

South Australian Sardine (*Sardinops sagax*) Fishery: Stock Assessment Report 2015



T. M. Ward, A. R. Whitten, and A. R. Ivey

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Report to PIRSA Fisheries and Aquaculture

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EXECUTIVE SUMMARY

This report synthesises information for the South Australian Sardine Fishery (SASF), assesses stock status, discusses management implications and identifies research needs.

The SASF was established in 1991 to provide fodder for the mariculture of Southern Bluefin Tuna (*Thunnus maccoyii*) and operates mainly in southern Spencer Gulf.

The Total Allowable Commercial Catch (TACC) was set at 1,000 t in 1991 and peaked at 51,100 t in 2005. Between 2007 and 2009, the Total Allowable Commercial Catch (TACC) was set at 30,000 t. In 2010, an additional catch of 4,000 t was made available outside Spencer Gulf. The TACC from 2010 to 2014 was 34,000 t. The TACC for 2015 is 38,000 t.

Total annual catches rose from 7 t in 1991 to reach 42,475 t in 2005, before stabilising at ~30,000 t in 2007-2009. During 2010-14, the catch ranged between 32,262 t and 33,972 t.

Annual effort peaked at 1,274 net-sets in 2005 and remained stable at 760-1077 net-sets between 2007 and 2014. Effort and catches usually peak in March-June.

During 2000-2009, the mean length of Sardine (*Sardinops sagax*) taken from Spencer Gulf was >142 mm Fork Length (FL). Between 2010 and 2012, mean length declined from 140 to 128 mm FL. In 2013 and 2014, mean length increased to 147 and 139 mm FL, respectively. The mean size of Sardine taken from Spencer Gulf from 1 January to 30 June 2015 was 144 mm (which is above the target reference point of 142 mm).

Between 2005 and 2012, 2+ year old fish usually dominated catches. In 2013 and 2014, 3+ year olds were the dominant age class.

Between 2003 and 2014, estimates of spawning biomass obtained using the Daily Egg Production Method (DEPM) ranged from 152,000 to 263,000 t. The estimate of spawning biomass for 2014 was 244,000 t (which was above the target reference point of 150,000 t).

Estimates of spawning biomass obtained using the DEPM currently provide the best indications of the status of Sardine off South Australia. Catch-at-age data and preliminary outputs from a recently developed age-structured population model do not suggest that stock status has changed appreciably since the DEPM was last applied in 2014.

Further testing and development of the model is required to ensure that its structure and assumptions are appropriate for the SASF. This should include investigation of the effects of changes in fishing patterns on estimates of recruitment and projections of future spawning biomasses.

On the basis of evidence provided in this report, the SASF is classified as **sustainable**.

1.0 GENERAL INTRODUCTION

1.1 Rationale and Objectives

This is the tenth stock (fishery) assessment report by SARDI Aquatic Sciences on the South Australian Sardine Fishery (SASF). The objectives of the report are to: review scientific literature on the biology, ecology and fisheries for small pelagic species, especially the Australian Sardine, *Sardinops sagax* (Jenyns 1842, Clupeidae), and describe the development and management of the SASF (Chapter 1); present catch, effort, catch-per-unit-effort (CPUE) and size composition data for the fishery from 1991 to 2014 (Chapter 2); describe the age-composition of the commercial catch and key elements of the reproductive biology of Australian Sardine (Chapter 3); provide estimates of spawning biomass obtained using the Daily Egg Production Method (DEPM) during 1995-2014 (Chapter 4); use an age-structured stock assessment model to project future levels of spawning biomass under a range of different catches (Chapter 5); and assess the current status of the Sardine resource, discuss management implications and identify future research needs (Chapter 6).

1.2 Literature Review

1.2.1 Taxonomy

Historically, five species have been recognised in the genus *Sardinops*: *S. ocellatus* off southern Africa; *S. neopilchardus* off southern Australia and New Zealand; *S. sagax* off the west coast of South America; *S. caeruleus* off the west coast of North America; and *S. melanostictus*, around Japan (Whitehead 1985). However, most fisheries scientists now follow the taxonomy for the genus proposed by Parrish *et al.* (1989), who suggested that the genus *Sardinops* is mono-specific with no valid sub-species and that the name *Sardinops sagax* (Jenyns 1842) has taxonomic priority. This finding was confirmed by Grant and Leslie (1996). Grant *et al.* (1998) suggested that cluster and parsimony analyses of haplotypic divergences supported the hypothesis that there were three lineages within the genus: southern Africa (*ocellatus*) and Australia (*neopilchardus*); Chile (*sagax*) and California (*caeruleus*); and Japan (*melanostictus*). Polymorphic micro-satellites that have been isolated have the potential to help resolve some of the minor taxonomic questions that remain for this species (Pereya *et al.* 2004).

The common and scientific names of the Australian Sardine or Pilchard have been debated for many years. The names pilchard and *Sardinops neopilchardus* (Steindachner 1879) were used in many Australian publications prior to 2000. However, the terms Australian Sardine and *Sardinops sagax* (Jenyns 1842) have been listed in the Standard Fish Names List for Australia since May 2006. *Sardinops sagax* is also the name used in the Australian

Faunal Directory and Eschmeyer's Catalogue of Fishes. In this report we use the term Sardine to refer to *S. sagax* in Australia and elsewhere.

1.2.2 Distribution

Sardine occur in cool temperate to sub-tropical waters of the Northern and Southern Hemispheres where, along with a local species of anchovy (*Engraulis* spp.), they commonly dominate the fish biomass in upwelling regions. Sardine support important fisheries in the eastern boundary current systems off the west coasts of northern and southern Africa and North and South America. These globally important upwelling regions are known as the Canary, Benguela, California and Humbolt Current Systems, respectively. The Sardine is also found in the rich coastal waters surrounding Japan, and the generally less productive waters off southern Australia and around New Zealand.

In Australia, Sardine are found throughout temperate and sub-tropical waters between Rockhampton (Queensland) and Shark Bay (Western Australia), including northern Tasmania (Gomon *et al.* 1994). Waters off South Australia are the centre of the Sardine's Australian distribution and support the largest component of the Australian population (Ward *et al.* 2006). Shelf waters off South Australia also include Australia's largest upwelling system, the Flinders Current system (Middleton and Cirano 2002). Sardine is the dominant clupeid off South Australia, occurring in the southern portions of Gulf St Vincent and Spencer Gulf and over the continental shelf (Ward *et al.* 2001a, b). As in other upwelling systems worldwide, one species of engraulid, the Australian anchovy (*Engraulis australis*) is also abundant off South Australia (Dimmlich *et al.* 2009). When Sardine biomass is high, the Australian anchovy occurs mainly in the northern gulfs, but when Sardine biomass is low this species has the capacity to increase in abundance and expand its distribution into shelf waters (Ward *et al.* 2001a; Dimmlich *et al.* 2004; Dimmlich and Ward 2006).

1.2.3 Movement patterns and stock structure

Sardine are known to undergo extensive migrations. For example, off Africa, Sardine migrate along the coast to access conditions that are favourable for spawning and the survival of recruits (van der Lingen and Huggett 2003). Similarly, it has been hypothesised that schools of Sardine migrate into waters off northern New South Wales and southern Queensland during winter-spring to spawn (Ward and Staunton-Smith 2002). The movement patterns of Sardine in waters of South Australia are largely unknown although there is evidence of an ontogenetic shift in distribution with larger, older fish most commonly found in shelf waters and smaller, younger fish mainly found in embayments including Spencer Gulf (Rogers and Ward 2007).

Fishing effort in the SASF is concentrated in southern Spencer Gulf but a substantial proportion of the spawning biomass is located in the Great Australian Bight; hence, understanding the rate of movement between shelf and gulf waters has been identified as a high priority for the fishery. A collaborative project funded by the Fisheries Research and Development Corporation (FRDC) (Izzo *et al.* 2012) provided some evidence of separation between the southern Australian and east coast populations using otolith shape and elemental composition. This study suggested inter-annual variations in the population sub-structuring off South Australia (Izzo *et al.* 2012), possibly driven by environmental factors.

A high level of genetic heterogeneity is apparent within the Australian population of Sardine, but there is limited evidence of spatially consistent stock structure (e.g. Izzo *et al.* 2012). The existence of separate eastern and western stocks has been proposed for species, including Sardine, that are targeted in the Commonwealth Small Pelagic Fishery (Bulman *et al.* 2008), with Bass Strait suggested as a significant barrier to genetic flow. The possibility of a stock division for small pelagic species, such as Sardine, off southern Australia (between western Tasmania and southern west coast of Western Australia) was also proposed by Bulman *et al.* (2008), but the level of separation was considered less distinct than for the east coast because of the lack of a clearly defined barrier to movement (like Bass Strait). Several studies suggest that there are distinct breeding stocks off the west and south coasts of Western Australia (Edmonds and Fletcher 1997; Gaughan *et al.* 2001, 2002). There is growing consensus that for purposes of fisheries management, the Australian Sardine population can be considered to be comprised of four stocks: i.e. the Eastern Australian; Southern Australian (western Victoria and South Australia); Western Australian South Coast; and Western Australian West Coast stocks (Flood *et al.* 2014).

1.2.4 Schooling behaviour

The schooling behaviour of Sardine is complex and varies at both spatial and temporal scales. For example, Barange and Hampton (1997) found that schools remained at similar densities throughout the day, whereas Misund *et al.* (2003) found that schools were highly dynamic and densities changed during the afternoon. Similarly, in some parts of the California Current system (e.g. Oregon, USA), schools of Sardine have also been observed displaying patterns consistent with anti-predator behaviour, dispersing at night, reforming rapidly at sunrise and remaining in schools throughout the day (Kaltenberg and Benoit-Bird 2009). However, at other locations in the California Current system (e.g. Monterey Bay, USA) transitions between day and night behaviour occur more gradually (Kaltenberg and Benoit-Bird 2009). Factors such as habitat heterogeneity, food availability, predation levels

and vessel noise can influence schooling behaviour (Freon 1993; Giannoulaki *et al.* 2003). Schooling behaviour of Sardine in Australian waters varies within and among locations, days, months and years and complicates the application of acoustic techniques for stock assessment (T.M. Ward, unpublished data). There is evidence that spawning also influences schooling behaviour, with spawning females under-represented in commercial catches (Ward *et al.* 2011a).

1.2.5 Food and feeding

Sardine has two feeding modes: filter-feeding on micro-zooplankton and phytoplankton and particulate-feeding on macro-zooplankton. Sardine switch between these two modes depending on relative prey density (van der Lingen 1994; Louw *et al.* 1998; van der Lingen 2002). Sardine tend to feed on smaller zooplankton than anchovies (e.g. Espinoza *et al.* 2009). The prey composition of Sardine varies among regions. For example, in the northern Humboldt Current system, Sardine tend to feed on larger prey and consume more euphausiids than in the northern Canary and southern Benguela systems.

In South Australian waters, Sardine have been found to consume 12 prey taxa with krill (29.6% biomass) and unidentified crustacean (22.2% biomass) contributing the highest biomass (Daly 2007). However, krill occurred in greater numbers (65.3%) in the diet than crustaceans (27.0 %). Crab zoea, other decapods, copepods, polychaetes, fish eggs and larvae and gelatinous zooplankton were also present in the diet of Sardine in South Australia (Daly 2007).

1.2.6 Reproduction

Sardine are serial spawners with asynchronous oocyte development and indeterminate fecundity. Serial or batch spawning fishes release numerous batches of pelagic eggs throughout an extended spawning season. The number of eggs in a batch, or batch fecundity, is correlated with female size and varies among locations and years (Lasker 1985).

In Australia, Sardine usually spawn in open waters between the coast and shelf break (Blackburn 1950; Fletcher and Tregonning 1992; Fletcher *et al.* 1994). In most locations there is one spawning season per year, but off Albany in Western Australia there are two (Fletcher 1990). The size and age at which Sardine reach sexual maturity vary between locations, and range from 100 to 180 mm Fork Length (FL), and 1.8 to 2.8 years, respectively (Blackburn 1950; Joseph 1981; Stevens *et al.* 1984; Fletcher 1990; Macewicz *et al.* 1996).

The reproductive biology of Sardine in South Australian waters is relatively well known. Ward and Staunton-Smith (2002) found approximately 50% of males and females reach sexual maturity (L_{50}) at 146 and 150 mm, respectively. Spawning occurs during the summer-autumn upwelling period of January-April (Ward *et al.* 2001a, b; Ward and Staunton-Smith 2002). Females spawn batches of 10,000-30,000 pelagic eggs approximately once per week during the extended spawning season. Eggs are abundant in the southern gulfs and shelf waters (Ward *et al.* 2006).

1.2.7 Early life history and recruitment

Sardine have a relatively long larval phase: eggs hatch approximately two days after fertilization and larvae metamorphose at 1-2 months of age (Neira *et al.* 1998). Survival rates of Sardine eggs and larvae strongly affect recruitment success (Lo *et al.* 2005). The large variations in abundance that characterise Sardine populations worldwide have been attributed to fluctuations in recruitment, which can be influenced by environmental factors, regime shifts and over-fishing (e.g. Galindo-Cortes 2010). Larval survival is a key determinant of recruitment success, but the factors affecting survivorship may vary spatially and temporally. The effects of food availability on larval survival have been discussed at length (Lasker *et al.* 1975), but there has been less consideration of the effects of egg and larval predation on recruitment success (e.g. Agostini 2007).

In the Californian Current system, recruitment success and large population sizes have coincided with warm periods characterised by reduced primary productivity; during this time the centre of spawning shifts northward (e.g. Lluch-Belda *et al.* 1992). Surprisingly, a recent study linked high zooplankton abundance to poor recruitment of Sardine, suggesting that lower predation pressure on eggs and larvae may be a key factor contributing to strong recruitment in the Californian Current system (Agostini *et al.* 2007). Similarly, a reduction in zooplankton abundance was followed by an increase in Sardine recruitment in Peru (Carrasco and Lozano 1989) and the Sardine population off South Africa collapsed when zooplankton abundance increased (Verheye 2000).

In South Australia, Sardine larvae are highly abundant at temperature and salinity fronts that form near the mouths of the two gulfs during summer and autumn (Bruce and Short 1990) and in mid-shelf waters off the Eyre Peninsula (e.g. Ward *et al.* 2014). Spawning coincides with the summer-autumn upwelling period in South Australia (e.g. Ward *et al.* 2006). It is predicted that the intensity and duration of upwelling events could increase under future climate change scenarios (Hobday *et al.* 2009). The effects of such changes on the future recruitment success of Sardine in South Australia are poorly understood.

1.2.8 Age, growth and size

Age determination studies of Sardine have involved counting growth increments in scales (Blackburn 1950) and sagittal otoliths (ear bones) (Butler *et al.* 1996; Fletcher and Blight 1996), and modelling the formation of marginal increments in otoliths (Kerstan 2000). Daily deposition of growth increments in the otoliths of larvae and juveniles has been validated in laboratory trials (Hayashi *et al.* 1989). Age validation studies involving the capture and maintenance of Sardine and other clupeoids have proven to be problematic owing to logistical difficulties (Fletcher 1995) and sensitivity to handling (Hoedt 2002; Rogers *et al.* 2003). Other methodological approaches have been used to show that translucent zones form annually in the sagittae of 1+ year old Sardine off South Africa (Waldron 1998), $\leq 2+$ year olds off North America (Barnes *et al.* 1992) and $\geq 4+$ year olds off Western Australia (Fletcher and Blight 1996). Despite this theoretical basis for using increment-based age-determination methods, the application of these standard approaches has proven to be problematic in Western Australia, South Australia and California due to difficulties associated with interpreting and counting opaque and translucent zones (Butler *et al.* 1996; Fletcher and Blight 1996; Rogers and Ward 2007).

Studies of growth dynamics of Sardine in the Benguela and California Current systems suggest that growth rates of larvae (up to 0.85 mm.day^{-1}) and juveniles ($0.48\text{-}0.63 \text{ mm.day}^{-1}$) are high (Butler *et al.* 1996; Kerstan *et al.* 1996; Watanabe and Kuroki 1997; Quinonez-Velazquez *et al.* 2000; Skogen 2005). In South Africa, Sardine were found to reach larger asymptotic sizes ($L_{\infty} = 221 \text{ mm}$) and have lower growth constants ($k = 1.09 \text{ year}^{-1}$) than those off southern California ($L_{\infty} = 205 \text{ mm}$, $k = 1.19 \text{ year}^{-1}$, Thomas 1984, 1986; Butler *et al.* 1996). Parameter estimates for Sardine in Western Australia (Fletcher and Blight 1996) suggest that growth in this area is slower and that fish reach smaller asymptotic sizes than those in the more productive eastern boundary current systems.

A detailed study by Rogers and Ward (2007) showed that the growth rates of Sardine are higher in South Australian waters than off other parts of the Australian coastline, but lower than those in more productive boundary current ecosystems (Ward *et al.* 2006). A notable finding of the study was that fish in commercial catches were younger (and smaller) than those obtained in fishery-independent samples. This finding has implications for the use of age structured models (based on fishery samples) for stock assessment of the SASF (see Chapter 5).

1.2.9 Mass mortality events

Mass mortality events in 1995 and 1998/99, spread throughout the entire Australian range of Sardine and are thought to have killed more fish over a larger area than any other single-species fish-kill recorded (Jones *et al.* 1997). Characteristics of the mortalities, such as their focal origin, rapid spread throughout the entire geographical range of the population and high mortality rates suggest both events were caused by an exotic pathogen to which Australian Sardine were naïve (Jones *et al.* 1997; Gaughan *et al.* 2000; Whittington 2008).

Each event was estimated to have killed over 70% of the spawning biomass in South Australian waters (Ward *et al.* 2001b). Recovery of the South Australian population following these events has been monitored using the daily egg production method (DEPM; Lasker 1985; Ward *et al.* 2001c). Assessment of the impacts of the mortality events on the age structure of the South Australian population of Sardine and the use of age structured models to assess the capacity of the population to recover has been impeded by difficulties associated with obtaining reliable estimates of age (Ward *et al.* 2005a).

1.2.10 Role in the ecosystem

Small pelagic fishes such as Sardine live mainly in the upper layers of the water column, and convert energy produced by phytoplankton into a form that is available to higher vertebrates. Sardine are an important food source for many predatory fishes (Hoedt and Dimmlich 1995; Alheit and Niquen 2004; Ward *et al.* 2006c), squid (O'Sullivan and Cullen 1983), seabirds (Montevecchi *et al.* 1995; Dann *et al.* 2000; Crawford 2003) and marine mammals (Ohizumi *et al.* 2000; Page *et al.* 2005). Populations of predators fluctuate in response to changes in productivity in the regions where they feed. Therefore, aspects of the reproductive and feeding ecology of predators have been used to monitor the health of marine ecosystems, assess changes in environmental conditions, and monitor effectiveness of fishery management regimes (Wanless *et al.* 1982; Rindorf *et al.* 2000; Boyd *et al.* 2006). A study assessing the importance of Sardine in the diet of marine predators in waters of the eastern Great Australia Bight (Goldsworthy *et al.* 2011) found no evidence of ecological impacts from the SASF.

The effect of the Sardine mortality events on marine predators provides evidence of the important role in the pelagic ecosystems off southern Australia. In Victoria, negative impacts of the Sardine mortality events on apex predators were documented for little penguins (*Eudyptula minor*) and little terns (*Sterna albifrons*) in 1995/1996 (Dann *et al.* 2000; Taylor and Roe. 2004), and Australasian gannets (*Morus serrator*) in 1998/1999 (Bunce and Norman 2000; Bunce *et al.* 2005). In South Australia, McLeay *et al.* (2008) investigated the

diet, age structure, and morphology of a population of crested tern (*Sterna bergii*) to determine whether survival and growth were reduced for cohorts reared in years immediately following Sardine mortality events. Age-specific information collected from banded adults indicated that the cohort reared after the first Sardine mortality event in 1995 exhibited significantly lower rates of recruitment than predicted by life-table analyses. This suggested that survival was reduced in response to the absence of Sardine. Females from cohorts reared one year after the end of each Sardine mortality event (in 1996 and 1999) were smaller than other age classes, suggesting that chick growth was reduced during periods of low Sardine abundance.

1.2.11 Stock assessment

Daily Egg Production Method

The DEPM (Parker 1980; Lasker 1985) has been used to estimate the spawning biomass of Sardine in South Australia since 1995. The DEPM was originally developed for direct stock assessment of the northern anchovy, *Engraulis mordax*, off the west coast of North America (Parker 1980). The method relies on the premise that the biomass of spawning adults can be calculated by dividing the mean number of pelagic eggs produced per day throughout the spawning area, i.e. total daily egg production, by the mean number of eggs produced per unit mass of adult fish, i.e. mean daily fecundity (Lasker 1985).

The DEPM can be applied to fishes that spawn multiple batches of pelagic eggs over an extended spawning season (e.g. Parker 1980). Data used to estimate DEPM parameters are typically obtained during fishery-independent surveys. The key assumptions of the method are that: 1) surveys are conducted during the main (preferably peak) spawning season; 2) the entire spawning area is sampled; 3) eggs are sampled without loss and identified without error; 4) levels of egg production and mortality are consistent across the spawning area; and 5) representative samples of spawning adults are collected during the survey period (Parker 1980; Alheit 1993; Hunter and Lo 1997; Stratoudakis *et al.* 2006).

