September 2013; (3) information on movement by King George whiting in the two South Australian gulfs, based on results from tag-recapture studies undertaken in the 1960s, 1970s, and 1980s (Jones et al. 1990, Fowler et al. 2002). Migration rates from the northern to southern gulf regions are estimated with other parameters in the overall model likelihood (McGarvey and Feenstra 2002). WhitEst uses a partition of model fish numbers by length within each age group, dividing the gaussian length distribution of each yearly cohort into length bins called ‘slices’. A new slice of fish is

created in each monthly time step, a slice being defined as the fish that grow across the legal minimum length into legal size each month. The growth of each cohort, as mean and standard deviation of length-at-age at each monthly age, estimated from the age-length samples while accounting for the sharp cut-off in samples below legal minimum length (McGarvey and Fowler 2002), is used as input to the slice-partition sub-model. This slice-partition framework (McGarvey et al. 2007) quantifies the on-going monthly arrival of each cohort into the legally harvestable size range, with faster growth observed during the months of late summer and autumn of each year. This annual arrival via growth of each cohort to legal size is an important aspect of the fishery dynamics of this stock, as it attracts a large shift of fishing effort to these newly legal-size fish each winter, with commercial effort often peaking in July. The slice-partition method separates these heavily-exploited, legal-sized fish from sub-legal fish, and keeps account of the changing numbers of legal fish by both age and length. The fits of the assessment model to age and sex proportions from catch sampling are plotted in Figs. 9.4 and 9.5.

The model is fitted to monthly catches, conditional upon the effort in fisher days required to take each catch (Fig. 9.1). Commercial catch and effort data are analysed and modelled separately for the four gear types (handline, hauling net, gillnet, and all other gears combined) and three target types (targeting King George whiting, targeting any other species, and not targeting any species in particular), as reported in monthly commercial catch returns.

Recreational catch and effort estimates by month and spatial cell used in WhitEst are taken from the two recent telephone-diary surveys done in 2000/01 and 2007/08 (Fowler et al. 2011). Each survey covered one full year, providing estimates of monthly recreational catches, both charter and non-charter. To fit the assessment model to recreational catch data, the procedure was modified this year to reduce the importance of assumptions about how the recreational sector's catch and effort varied outside the two 12-month survey time periods. Monthly recreational efforts prior to the 2000/01 survey were interpolated backward in time in yearly proportion to South Australian population size (Fig. 5.2). No interpolation was undertaken for years after the second survey, the monthly catches from the second 12-month survey (2007/08), by spatial cell, assigned to equal those for all subsequent model years (Fig. 5.2). Between the two surveys, catch and effort numbers were interpolated assuming they vary linearly between the levels estimated by the two surveys, by spatial cell (Fig. 5.2). This year, to improve the fits of survey and charter boat logbook reported catches, a

large number of additional recreational catchability parameters were added by month and spatial cell. This had the effect of permitting very close fits to recreational catch (Fig. 9.2) while also down-weighting the relative influence of recreational catch rates on estimated stock size, allowing the model estimates of biomass to more strongly respond to the principal biomass trend information from commercial catch rates, notably from handlines (Fig. 9.3).

Catch logbook data from the charter boat sector are now included in the model. In July 2007, charter operators began reporting their catches, in numbers of fish landed, and their effort, as numbers of anglers aboard each trip and hours of fishing. This provides high-quality information about this component of the recreational harvest. A new effort type was created in the WhitEst model to fit to these monthly catch and effort charter data, beginning in November 2007, the first month of the most recent recreational survey. Because catch from charter boats was included in the two recreational surveys of 2000/01 and 2007/08, for model years prior to 2007, charter catches were fitted as part of overall recreational survey data. However, the recreational surveys are not precise. For the year 2007/08 when two estimates of charter catch are available, a direct measure of the reliability of the survey estimate is obtainable by comparing it with the more reliable reported totals, by spatial cell, from charter logbooks. In Fig. 5.2, the survey-estimated charter catches are given as the difference of the red cross-hatched bars from the top of the green bars, the latter showing the estimated survey catches with charter excluded (Fig. 5.2, years 2008-2010). The charter logbook catches are given as the height of the light blue bars. The much larger size of the blue bars imply that the survey greatly underestimated charter catches in 2007/08 in SGSV and SSG. Charter catches in WhitEst from November 2007 onward are now fitted separately and modelled using the census (total) logbook data of reported monthly charter catch (in numbers of fish landed) and effort (in angler hours).

The model estimates three principal biological performance indicators; recruitment, legal-size population biomass, and exploitation rate. Biomass and exploitation rate are given as monthly model estimates, and also as yearly averages. Yearly biomass is computed as the mean of monthly model biomass estimates in each calendar year. Exploitation rate (also known as harvest fraction) is the fraction of biomass harvested yearly. For King George whiting, the yearly exploitation rate is calculated as the sum across all gear and target types of monthly model catches in each calendar year divided by the (year average) legal biomass. Recruitment for each yearly cohort is

estimated in the model as numbers of approximately 2 year olds. In the recruitment time series graphs, the year shown on the X-axis is the year each cohort has fully entered the fishable stock and is principally targeted in the fishery as 3 year olds.

Because of the increasing importance of the recreational sector in this fishery, the catches by sector, by year, for the three main regions are presented in Fig. 5.3. These are model-estimated catches for both sectors. One clear trend is the declining levels of commercial catches in the two gulfs (see also Chapter 3). The large increase in recreational take estimated for Gulf St. Vincent in 2008 reflects higher recreational estimates from the 2007/08 survey, and the inclusion of charter logbooks as an additional data source (Fig. 5.2).

Further details of WhitEst are included in the FRDC final report (Fowler and McGarvey 2000). The model was externally reviewed by Dr André Punt (University of Washington, Seattle, USA).

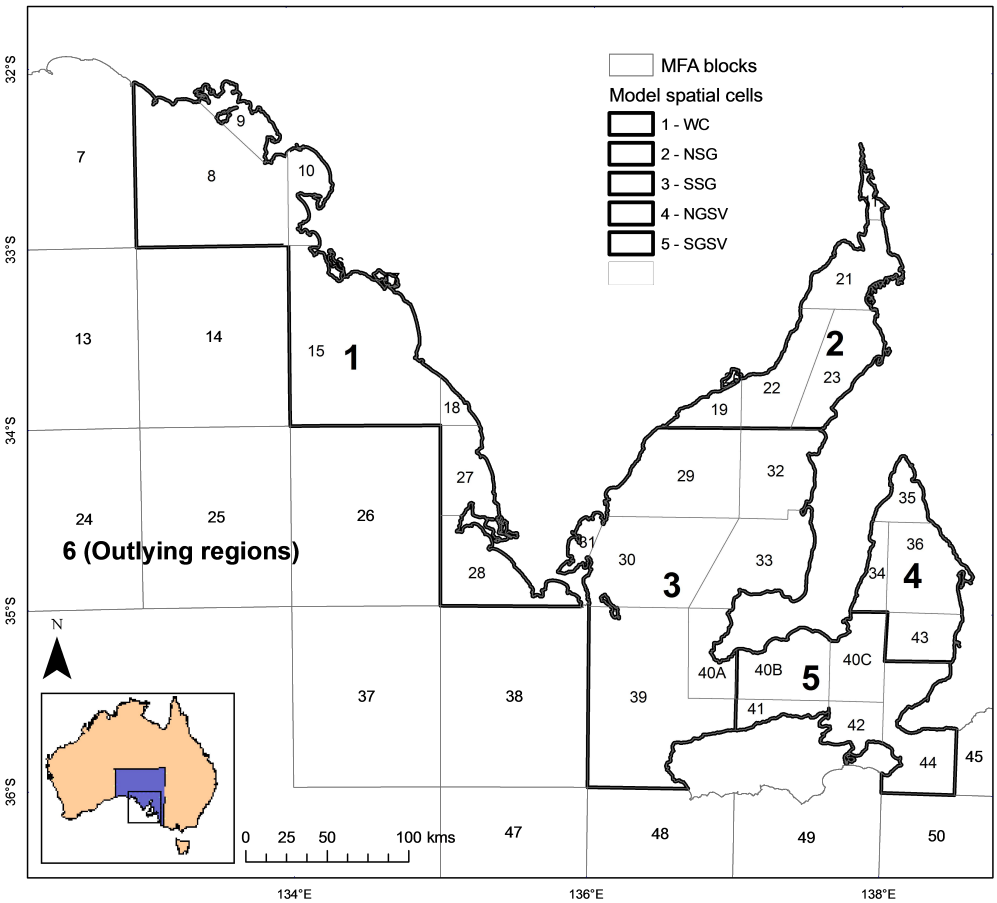

Fig. 5.1 Map of South Australia showing the six spatial cells used in the WhitEst model, identifying the Marine Fishing Areas of which they are comprised.

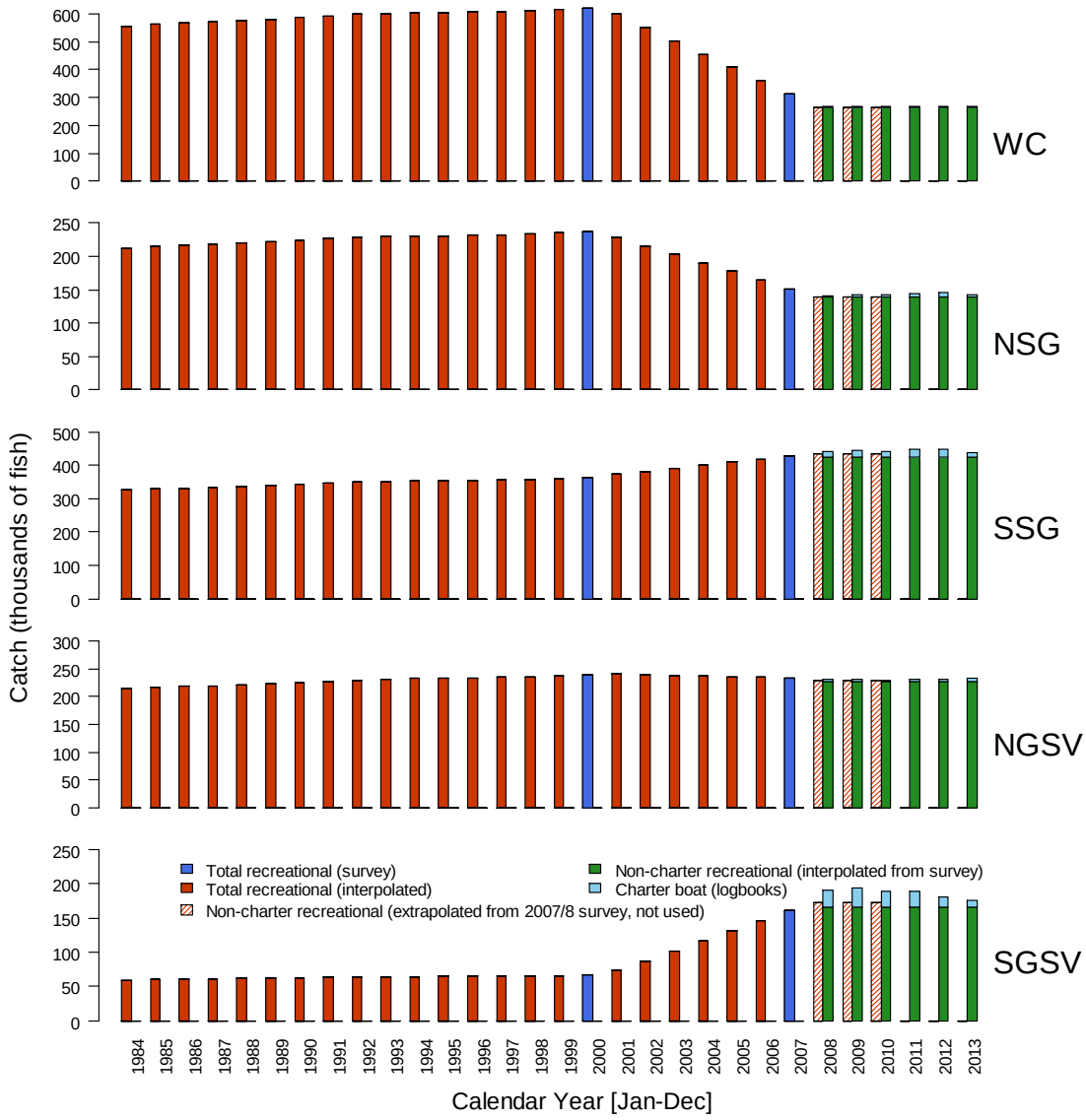

Fig. 5.2. Model input data for recreational catch, in estimated numbers of fish landed, by year and spatial cell. Telephone and diary surveys giving monthly estimates of recreational catch and effort for all recreational fishing, including charter boats, were held in 2000/01 and 2007/08. A second data source, from charter logbooks, gives the reported numbers landed by charter boats shown as light blue bars. The red, blue, light blue, and green catches were used in the model. Actual recreational data are shown for survey (dark blue) or charter logbooks (light blue). The cross-hatched red bars show what the 2007/08 survey estimates for total recreational catch in 2008-2010. For how these permit a direct comparison of survey and logbooks charter catches in 2007/08, see Methods of Section 5.2, p. 49.

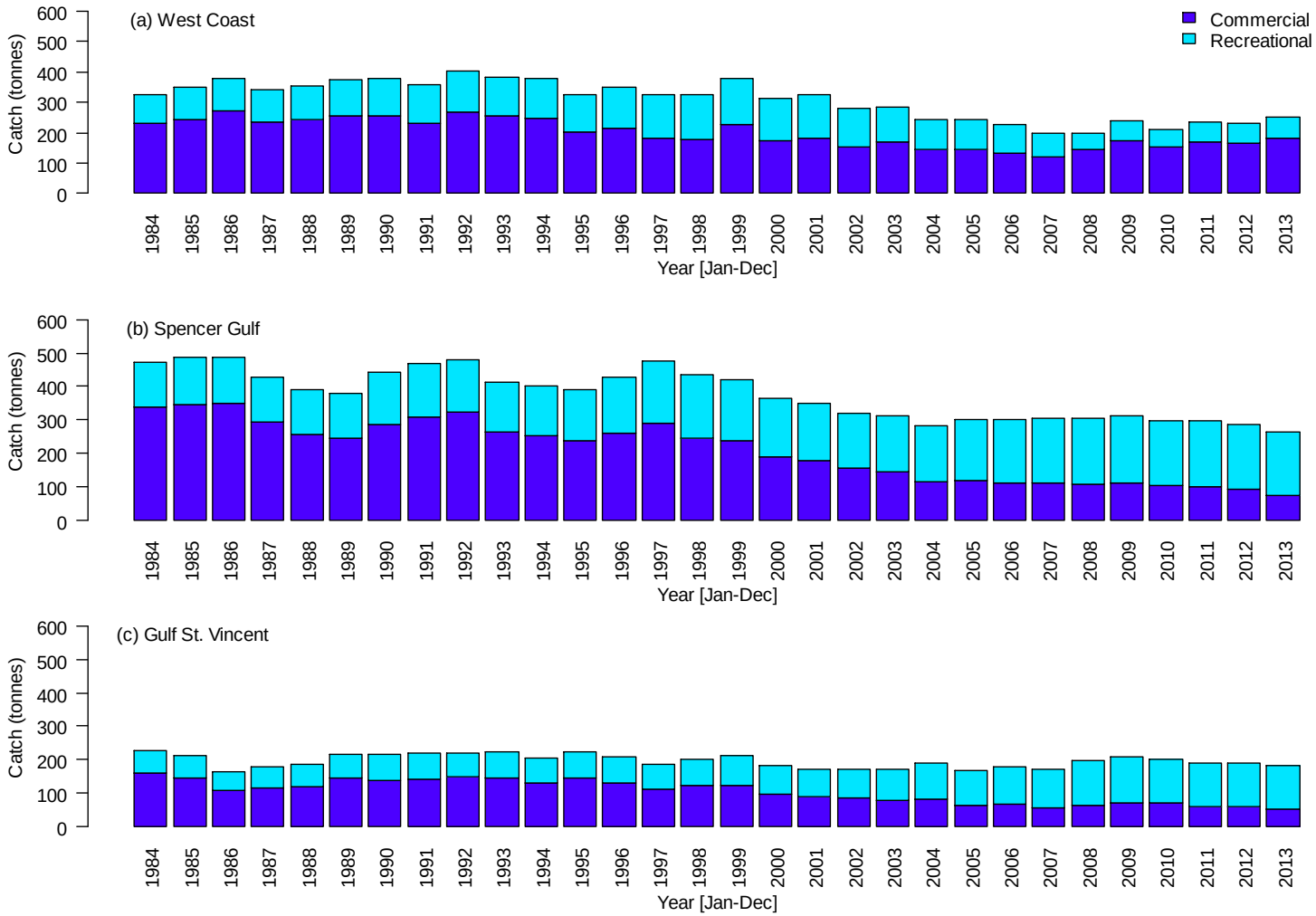

Fig. 5.3. Model estimated catches of King George whiting, in landed weight, by commercial and (total) recreational fishing.

5.3. Results

Trends in State-wide estimates of output parameters

The time-series of State-wide estimates of model output parameters are presented in Fig. 5.4. From 1984 onwards, the model-estimated values for recruitment and fishable biomass varied over cycles that involve a number years, but have also shown consistent increasing trends over time. As such, the estimated values in 2013 for both variables were close to the highest ever. In contrast, State-wide, model-estimated exploitation rates have shown a steady and substantial decline over a number of decades to the minimum value estimated for 2013.

Trends in stock-wide estimates of output parameters

The trends in output parameters for the three model stocks of WC, SG and GSV/KI differed considerably (Fig. 5.5). Recruitment has always been higher for the WC, while the estimates for this stock have increased considerably since 2002 (Fig. 5.5a). Recruitment levels were estimated to be considerably lower in the two gulfs. For SG, they were marginally higher than for GSV/KI. Also, for SG, there was a period of declining recruitment from the high value for 1997 until 2004, followed by another strong year class in 2005, and then another period of declining recruitment to 2013. Model-estimated recruitment has been relatively consistent in GSV/KI, but has declined marginally to 2013 from the high values estimated for 2008 and 2009.

The trends in model-estimated fishable biomass largely reflect the trends in recruitment (Fig. 5.5b). The WC supports the highest levels of biomass amongst the three stocks. Whilst estimated biomass for this stock fell between 1999 and 2004, it has subsequently increased considerably to the highest estimated level in 2013. Clearly, the results for this stock have driven the State-wide estimates of biomass (Fig. 5.4b). This is because the estimates of fishable biomass for both SG and GSV/KI are substantially lower.

There are also differences amongst stocks in the trends in exploitation rate (Fig. 5.5c). Exploitation rate has always been lower for the WC than for the two gulf stocks. Furthermore, it has declined from 1984 to 2008, and subsequently remained consistently low. Exploitation rate has always been higher in SG than for the WC, and has declined considerably over the same period of decline. For GSV, exploitation rate showed a slowly decreasing trend until 2006, before increasing significantly in 2008 and subsequently remaining high.

The time-series of output parameters for the two gulf stocks are further divided spatially in Fig. 5.6, which shows the model outputs for the northern and southern regions of each stock. The declining recent trends in recruitment and biomass from 2008 onwards are evident for both NSG and SSG. Furthermore, the lower recruitment and biomass from 2010 to 2013, relative to 2008 and 2009, are evident for both NGSV and SGSV. Similarly large estimated increases in exploitation rate from 2007 are evident for NGSV and exploitation rate remains at a high level in SGSV.

Monthly estimates of biomass and also commercial exploitation rates show significant seasonal variation for the three stocks (Fig. 5.7). Recreational exploitation is also seasonal, with a different temporal pattern to that of the commercial sector (Fig. 5.7).

5.4. Discussion

The model estimates of output parameters were considered at several spatial and temporal scales. At the State-wide spatial scale, the estimates of fishable biomass increased considerably after the downturn between 1999 and 2002. This reflected the combination of increasing recruitment rates and declining exploitation. The latter reflected declining commercial fishing effort and numbers of licence holders, as discussed in Chapter 3. Nevertheless, consideration of the model outputs at the stock level indicates that the State-wide trends were significantly influenced by those from the WC. The model outputs for this stock indicated that it has always supported the highest fishable biomass of the three stocks. Furthermore, fishable biomass for this stock has experienced a significant increasing trend through the 2000s that reflected increasing levels of recruitment as well as long-term declining exploitation rate. The declining exploitation is a consequence of commercial fishing effort having declined by >50% since 1984.

The trends in output parameters were very different for the SG and GSV/KI stocks compared to the WC stock. For both these stocks, estimated recruitment demonstrated marginal declines, at least over the most recent four years. Furthermore, estimated biomass had trended downwards since 2008, although from relatively low levels. Exploitation rates for both gulf stocks were higher than for the WC, particularly for GSV. The increase in exploitation rate for GSV/KI between 2007 and 2008 relates to the increase in recreational catch and effort recorded for the GSV/KI stock between the recreational surveys in 2000/01 and 2007/08 (Fowler et al.

2011). Given that this sector accounted for >60% of the total catch from this stock (Fig. 5.3), it indicates the dominant influence that the recreational sector has on exploitation rates of King George whiting in the two gulfs .

There are currently only two temporal data points for estimates of recreational catch and effort from the recreational sector, i.e. for 2000/01 and 2007/08 (Fowler et al. 2011). A conservative approach was used in applying WhitEst in 2013 to estimate recreational fishery statistics for the other years between 1984 and 2013 to downplay their influence. Nevertheless, the reality is that the recent trends in recreational statistics are unknown, which impacts on the extent to which the model outputs can depict reality. As such, despite the significance of recreational catch and effort for King George whiting, the lack of reliable catch and effort data for this sector remains the principal data gap in the modelling and assessment for this species. A third State-wide, telephone-diary recreational survey is currently underway in South Australia, which will help to determine the recent trends in the spatial and temporal aspects of recreational activity. Nevertheless, the most reliable information on catch and effort for King George whiting in South Australia comes from the commercial sector.

There was seasonal variation in the estimates of biomass of King George whiting for the three stocks. This species is most abundant in late summer, autumn and early winter subsequent to the late summer and early autumn season of fastest growth when each age-3 cohort predominantly recruits to harvestable size. Seasonal peaks in commercial catch occur in mid-winter, when effort is principally targeted on this newly recruited year class of 3-year-olds. In the two gulfs, the commercial exploitation rates lagged behind the seasonal trend in biomass by several months. The model estimates that the catchability of age-3 fish is more than twice that of other age classes, which is consistent with this seasonal variation, whereby commercial effort increases during winter to target the enhanced biomass of the newly recruited age-3 cohort. Recreational exploitation is also seasonal, with spikes evident in the months of school holidays.