The DEPM has been used for stock assessment of at least 15 species of small pelagic fishes, mostly clupeoids (e.g. Stratoudakis *et al.* 2006). Although the method is used widely, a range of problems have been encountered and estimates of spawning biomass are generally considered to be accurate (unbiased) but relatively imprecise (e.g. Alheit 1993; Hunter and Lo 1997; Stratoudakis *et al.* 2006). The imprecision that characterises the DEPM is mainly due to uncertainties associated with the estimation of total daily egg production (P_0) and spawning area (A) (Fletcher *et al.* 1996; McGarvey and Kinloch 2001; Ward *et al.* 2001a;

Gaughan *et al.* 2004; Stratoudakis *et al.* 2006). However, many studies have also been impeded by difficulties associated with obtaining representative samples of spawning adults for estimation of adult reproductive parameters, especially spawning fraction (S) (see Stratoudakis *et al.* 2006). There are relatively few published examples where the DEPM has been applied for extended periods and robust estimates of all parameters have been obtained consistently.

At least two reviews have concluded that the DEPM may be better tailored to anchovies (*Engraulis* spp.) than Sardine (Alheit 1993; Stratoudakis *et al.* 2006). The main argument used to support this assertion is that a higher proportion of anchovies are actively spawning during the peak spawning season and allowing daily fecundity to be estimated more precisely for anchovies than Sardine (e.g. Alheit 1993; Stratoudakis *et al.* 2006). Despite the possible limitations of the method for stock assessment of Sardine, the DEPM is currently considered the best technique available for this species off the west coast of North America (e.g. Lo *et al.* 1996, 2005) and the western and southern coasts of Australia (Fletcher *et al.* 1996; Ward *et al.* 2001b; Gaughan *et al.* 2004). However, there are important differences between locations in the manner in which egg and adult samples are collected, data are analysed and estimates of spawning biomass are used to support fisheries management. For example, adult samples are usually collected by mid-water trawling off California, purse-seining off Western Australia (Gaughan *et al.* 2004) and gill-netting off South Australia (Ward *et al.* 2001b).

Acoustic techniques

Acoustic techniques have been widely used for the stock assessment of small pelagic fishes (Beckley and van der Lingen 1999; van der Lingen and Huggett 2003; Simmonds and MacLennan 2005), and these studies have significantly contributed to understanding Sardine movement (Barange *et al.* 1999), stock structure (Barange and Hampton 1997), relationships with oceanographic features (Lynn 2003; Tameishi *et al.* 1996), predator-prey interactions and inter-annual variability in abundance (Barange *et al.* 1999). Sources of error in acoustic estimation of biomass include: variations in target strength due to spatial or temporal differences in fish behaviour (Freon *et al.* 1993), difficulties associated with discrimination of species and size classes, and spatial sampling error (Simmonds and MacLennan 2005). Acoustic surveys often produce biased estimates of biomass and require more sophisticated and expensive infrastructure, higher levels of technical support and expertise, and a longer developmental phase than the DEPM.

1.2.12 Management procedures in small pelagic fisheries

Modern fisheries management aims to constrain exploitation rates within ecologically sustainable limits while maximising potential yields. This is done by establishing harvest strategies with performance indicators and reference points (Gabriel and Mace 1999). Harvest strategies that include agreed operational targets and decision rules have been successfully incorporated into the management systems of several commercial small pelagic fisheries, including the South African Pelagic Fishery, Western Australian Pilchard Fishery, Pacific Sardine Fishery and SASF (Cochrane *et al.* 1998; De Oliveira *et al.* 1998; Cochrane 1999; Gaughan *et al.* 2004; Gaughan and Leary 2005; Hill *et al.* 2005).

Smith *et al.* (2015) suggested that target and limit reference points for spawning biomass of small pelagic species in Australian waters, including Sardine, of 50% (B_{50}) and 20% (B_{20}) of the unfished level, respectively, are “safe from an ecosystem perspective and provide reasonable levels of yield”. Smith *et al.* (2015) also suggest that exploitation rates below 33% are likely to maintain the median spawning biomass of Sardine above B_{50} and the chance of falling below B_{20} at less than 10%.

The South Australian Sardine Fishery

The SASF is currently managed by the *Fisheries Management (Marine Scalefish Fisheries) Regulations 2006*, *Fisheries Management Act 2007* and *Fisheries Management (General) Regulations 2007*. Management goals for the SASF are consistent with the objectives of the *Fisheries Management Act 2007* and are outlined in the current Management Plan (PIRSA 2014). Management measures include entry limitations, gear restrictions and individual transferable quotas. Purse seine nets must not exceed 1,000 m in length or 200 m depth. There are currently 14 license holders with several companies operating multiple licenses. The costs of the policy, compliance and research programs that are needed to manage the SASF are recovered through license fees collected by PIRSA Fisheries and Aquaculture.

The Total Allowable Commercial Catch (TACC) was set at 1,000 t in 1991 and 1992, and increased to 3,500 t during 1993-1997 (Figure 1-1). In 1998, the TACC was set at 12,500 t, but this was reduced to 4,700 t and 3,800 t in 1999 and 2000, respectively, after the mass mortality event in late 1998. The TACC increased to reach 51,100 t in 2005 and was reduced to 25,500 t in 2006. From 2007 to 2009, the TACC was set at 30,000 t. During 2010 to 2014, the TACC was set at 34,000 t (PIRSA 2014). From 2010, onwards, there has been a cap of 27,000 or 30,000 t on the catch taken from Spencer Gulf (Figure 1-1, Figure 1-2).

In this report the SASF is divided into three broad spatial regions: Spencer Gulf, Outside Zone and Gulf St Vincent (Figure 1-2).

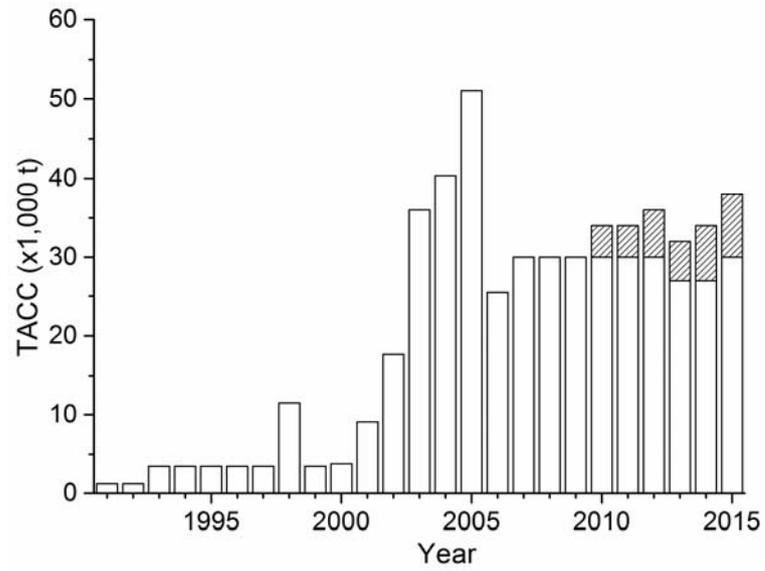


Figure 1-1. Total Allowable Commercial Catch (TACC) for the SASF between 1991 and 2015 (hashed TACC for 2010-2015 is to be caught outside traditional fishing area).

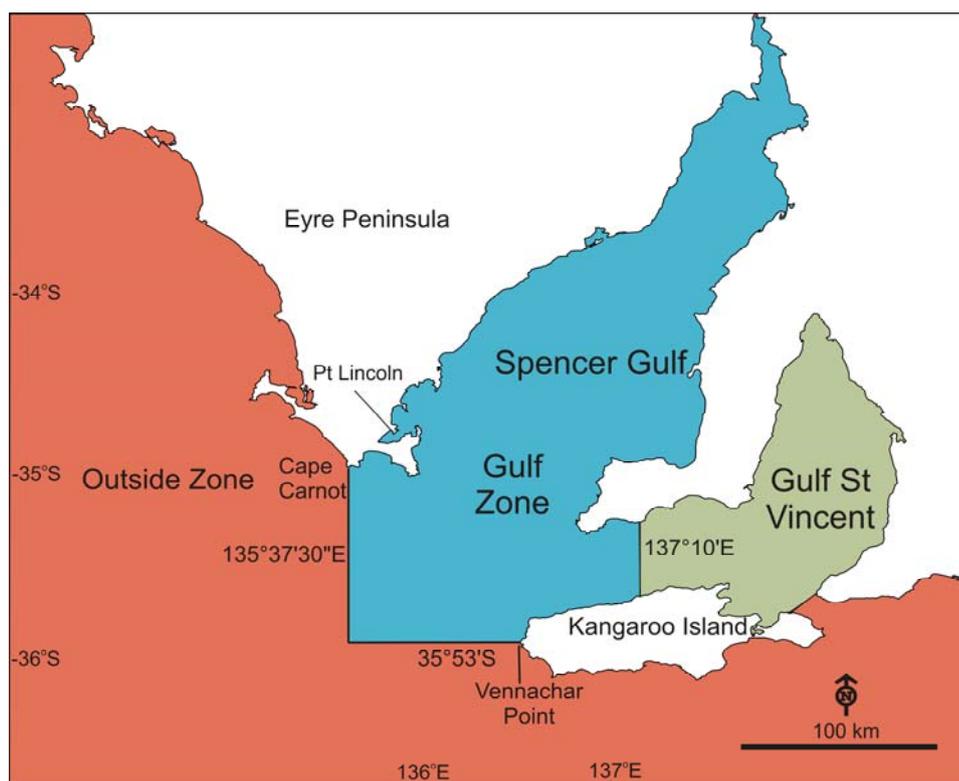


Figure 1-2. Locations along the coastline of South Australia mentioned in the text of this report.

Harvest Strategy

Since 1998, the key biological performance indicator for the SASF has been the estimate of spawning biomass obtained using the DEPM. From 1997 to 2006, the TACC for the following calendar year was set as a proportion of the spawning biomass (i.e. 10.0-17.5%, depending on the size of the spawning biomass). From 2007 to 2009, the indicative TACC was set at 30,000 t (PIRSA 2007), while the latest estimate of spawning biomass obtained using the DEPM remained between 150,000 and 300,000 t. In 2010, spatial management was established in the fishery.

In 2014, a spatial management framework was formalised for the SASF (Figure 1-3). A tiered Harvest Strategy (Figure 1-4) was established that sets the TACCs based on the size of the spawning biomass and level of monitoring (Table 1-1). At Tier 3, the DEPM and fishery assessments are done in alternate years and the maximum TACC is 38,000 t. At Tier 1, the DEPM and fishery assessments are both undertaken annually and the maximum TACC is 47,500 t. At Tier 2, either DEPMs or assessments are done annually (with the other done biennially) and the maximum TACC is 42,750 t. Lower TACCs are set at each Tier if the spawning biomass is below 190,000 t.

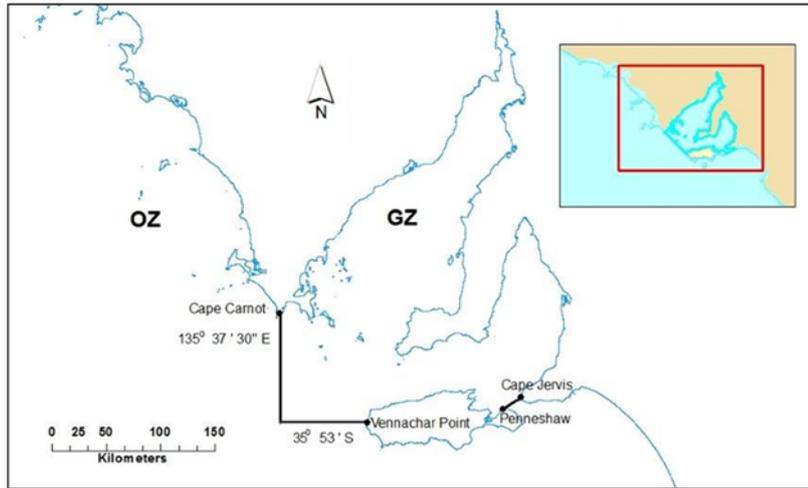


Figure 1-3. The two spatial management zones defined in the harvest strategy for the SASF. Abbreviations: OZ, Outside Zone; GZ, Gulfs Zone (source PIRSA 2014).

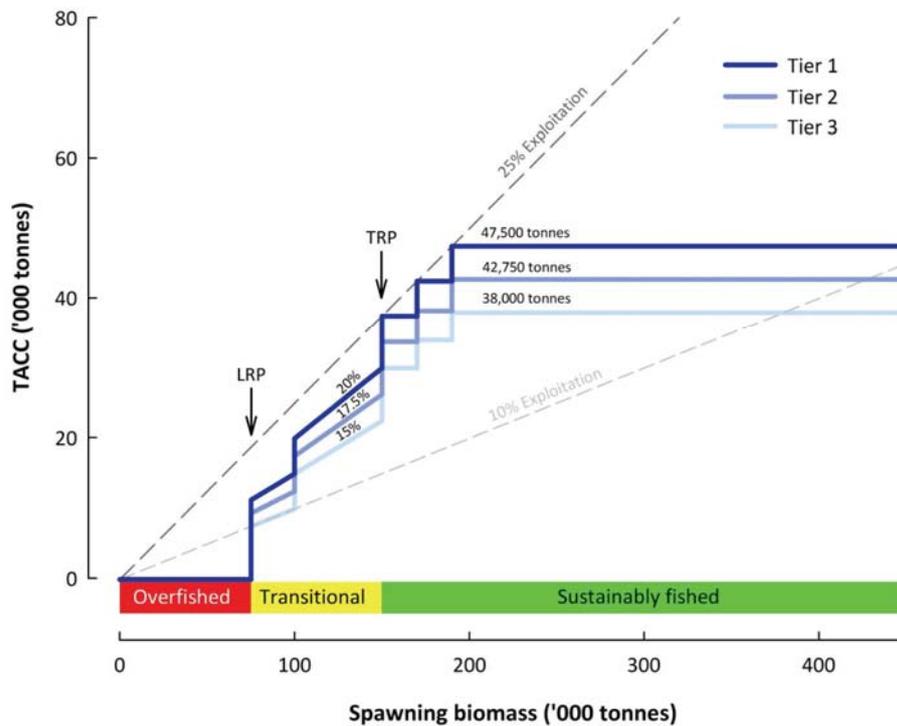


Figure 1-4. The relationship between spawning biomass, stock status and level of exploitation (or TACC) of the Sardine harvest strategy for each tier (LRP = limit reference point; TRP = target reference point).

The catch that can be taken from Spencer Gulf is controlled on the basis on the mean size (Fork Length, FL) of Sardine taken in catches from Gulf Zone in the previous year (Table 1-2; Figure 1-3). If the mean size is above 142 mm FL, up to 30,000 t can be taken from Spencer Gulf whereas if it is below 135 mm FL, the maximum catch from Spencer Gulf is

24,000 t. If the mean size between 135 and 142 mm, the maximum catch from Spencer Gulf is 27,000 t.

Table 1-1. Decision making rules for the tiered Harvest Strategy.

Spawning Biomass			Tier 1		Tier 2		Tier 3	
			TACC (t)	Maximum Exploitation	TACC (t)	Maximum Exploitation	TACC (t)	Maximum Exploitation
190000 t <	SpB		47,500 t	25%	42,750 t	22.5%	38,000 t	20%
170000 t <	SpB	≤ 190000 t	42,500 t	25%	38,250 t	22.5%	34,000 t	20%
150000 t <	SpB	≤ 170000 t	37,500 t	25%	33,750 t	22.5%	30,000 t	20%
100000 t <	SpB	≤ 150000 t	20% of SpB	20%	17.5% of SpB	17.5%	15% of SpB	15%
75,000 t <	SpB	≤ 100000 t	15% of SpB	15%	12.5% of SpB	12.5%	10% of SpB	10%
	SpB	≤ 75000 t	Closed	0%	Closed	0%	Closed	0%

Table 1-2. Catch allocation decision table for the harvest strategy for the SASF to guide the maximum TACC allowed from the Gulf Zone (GZ) (PIRSA 2014).

Mean size of Sardines (MSS) in GZ	Maximum catch limits for GZ
142 mm < MSS	30,000 t
135 mm < MSS ≤ 142 mm	27,000 t
MSS ≤ 135 mm	24,000 t

1.6 Stock Status Classification

A national stock status classification system has been developed to assess key Australian fish stocks (Table 1-3; Flood *et al.* 2014). The classification system combines information on current stock size and the level of fishing pressure to assess 'stock status' (Flood *et al.* (2014). Each stock is classified as: 'sustainable', 'transitional-recovering', transitional-depleting', 'overfished', 'environmentally limited', or 'undefined' as outlined in Table 1-3.

As outlined in section 1.2.3 of the current report, for the purposes of fisheries management the Australian Sardine population is considered to be comprised of four separate stocks (Whittington *et al.* 2008; Izzo *et al.* 2012). The SASF targets the Southern Australian stock, which occurs off South Australia and western Victoria (Izzo *et al.* 2012). The Southern

Australian stock was assessed as being sustainable in the most recent Status of Key Australian Fish Stocks (Flood *et al.* 2014).

Table 1-3. Stock status terminology (Flood *et al.* 2014).

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

2.0 FISHERY INFORMATION

2.1 Introduction

This chapter presents catch, effort, catch-per-unit-effort (CPUE) and size/age composition data for the SASF from 1 January 1991 to 31 December 2014. Information is used to describe spatial and temporal patterns in fishing activities. Data presented in this chapter are key inputs to the population model (Chapter 5).

2.2 Methods

2.2.1 Data collection

Catch and effort data were collated from data in fishery logbooks. Prior to 2001, effort and catch were reported with respect to the pre-existing South Australian Marine Fishing Areas (MFAs). In 1998, following the implementation of the Sardine fishery logbook, effort and catch were reported by latitude/longitude. Estimated annual catches are aggregates of daily catches recorded in logbooks. CPUE is estimated from aggregates of catch and effort data in fishery logbooks. Actual total annual catches were estimated from Catch Disposal Records (CDR) collated by PIRSA Fisheries and Aquaculture.

2.2.2 Commercial catch sampling

Between 1995 and 2014, samples of the commercial catch were collected from vessels under a range of sampling protocols, most recently by independent observers who are present on about 10% of fishing trips. Size frequencies were constructed from caudal fork lengths (FL), aggregated into 10 mm length classes for all samples. Age determination methods are described in Chapter 3.

Sex ratio

The proportion of females in commercial catch samples was calculated using the equation:

$$SR = \frac{nF}{(nF + nM)}$$

where, nF is the number of females and nM is the number of males in samples. Two sided exact ratio tests (Fay 2010) were used to determine if the proportion of females in the population was significantly different from 0.5. To account for the application of multiple significance tests a Bonferroni adjustment was made to the alpha value at which the null hypothesis is accepted (Kutner *et al.* 2005). Sex was not recorded for commercial samples obtained in 2007.

2.3 Results

2.3.1 Effort, catch and CPUE

Annual patterns

The SASF expanded quickly after its inception in 1991 with total effort and catches recorded in logbooks increasing from 5 boat-nights and approximately 7 t during 1991 to 736 boat-nights and 3,241 t in 1994 (Figure 2-1). However, total effort and catch were reduced significantly in 1995 as a result of the first mass mortality event (Ward *et al.* 2001b), but increased rapidly to reach 530 boat-nights and 5,973 t in 1998. In 1999, after the second mass mortality event in late 1998 (Ward *et al.* 2001b), effort and catch declined to 345 boat-nights and 3,081 t, respectively.

Since the second mortality event, the fishery has expanded rapidly, with total effort reaching 1,274 net-sets across 1,233 boat-nights in 2005, with an estimated total catch of 39,831 t (Figure 2-1). Between 2007 and 2012, total effort was relatively stable at approximately 850-1100 net-sets over 700-900 boat-nights with an estimated catch of 27,500-32,000 t. In 2013, effort declined to 760 net-sets made over 688 boat-nights for an estimated catch of 30,506 t. In 2014, 816 net-sets were over 706 nights for a catch of 32,357 t.

Total annual catches recorded in CDRs have exceeded catches estimated in logbooks in most years. Actual catches increased from 2,597 t in 1995 to 42,475 t in 2005, and fell to 25,137 t in 2006 (Figure 2-1). Since 2007, catches in CDRs have ranged from 29,854 to 33,990 t.

Mean CPUE was calculated per boat-night between 1991 and 2001 and per net-set and boat-night between 2001 and 2014 (Figure 2-1). Mean $CPUE_{(boat-night)}$ increased from 1.3 t.boat-night⁻¹ in 1991 to 11.3 t.boat-night⁻¹ in 1998 and reached 35.6 t.boat-night⁻¹ in 2004. Between 2004 and 2011 $CPUE_{(boat-night)}$ ranged between 32.3 and 37.6 t.boat-night⁻¹. $CPUE_{(boat-night)}$ then increased to 44.2 t.boat-night⁻¹ in 2012 and was 45.8 t.boat-night⁻¹ in 2014. Mean $CPUE_{(net-set)}$ increased from 7.6 t.net-set⁻¹ in 2001 to 32.4 t.net-set⁻¹ in 2004. $CPUE_{(net-set)}$ remained between 28.2 and 33.5 t.net-set⁻¹ between 2004 and 2012, increased to 40.1 t.net-set⁻¹ in 2013 and was 39.7 t.net-set⁻¹ in 2014.