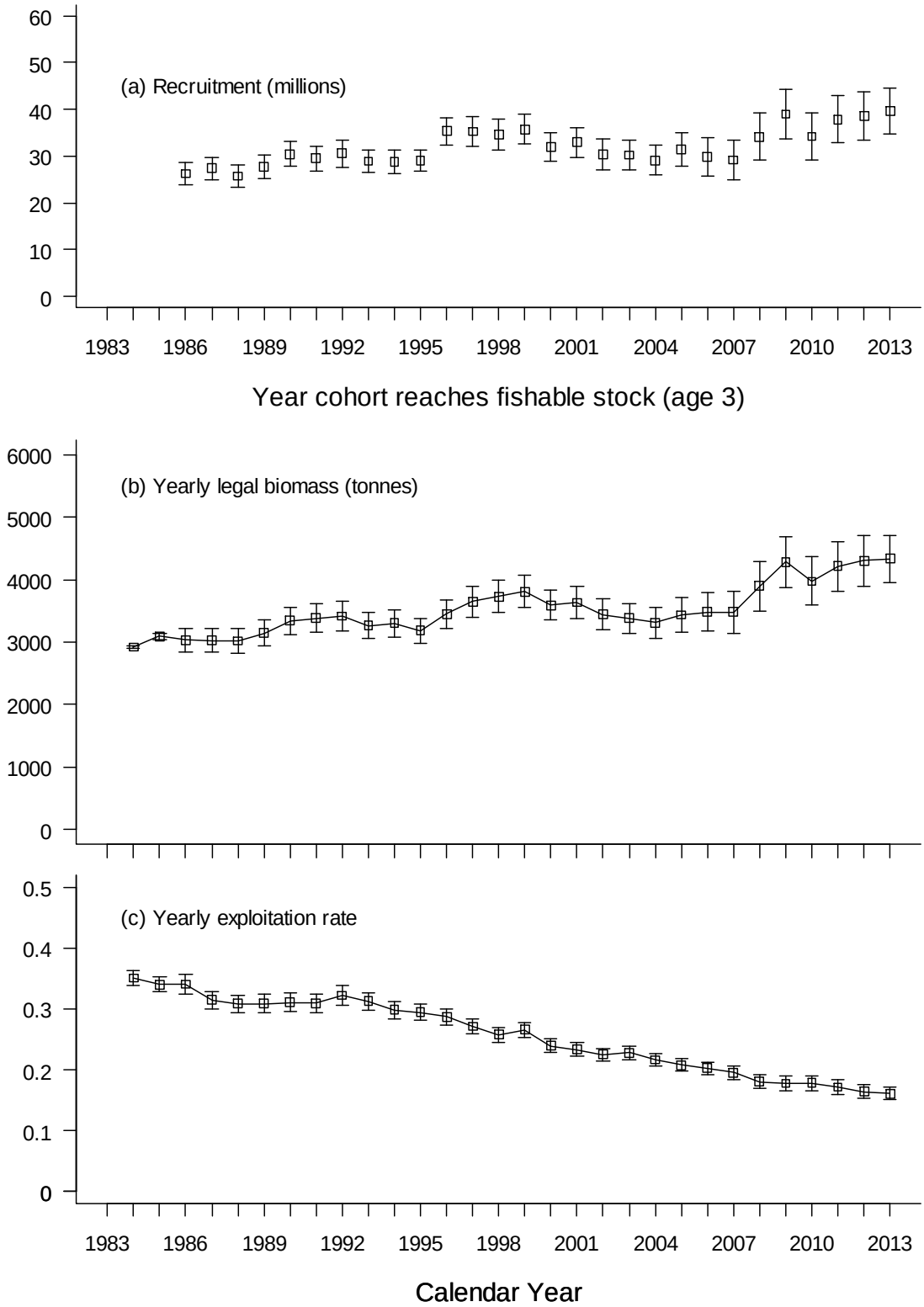

Fig. 5.4 Yearly State-wide (excluding spatial cell 6) model biological indicators 1984-2013 for South Australian King George whiting: (a) yearly recruit numbers, (b) legal biomass averaged over the 12 months of each calendar year, and (c) harvest fraction as the yearly model-estimated catch divided by the yearly average legal biomass. These performance indicators were estimated by the spatial dynamic stock assessment model (WhitEst). Error bars show 95% model estimate confidence intervals.

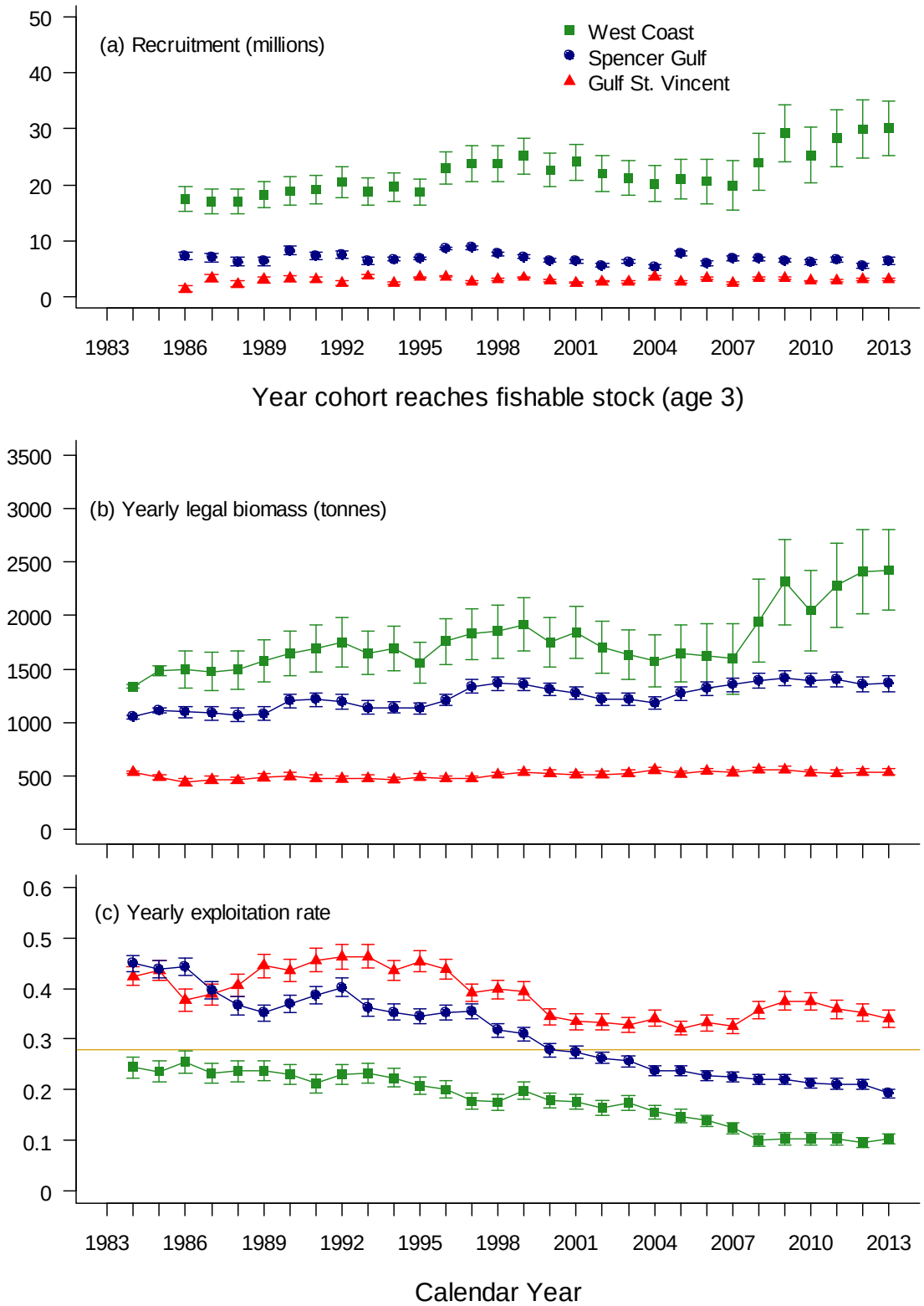

Fig. 5.5 Yearly model biological indicators 1984-2013 by stock. Stocks are the West Coast (including Far and Mid West Coast, and Coffin Bay, spatial cell 1 shown in Fig. 5.1), Spencer Gulf (spatial cells 2 and 3), and Gulf St. Vincent/ Kangaroo Island (spatial cells 4 and 5). Error bars show 95% confidence intervals. The yellow horizontal line in (c) shows the 28% upper bound target reference point for exploitation rate.

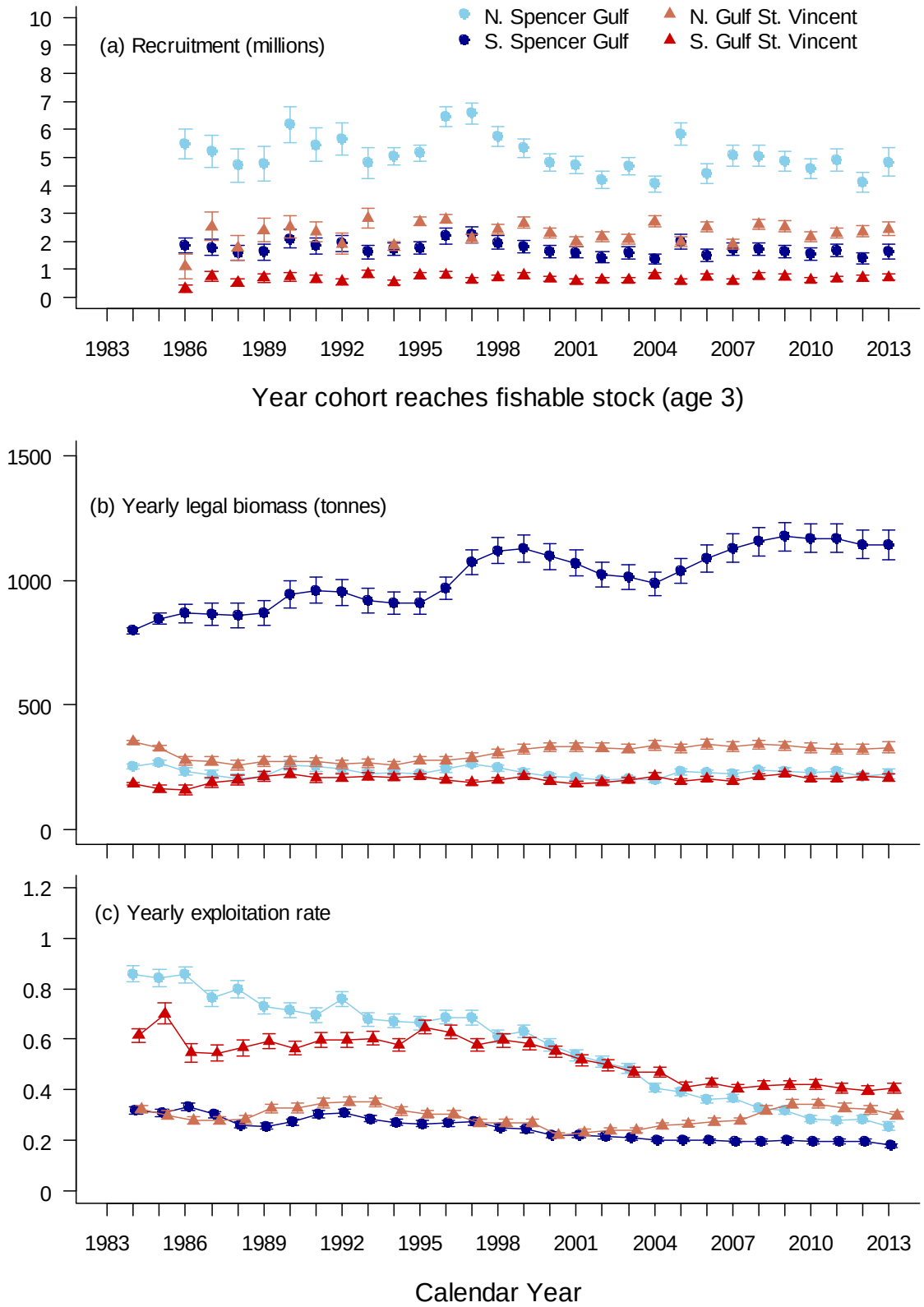

Fig. 5.6 Yearly model biological indicators 1984-2013 by region within the two gulfs. Error bars show 95% confidence intervals.

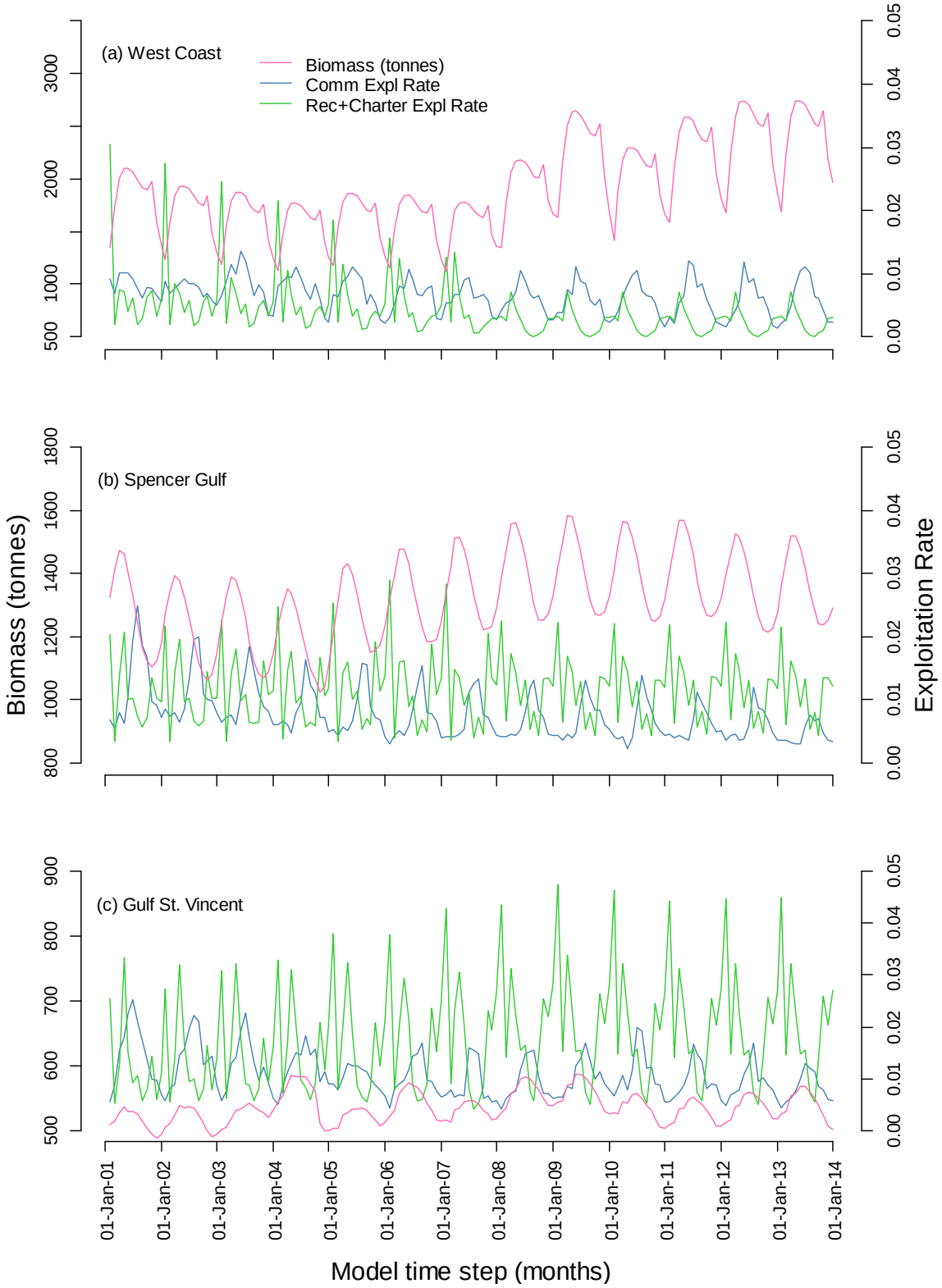

Fig. 5.7 Monthly estimates of fishable biomass and exploitation rate (here, as monthly proportion removed) by the recreational and commercial sectors from 2001 to 2013 for the three stocks of West Coast, Spencer Gulf and Gulf St Vincent/Kangaroo Island.

6. ASSESSMENT OF FISHERY PERFORMANCE INDICATORS

6.1. Introduction

The Management Plan for the commercial sector of the Marine Scalefish Fishery (PIRSA 2013) includes a harvest strategy for the King George whiting fishery, which outlines the processes for monitoring and assessment of the performance of the fishery, thereby providing a pointer to the effectiveness of current management arrangements. The harvest strategy specifies: the operational objectives for the management of the fishery; the performance indicators; and the trigger reference points against which the indicators are assessed. The aim of this chapter is to assess the status of South Australia's King George whiting fishery by considering the two operational objectives:

1. ensure the long-term sustainable harvest of King George whiting;
2. maintain catches within agreed allocations for each sector.

In order to address the first operational objective, two sets of fishery performance indicators have been established, i.e. 'general' and 'biological' (Table 6.1 based on Tables 21 and 22 and Appendix 4 in PIRSA 2013). The former are based entirely on commercial fishery statistics whilst the latter are based on output from the computer fishery model 'WhitEst', as well as population age structures from market sampling. The harvest strategy also re-categorises these 'general' and 'biological' indicators into 'primary' and 'secondary' ones (Table 6.1). The primary indicators are considered the most significant determinants of fishery performance, whilst the secondary ones are considered less reliable as indicators of fishery status but nevertheless augment the primary indicators in a weight of evidence approach (PIRSA 2013).

With respect to addressing the second operational objective, the share allocated to a particular sector is that to which it had access at the time the Minister requested the Fisheries Council prepare the Management Plan, based on the most recent information available (PIRSA 2013). For the Marine Scalefish Fishery, the most recent data were those from 2007/08, i.e. the year when the last recreational survey was done (Jones 2009). In the current assessment, the recent catches of the different fisheries that comprise the commercial sector were compared against their allocations that are specified in the Management Plan (PIRSA 2013).

6.2. Methods

General Fishery Performance Indicators

In order to address the first operational objective regarding the long-term sustainability of the King George whiting fishery, both the 'general' and 'biological' performance indicators were assessed at two spatial scales. These scales were; State-wide and for the three stocks for which the fishery statistics were summarised in Chapter 3. The general fishery performance indicators considered here were; total catch, handline effort, and handline CPUE (Table 6.1). At the State-wide scale and for each of the three stocks, the time series of data from 1984 to 2013 for each indicator was prepared. Then, the value for 2013 was compared against a number of trigger reference points calculated for the 'reference period', i.e. the historical data time series back to 1984 (Table 6.1). This comparison was done by addressing four questions:

- was the value of the indicator in 2013 among either the top three or bottom three values over the reference period of 1984 to 2013?;
- was the change in the indicator between 2012 and 2013, i.e. the two most recent years, the greatest inter-annual increase or decrease over the reference period?;
- was the slope of the linear trend over the last three years to 2013, the greatest rate of increase or decrease over three-year periods throughout the reference period?;
- and did the indicator decrease over the last five consecutive years?

Then separate 'results' tables were prepared that showed the outcomes of these comparisons, indicating whether or not the target reference points had been breached.

Biological Fishery Performance Indicators

For King George whiting, there are four biological performance indicators: fishable biomass; harvest fraction; recruitment; and age structure (Table 6.1). The first three are yearly time-series outputs from the WhitEst model (Chapter 5), whilst the age structures are measured catch proportions by age from market sampling (Chapter 4). The estimates of output indicators were computed and compared with for the three main fishery stocks, i.e. WC, SG and GSV/KI, as well as for the State overall, i.e. for the three regions combined. For each time-series of biomass estimates, the average biomass from the most recent three years (2011-2013) was compared with the average calculated across the earlier years (i.e. 1984-2010). For recruitment, the abundance of pre-recruits from the 2010 year class was compared with the average

recruitment from the preceding five years. For harvest fraction, the estimated value from the last year was chosen for consideration as it would be expected to not differ meaningfully from the average of the last three years since it is likely that this indicator changes slowly over time. In each case, this estimated value of harvest fraction was compared against the trigger reference point of 28%, as specified in the Management Plan (PIRSA 2013). The trigger reference points for the last indicator, i.e. the most recent annual age structure, are; significant change over the previous five years, and significant change over the long-term (Table 6.1).

Table 6.1 Fishery performance indicators and trigger reference points used to assess South Australia's King George whiting fisheries (from Tables 21, 22 and Appendix 4 in PIRSA 2013). Note that the general indicators relate only to the commercial fishery statistics.

Type	Performance Indicator	Category	Trigger Reference Point
General	Total catch	Secondary	3rd lowest/3rd highest Greatest interannual change (±) Greatest 5-year trend Decrease over five consecutive years ?
	Handline effort	Primary	3rd lowest/3rd highest Greatest interannual change (±) Greatest 5-year trend Decrease over five consecutive years ?
	Handline CPUE	Primary	3rd lowest/3rd highest Greatest interannual change (±) Greatest 5-year trend Decrease over five consecutive years ?
Biological	Fishable biomass	Primary	Most recent 3-yr average is +/-10% of average of previous years
	Exploitation rate	Primary	Exceeds 28% (international standard)
	Recruitment	Secondary	Abundance of pre-recruits is +/-10% of average of previous five years
	Age structures	Primary	Significant change in long-term or previous 5 years

Comparison with allocations for commercial sectors

The comparisons between reported catches and allocations for the different commercial fisheries were done using the fishery statistics from 2009 to 2013. For the comparisons, trigger limits are specified in the Management Plan that provide for some variability in the proportional contributions to total catch between years, allowing limited ability for sectors to exceed allocations without triggering a review. The assessment was done by addressing the following questions about relative contributions to the total commercial catch:

- did a fishery's contribution to total commercial catch at the State-wide scale exceed its allocation by the percentage nominated as Trigger 2 in Table 6.2,

(from Table 8 in PIRSA 2013), in three consecutive years or in four of the five previous years up to 2013?;

- did the fishery's contribution in 2013 exceed its allocation by the amount nominated as Trigger 3 in Table 6.2?

The total annual catches for each commercial fishery were determined for each year from 2009 to 2013. From these, their percentage contributions in these years were calculated. These were then assessed against the trigger limits specified below in Table 6.2, according to the criteria specified above.