Intra-annual patterns

Between 1991 and 2014, there has been a reasonably consistent intra-annual pattern in fishing effort (Figure 2-2). Relatively little fishing is usually conducted during August to

October. Effort and catches often begin to increase in November/December, prior to the start of the Southern Bluefin Tuna farming season. Catches continue to increase during January-February and usually peak in March-June. The peak fishing season reflects the extended periods of calm weather between April and June and the high demand for Sardine to feed Southern Bluefin Tuna following their capture during summer. The months in which significant catches have been taken from the Outside and Gulf St Vincent Zone have varied among years.

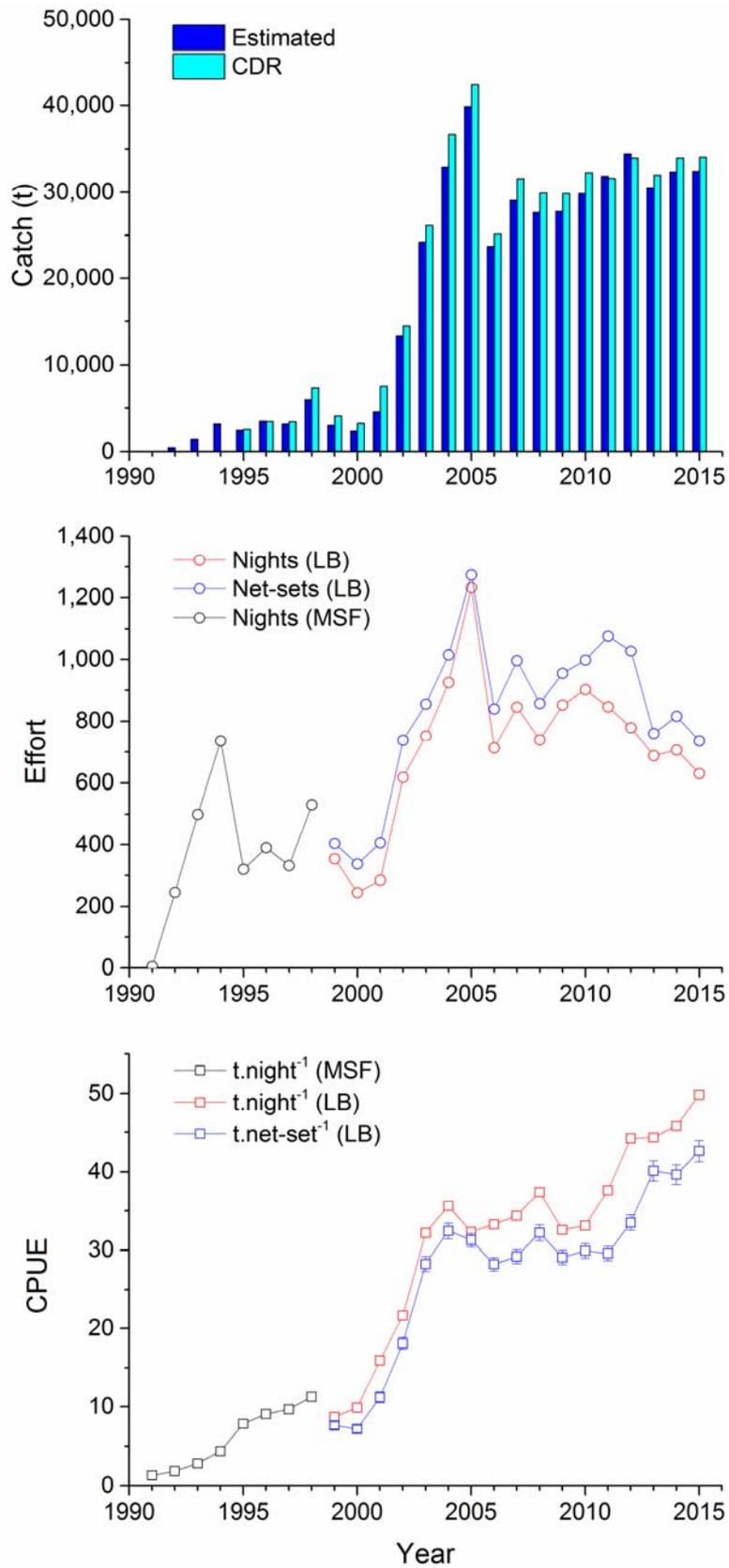


Figure 2-1. Total catches (logbooks, CDR), fishing effort (nights, net-sets), and mean annual CPUE (t.night⁻¹, t.net-set⁻¹, ±SE). Data prior to 1999 is derived from Marine Scalefish records, specific SASF logbooks were introduced in 1999.

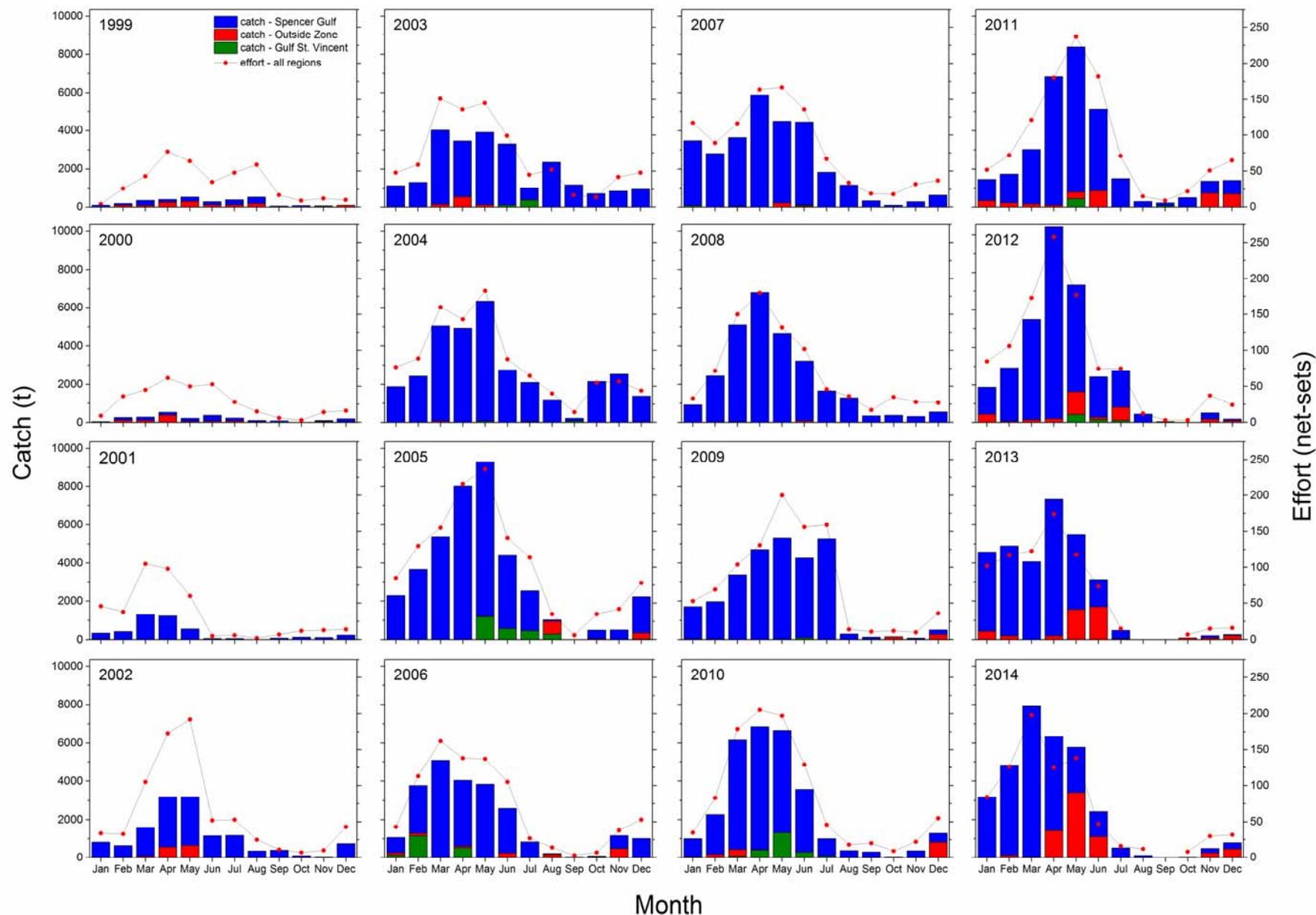


Figure 2-2. Intra-annual patterns in Sardine catch (tonnes, bars) by region, and effort (number of net-sets, red circles, all regions) in the SASF between 1999 and 2014.

Spatial patterns

From 1992, up until the first mortality event in 1995, most Sardines were taken from Spencer Gulf (Figure 2-3). A small proportion of the catch was taken from the Outside Zone in 1999 and 2000 (Figure 2-3, 2-4). In 2002, ~90% of the catch was taken north-east of Thistle Island and ~9.5% was taken off Coffin Bay (Figure 2-4). In 2003, as the TACC increased the fishery expanded northwards in Spencer Gulf and an increasing proportion of the catch was taken closer to shore. Further spatial expansion occurred during 2004, and a large proportion of the total catch was taken near Wedge Island and east of Althorpe Island. Significant catches were also taken along the northern coast of Kangaroo Island, between Cape Borda and Marsden Point. In 2005, when the TACC was set at 51,100 t, the spatial extent of the SASF expanded substantially. The eastern Great Australian Bight and inshore areas around the Sir Joseph Banks Group and along the west coast of Spencer Gulf were fished more heavily than in previous years. The TACC was reduced to 26,000 t in 2006 and the area fished contracted, with the largest catches taken from southern Spencer Gulf, near Thistle, Wedge and Althorpe Islands and further north near Arno Bay. Relatively large catches were also taken in Investigator Strait. Between 2007 and 2009, the area fished remained relatively consistent with the majority of fishing occurring in southern Spencer Gulf (Figure 2-5). Since 2010, when additional quota was allocated outside of the Spencer Gulf, a significant amount of catch has been taken from Investigator Strait, Gulf St Vincent and waters between Anxious Bay and Flinders Island.

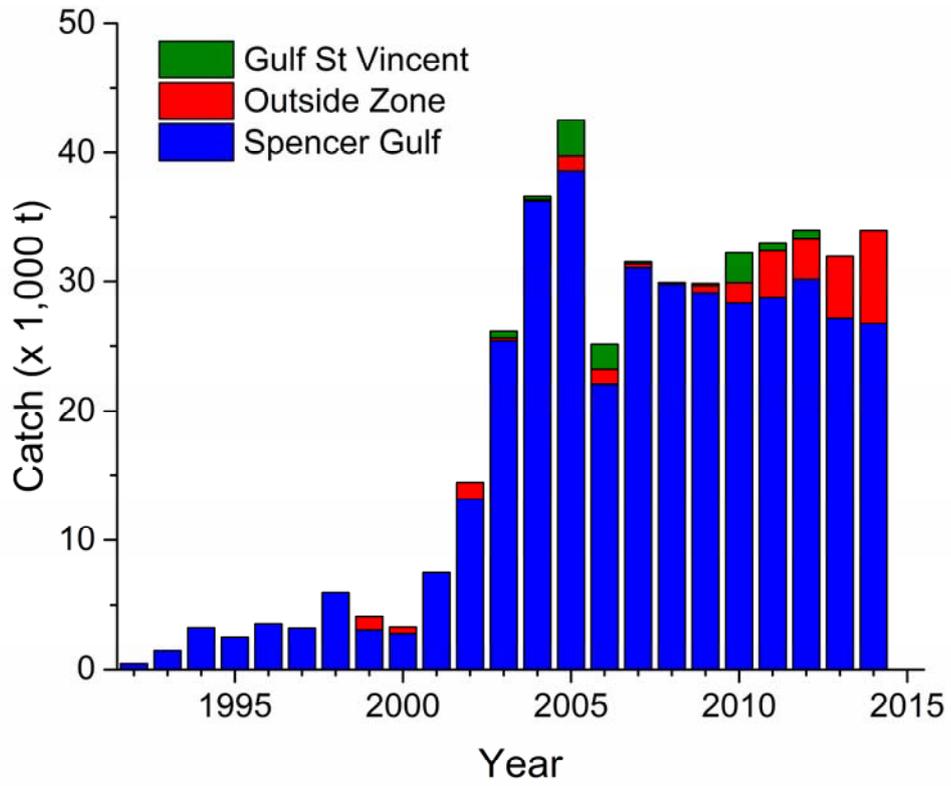


Figure 2-3. Spatial trends in catch and between 1991 and 2014.

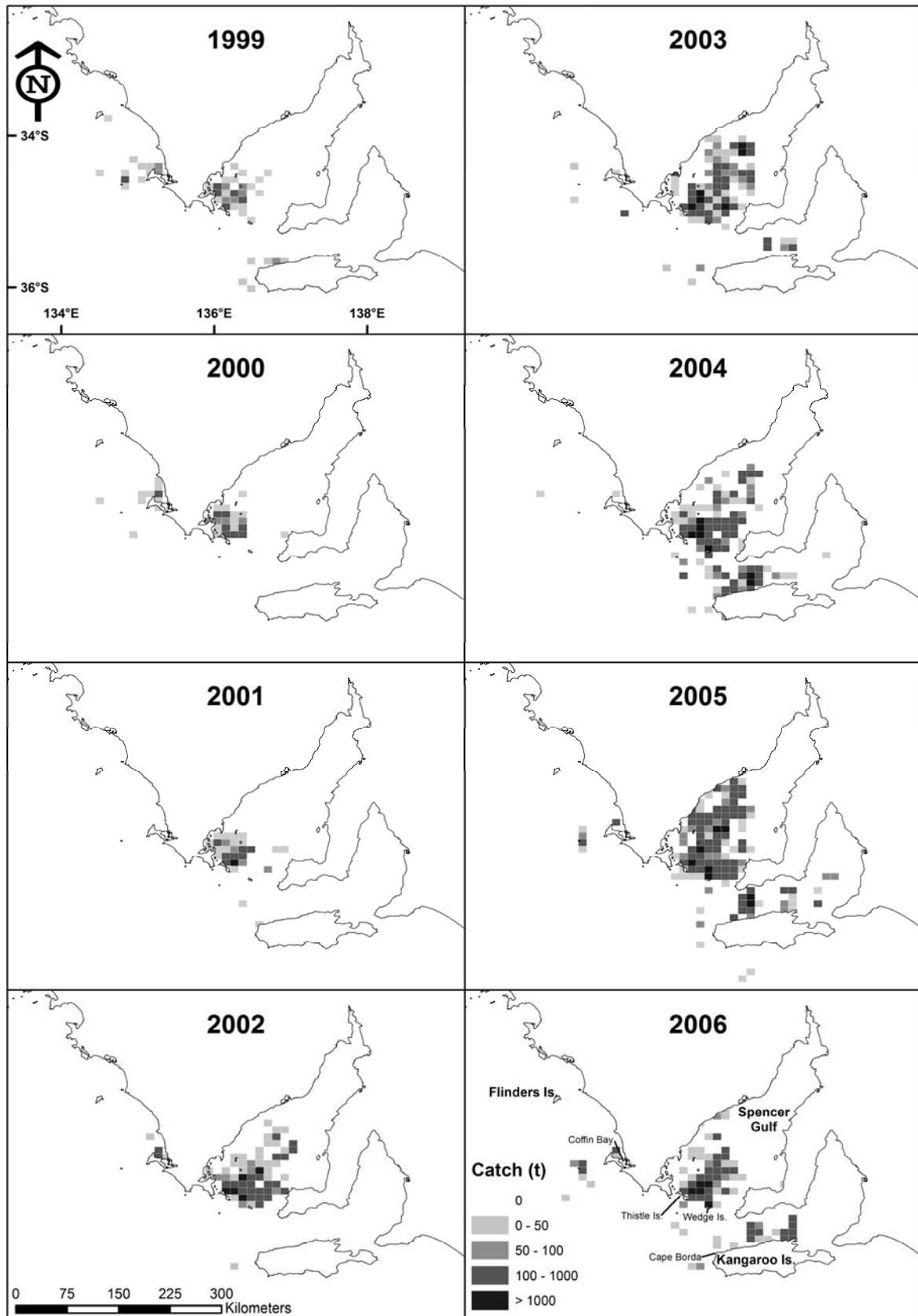


Figure 2-4. Spatial trends in annual catches between 1999 and 2006.

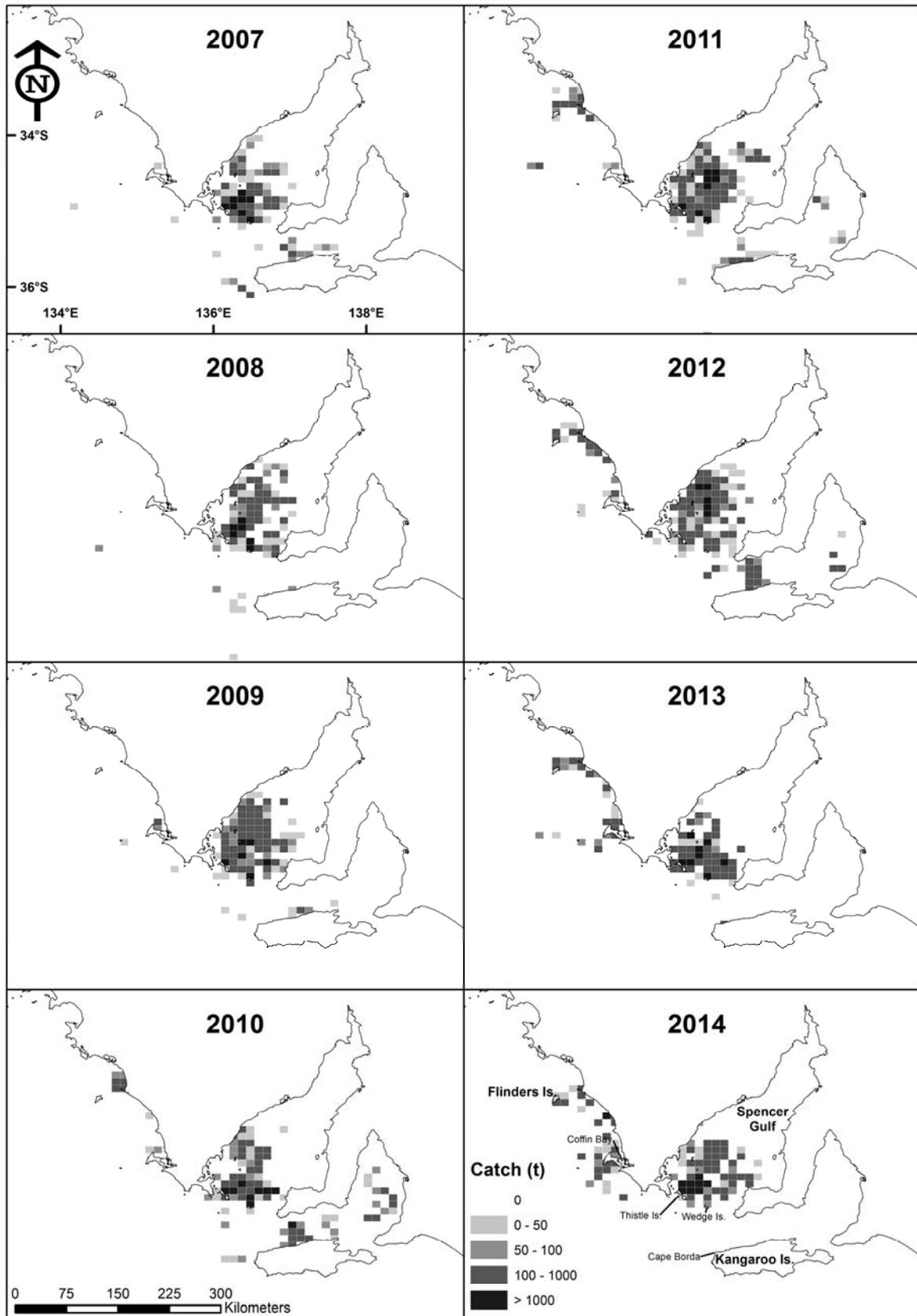


Figure 2-5. Spatial trends in annual catches between 2007 and 2014.

2.3.2 Catch composition

Size frequency

Between 1995 and 1999, Sardine taken from Spencer Gulf were mostly 120-170 mm FL, with modes at 130-140 mm (Figure 2-6). Between 2000 and 2002, Sardine were mostly >150 mm FL with modes between 160 and 170 mm FL. In 2003 and 2004, catch samples were bimodal as significant quantities of juveniles (80-120 mm) were caught in addition to adults (150-180 mm). Prior to 2003, no catch samples included Sardine ≤ 100 mm FL. Between 2005 and 2009, size distributions for commercial catches remained stable with a mode at 150 mm FL and fish ranging from 120 to 200 mm. In 2010, the modal size of fish remained at 150 mm FL, but for the first time since 1999 more fish were below the mode size than above it (Figure 2-6). The mode declined to 140 and 130 mm FL in 2011 and 2012, respectively. In 2013 and 2014, the mode increased to 140 mm FL with ~50% and 40% greater than 140 mm FL, respectively.

In the Outside Zone Sardine of 150-180 mm FL dominated catches between 1995 and 1998 (Figure 2-7). In 1999, after the second mortality event the modal length fell to 130 mm FL, but increased to 150 mm FL in 2000. Catches from the Outside Zone were bimodal in 2002 and 2003, but sample sizes were relatively small. In 2004, the modal size was 140 mm FL and this increased to 170-190 mm in 2005-07. In 2008, the modal length was 160 mm FL, but sample size was again small in this year. Between 2010 and 2012, the modal size for fish from the Outside Zone remained at 170 mm FL. In 2013, the modal size was 160 mm FL and in 2014 catches were bimodal, with modes at 140 and 180 mm FL.

Catches from Gulf St Vincent were comprised of relatively large Sardine in 2008 (mode 170 mm FL) with a smaller mode of ~140 mm FL in 2009 and 2010 (Figure 2-8). In 2011, the modal size of Sardine from Gulf St Vincent decreased further to ~130 mm FL and was bimodal in 2012 at 120 and 140 mm FL. In 2013 and 2014, the modal size of Sardine from Gulf St Vincent was 150 mm FL.

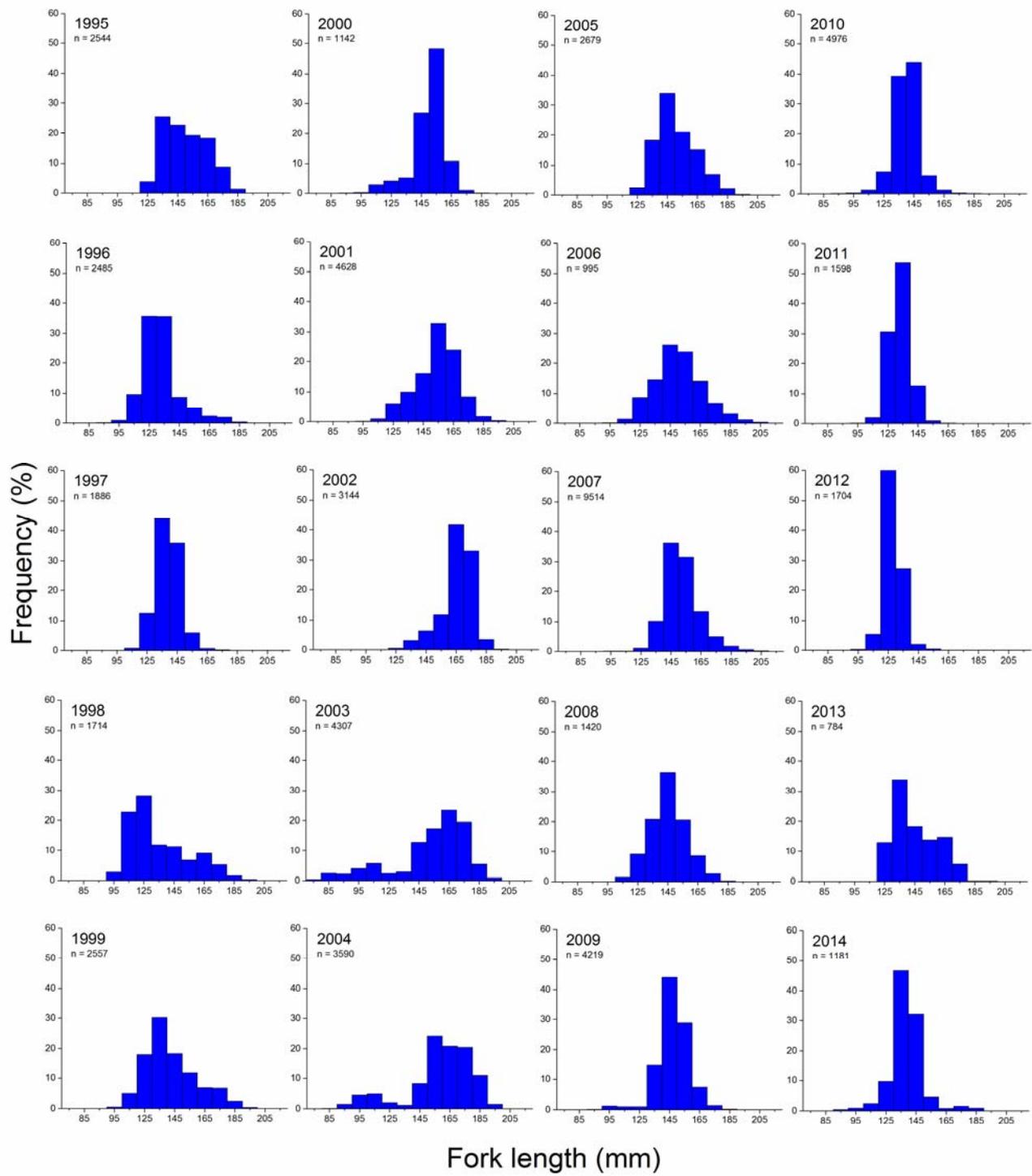


Figure 2-6. Length frequency distributions of Sardine from commercial catch samples for Spencer Gulf between 1995 and 2014.

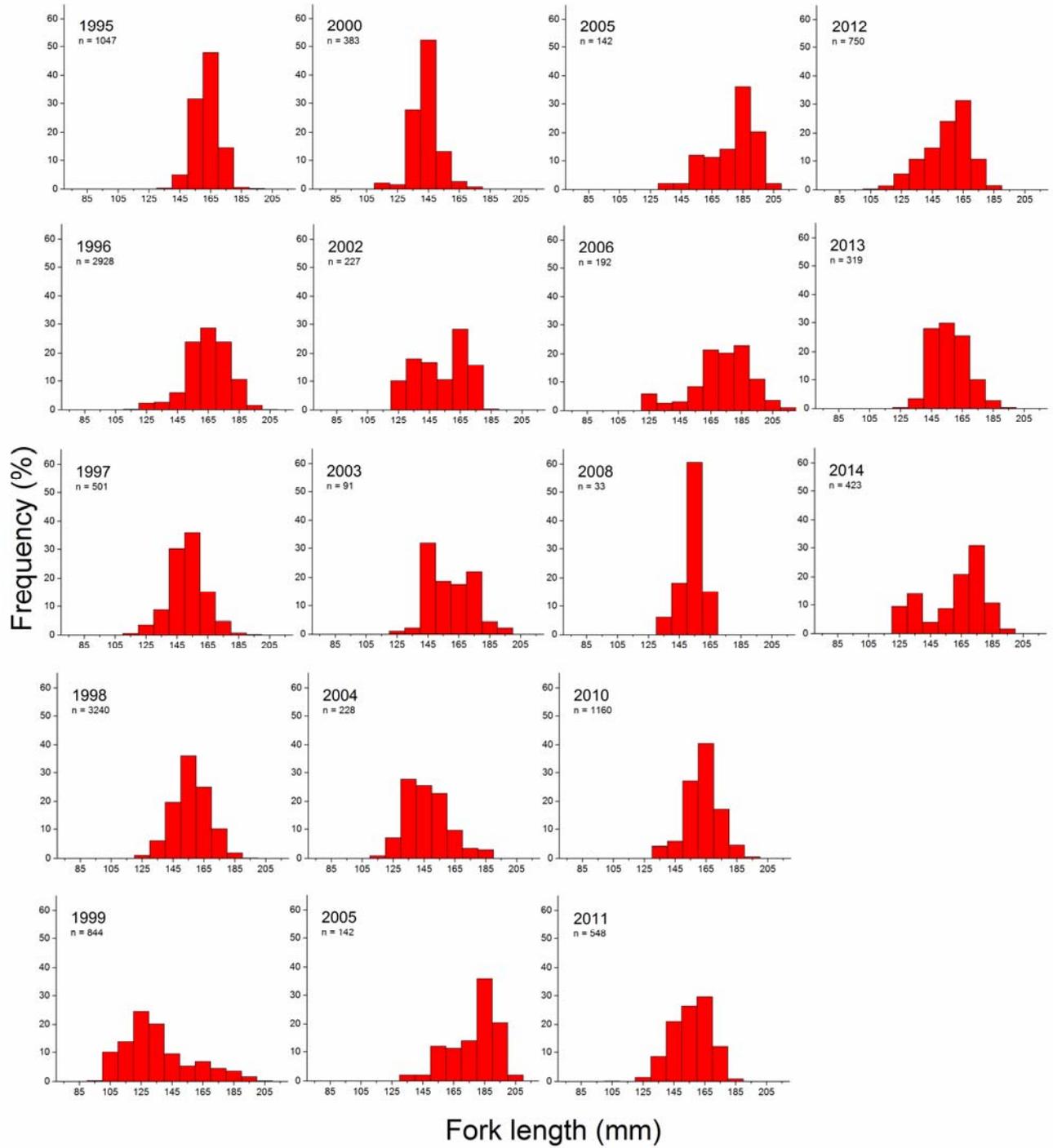


Figure 2-7. Length frequency distributions of Sardine from commercial samples for the Outside Zone between 1995 and 2014.

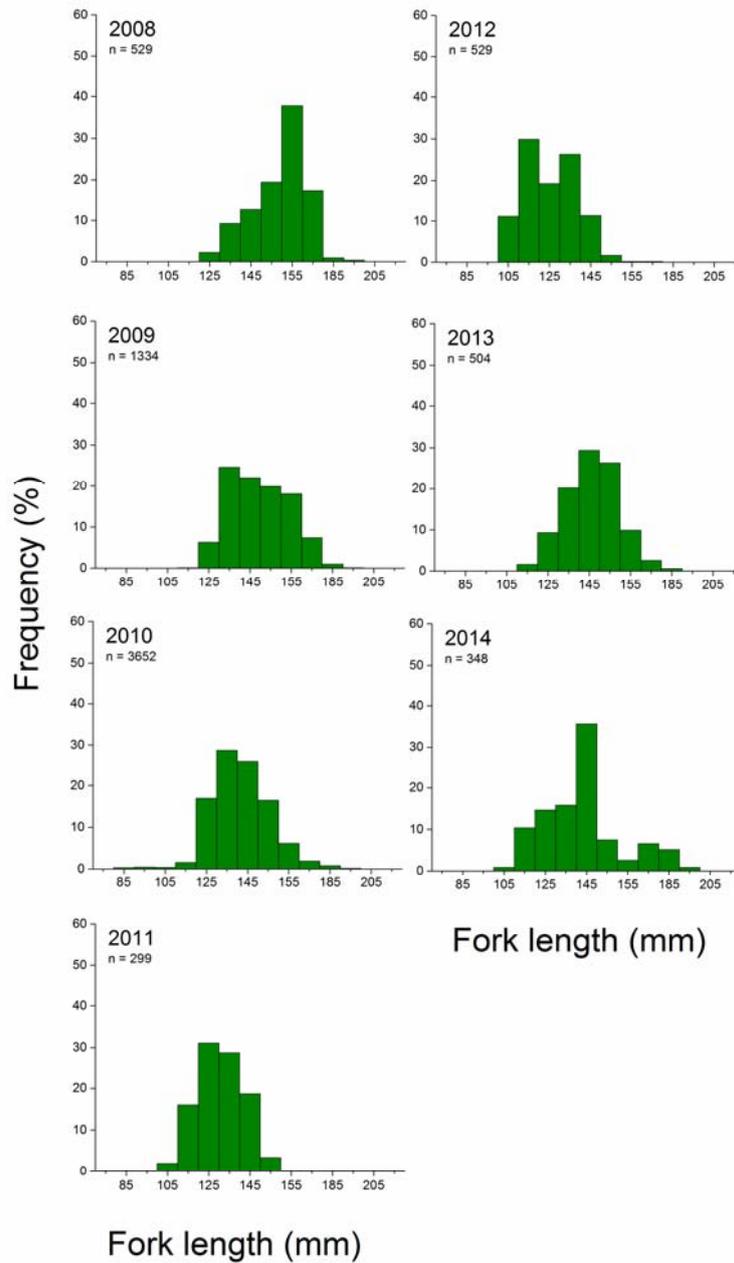


Figure 2-8. Length frequency distributions of Sardine from commercial samples for the Gulf St Vincent Region between 2008 and 2014 for years when samples were available.

Mean size

The mean size of Sardine from Spencer Gulf ranged from 133 to 143 mm FL between 1995 and 1998 and rose to 166 in 2002 (Figure 2-9). Between 2003 and 2009 mean fish length in Spencer Gulf was relatively stable between 146 and 159 mm FL and declined to 128 mm FL in 2012. In 2013 and 2014 the mean size of Sardine from Spencer Gulf was 147 and 139 mm FL, respectively.

The mean size of Sardine from the Outside Zone was generally higher than Spencer Gulf (Figure 2-9), particularly in 2005 and 2006. Between 2010 and 2014, when mean fish size declined in Spencer Gulf the mean size from the Outside Zone remained relatively high, ranging between 155 and 163 mm FL. Samples from Gulf St Vincent were only available from 2009 to 2014 and although initially higher, subsequently followed a similar trend to Spencer Gulf (Figure 2-9).

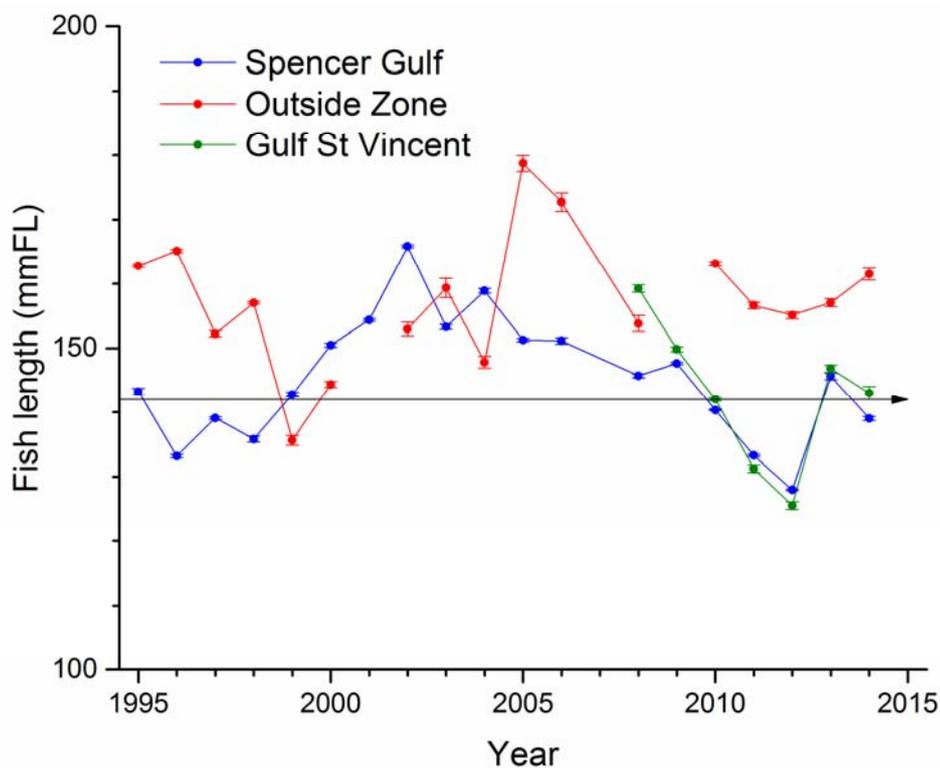


Figure 2-9. Average fork length (FL) by year for commercial samples from the three regions of the SASF, error bars are standard error. Horizontal line indicates the reference point for maximum catch limit for Spencer Gulf (Table 1-2).

2.4 Discussion

One of the most notable features of the SASF has been its rapid growth. The TACC for 2014 (34,000 t) was 34 times the TACC in 1992 (1,000 t) and almost ten times the TACC in 2000 (3,500 t). The TACC for 2015 is 38,000 t. This rapid growth occurred despite the impacts of two mass mortality events, each of which is thought to have killed more fish than any other single-species mortality event recorded (Jones *et al.* 1997; Ward *et al.* 2001b).

Another notable feature of the SASF is the stability in catches over recent years. This stability has been achieved by establishing harvest strategies that address the imprecision in estimates of spawning biomass obtained using the DEPM. Under the previous harvest strategies for the SASF, and the management arrangements for many other Sardine fisheries (e.g. US Pacific Sardine Fishery, Hill *et al.* 2005, 2008), TACCs can vary significantly among years in response to changes in estimates of spawning biomass that may be more reflective of the imprecision in the DEPM rather than changes in stock size.

The concentration of fishing effort in a relatively small proportion of the total area over which the managed population is distributed has been a notable feature of the SASF. Since 2010, a range of management arrangements have been implemented to limit the catch from Spencer Gulf and increase the catch from the Outside Zone. This has culminated in explicit rules for limiting the total catch that can be taken from Spencer Gulf based on the mean size of fish taken from that Zone (Gulf Zone, PIRSA 2014), which appear to have been successful in improving the mean size of fish taken in the fishery.

3.0 AGE COMPOSITION AND REPRODUCTIVE BIOLOGY

3.1 Introduction

This chapter describes the methods used to determine age compositions from the commercial catch of Sardine in South Australian waters. Methods described in this chapter to develop the catch-at-age data are key inputs to the population model presented in Chapter 5.

3.2 Methods

3.2.1 Age-determination

Otolith preparation and interpretation

Sagittal otoliths were collected from sub-samples of the commercial catch sample ($n = 10-20$) and fishery-independent samples. Otoliths were soaked overnight in 10% sodium hypochlorite solution to remove excess tissue, rinsed in distilled water and dried in IWAKI™ plastic microplates. Translucent zone counts were made for one whole otolith from each fish under reflected light, immersed in water against a flat black background (Butler *et al.* 1996).

Readability indices (RI)

Sardine otoliths were classified as 1 = excellent, 2 = good, 3 = average, 4 = poor and 5 = unreadable based on standard criteria relating to their interpretability (see Rogers and Ward 2007).

Decimal age estimated from annuli counts

To estimate decimal age for adults with a translucent zone count of one or more an arbitrary birth-date of March 1 was assigned, which represents the time of peak spawning. The midpoint of translucent zone formation was assumed to be mid-winter (Rogers and Ward 2007). Decimal age (A) was calculated as:

$$A = \begin{cases} (\alpha - \beta_p)/365 + TZC + 0.334 & \alpha \leq \beta_s \\ (\alpha - \beta_s)/365 + TZC + 0.334 & \alpha > \beta_s, \end{cases}$$

where α is the date of capture, β_s is the assumed translucent zone formation date from the same year as α , β_p is the assumed translucent zone formation date from the previous year, TZC is the translucent zone count and 0.334 (4 decimal months) adjusts for the difference between the assigned birth-date and the approximate timing of the first translucent zone.

Age estimated from otolith weight

The relationship between age and otolith weight was determined using a linear model fitted to decimal age and otolith weight data from those otoliths with readability scores of 1 and 2. Aged otoliths from commercial catch samples between 1995 and 2014 and fishery-independent samples between 1998 and 2014 were pooled for the analysis. The resulting model was used to derive an age estimate for all otoliths based on otolith weight. Due to the change in the spatial patterns of fishing over time it is not possible to separate annual effects from regional effects on the relationship (i.e. region and season were confounded), so data from all regions were used in the analysis.

3.2.2 Size at maturity

Ovaries were staged macroscopically where Stage 1 = immature, Stage 2 = maturing, Stage 3 = mature, Stage 4 = hydrated (spawning) and Stage 5 = spent (recently spawned). Testes were staged where Stage 1 = immature, Stage 2 = mature and Stage 3 = mature (running ripe).

The length at which 50% of the population was mature (L_{50}) was estimated using Binomial GLM with a logit link function (logistic regression) from fish sampled during the spawning season. The model was fitted to the numbers of immature (stage 1) and mature (stages ≥ 2) fish in 5 mm size classes, separately for males and females. The use of a GLM allowed weighting by sample size.

Fish of indeterminate sex and those without gonad stage information were excluded along with fish sampled outside the spawning season (1 December to 31 March). Sample sizes were insufficient to estimate size at maturity in all years or for regions other than Spencer Gulf.

3.2.3 Growth

Standard von Bertalanffy growth functions were fitted separately to age (derived from otolith weights) and length data for males and females. Data from commercial catches and fishery-independent sampling were pooled for the analysis.

3.2.4 Gonosomatic index

Mean monthly gonosomatic indices (GSI) were calculated from commercial samples using the equation:

$$GSI = \left[\frac{Gwt}{Fwt_{gonadfree}} \right] \cdot 100$$

where *Gwt* is gonad weight and *Fwt* is gonad-free fish weight for fish with gonads of macroscopic stages ≥ 2 . The mean estimate of GSI of all fish above size at maturity was used for both males and females to determine spawning season. It is important to note that it is sometimes difficult to macroscopically distinguish between Stage 2 and Stage 5 gonads in frozen samples.

3.3 Results

3.3.1 Age-determination

Between 1995 and 2014, a total of 18,809 otoliths from commercial and fishery-independent samples were read. Only 0.2% were assigned a Readability Index (RI) score of 1, while 6.0%, 50.6% and 27.8% were assigned scores of 2, 3 and 4, respectively. Approximately 15.5% were assigned an RI of 5 (Figure 3-1, Table 3-1 and 3-2).