Table 6.2 Allocation triggers for commercial fisheries. The table shows the commercial allocation to each commercial fishery (%), and their trigger reference points for each of Triggers 2 and 3. Note that for the MSF fishery, no trigger limits are set as allocation is >95%. Fisheries are identified as MSF = Marine Scalefish Fishery; SZRL = Southern Zone Rock Lobster Fishery; NZRL = Northern Zone Rock Lobster Fishery.

Fishery	MSF	SZRL	NZRL
Commercial allocation (%)	98.1	0.00	1.9
Trigger 2	na	0.5	2.97
Trigger 3	na	0.75	3.96

6.3. Results

General Performance Indicators

For the State-wide fishery statistics, three general performance indicators exceeded the trigger reference points (Table 6.3). These reflected that 2013 produced the lowest ever commercial catch, attracted the lowest handline effort whilst producing the highest recorded handline CPUE.

Table 6.3 Summary of comparisons between general performance indicators and trigger reference points for 2013 for the State-wide data.

Performance Indicator	Trigger Reference Point	Breached ?	Details
Total commercial catch	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	
	Decrease over five consecutive years?	No	
Handline effort	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	
Handline CPUE	3rd lowest/3rd highest	**Yes**	**Highest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	

Whilst the State-wide results presented in Table 6.3 are relatively positive, nevertheless different trigger reference points were activated for the three stocks, suggesting different levels of stock status (Tables 6.4 to 6.6).

For the West Coast (WC) stock two trigger reference points were activated (Table 6.4). These related to the record level of handline CPUE as well as the 2nd lowest handline effort ever recorded.

Table 6.4 Summary of comparisons between general performance indicators and trigger reference points for 2013 for the WC stock.

Performance Indicator	Trigger Reference Point	Breached ?	Details
Total commercial catch	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	
	Decrease over five consecutive years?	No	
Handline effort	3rd lowest/3rd highest	**Yes**	**2nd lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	
Handline CPUE	3rd lowest/3rd highest	**Yes**	**Highest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	

In contrast to the results from the WC, for each of the Spencer Gulf (SG) and Gulf St. Vincent/Kangaroo Island (GSV/KI) stocks two trigger reference points were activated. In both cases these related to the lowest total catch ever captured and lowest handline effort ever expended (Tables 6.5, 6.6).

Table 6.5 Summary of comparisons between general performance indicators and trigger reference points for 2013 for the SG stock.

Performance Indicator	Trigger Reference Point	Breached ?	Details
Total commercial catch	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	
	Decrease over five consecutive years?	No	
Handline effort	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	
Handline CPUE	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	

Table 6.6 Summary of comparisons between general performance indicators and trigger reference points for 2013 for the GSV/KI stock.

Performance Indicator	Trigger Reference Point	Breached ?	Details
Total commercial catch	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend (±)	No	
	Decrease over five consecutive years?	No	
Handline effort	3rd lowest/3rd highest	**Yes**	**Lowest**
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	
Handline CPUE	3rd lowest/3rd highest	No	
	Greatest interannual change (±)	No	
	Greatest 3-year trend	No	
	Decrease over five consecutive years?	No	

Biological Performance Indicators

Overall, the outcomes from consideration of the biological performance indicators were mixed (Table 6.7). The biomass indicator triggered positively for the WC stock, with 40% higher biomass in the last three years compared to previous years, reflecting the strong rising trend for the WC (Fig. 5.5b). Biomass was also 12% higher in the last three years in SG, just exceeding the 10% reference point. A total of 56% of the State's estimated biomass of King George whiting is now accounted for by the WC stock with SG and GSV/KI accounting for 32% and 12%, respectively. As such, the high biomass for the WC stock caused the State-wide estimate to also exceed the trigger reference point at 25% higher overall.

Recruitment for the last year class (2010) was compared with the average calculated across the previous five years. This biological performance indicator triggered for the WC stock, as estimated recruitment in 2010 was the second highest value ever estimated (Table 6.7).

The estimates of exploitation rate (i.e. yearly harvest fraction) for the WC and SG stocks in 2013 were 10% and 19%, respectively, and did not exceed the trigger reference point of 28% (Table 6.7). Alternatively, the high value of 34% exploitation rate for GSV/KI exceeded the trigger reference point. In contrast to the other two stocks, exploitation rate in GSV/KI has remained relatively high, despite trending marginally lower since 2009 (Fig. 5.5c). There has been no apparent change in population age structure over the past five years.

Table 6.7 Yearly biological performance indicators, including three estimated by the WhitEst model, for the three stocks and for the State overall (excluding offshore cell 6). Limit reference points that have been breached are highlighted in yellow.

Biological performance indicator	Category	Trigger reference point	WC	SG	GSV/KI	State-wide
Fishable Biomass	Primary	3 yr average is +/- 10% of previous years	2011-2013 biomass 40% above average of previous years (1984-2010)	2011-2013 biomass 12% above average of previous years (1984-2010)	2011-2013 biomass 6% above average of previous years (1984-2010)	2011-2013 biomass 25% above average of previous years (1984-2010)
Harvest fraction	Primary	Exceeds international standard (28% yearly)	10%	19%	34%	16%
Age structure	Primary	Significant change in long-term or previous 5 years	No change over time	No change over time	No change over time	No change over time
Recruitment	Secondary	Ref year +/- 10% of previous 5-yr average	2010 year class 10% above average of previous 5 years	2010 year class 2% above average of previous 5 years	2010 year class 2% below average of previous 5 years	2010 year class 8% above average of previous 5 years

Comparison with allocations for commercial sectors

The reported catches of King George whiting by the three commercial fisheries and their relative contributions to the total commercial catch in each year from 2009 to 2013 are shown in Table 6.8. The Marine Scalefish fishers dominated the catches in each year accounting for >97% of the reported catch. The reported catches from the Northern Zone Rock Lobster fishers accounted for <3% of the annual totals, whilst those of the Southern Zone Rock Lobster fishers were largely incidental at significantly less than 1% in each year. These contributions of the various commercial fisheries to total catch did not vary significantly from their allocations (Table 6.9).

Table 6.8 Comparison of catches of King George whiting (tonnes) and relative contribution to total catch (percentage) by the different commercial fisheries that reported taking King George whiting in each year between 2009 and 2013. Fisheries are identified as MSF = Marine Scalefish Fishery; NZRL = Northern Zone Rock Lobster; SZRL = Southern Zone Rock Lobster.

Year	MSF	NZRL	SZRL	Total	%MSF	%NZRL	%SZRL
2009	349.6	8.6	0.3	358.5	97.5	2.4	0.1
2010	317.9	8.6	0.2	326.7	97.3	2.6	0.1
2011	319.2	8.7	0.8	328.0	97.3	2.7	0.0
2012	304.1	6.6	0.2	310.9	97.8	2.1	0.1
2013	284.2	8.3	0.0	292.5	97.2	2.8	0.0

Table 6.9 Comparisons between the catches of King George whiting by the different commercial fisheries in 2013 with trigger limits specified in the Management Plan (PIRSA 2013). Fisheries are identified as MSF = Marine Scalefish Fishery; NZRL = Northern Zone Rock Lobster; SZRL = Southern Zone Rock Lobster.

Commercial sector	Draft Trigger Limit	Breached?
MSF	Trigger 2 – no trigger limit set as allocation >95%	n.a.
	Trigger 3 – no trigger limit set as allocation >95%	n.a.
NZRL fishery	Trigger 2 – exceeds allocation of 2.97% in multiple years	No
	Trigger 3 – exceeds allocation of 3.96% in 2013	No
SZRL fishery	Trigger 2 – exceeds allocation of 0.5% in multiple years	No
	Trigger 3 – exceeds allocation of 0.75% in 2013	No

6.4. Discussion

The first management objective of ensuring the long-term sustainable harvest of King George whiting was assessed using the general fishery performance indicators at two spatial scales, i.e. State-wide and at the level of stock. Breaches of reference points at the larger scale are difficult to interpret in terms of stock status as different reference points were breached for the different stocks. For the WC stock, in 2013 the highest level of handline CPUE was recorded, relating to a moderate level of catch and the 2nd lowest level of handline fishing effort (Fig. 3.3). These are positive indicators of status for this stock. In contrast, for SG, the lowest ever catch was recorded in 2013, having attracted the lowest annual handline fishing effort. These resulted in a relatively low level of CPUE that had declined since 2007. The results were similar for GSV/KI with the lowest ever handline catch and effort, and CPUE having declined since 2007. Such results suggest weaker levels of stock status for these two stocks than is the case for the WC.

There were several biological performance indicators that breached trigger reference points. Firstly, for WC, the average estimated biomass from 2011 to 2013 was 40% above the long-term average, which resulted in the State-wide estimates also being substantially above the long-term average. Also, for this stock, recruitment of the 2010 year class was 10% above the average of the previous five years. These strongly positive indicators are consistent with outcomes for the general performance indicators for the same stock as discussed above. For SG, there was one biological performance indicator that breached the trigger reference point. Estimated biomass in 2011-13 was marginally above the average through the years of 1984 to 2010. However, for GSV/KI, the high exploitation rate of 34% exceeded the trigger reference point (PIRSA 2013). This was the result of greatest concern for these biological performance indicators. Estimated exploitation rate has not trended downward for GSV/KI over the long-term as has occurred for the other two stocks. Rather, it increased substantially in 2008 and has remained high since. In Chapter 5 it was suggested that this resulted from the substantial increase in recreational catch and effort for this stock that occurred between 2000/01 and 2007/08 (Fowler et al. 2011).

7. GENERAL DISCUSSION

7.1. Context of this assessment

In the early 2000s there was considerable concern about the long-term sustainability of the South Australian King George whiting fishery (McGarvey et al. 2003). It was apparent from several indicators that the abundances in each of the three South Australian stocks had declined considerably between 1999 and 2002. This concerning status prompted a review of the management of the fishery through 2004 that culminated in significant changes that came into force on the 1st October 2004. This is the fourth stock assessment undertaken since then. Each triennial stock assessment has provided the opportunity to assess whether stock status has improved following implementation of these management changes. The first of these reports suggested that there had been a turn-around in the downward trend for each stock (McGarvey et al. 2005). The second report in 2008 indicated that the status of the fishery had improved considerably and that there was no immediate concern about the status of the fishery (Fowler et al. 2008). The third report indicated that for a number of years up to 2010, the fishery had been relatively stable and there remained no concern about the status of the fishery (Fowler et al. 2011). Largely on the basis of the latter assessment, the three South Australian stocks were assigned the status of 'sustainable' in the national stock status report completed in 2012 (Kemp et al. 2012).

This current stock assessment provides opportunity to assess the status of the three South Australian stocks of King George whiting, based on data collected up to the end of 2013, i.e. over nine years after implementation of the new management arrangements. There were several sets of data considered here to assess stock status. Firstly, the commercial catch, effort and CPUE data were considered at the State-wide and stock-wide scales up to December 2013. Secondly, the size and age structures of populations in the various regions across the fishery were considered. Finally, these two independent datasets were integrated with historic recreational fishery data using the WhitEst fishery assessment model, to generate a number of output parameters as indicators of stock status. Overall, five primary and two secondary fishery performance indicators were assessed against prescribed trigger reference points in a weight of evidence approach for each stock (PIRSA 2013).