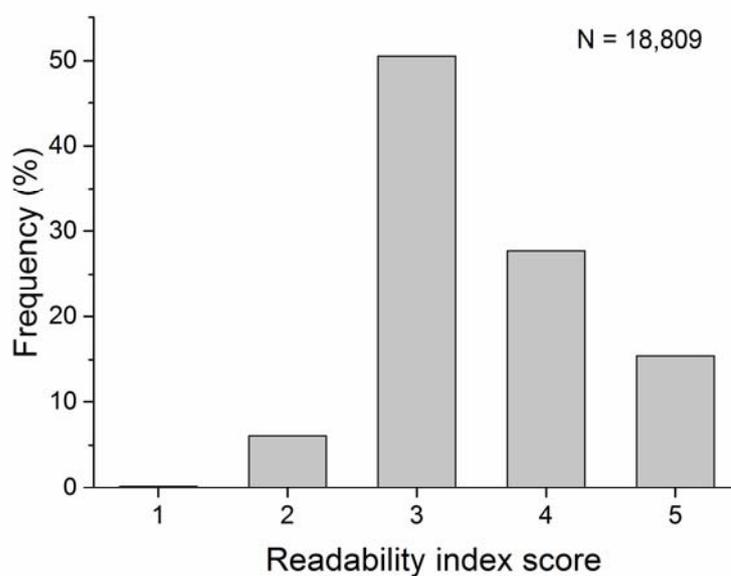


Figure 3-1. Readability Index scores assigned to otoliths from all commercial catch samples between 1995 and 2014.

Table 3-1. Summary of otolith Readability Index scores for otoliths collected between 1995 and 2014.

Year	Readability					Total
	1	2	3	4	5	
1995		86	399	152	1	638
1996	1	143	366	107	8	625
1997		153	270	54	2	479
1998	18	200	789	257	11	1275
1999		50	546	388	18	1002
2000	2	80	489	65	1	637
2001		59	1405	674	105	2243
2002		53	1507	885	131	2576
2003		39	1055	229	18	1341
2004	9	120	684	463	264	1540
2005	1	13	300	235	366	915
2006		9	178	135	467	789
2008		9	144	183	303	639
2009		27	314	370	784	1495
2010	4	64	467	577	73	1185
2011	1	7	111	137	91	347
2012			9	14	13	36
2013		15	222	146	143	526
2014		9	253	149	110	521
All Years	36	1136	9508	5220	2909	18809

Table 3-2. Ring counts of readability 1 and 2 otoliths by year.

Year	Ring Count						Total 1&2	Total	%	1&2
	0	1	2	3	4	5				
1995		34	31	14	6	1	86	638	13.5	
1996		100	34	6	4		144	625	23.0	
1997		118	29	3	3		153	479	31.9	
1998	2	129	37	36	13	1	218	1275	17.1	
1999		25	17	8			50	1002	5.0	
2000		6	36	38	2		82	637	12.9	
2001			12	37	9	1	59	2243	2.6	
2002			8	22	22	1	53	2576	2.1	
2003	1	5	6	13	12	2	39	1341	2.9	
2004	27	23	30	32	16	1	129	1540	8.4	
2005		4	6	3	1		14	915	1.5	
2006	3		2	3	1		9	789	1.1	
2008			4	3	2		9	639	1.4	
2009		10	12	5			27	1495	1.8	
2010		11	33	22	1	1	68	1185	5.7	
2011			6	2			8	347	2.3	
2012							0	36	0.0	
2013		4	4	5	1	1	15	526	2.9	
2014		1	4	3		1	9	521	1.7	
Total	33	470	311	255	93	10	1172	18809	6.2	

Otolith weight relationship

The modelled relationship between decimal age and otolith weight provided a reasonable fit to the observed data ($R^2 = 0.615$; Figure 3-2). Ages predicted by the model were slightly biased, with age over-estimated in younger fish and under-estimated in older fish.

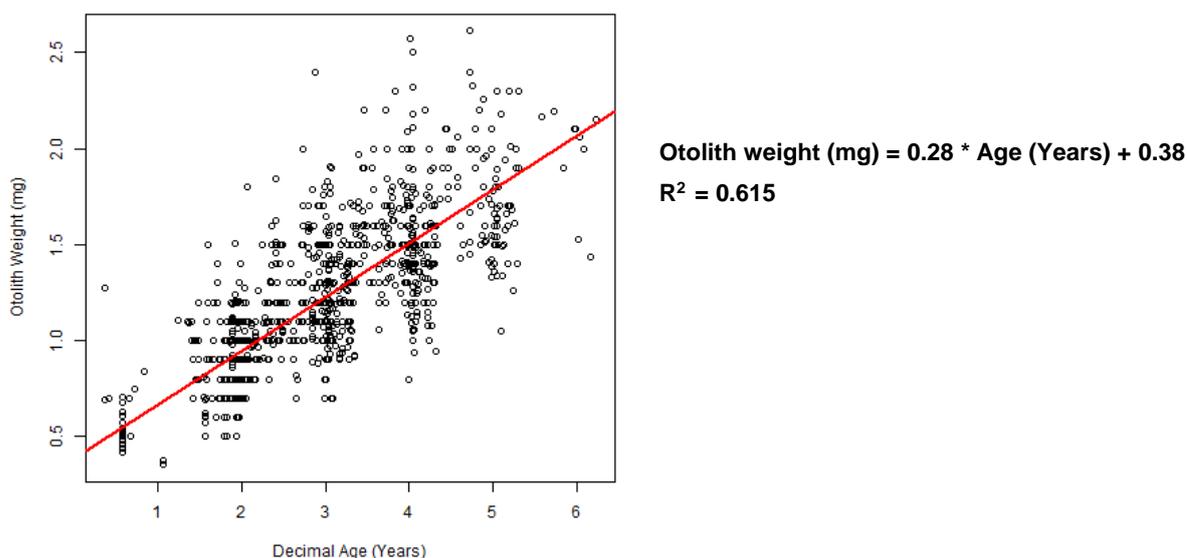


Figure 3-2. Regression of decimal age and otolith weight for Sardine otoliths of readability 1 and 2 from commercial and fishery-independent samples collected between 1995 and 2014.

3.3.2 Age Composition

Age composition data from commercial catches were available from 1995 to 2014, with the exception of 2007 when no otoliths were collected. Ages ranged from 0+ to 8+ years. In 1995, fish aged 2+, 3+, and 4+ years dominated catches, but in 1996-1998, catches were mostly dominated by age 1+ and 2+ fish, with a noticeable decline in older fish in 1997. These trends reflect the 1995 mass mortality event which affected mostly adult fish. In 1999, 2+ year olds (fish that were juveniles in 1998 and largely unaffected by the 1998 mass mortality event) dominated the catch. Fish that were spawned during 1997 and 1998 continued to dominate catches as 2+ and 3+ year olds in 2000. From 2001 to 2009, 3+ year olds dominated the catch in all years, except 2005, 2006 and 2008, when 2+ year olds were most abundant in catch samples (Figure 3-3). From 2010 to 2012, 2+ year olds dominated the catch whereas in 2013 and 2014, 3+ year old fish were most abundant. The recent increase in the abundance of older fish in catches reflects the increased proportion of catches taken outside Spencer Gulf, especially since 2010.

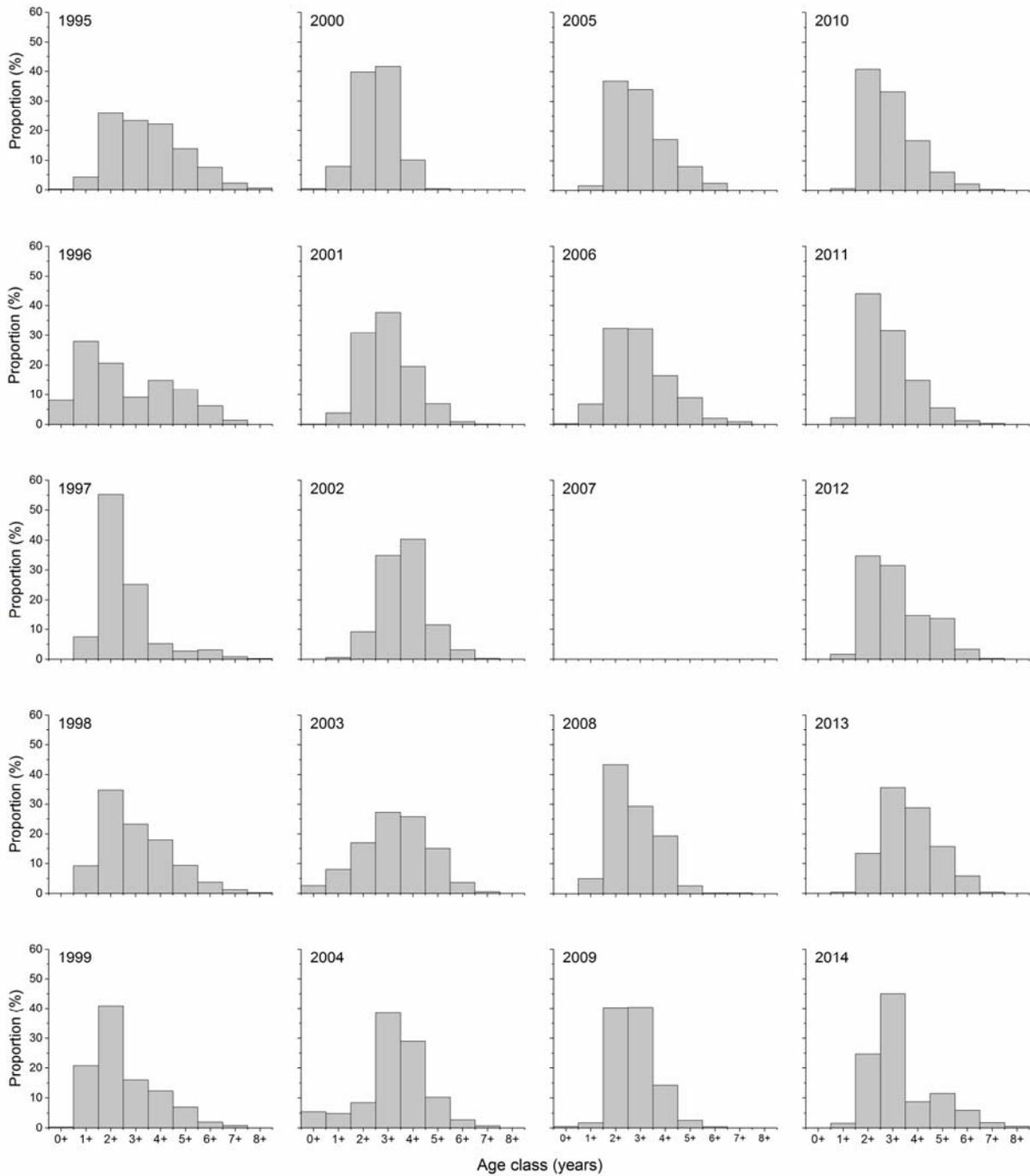


Figure 3-3. Age distributions for commercial catch samples of Sardine from all regions between 1995 and 2014. Note that no data were available for 2007. Ages are derived from an otolith-weight-age relationship calculated for all years from readability 1 and 2 otoliths and applied to all weighed otoliths for each year.

3.3.3 Growth

Application of von Bertalanffy growth functions (Figure 3-4), showed males and females to have similar growth coefficients and expected asymptotic lengths.

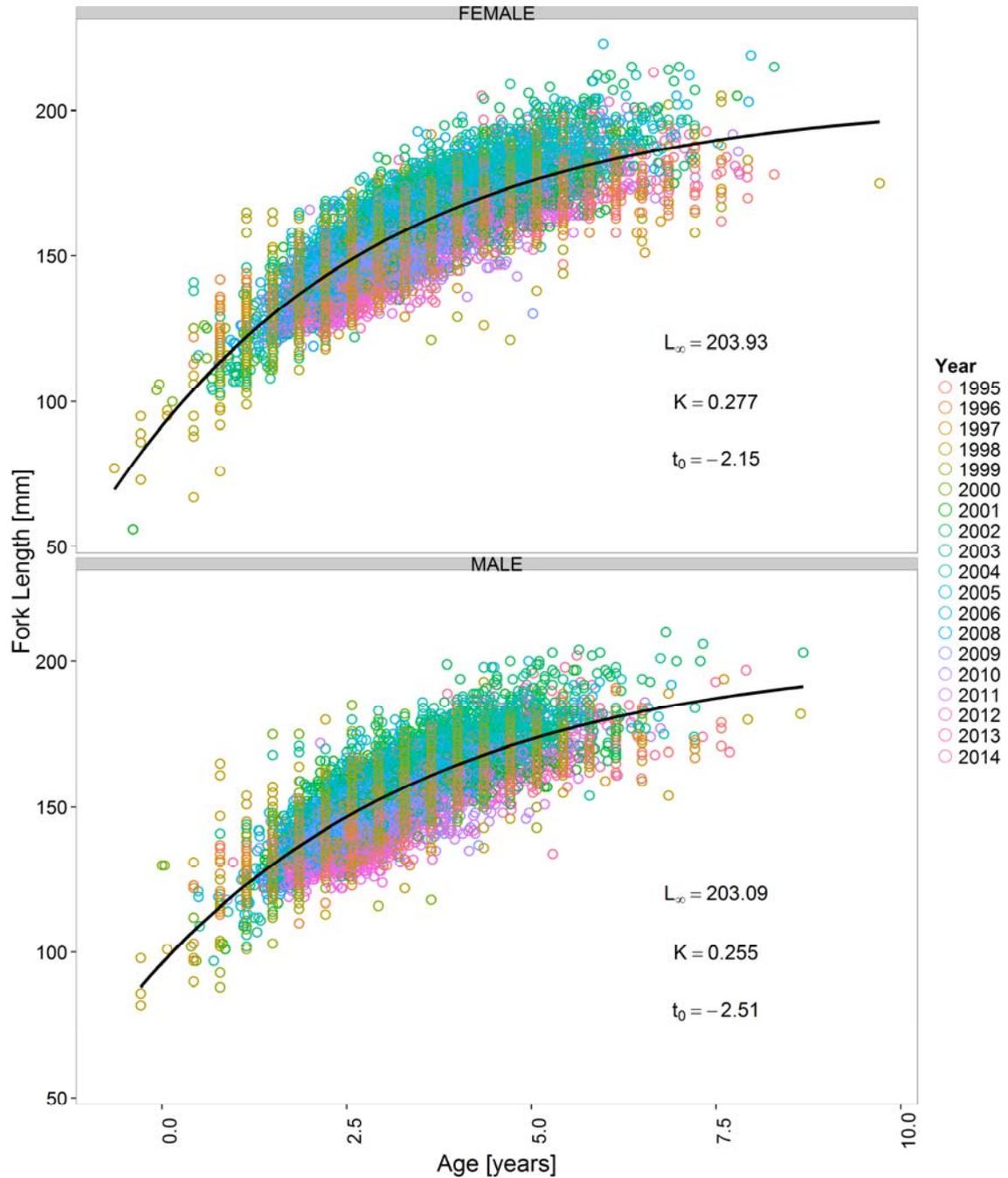


Figure 3-4. Growth parameters for male and female Sardine estimated with the von Bertalanffy growth function (solid line). Plots are fish length (mm FL) by age (estimated from otolith weight; years).

3.3.4 Size at maturity

Size at maturity (SAM, L_{50}) estimated for Sardine from the commercial catch samples from Spencer Gulf between 1995 and 2014 varied slightly among seasons (Figure 3-5). However, small sample sizes produced wide confidence intervals with no statistically significant differences detected between seasons. All males below 116 mm FL and females below 118 mm FL had immature gonads. The estimate for SAM using data from all years combined was 139.6 mm FL (95%CI = 135.5 – 144.0) and 143.4 mm FL (139.6 – 147.4) for males and females, respectively (Figure 3-6).

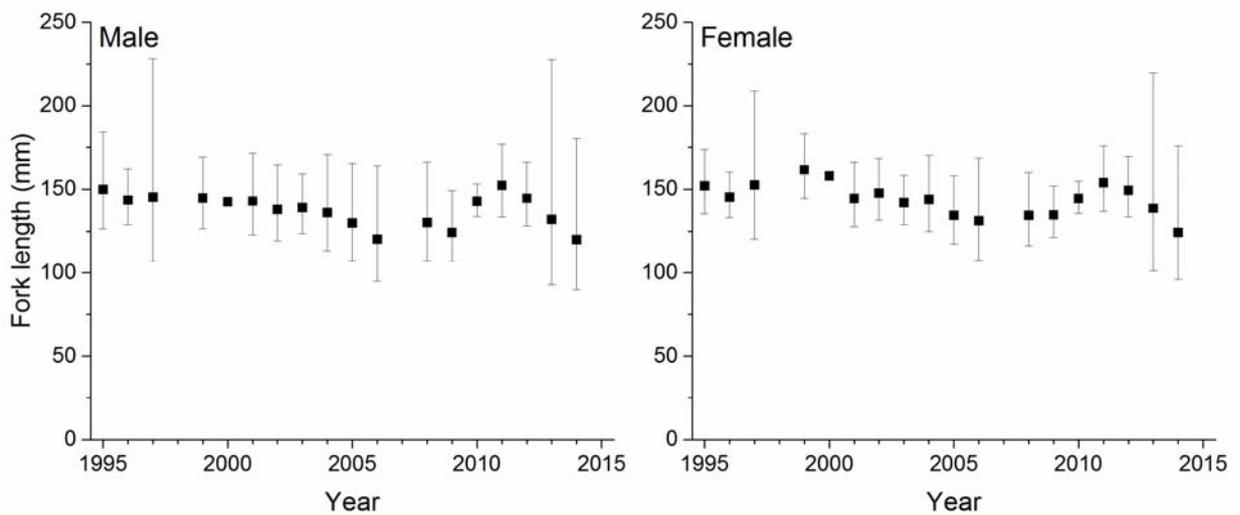


Figure 3-5. Size at 50% maturity (L_{50}) for male and female Sardine collected in Spencer Gulf by year, between 1995 and 2014. Some years were omitted due to low sample size. Error bars are 95% confidence intervals, and are absent where insufficient data were available for estimation.

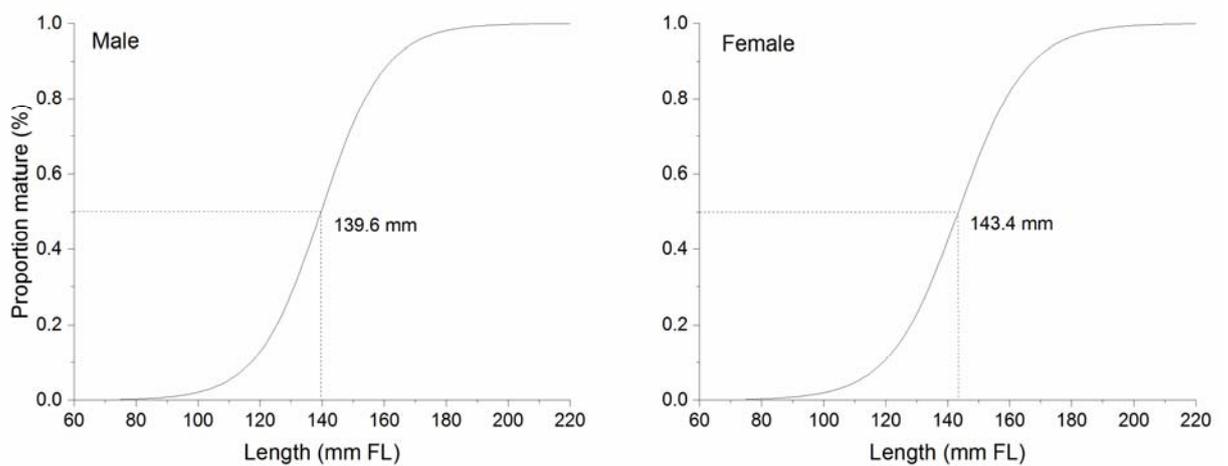


Figure 3-6. Size at 50% maturity (L_{50}) for male and female Sardine collected in Spencer Gulf for all years combined.

3.3.5 Gonosomatic index (GSI)

There was a large amount of seasonal and regional variability in GSI. However, sample size was variable, with sufficient samples obtained only from Spencer Gulf in most years. GSI peaked between November and March (Figure 3-7). Higher mean GSI values were observed for males than females, which may be caused by male gonads not decreasing in size as much as females after each spawning event. Higher mean GSI values were also observed from larger fish.

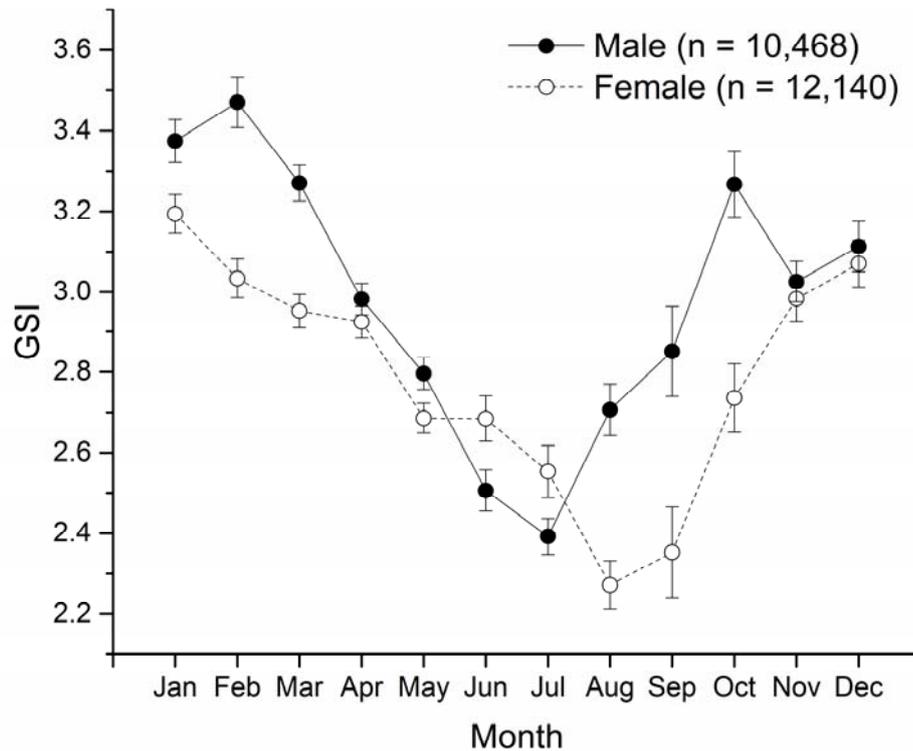


Figure 3-7. Mean monthly gonosomatic index of male and female Sardine from Spencer Gulf commercial samples from 1995 to 2014 combined. Error bars are standard error. Fish below the size at 50% maturity have been excluded.

3.4 Discussion

The relatively high level of uncertainty associated with the estimation of the age of Sardine from annual growth increments in otoliths has been noted elsewhere (Fletcher 1994; Rogers and Ward 2007). This issue can be partly overcome by using an age-otolith weight relationship developed from otoliths with high readabilities to estimate the age of Sardine with otoliths that are more difficult to read. This approach requires a large number of otoliths to be read each year to provide adequate numbers of otoliths with high readability.

The growth rates of individuals vary with age, (Rogers and Ward 2007), which reflect the moderate to high growth rates prior to the onset of sexual maturity and slower growth rates as adults. Other studies have found that fish length displayed no consistent modal progression through samples, whereas, cohorts could be tracked using otolith weight (Fletcher 1994; Rogers et al. 2004). This variability in growth rates limits the effective use of age-length keys for estimating the age of Sardine.

Although the most important fishing months are between March and June (i.e. partially overlap with the spawning season), actively spawning females (Stage 4) comprised only a small proportion (<1%) of the catch. This finding provides evidence that spawning Sardine may be poorly sampled using purse-seine gear (Hewitt 1985) and further demonstrates the need to obtain fishery-independent samples to estimate the reproductive parameters required for application of the DEPM.

4.0 ESTIMATES OF SPAWNING BIOMASS

4.1 Introduction

This chapter presents the time series of estimates of Sardine spawning biomass for South Australia that have been obtained using the DEPM between 1995 and 2014. This information is used to make inferences about the recent status of the South Australian Sardine resource and is a key input to the population model in Chapter 5.

4.2 Methods

4.2.1 Daily Egg Production Method

SARDI Aquatic Sciences has used the DEPM to estimate the spawning biomass of Sardine in South Australia since 1995. This method relies on the premise that spawning biomass can be calculated from estimates of the number of pelagic eggs produced per day in the spawning area (daily egg production, P_0) and the number produced per female (daily fecundity). Spawning biomass (B) is calculated according to the equation:

$$B = \frac{P_0 \cdot A \cdot W}{R \cdot F \cdot S}$$

Where, P_0 is mean daily egg production, A is the spawning area, W is the mean weight of mature females, R is the sex ratio, F is the mean batch fecundity and S is the mean spawning fraction (Lasker 1985; Parker 1985; Alheit 1993).

The method used to estimate spawning biomass was recently the subject of a comprehensive review (Ward *et al.* 2011b) that resulted in minor modifications to the methods used in previous reports (e.g. Ward *et al.* 2007). Four generalised linear models (GLM), the exponential model (Lo *et al.* 1985) and the log linear model were tested. The model chosen was the log linear model applied to all stations with eggs of Stages 2 to 11 with one egg added to all day 1 and day 2 densities (Ward *et al.* 2011b). Spawning area is now calculated using the Voronoi natural neighbour (VNN) method to assign station boundaries objectively. A temperature-dependent model was used to assign ages to eggs based on the sea surface temperature, stage and time of sampling. Egg density was calculated using the log linear model applied to all stations with eggs of stages 2 to 11. A one egg correction factor was added to all day 1 and day 2 densities at positive stations to eliminate zeros. Revised estimates of spawning biomass are presented in this chapter.

Sampling area

Between 1995 and 2007, annual ichthyoplankton and adult Sardine sampling surveys of ~28 days duration were conducted during each spawning season (January-March) from the *RV Ngerin*. Since 2009, surveys have been biennial. The location of plankton sampling stations used in 2014 is shown in Figure 4-1; note additional sites determined by the presence of eggs collected by the Continuous Underway Fish Egg Sampler (CUFES). The number of stations and orientation of transects varied among years as the survey design was refined. During 1995 and 1996, few stations were sampled, as the primary goal was to identify the main spawning area. After 1997, transects were orientated northeast-southwest (*c.f.* north-south) to improve sampling efficiency. In 2006, stations that had not yielded any eggs in the preceding decade were excluded in favour of additional stations in Spencer Gulf.

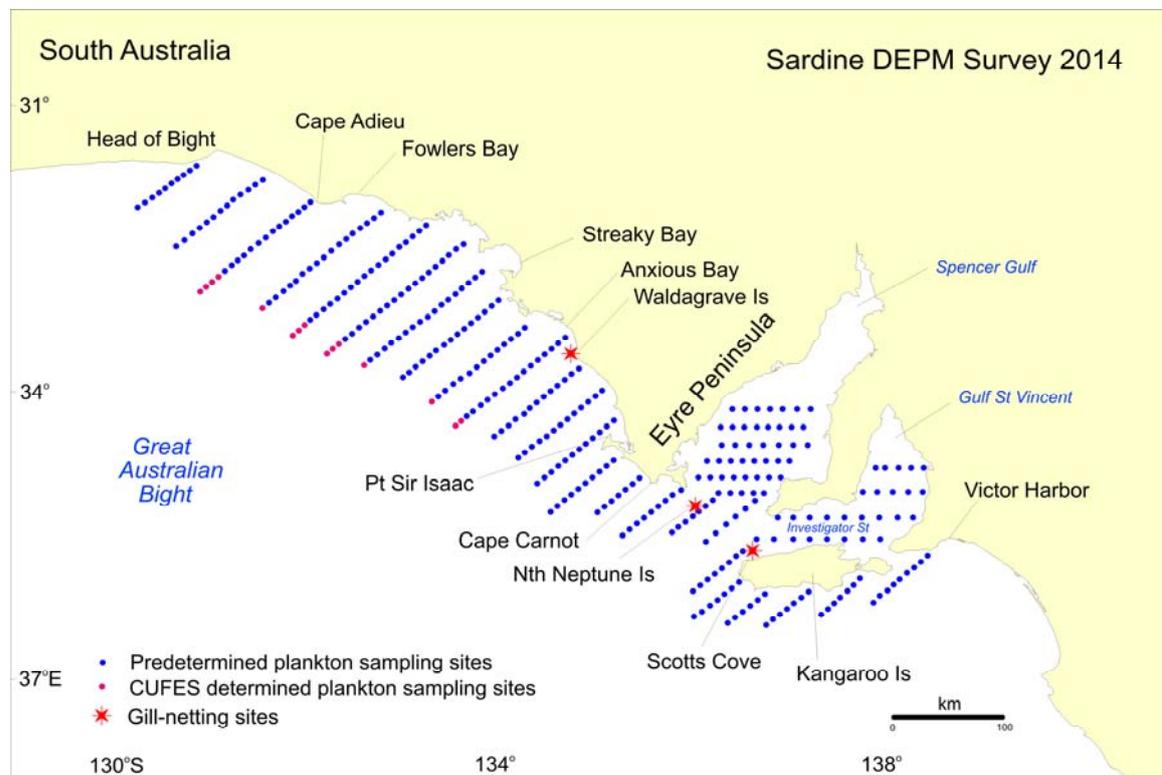


Figure 4-1. Map showing stations where Sardine egg and adult samples were collected during the 2014 DEPM surveys.

Plankton sampling

Plankton samples were collected at each station using Californian Vertical Egg Tow (CaIVET) plankton nets. CaIVET nets had an internal diameter of 0.3 m, 330 µm mesh and plastic cod-ends. During each tow the nets were deployed to within 10 m of the seabed at depths <80 m or to a depth of 70 m at depths >80 m. Nets were retrieved vertically at a

speed of $\sim 1 \text{ m.s}^{-1}$. General Oceanics™ flowmeters were used to estimate the volume of water sampled by each net. Samples from the two cod-ends were combined and stored in 5% buffered formaldehyde and seawater.

Egg distribution and abundance

Sardine eggs were identified, counted, staged and assigned ages according to descriptions and temperature-development keys in White and Fletcher (1998). The number of eggs of each stage under one square metre of water (P_t) is estimated at each station according to equation 2:

$$P_t = \frac{C.D}{V}$$

Where, C is the number of eggs of each age in each sample, V is the volume of water filtered (m^3), and D is the depth (m) to which the net was deployed (Smith and Richardson 1977).

Spawning time

Sardine eggs in each sample were counted and staged according to criteria in White and Fletcher (1998). The age of each developmental stage was estimated using a temperature dependent egg development model that incorporated time of sampling, sea surface temperature and egg stage (Ward *et al.* 2011b).

The peak daily spawning time calculated from combined data between 1995 and 1999 was 0200 hours (Ward *et al.* 2001b). This was used as the standard spawning time in subsequent egg production and spawning biomass calculations.

Spawning area

A key premise of using the DEPM is to accurately estimate the entire spawning area (Lasker 1985; Somarakis 2004). After the surveys were completed, the survey area was divided into a series of contiguous grids approximately centred on each station using the Voronoi natural neighbour method in the statistical package 'R' (Badderly and Turner 2005, R Development Core Team 2014, Figure 4-2). Then the area represented by each station (km^2) was calculated. The spawning area (A) was defined as the total area of grids where live Sardine eggs were found (see Fletcher *et al.* 1996).

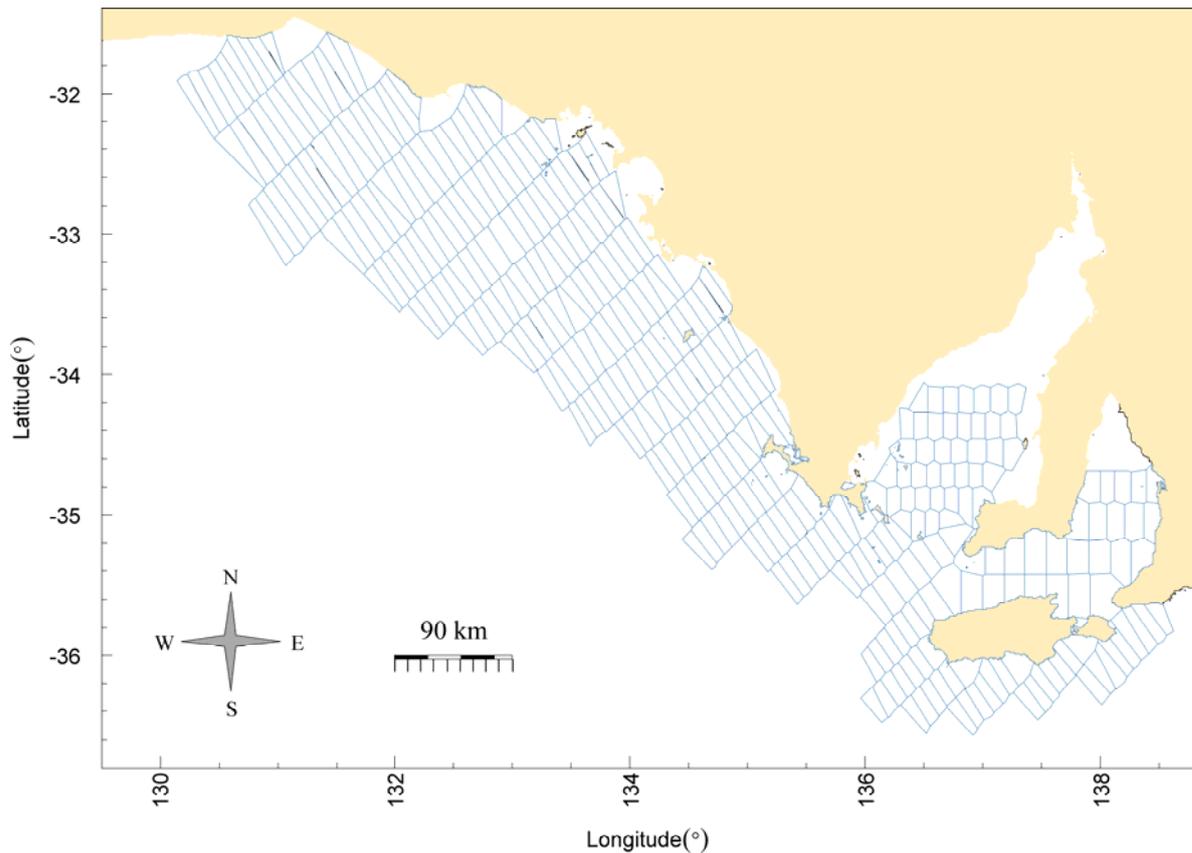


Figure 4-2. Spatial grids generated using the Voronoi natural neighbour method to estimate the spawning area of Sardine in 2014.

Egg production P_0

Biased mean daily egg production (P_b) was calculated by fitting the linear version of the exponential egg mortality model to estimates of egg age and density at each station (Picquelle and Stauffer 1985). To allow the inclusion of data from stations where either day 1 or day 2 eggs were absent, one egg was added to the counts of both day 1 and day 2 eggs at every positive station. The linear version of the exponential egg mortality model is:

$$\ln P_b = \ln(P_i) - Zt$$

Where, P_i is the density of eggs of age t at site i and Z is the instantaneous rate of egg mortality.

Estimates of P_b obtained using the linear version of the exponential mortality model have a strong negative bias, therefore a bias correction factor was applied following the equation of Picquelle and Stauffer (1985):

$$P_0 = e^{(\ln P_b + \sigma^2/2)}$$

Where, σ^2 is the variance of the estimate of biased mean daily egg production (P_b).

Adult reproductive parameters

Between 1995 and 1997, there were difficulties collecting samples of mature Sardine. Mid-water trawling and sampling from commercial catches during the spawning season were attempted with minimal success. The resultant paucity of data and uncertainty associated with estimates of adult reproductive parameters reduced confidence in estimates of spawning biomass over this period (Ward *et al.* 2001a).

From 1998 to 2014, samples of mature Sardine were collected during research surveys in the eastern Great Australian Bight, southern Spencer Gulf and the Investigator Strait using surface and sub-surface lights and a multi-panelled gillnet (Ward *et al.* 2001a). Upon retrieval of the net, fish were removed and dissected by ventral incision. Mature and immature males and females were counted. Mature females were fixed in 5% buffered formaldehyde solution and immature females and males were frozen. Calculations of female weight, sex ratio, batch fecundity and spawning fraction were based on these samples.

Mean female weight (W)

Mature females from each research sample were removed from formalin and weighed (± 0.01 g). W was calculated from the average of sample means weighted by proportional sample size:

$$W = \left[\overline{W}_i * \frac{n_i}{N} \right]$$

Where, \overline{W}_i is the mean female weight of each sample i ; n is the number of fish in each sample and N is the total number of fish collected in all samples.

Sex ratio (R)

For fishery-independent samples, R was calculated from the average of sample means weighted by proportional sample size:

$$R = \left[\overline{R}_i * \frac{n_i}{N} \right]$$

Where, n_i is the number of fish in each sample, N is the total number of fish collected in all samples and \overline{R}_i is the mean sex ratio of each sample calculated from the equation:

$$\overline{R}_i = \frac{F}{(F + M)}$$

Where, F and M are the respective total weights of mature females and males in each sample, i .

Spawning fraction

Ovaries of mature females were examined histologically. The ovaries were sectioned and stained with haematoxylin and eosin then examined to determine the presence/absence of post-ovulatory follicles (POFs). POFs were aged according to the criteria developed by Hunter and Goldberg (1980) and Hunter and Macewicz (1985). The spawning fraction of each sample was estimated as the mean proportion of females with hydrated oocytes plus day-0 POFs ($d0$) (assumed to be 0-23 hours old), day-1 POFs ($d1$) (assumed to be 24-48 hours old) and day-2 POFs ($d2$) (assumed to be 48+ hours old). Then the mean spawning fraction of the population was calculated from the average of sample means weighted by proportional sample size from:

$$S = \left[\overline{S}_i * \frac{n_i}{N} \right]$$

Where, n_i is the number of fish in each sample, N is the total number of fish collected in all samples and \overline{S}_i is the mean spawning fraction of each sample calculated from equation:

$$\overline{S}_i = \frac{[(d0 + d1 + d2 POFs) / 3]}{n_i}$$

Where, $d0$, $d1$ and $d2$ POFs are the number of mature females with POFs in each sample and n_i is the total number of females within a sample. Note: $d0$ includes hydrated oocytes.

Batch fecundity

Batch fecundity was estimated from ovaries containing hydrated oocytes using the methods of Hunter *et al.* (1985). Both ovaries were weighed and the number of hydrated oocytes in

three ovarian sub-sections were counted and weighed. The total batch fecundity for each female was calculated by multiplying the mean number of oocytes per gram of ovary segment by the total weight of the ovaries. The relationship between female weight (ovaries removed) and batch fecundity was determined by linear regression analysis and used to estimate the batch fecundity of mature females in all samples.

Confidence intervals

Confidence intervals were obtained from a two stage bootstrap process with 100,000 iterations (Efron and Tibshirani 1993). The two stage bootstrap method allowed the incorporation of the covariance of adult parameters within individual samples, which improved their precision (Ward et al. 2011b).

4.3 Results

Sampling area

The total area sampled during the DEPM surveys varied from 46,525 to 122,437 km² between 1998 and 2014 (Figure 4-5). The survey area was relatively consistent between 2006 and 2013 at ~115,000 km². In 2014, the CUFES detected the presence of Sardine eggs at the end of several transects, thus additional stations were added (Figure 4-1) and the total survey area was increased to 122,437 km².

Egg distribution and abundance

The distribution and abundance of Sardine eggs has varied considerably among years. Important spawning areas include the eastern Great Australian Bight, between Coffin Bay and Ceduna, southern Spencer Gulf, and the western end of Investigator Strait (Figures 4-3, 4-4). Mass mortality events in 1995 and 1998 had substantial effects on both the abundance of eggs and their spatial distribution (Ward et al. 2001a). The densities of Sardine eggs during 2014 were relatively high compared to previous years.

Spawning area

Estimates of spawning area varied among years and reflected both the size of the sampling area and the status of the spawning biomass. The spawning area declined substantially following the two mass mortality events in 1995/96 and 1998/99, from 68,260 km² in 1995 to 17,990 km² in 1996 and from 31,510 km² in 1998 to 14,876 km² in 1999 (Figure 4-5). The spawning area increased between 2001 and 2007 from 34,182 km² to 49,628 km². In 2014, the spawning area was estimated at 71,859 km². It is important to note that the survey

design also varied between years, (e.g. four transects were excluded in the central Great Australian Bight in 2004 due to bad weather).

Egg production P_0

Figure 4-5 shows estimates of egg production and their associated 95% CI between 1995 and 2014. Following the second mass mortality event, egg production declined from 111.78 eggs.day⁻¹.m⁻² in 1998 to 38.12 eggs.day⁻¹.m⁻² in 1999. Between 2000 and 2014, egg production was highly variable and ranged between 44.0 and 120.9 eggs.day⁻¹.m⁻². In 2014, egg production was estimated at 85.0 eggs.day⁻¹.m⁻².

Sex ratio (R)

Estimates of sex ratio from fishery-independent samples ranged between 0.44 in 2003 and 0.68 in 2013 (Figure 4-5). The variability in estimates of R reflects the stability of this parameter between years and the relatively low potential to influence estimate of spawning biomass.

Mean female weight (W)

Estimates of W ranged from 45.2 g in 1998 to 78.7 g in 2004 (Figure 4-5). In 2014 W was estimated to be 47.4 g. Fishery-independent samples were mainly taken from shelf waters and typically larger than commercial catch samples that were mainly taken from Spencer Gulf.

Batch fecundity (F)

Batch fecundity was not estimated in 1995 and 1996 because no hydrated females were caught in adult sampling. Between 1997 and 2014, estimates of F from fishery-independent samples ranged between 13,600 and 23,736 hydrated oocytes (Figure 4-5). Variations in F between years mainly reflected variations in gonad-free female weight (and W).

Spawning fraction (S)

Estimates of S varied between 0.04 in 2014 and 0.18 in both 1999 and 2001 (Figure 4-5). Estimates of S for 2003 and 2004 were based on less than 500 females.