7.2. Determination of stock status

Commercial fishery statistics

The most complete and informative data that relate the status of the King George whiting stocks are the estimates of catch, effort and CPUE from the commercial fishery statistics. Handline effort and CPUE are primary performance indicators, whilst total catch is a secondary indicator (PIRSA 2013). The considerable reductions in net fishing effort have eroded the value of data from that sector as fishery indicators. It is considered that commercial handline CPUE provides the best index of relative abundance although it must be interpreted cautiously as it can provide an optimistic view of relative abundance. This is because raw catch rates do not take into consideration the increasing 'effective' effort in the fishery that is associated with technological advancements adopted by the fishing industry. The advancements in fishing gear, power of vessels and electronic equipment has significantly increased the capacity of fishers to find and catch fish since fishery statistics were first recorded in 1984 (Jones and Luscombe 1993a, b). Furthermore, the unit of fishing effort used in this fishery, i.e. 'fisherday' is relatively course, as it contains no information about the numbers of hours fished or travelling times and distances. As such, declines in CPUE are considered to reliably indicate decreases in abundance of King George whiting, but can underestimate the magnitude of reductions.

Commercial handline fishing effort is also a primary performance indicator of the relative abundance of the stock (PIRSA 2013). This is based on the fact that King George whiting remains the premium species that returns the highest value per unit weight to the commercial fishers. As such, high levels of biomass should attract considerable effort, whilst declining levels of biomass will result in lower effort as the fishers shift their effort to other Marine Scalefish species. The challenge, with respect to this indicator, is to differentiate the effects of shifting effort away from King George whiting from declining effort associated with decreases in numbers of fishers.

The overwhelming trends in the commercial handline fishery statistics for King George whiting were significant declines in catch and effort. Such declines were apparent for each of the seven regional fisheries and consequently also in the integrated data at both the stock-wide and State-wide levels. Fishery statistics from the net sector for the two regions of NSG and GSV, where the majority of hauling net activity remains, also showed declining hauling net effort for King George whiting. This resulted in net catches having fallen to approximately one third of those of the 1980s and 1990s.

These declining trends must, at least partly, relate to the effective halving of numbers of commercial licence holders since 1984, which has contributed to fewer targeted handline fishing days across the State and fewer hauling net fishing days in the northern gulfs. However, the fall in numbers of fishers does not fully account for the declines in catch and effort. Fishing effort has also been directed away from King George whiting onto snapper and southern calamary (Fowler et al. 2013). Furthermore, for King George whiting, changes in catch rates have also contributed to changes in catches. Prior to 1999, declining levels of catch and effort for the three stocks were generally associated with rising levels of CPUE. However, around 1999 to 2002, there were declines in stock-wide estimates of CPUE that were associated with accelerated declines in catch and effort. Such results are consistent with declining levels of fishable biomass. Nevertheless, after 2004, the stock-wide rates of decline in handline catch and effort slowed down, whilst handline CPUE increased for several years, suggesting some recovery in the biomass of the stocks.

The trends in CPUE since 2007 are significant in determining the current stock status. For the WC stock, the declining fishing effort flattened out, catch increased for a number of years and the handline CPUE increased to 2013, resulting in the highest ever recorded level of handline CPUE. In contrast, for the SG stock, total catch decreased from 2007 to the lowest recorded level in 2013, whilst handline fishing effort also declined between 2009 and 2013. Furthermore, handline CPUE has been on a declining trajectory since 2007. For the GSV/KI stock, total catch and handline effort declined considerably from 2010 to 2013 and CPUE declined from 2007. These results are consistent with declining levels of biomass for both the SG and GSV/KI stocks. Recent concomitant declines in catch, effort and CPUE for both SG and GSV/KI are consistent with declining levels of biomass.

Population structure

The second set of data considered as indicators of stock status were population size and age structures. Through broad-scale population sampling during the 1990s it became evident that King George whiting in South Australia are not distributed evenly with respect to size and age (Fowler and McGarvey 2000, Fowler et al. 2000). Whilst some populations primarily involve relatively small, young fish, others support broader age and size distributions. The latter form the spawning aggregations during the reproductive season (Fowler et al. 1999), which are supplemented by movement of small, young adults from inshore areas (Fowler et al. 2002). The different size and age distributions of fish in different regions are the culmination of a complicated

sequence of life history and demographic processes. As such, the regional estimates of population structure provide indicators of stock status (PIRSA 2013). In this study, market sampling for King George whiting was undertaken across the geographic range of the fishery during each financial year of 2006/07, 2008/09, 2009/10, 2011/12 and 2012/13 and the size and age distributions from these years were considered against historical data. The within-region comparisons did not show any evidence of significant change in population structure that might be attributable to the fishery. As such, the trigger reference points for this indicator were not activated for any of the three stocks.

Fishery assessment model

The computer fishery assessment model 'WhitEst' integrates the fishery and biological data to provide annual estimates of recruitment, fishable biomass and annual exploitation rate. These represent the remaining fishery performance indicators, of which the latter two are considered primary indicators (PIRSA 2013). Up to 2002, these output parameters presented some concerning trends (McGarvey et al. 2003). Since then, there have been considerable changes in the trends that differ amongst the three stocks.

For the WC stock, estimated recruitment increased considerably from 2002 onwards, culminating in the highest ever estimate in 2013. The trend in fishable biomass for this stock also increased appreciably between 2007 and 2013, culminating in the highest ever estimate in 2013. Furthermore, the time series of exploitation rates declined from 1984 and by 2008 had fallen to around 10% of the fishable biomass. In 2013, two limit reference points were activated, i.e. fishable biomass and recruitment were above average. These are positive indicators of stock status.

The trends in output parameters from WhitEst for SG differed considerably from those for the WC. From 2005 to 2013, estimated recruitment declined marginally with the lowest ever value estimated for 2012. Estimated fishable biomass also declined marginally between 2009 and 2013. These declines occurred despite a trend of declining exploitation rate that fell from >40% in 1992 to around 20% in 2013. No negative trigger reference points were activated for any of the biological performance indicators for this stock.

For the GSV/KI stock, the estimates of fishable biomass have always been much lower than for the other two stocks, reflecting lower recruitment levels. The estimated

fishable biomass showed a general trend of slowly increasing biomass over time, although this slowed from 2009. Recruitment has been flat for the last decade, with marginal increases in 2006, 2008 and 2009. Since 2003, the estimated exploitation rates have been higher than for the other two stocks. In 2013, the exploitation rate remained high at 34%, which activated the trigger reference point.

Stock status

In this report, the status of each of South Australia's three King George whiting stocks was classified using the national system that involves four classification levels: sustainable; transitional depleting; transitional recovering; and overfished (Flood et al. 2012). However, the Management Plan for the Marine Scalefish Fishery (PIRSA 2013) does not identify performance indicators or reference points that differentiate between these classification levels. Rather, stock status is determined based on seven fishery performance indicators using a weight of evidence approach. This approach was adopted for the national stock status report in 2012, when the three South Australian stocks were classified as 'sustainable' (Kemp et al. 2012). Those classifications were based on the largely positive findings of the stock assessment at that time (Fowler et al. 2011), although that assessment highlighted concerning signs of declining catches and catch rates for two regions (i.e. NSG and KI).

Catches and handline CPUE for the West Coast stock have been increasing since 2004. The stock assessment model WhitEst indicated trends of increasing biomass and recruitment over this period. Between 1984 and 2013, the exploitation rate fell from 22% to 10%. Evidence suggests that the current level of fishing mortality is unlikely to cause this stock to become recruitment overfished. The stock is classified as **sustainable**.

The current situation is different for both the SG and GSV/KI stocks, where the previously raised concerning signs of declining catches and catch rates have continued. King George whiting is the premium species in the Marine Scalefish Fishery and attracts the highest price per unit weight for commercial fishers. Despite this high incentive to catch King George whiting, catch and effort in 2013 fell to their lowest recorded levels in both gulfs. This reflects declining trends in both catch and effort in both gulfs since 2007. We interpret the switch of effort away from King George whiting towards lower value species as, at least partly, a response by commercial fishers to reduced availability of King George whiting. The declines in handline CPUE in both gulfs since 2007 suggest that fishable biomass has most likely

declined. As our current estimates of CPUE do not take into account likely increases in 'effective' effort, we believe that the decline in fishable biomass may be greater than suggested by the reduction in raw CPUE alone. Increases in effective effort associated with improvements in vessel speed and navigational equipment mean that comparisons of CPUE over the last decade with those recorded in the first 20 years of the catch history are difficult, particularly with respect to interpreting relative abundance during those two periods. If 'effective' effort has continued to increase over the last decade, then the declines in fishable biomass over the last decade may be greater than suggested by the observed reductions in CPUE.

Estimates of fishable biomass in the two gulfs from the WhitEst stock assessment model were relatively flat or have trended downwards since 2009. We consider that these trends may under-estimate declines in fishable biomass for two reasons. Firstly, they are largely driven by commercial CPUE, which has not been corrected for increases in 'effective' effort. Secondly, total catch and effort used in the WhitEst model are based on estimates of recreational catches that have been extrapolated from surveys done in 2000/01 and 2007/08. These extrapolated catches have not changed over time. If recreational catches have increased since 2007/08, the decline in fishable biomass would be greater than suggested by WhitEst.

The status of each of the SG and GSV/KI stocks was not easily defined. It is difficult to distinguish whether these stocks should be classified as 'sustainable' or 'transitional depleting'. This difficulty relates in part to the absence of a defined trigger reference point that separates the two categories. However, the difficulty also reflects limitations in the reliability of the primary indicator of fishable biomass, i.e. CPUE, as an index of abundance for a schooling species in which CPUE is likely to display hyper-stability. The interpretation of trends in CPUE is also complicated by the crude nature of the current measure of effort (fisherdays) and the most likely increased effectiveness of fishing effort over time in the Marine Scalefish Fishery. A precautionary interpretation of the data suggests that both stocks are best described as **transitional depleting**.

7.3. Uncertainties about stock status

As indicated above, there are uncertainties in our data and their interpretation that affects our understanding of the influence of the fishery on the population biology of King George whiting, and the outcomes of the stock assessment process. Firstly, the estimates of commercial CPUE considered here were not corrected for increasing 'effective' effort that results from technology creep. Although there is some

understanding of the timing of the uptake of electronic navigational and fish detecting devices on Marine Scalefish vessels (Jones and Luscombe 1993a, b), the influences of these and subsequent developments on the rate of increase in effective effort are unknown. As such, the recent declining levels of commercial handline CPUE in SG and GSV/KI and the declining trends in model-estimated biomass, may underestimate the true rate of decline in fishable biomass of these stocks.

A further significant uncertainty relates to the poor understanding of temporal trends in catch and effort by the recreational sector. It is apparent from the two State-wide telephone/diary surveys undertaken through the 2000s that this sector accounts for a significant proportion of the total catch of King George whiting (Jones and Doonan 2005, Jones 2009). The estimates of recreational catch and effort used in the WhitEst model were extrapolated from the limited data available from 2000/01 and 2007/08. In reality, it is unlikely that such extrapolated values provide a satisfactory time series of recreational catch and effort. Yet, this extrapolated dataset is likely to have had considerable impact on the output parameters from WhitEst. The recent declines in model-estimated biomass were considerably less than those in the estimates of commercial CPUE, possibly reflecting that they may be conservative compared to real trends in changing biomass.

Finally, there is also uncertainty about whether reproductive output and successful recruitment in the two gulfs may have declined in recent years. These may have been impacted by the targeted fishing of spawning aggregations that are located in the deep, off-shore waters of south east Spencer Gulf, Investigator Strait and south west Gulf St. Vincent. In recent years such places have become accessible to commercial and recreational fishers due to technological advancements in fishing boats and electronic equipment. The fishing of spawning aggregations may have disrupted the spawning activity and reduced egg production by the fish in such areas.