Spawning biomass

The spawning biomass estimate for 1995 of 165,000 t may be negatively biased, as the survey did not coincide with the peak spawning season or sample the entire spawning area, and also because estimates of adult reproductive parameters were obtained from other studies. Hence, there is no reliable estimate of the spawning biomass prior to the first mass

mortality event in late 1995. The estimate of spawning biomass declined to 37,000 t in 1996 following this mass mortality event but increased to 59,000 t in 1997 (Ward *et al.* 2001a).

Estimates of spawning biomass between 1998 and 2009 (Figure 4-6) have been recalculated after a review by Ward *et al.* (2011b). Spawning biomass estimates increased from 22,906 t (95% CI = 13,518-41,151) in 1999 to 180,787 t (103,493-337,037) in 2002. Estimates of spawning biomass remained between 152,000 and 170,000 t for 2003 to 2005, and then increased to 202,624 t (119,317-363,363) in 2006 and 263,049 t (161,321-435,205) in 2007. The estimates of spawning biomass in 2009, 2011, 2013 and 2014 were 171,532 t (122,100-242,479), 193,201 t (104,151-381,961), 162,645 (78,854-287,533) and 243,925 t (171,717-349,858), respectively (Ward *et al.* 2011a,b, 2013; 2014).

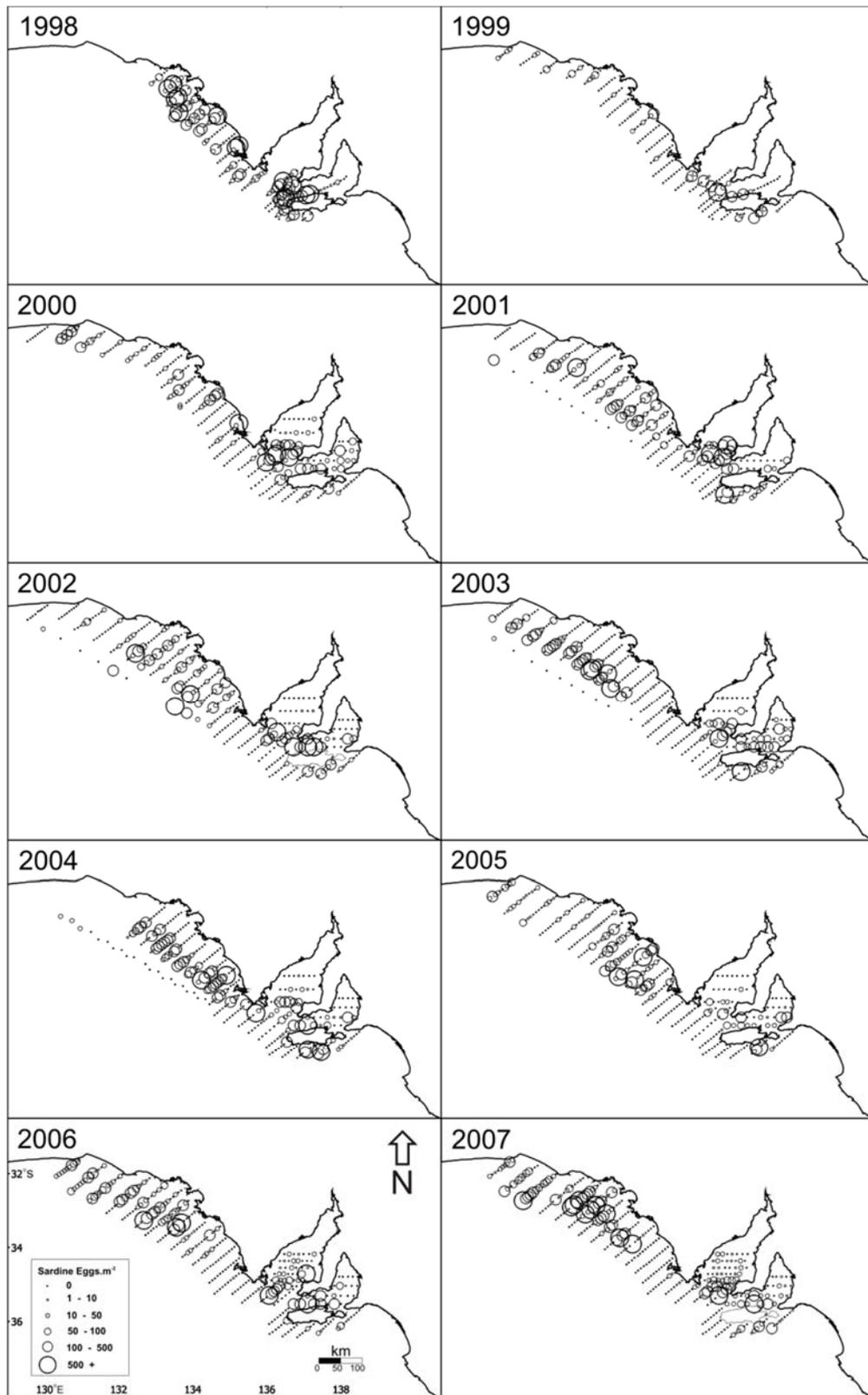


Figure 4-3. Distribution and abundance of Sardine eggs collected during surveys between 1998 and 2007.

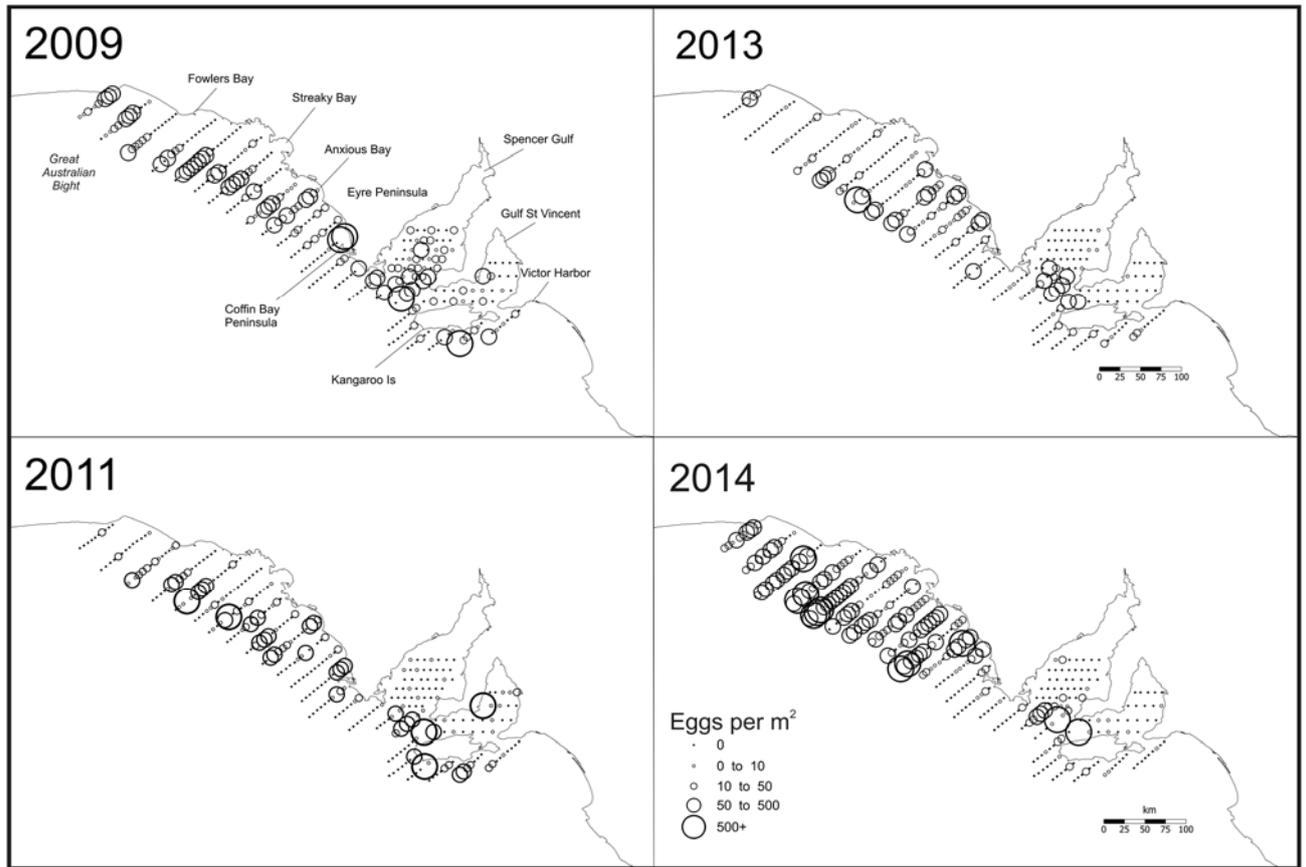


Figure 4-4. Distribution and abundance of Sardine eggs collected in 2009 and 2014.

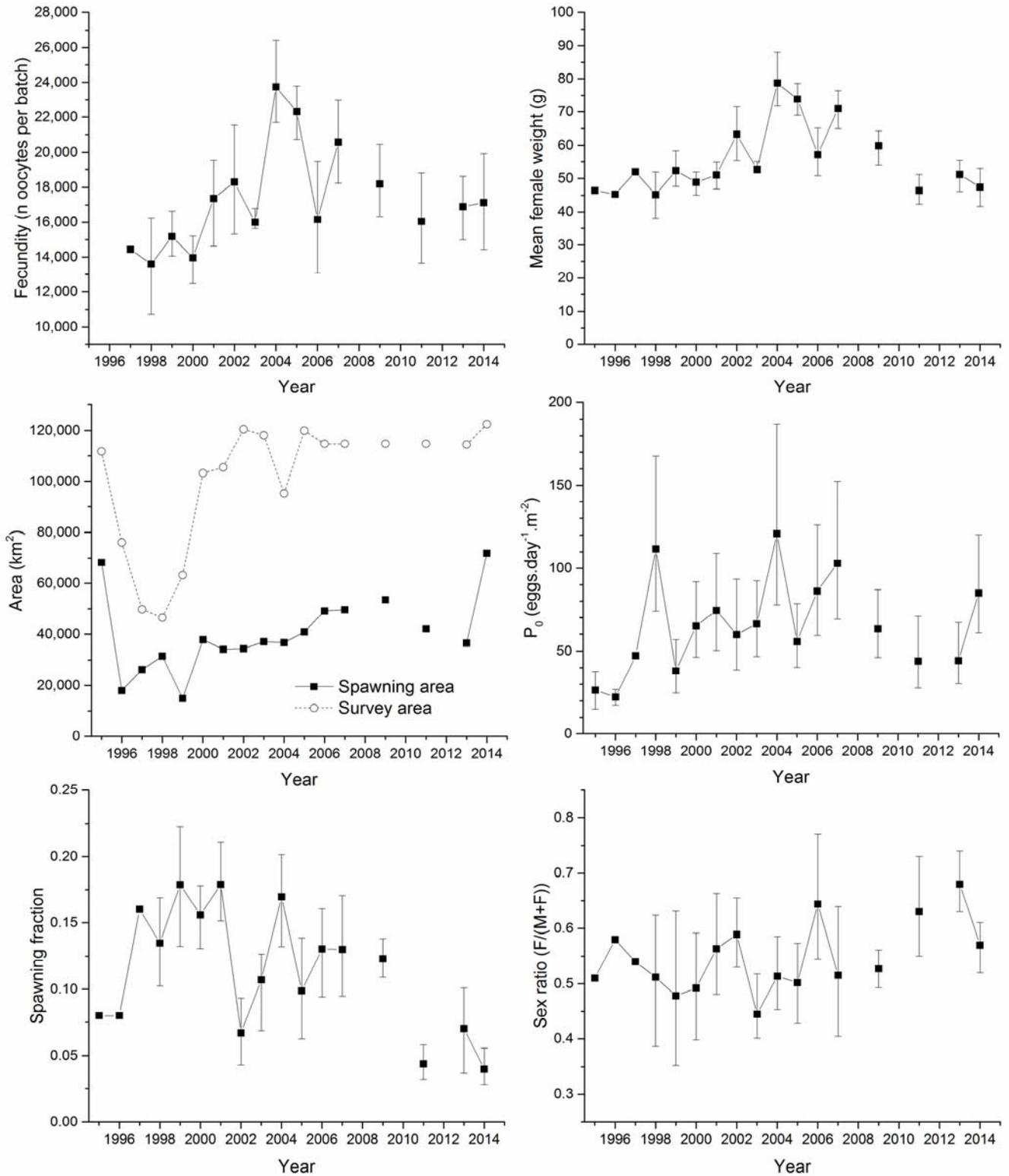


Figure 4-5. Spawning biomass parameters ($\pm 95\%$ CI) used for Sardine from 1995-2014. Values from: 2014 Ward *et al.* (2014), 2013 Ward *et al.* (2013), 2011 Ward *et al.* (2011a) 1998-2009 are from Ward *et al.* (2011b), earlier values from Ward *et al.* (2001c).

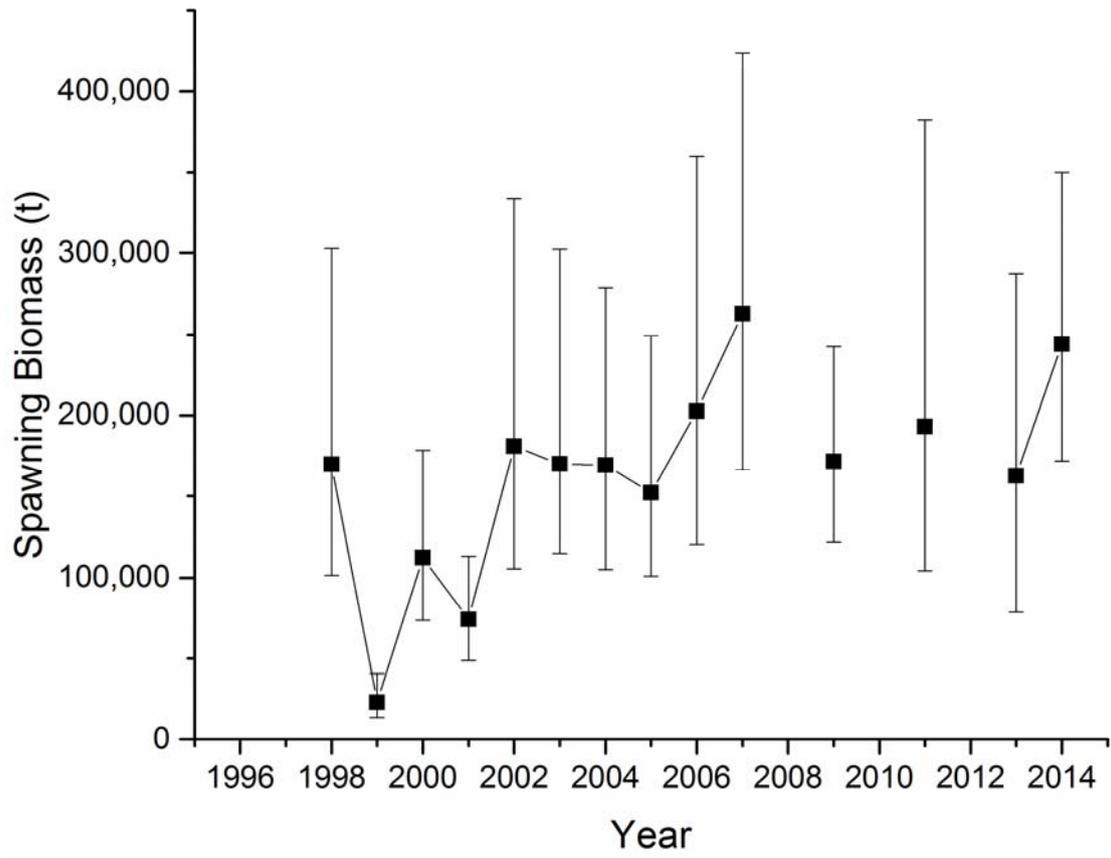


Figure 4-6. Daily Egg Production Method (DEPM) estimates of spawning biomass ($\pm 95\%$ CI) for Sardine in South Australian waters from 1995 - 2014.

4.4 Discussion

The DEPM has been integral to the rapid and sustainable development of the SASF. The main limitation of the method is that estimates of spawning biomass obtained using the DEPM are relatively imprecise (Cochrane 1999). This has mainly been attributed to patchiness in egg distribution and abundance (McGarvey and Kinloch 2001; Gaughan *et al.* 2004; Stratoudakis *et al.* 2006), and the high variance levels associated with estimates of mean daily egg production. However, difficulties obtaining representative samples of adult fish, especially for estimating spawning fraction, can also add significant uncertainty (e.g. Ward *et al.* 2014). Variances for estimates of spawning biomass are typically large, e.g. Coefficients of Variation (CV) are commonly >35% of the mean (Fletcher *et al.* 1996; Ward *et al.* 2001a; Gaughan *et al.* 2004; Stratoudakis *et al.* 2006).

To address this uncertainty a conservative approach (i.e. the log linear-model) has been adopted to estimate mean daily egg production off South Australia. Ward *et al.* (2011b) demonstrated that the log-linear model provides more conservative estimates of egg production and spawning biomass than other methods (i.e. exponential model, various GLMs). Furthermore, the log-linear model does not provide unrealistically high estimates of egg production in years when a few samples contain very large numbers of young eggs (Ward *et al.* 2011b). An FRDC project (No. 2014/026) is currently underway to develop methods that will provide more precise estimates of egg production.

5.0 STOCK ASSESSMENT MODELLING

5.1 Introduction

This chapter describes the application of an integrated stock assessment model for the SASF. The assessment is conducted using a statistical catch-at-age model that describes a single stock and single area fishery, developed using Stock Synthesis (SS3; Methot and Wetzel 2013; Version 3.24S). The model fits to commercial catch data, fishery-independent spawning biomass estimates, and fishery-dependent age composition data, in keeping with similar models used in previous assessments (Ward *et al.* 2012). This chapter presents results of the analyses, including fits to data, estimates of the time-series of spawning stock biomass, and stock projections given a range of expected future catch values. Recommendations are made for further model development and data processing that might improve model-based estimates of quantities important to management, especially estimates of spawning biomass.

The model is used to estimate numbers at age for all years in the fishery (from 1992 to 2015, using data up until 2014) and to calculate quantities of importance to fisheries management, including spawning stock biomass. The model is also used to forecast changes in total population and spawning stock biomass, with initial projections being for one year into the future and further projections with three alternative TACCs (30,000 t, 38,000 t and 47,500 t) for a ten year period.

This stock was previously assessed using a simpler age-structured stock assessment model developed as part of an FRDC funded project (Ward *et al.* 2005). That model was used again in 2010 and 2012 (Ward *et al.* 2010; 2012). Known limitations with the previous assessment model included large uncertainties and wide confidence bounds on estimates of spawning biomass; difficulties in estimating natural mortality, especially time-varying natural mortality; and difficulties with fitting to age composition data. Previous assessments also relied on model weightings that were chosen subjectively.

Use of the Stock Synthesis (SS3) modelling framework has permitted a number of innovations for the assessment of the SASF. These include: estimation of stock recruitment deviations from an assumed underlying stock recruitment relationship using penalized likelihoods and recruitment bias adjustments methods (Methot and Taylor 2011); estimation of time-varying and age-specific natural mortality to better represent the mass mortality in 1995 and 1998; improved fits to age composition data; and estimation of dome-shaped selectivity in the form of a 'double-normal' selectivity curve that better accounts for reduced availability of older fish in the Spencer Gulf fishing grounds. Furthermore, model weighting was performed objectively following a data-weighting approach consistent with Francis

(2011) and other methods applied using SS3 together with the plotting and model diagnostics package 'r4ss' (Version 1.23.5, Taylor et al. 2015).

5.2 Analytical Assessment

5.2.1 Base-case model

The 2015 stock assessment model was developed using the freely available software Stock Synthesis (Methot and Wetzel 2013). Stock Synthesis was written using the open-source model development software ADMB (Fournier et al. 2012). Stock synthesis uses maximum likelihood in ADMB to estimate the parameters of the underlying age-based stock assessment model. Model diagnostics including model selection, and plotting of model outputs, were achieved using the open-source R package 'r4ss' (Taylor et al. 2015).

Model structure

The base-case assessment model is age-structured, sex-dependent, and assumes a single area and single stock for the SASF. The model integrates data available from 1992 to 2014. Fish recruit to the model at age 0+ and experience annual mortality from fishing and natural causes. Each year they progress through to the next age class until they reach the plus group (9+) where they remain until they are fished or die from natural causes.

Before 1992, the Sardine population is assumed to have been in a state of unfished equilibrium. Unfished equilibrium recruitment (R_0) is estimated in relation to an assumed Beverton-Holt stock-recruitment relationship, parameterised in terms of steepness (h), and fixed at $h = 0.9$.

Annual recruitment deviations are estimated, with the standard deviation of variation about the stock-recruitment relationship (quantified by σ_R) fixed at 0.8. Analyses of recruitment standard error estimates and bias-adjustment methods following Methot and Taylor (2011), resulted in a main series of estimated and bias-corrected recruitment deviations between 1992 and 2011. Recruitment estimates for 2012-2014 were kept constant, whilst still being influenced by the data, and forecast recruitments (2015 and beyond) were assumed to follow the underlying stock-recruitment relationship. Figure A-1 (Appendix) shows recruitment estimation diagnostic plots including the bias adjustment ramp.