7.4. Future work

The various monitoring programs for the King George whiting fishery will continue into the future. These include the monitoring of the commercial catch and effort data and that from the Charter Boat sector by SARDI's Information Systems and Database Support Program. Market sampling for King George whiting is currently planned to resume in October 2014 and to continue until September 2016. These data will be used to inform the WhitEst fishery assessment model for future assessments, and to monitor for possible truncation in the size and age structures. There is a State-wide

recreational fishing survey underway through 2014, whose results, in association with those from the surveys done in 2000/01 and 2007/08, will help to better understand the trends in recreational catch and effort for King George whiting. The results will be reported and used in the next stock assessment scheduled for 2017.

There are a number of ways by which the research program for King George whiting could be augmented to improve certainty in the status of the stocks in SG and GSV/KI. The surveys that were undertaken in the nursery areas of the northern parts of both gulfs during the late 1980s and 1990s to quantify post-larval and pre-recruit abundances could be re-established (Fowler and Short 1996, Fowler and McGarvey 2000). This might help determine whether recruitment rates have declined since the 1990s. The size and age structures at known spawning aggregation sites could be determined and compared with those from the 1990s and early 2000s, to determine whether truncation of spawners has occurred. Furthermore, it might be possible to develop methods to estimate the biomass of the spawning stock using the daily egg production method (DEPM). It is highly likely that the genetic methods that will soon be developed to identify snapper eggs, thereby making the DEPM methodology tractable for this species, could also be applicable for King George whiting. This would overcome the issues of egg identification that were confronted when this method was attempted for King George whiting in the late 1990s (Fowler 2000). Finally, consideration should be given to collecting more refined data on commercial fishing effort. Herein lies the opportunity to work with this sector to determine appropriate measures of fishing effort and to revise the commercial logbook and database to report and record such refined data on a daily basis.

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9. APPENDIX: MODEL FITS TO DATA

Parameters and thus stock indicators in the WhitEst model are estimated by fitting to data for commercial catch totals by weight, recreational catch total numbers for some years (see Methods Chapter 5), and to commercial catch proportions by age and sex, in each month when sampling occurred. In this Appendix, graphs comparing fitted model and data indices are presented.

In Fig. 5.1, model fits to the reported monthly King George Whiting catch totals are plotted for commercial catch in weight landed for the 5 model spatial cells. In Fig. 5.2, the model fits to catches in number by the recreational sector are shown for the two gulfs and West Coast. This fit is nearly perfect by design, sufficient additional catchability parameters having been added to the model to guarantee a close fit, in effect achieving a catch-conditioned outcome for catch in this effort-conditioned model formulation. Fig. 9.3 shows the extent of agreement between model-predicted biomass and the principal informing indicator for trends in biomass, namely targeted handline CPUE, noting that this (effort-conditioned) model does not fit to CPUE directly. Plots of fit to the proportions landed by age (Fig. 9.4) and to sex ratios (Fig. 9.5) from catch sampling are also plotted below. Age data were obtained for most combinations of the five spatial cells and both sexes, and for each month of the four age and length sampling programs which ran from September 1994 to June 1997, July 2004 to June 2007, July 2008 to December 2010, and October 2011 to September 2013. We present only the 24 most recent fits to these age and sex catch proportions.

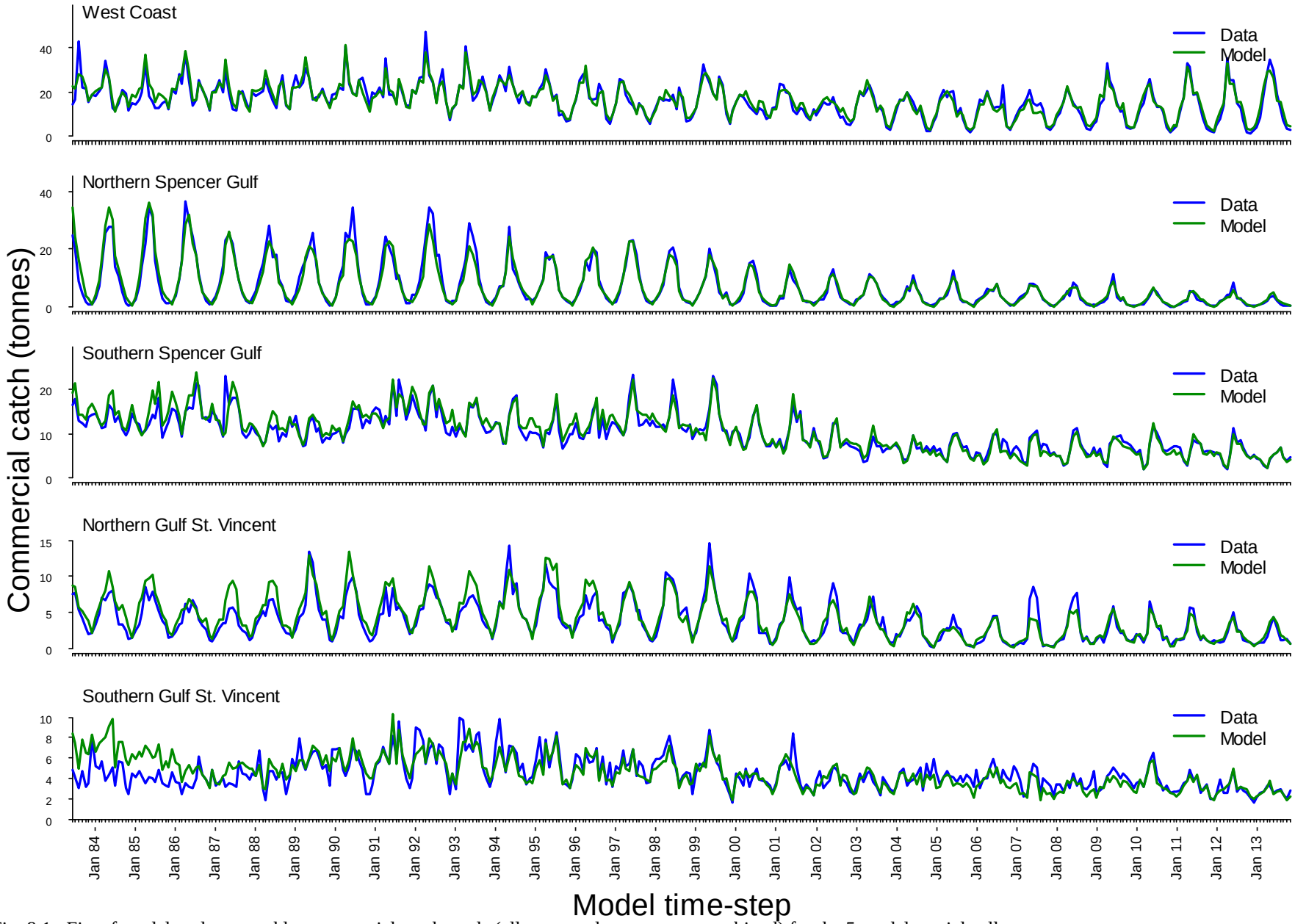

Fig. 9.1. Fits of model to data monthly commercial catch totals (all gears and target types combined) for the 5 model spatial cells.

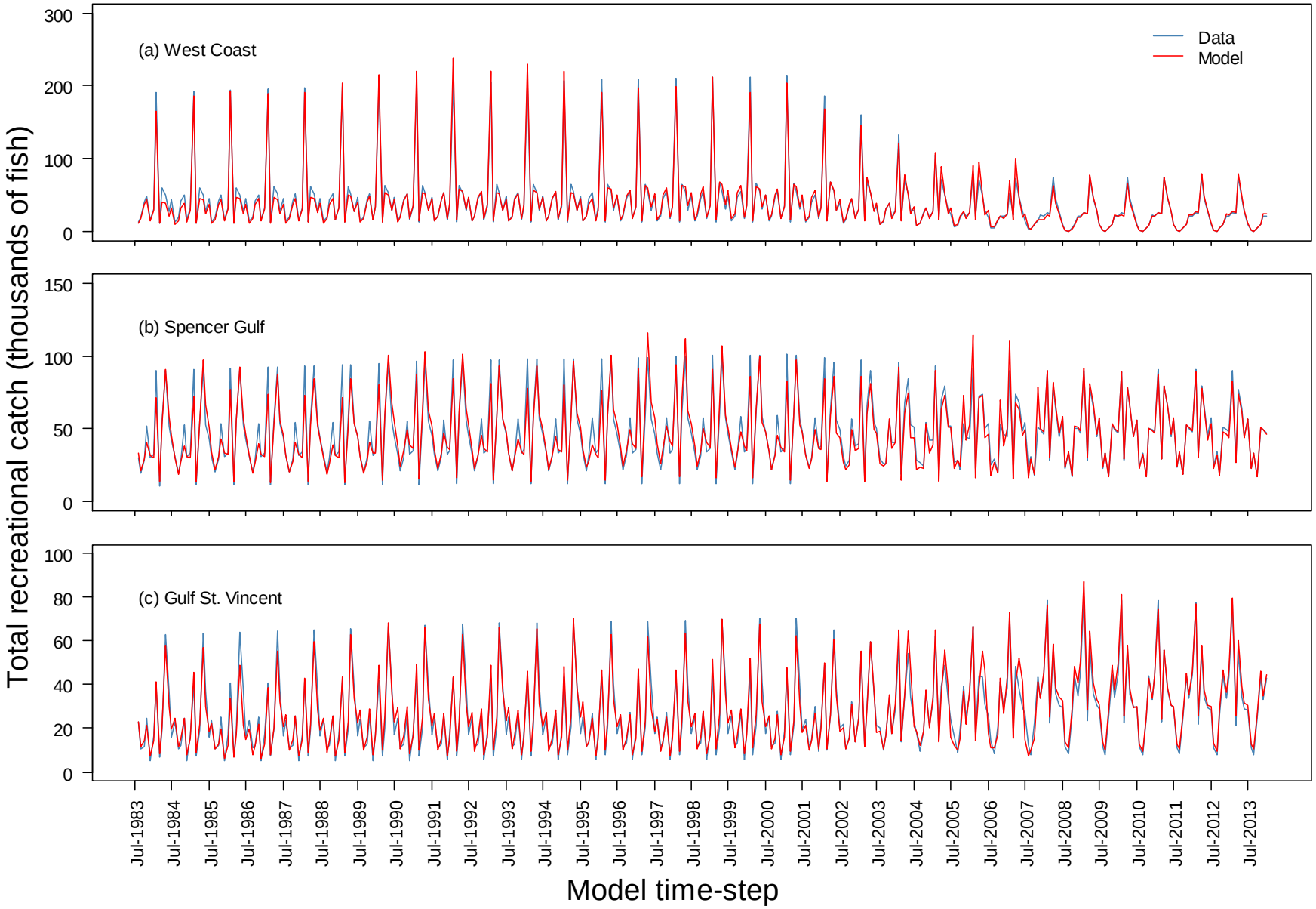

Fig. 9.2. Fits of model to data monthly recreational catch totals, for the 3 principal King George whiting regions.

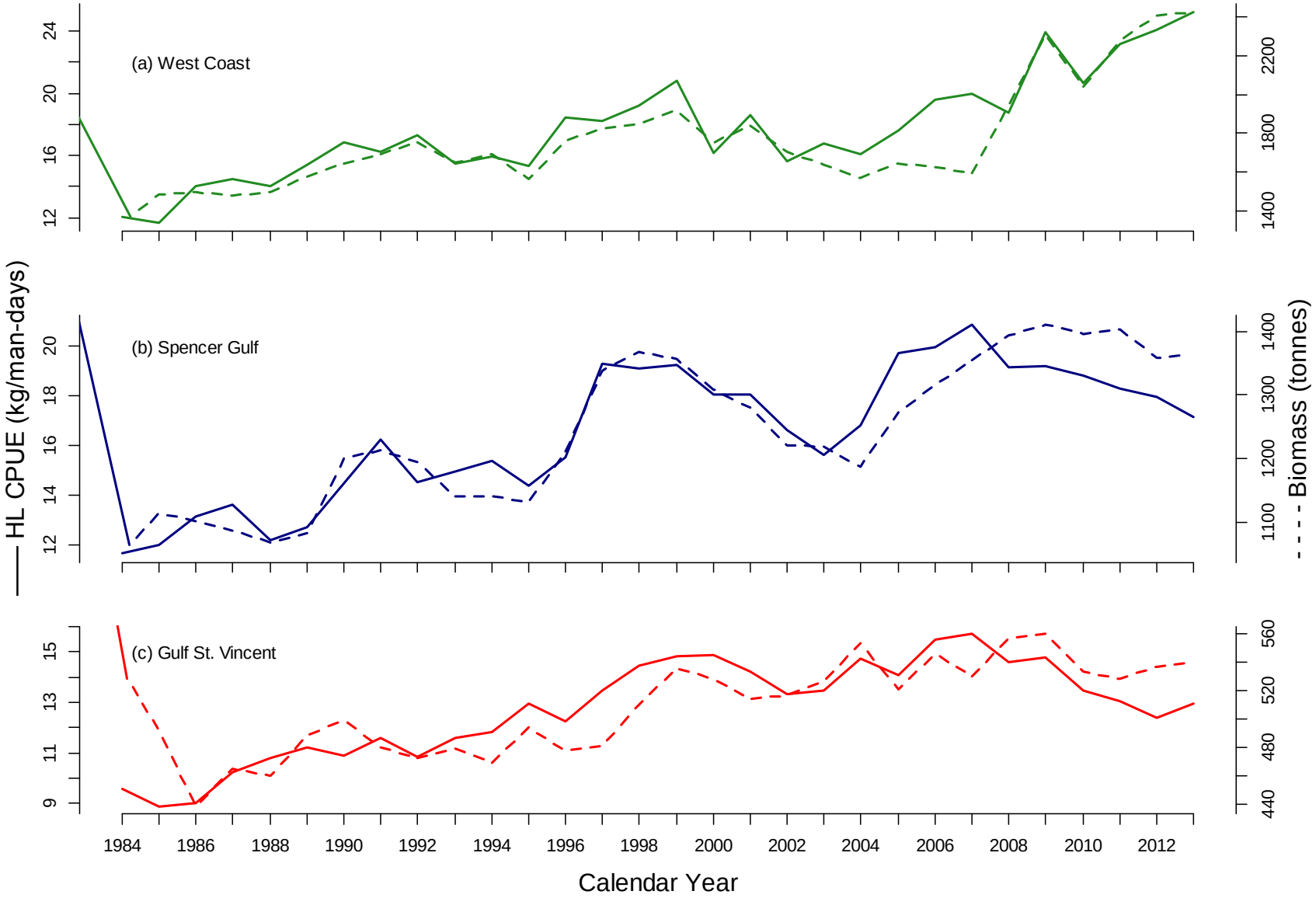

Fig. 9.3. Yearly comparison of model-estimated legal-size biomass (dashed line) with the principal indicator of commercial catch rate (targeted handline) for the three principal King George whiting regions.

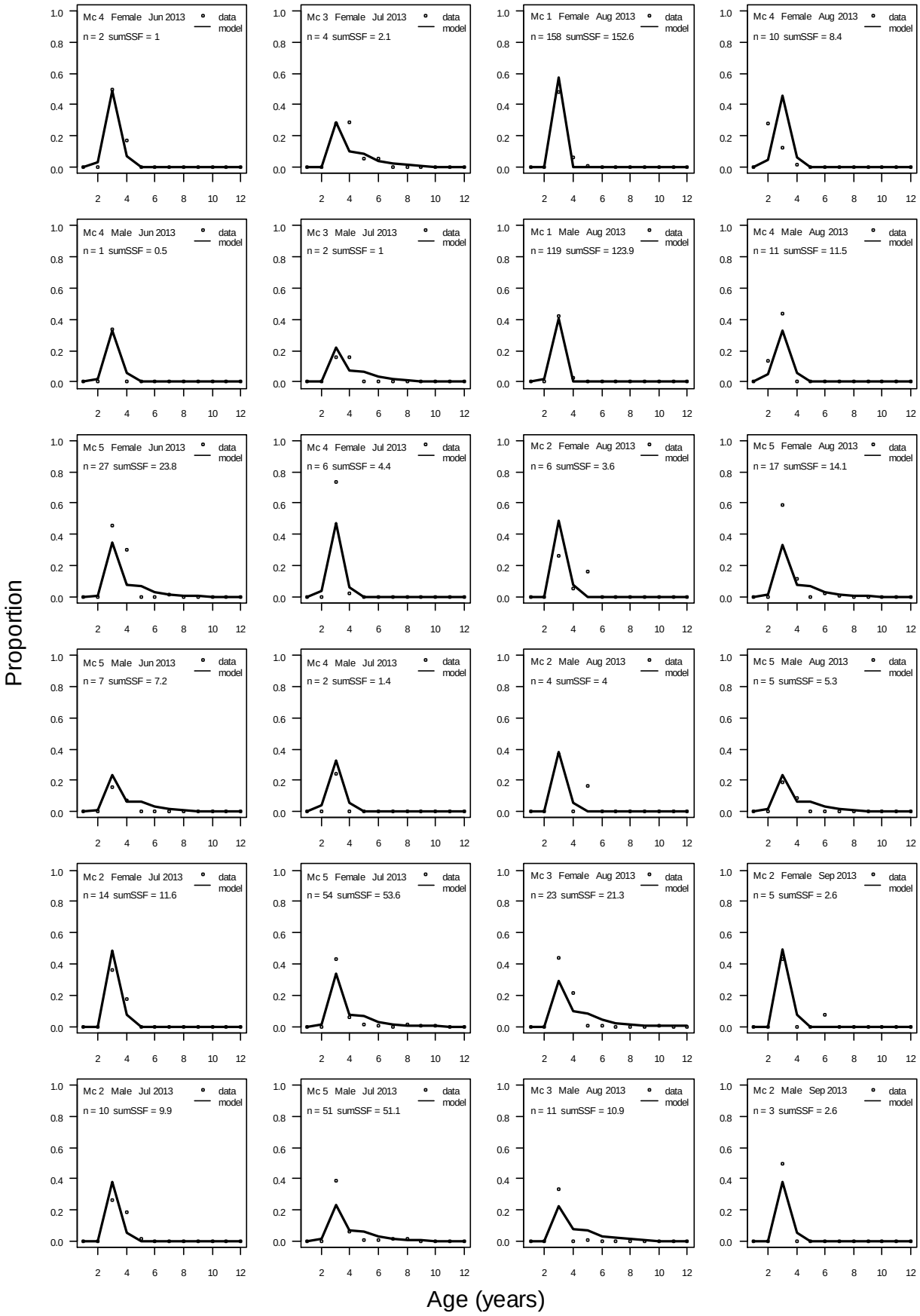

Fig. 9.4. Model fits to age proportions from catch samples. Of 591 age proportion data sets, by month, sex, and spatial cell since the mid 1990's, here the 24 most recent data sets are shown.

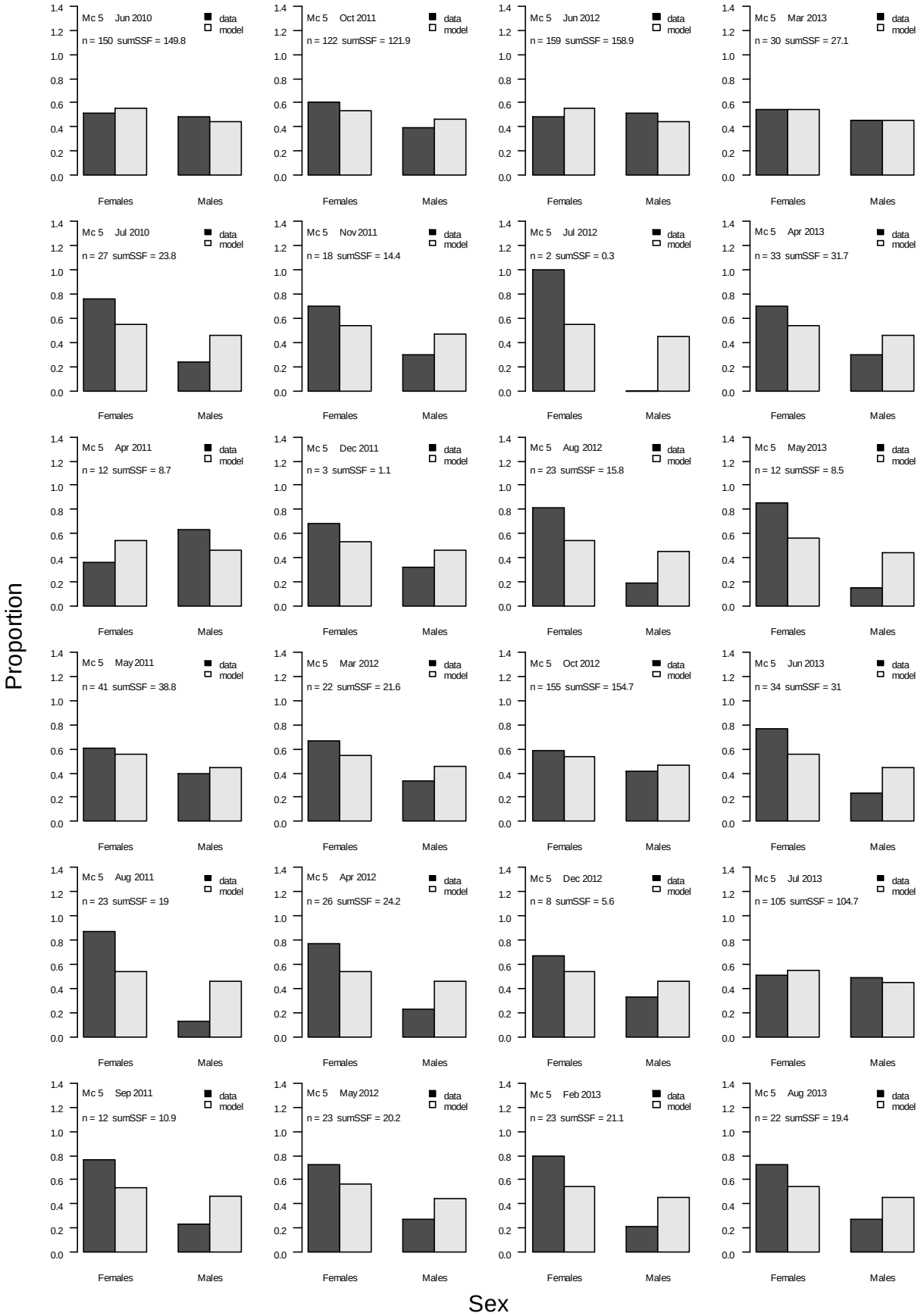

Fig. 9.5. Model fits to sex ratios from SAFCOL market samples. Of 305 sex proportion data sets, by month and spatial cell since the mid 1990's, here the 24 most recent are shown.