Biological parameters

Specifications for growth, age-at-maturity and fecundity were based on values reported in previous chapters, as well as the previous stock assessment report (Ward et al. 2012). Analyses in Ward et al. (2012) indicate no significant temporal changes to these biological parameters throughout the history of the fishery (or insufficient sampling to detect such

changes), and so each parameter was fixed at historical values and set constant through time.

Growth was assumed to follow the SS3 von Bertalanffy growth function (Figure 5-1), with sex-independent parameters (Table 5-1). Determination of the relationship between Sardine length and weight was estimated for males and females using data collected from both commercial catches and fishery-independent surveys. An assumed allometric relationship of the form: $W = A * FL^B$, where W is weight in kg, FL is caudal fork length, and A and B are the scaling and power parameters respectively, was applied. Parameters for the length-weight relationship were estimated via non-linear regression using R, and are shown in Table 5-1.

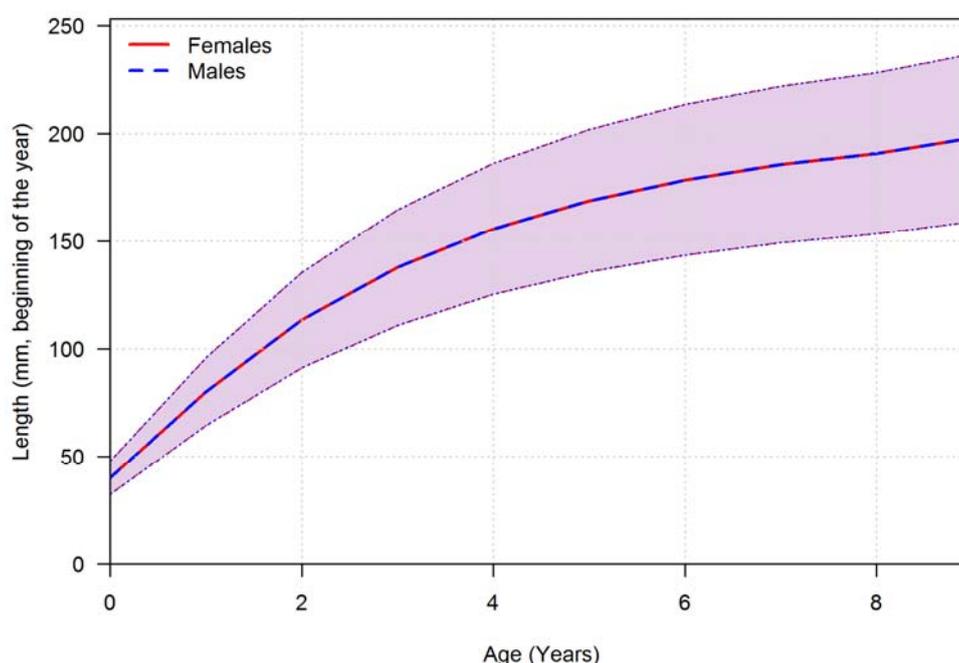


Figure 5-1 Model input relationship between age (years) and length (mm) for female and male Sardine (expected growth) with assumed CV = 0.1 for young and old ages.

Natural mortality (M) was assumed to be constant for all ages, and across all years, except in years 1995 and 1998. In those years, two mass mortality events each killed an estimated 70% of the mature population. Accordingly, natural mortality was configured in the model to vary from the underlying estimated M for adult Sardine in the years 1995 and 1998. Specifically, an underlying 'base M ' was estimated in the assessment model, and a deviation from that base parameter (additional mortality) was applied to fish aged ≥ 3 in 1995 and 1998. Maturity was configured as a logistic function of age, and implemented with an estimated age at 50% maturity (A_{50}) of 2.5 years and a corresponding slope parameter of -5. These values were determined via conversions from growth and maturity-at-length parameters presented in Chapter 3.

Fishery parameters

The base-case assessment assumes that fishing occurs across a single stock and single area, and that selectivity for the commercial fishing fleet is a time-invariant, dome-shaped function of age. This was implemented by estimating the parameters of a ‘double-normal’ function (available as a standard selectivity function in SS3). Table 5-1 lists the full specifications for the base-case assessment model.

Model selection and data weighting

The model fit to the spawning survey index is based on an assumption that the model-expected value of the index is equal to the expected DEPM-based value of spawning biomass in any particular year. That is, the survey expected value is related to the spawning biomass by a survey catchability coefficient, $Q = 1$.

Data weighting can have a substantial impact on the outcomes of integrated stock assessment modelling (Richards 1991; Francis 2011). The weighting philosophy of Francis (2011) was applied for the purposes of this assessment; this can be summarized as: (a) the model should fit the trends in the abundance indices as well as possible; and (b) the yearly effective sample sizes and CVs assigned to the data should match the variation implied by the residuals. This approach was implemented by conducting the initial model selection analyses while imposing high weight (i.e. $CV = 0.10$) on the index of spawning biomass, modifying the years for which recruitment deviations are estimated, and iteratively re-weighting the model by adjusting additional multiplicative weighting values for the age composition data. The CVs of the spawning biomass index were then re-turned to their original analytical values, after which additional re-weighting was performed (via an additive weighting value applied to all years). Then final changes were made to the recruitment bias-adjustment ramp, age-composition weightings, and index of abundance CVs using model diagnostics provided by the ‘r4ss’ package (Taylor *et al.* 2015).

Table 5-1. Model specifications for the base-case assessment model, developed using Stock Synthesis, Version 3.24S. Specifications relate to information presented in previous chapters.

Specification	Base-case Model Details
Time-step	1 Year
Model years	1992-2014
Catch data	1992-2014
Spawning Abundance (DEPM)	1995-2007; 2009; 2011; 2013-14
Model age classes	Ages 0 - 9+
Age composition data	Ages 0 - 8, 1995-2006, 2008-2014
Natural mortality (M)	Constant for all ages (except in 1995, 1998)
1992-94; 96-97; 1999+	Base M, estimated, $M = 0.60$
1995, 1998	Fixed relative to base M, $M = 1.47$ for ages 3+ (~0.75 mortality rate)
Growth parameters	Fixed, time-invariant SS-von-Bertalanffy
K	0.31
L_{∞}	20.5
L_{Amin}	8 cm (est. size at age 1)
CV_{Young}, CV_{Old}	0.1
Length-weight relationship	Fixed power function (approx. cubic)
<i>A</i> (Scalar parameter)	5.03×10^{-6} (Female), 4.94×10^{-6} (Male)
<i>B</i> (Power parameter)	3.26 (Female), 3.27 (Male)
Maturity	Fixed logistic function of age
Inflection point (A_{50})	2.50 years
Slope parameter	-5
Fraction female	0.54
Stock-recruitment	Beverton-Holt function
Steepness, <i>h</i>	0.9
Recruitment variance, σ_R	0.8
Bias-adjustment years	1982, 1994, 2014, 2015
Maximum bias-adjustment	0.91
Selectivity	
Commercial Fishery	Estimated, domed-shaped function of age (SS 'double-normal' function)

5.2.2 Input data

Data from multiple sources were integrated for the purposes of assessment, including age-composition data, spawning stock biomass estimates from DEPM surveys (Ward *et al.* 2014), and catch data from the commercial fishery. Table 5-1 shows the data used in the model by type, year, and data source.

Commercial catch data

Commercial catch data were available for all years between 1992 and 2014 from multiple sources. Data based on catch disposal records (CDR) were used for the purposes of this assessment, as they are considered most accurate. Full details on the collection and analyses of commercial catch data are presented in Chapter 2.

Fishery-independent spawning biomass estimates

Spawning biomass estimates obtained from annual DEPM surveys between 1995 and 2007, and 2009, 2011, 2013 and 2014 were used as an index of absolute abundance in the model. Estimates from each of 2013 and 2014 are known to be problematic due to difficulties with measurements and calculations of parameters relating to spawning area, and spawning fraction, respectively. Accordingly, estimates of spawning biomass were adjusted in those years using average values of spawning area (2013 estimate), and of spawning fraction (2014 estimate) from all previous years (Ward *et al.* 2013, 2014). Those adjusted values were consequently used as inputs to the stock assessment model, with assumed CVs equal to the average CV across all previous years. Chapter 4 presents more details relating to the determination of spawning biomass estimates.

Age data

Age composition data from commercial catches were available for all years between 1995 and 2014, except for 2007, when there was no commercial sampling. Ages were determined from an estimated otolith-weight-age relationship and applied to fish in commercial catch samples for which an otolith weight was available. Details on the collection of age-composition data and determination of age from otolith weights are presented in Chapter 3.

5.2.3 Sensitivity analyses and model diagnostics

The sensitivity of the base-case assessment model to changes in key parameters was tested in relation to important model outputs, such as the estimated spawning biomass time-series. Sensitivity to the value chosen for steepness of the stock-recruitment relationship (h) was tested for values of $h = 0.8$ and 0.95 . Sensitivity to the estimated value of the 'base' natural mortality (M) value was tested for fixed values of $M = 0.5$ and 0.7 . An additional sensitivity test was performed to consider the effects of allowing for time-varying selectivity.

In the alternative model, the descending limb of the dome-shaped selectivity curve for commercial fishing is allowed to vary in 2011, and remains constant from 2011-2014. This test was performed as a first step toward capturing the effects of changes in targeting by fishers that began around this time.

Likelihood profile analyses were performed for natural mortality (M), steepness of the stock-recruitment relationship (h), and unfished equilibrium stock recruitment (R_0) for the base-case model. These analyses indicate the degree to which various data sources (and all data sources integrated together) provide information on estimates of these key parameters.

5.2.4 Stock Projections

The forecast feature of SS3 was implemented to make projections of expected future biomass trajectories under three alternative future TACC levels. Projections of expected future biomass are made under the assumption that future recruitment levels follow the Beverton-Holt stock recruitment relationship (with steepness, h , equal to 0.9). Short-term forecasts of spawning biomass (e.g. 1-5 years into the future) are inherently reliant on estimates of recruitment at the end of the main modelling period (e.g. recruitment estimates for 2012-14), as those cohorts mature and enter the spawning component of the population in the first few years of the forecast period. Long-term estimates of spawning biomass (e.g. 5-10 years into the future) are more affected by average expected recruitment levels based on the stock recruitment relationship. Other biological parameters (growth, maturity, and natural mortality), and selectivity of the commercial fishing fleet are assumed to remain constant for the purposes of forecasting.

5.3 Results

5.3.1 Analytical Assessment

The base-case model fits well to commercial catch age composition data aggregated across all years (Figure 5-2), and generally well to the year-specific catch age composition data (Figure 5-3). Model fits are particularly good for years 2000-2001, and 2006-2009. In 1996 and 1997, the model fits are quite poor, potentially due to difficulties in modeling the mass mortality event in 1995. Overall, the base-case model fits to age-composition data suggest the model age-structure is well specified, and suitable for assessment purposes.

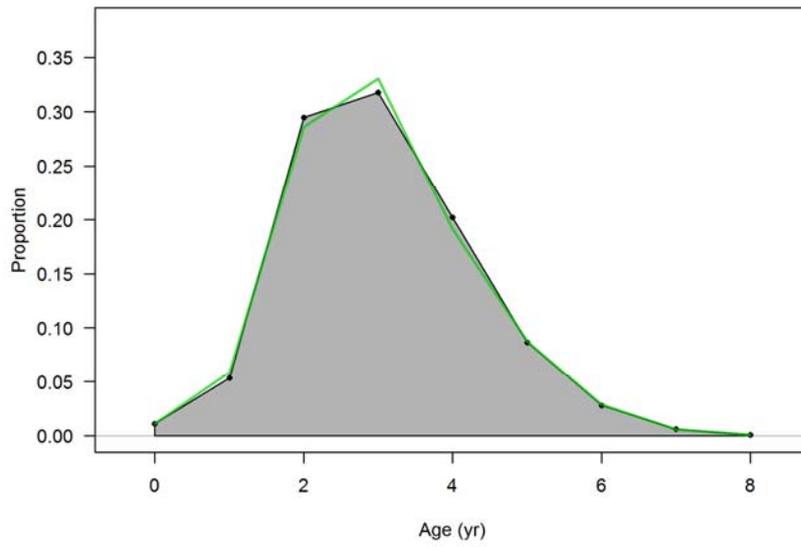


Figure 5-2. Base-case model fit (green line) to the aggregated age-composition data (black lines/points, grey fill) across all years for the commercial purse seine fishery of the SASF.

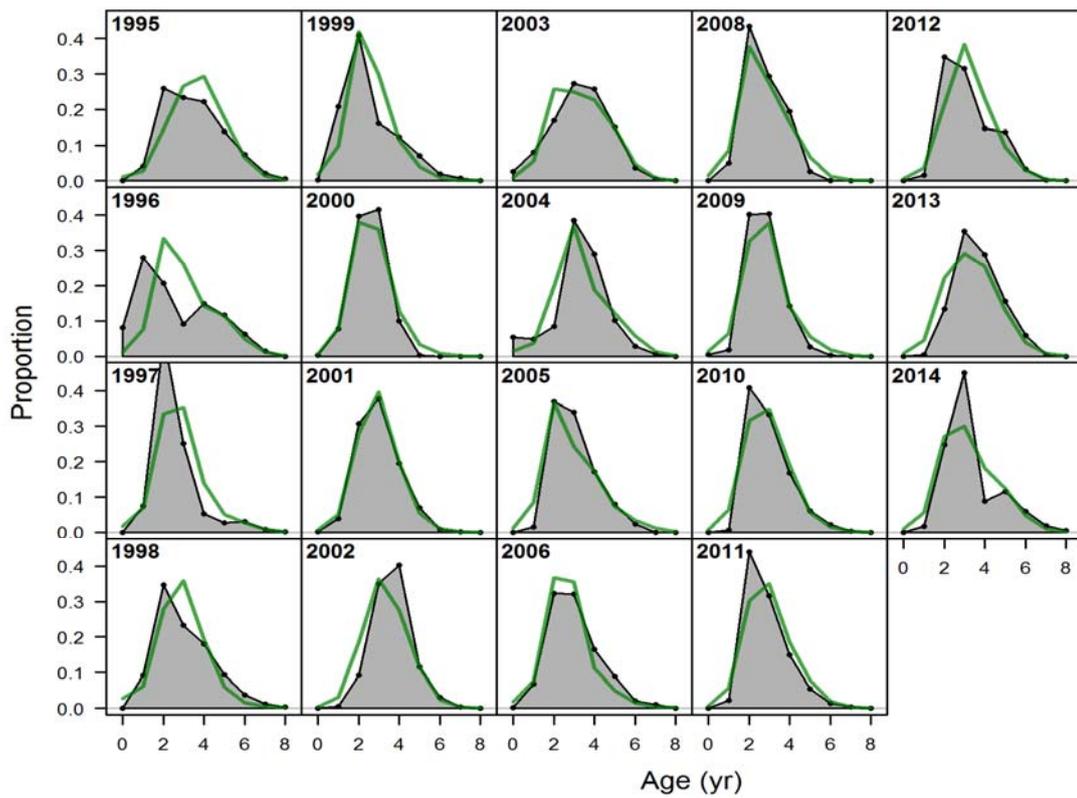


Figure 5-3. Base-case model fits (green lines) to year-specific age-composition data (black lines/points, grey fill) for the commercial purse seine fishery of the SASF.

The base-case model fits to the index of spawning biomass (Figure 5-4) lie within or close to the 95% confidence intervals of each data point from 1992 to 2014. The fit to the index of abundance indicates the adjustments to CVs and associated data weighting approach is performing satisfactorily. However, the model did not capture the peak in the estimated spawning biomass in 2006-07 and the increase in 2014.

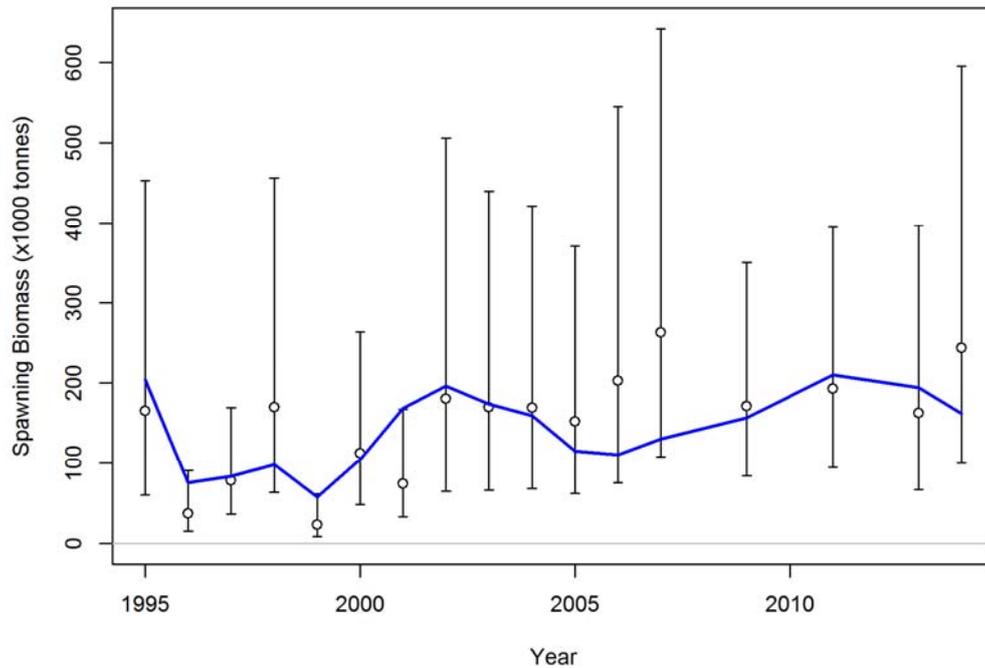


Figure 5-4. Base-case model fit (blue line) to the index of spawning-biomass (black circles, \pm final input CVs) derived from daily egg-production method (DEPM) surveys for the SASF.

Figure 5-5 summarises selectivity-at-age for the base case assessment model. Selectivity for the commercial fishing fleet is assumed to be a time-invariant dome-shaped function of age, with the parameters of a 'double-normal' selectivity curve estimated in the model. Parameter estimates result in a selectivity curve with a descending right-side limb that mimics the expected reduced availability of older fish to the main components of the fishery, where younger (and hence smaller) fish dominate. Figure 5-5 also shows the assumed selectivity-at-age for the DEPM survey, where all fish aged one and greater are assumed to be fully available to the survey, with the fully realised availability being proportional to the assumed maturity curve (Figure 5-6).

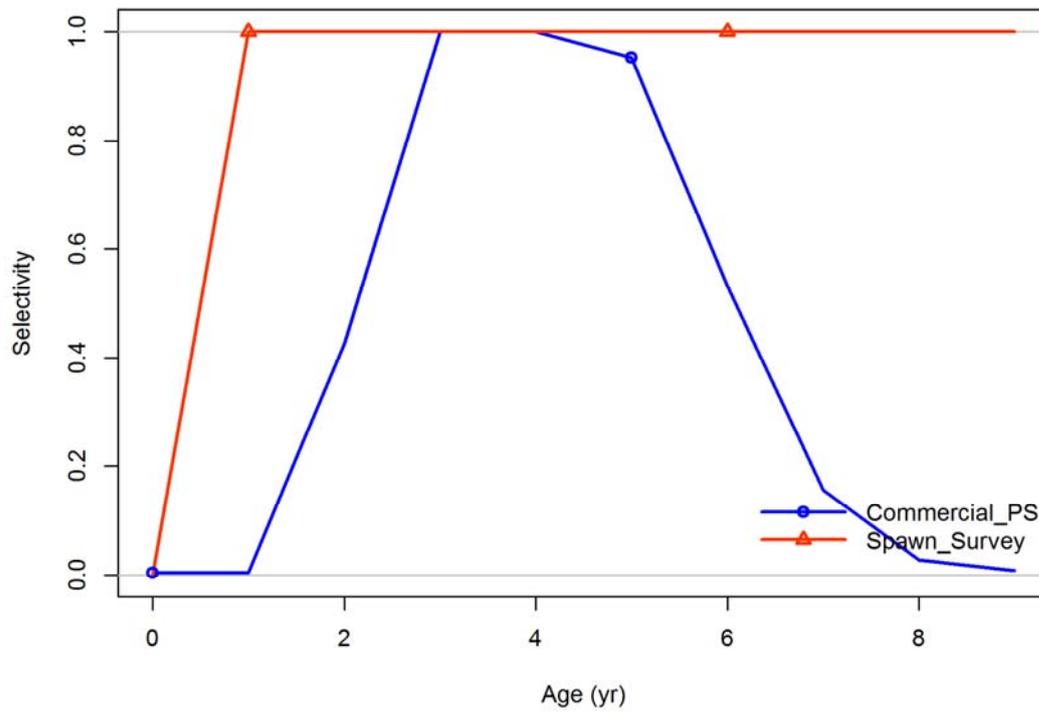


Figure 5-5. Age-based selectivity (expected proportion available to fishing/survey by age). Model estimated dome-shaped selectivity for the commercial purse seine fishery (blue line) and assumed selectivity-at-age for the spawning (DEPM) survey (red line).

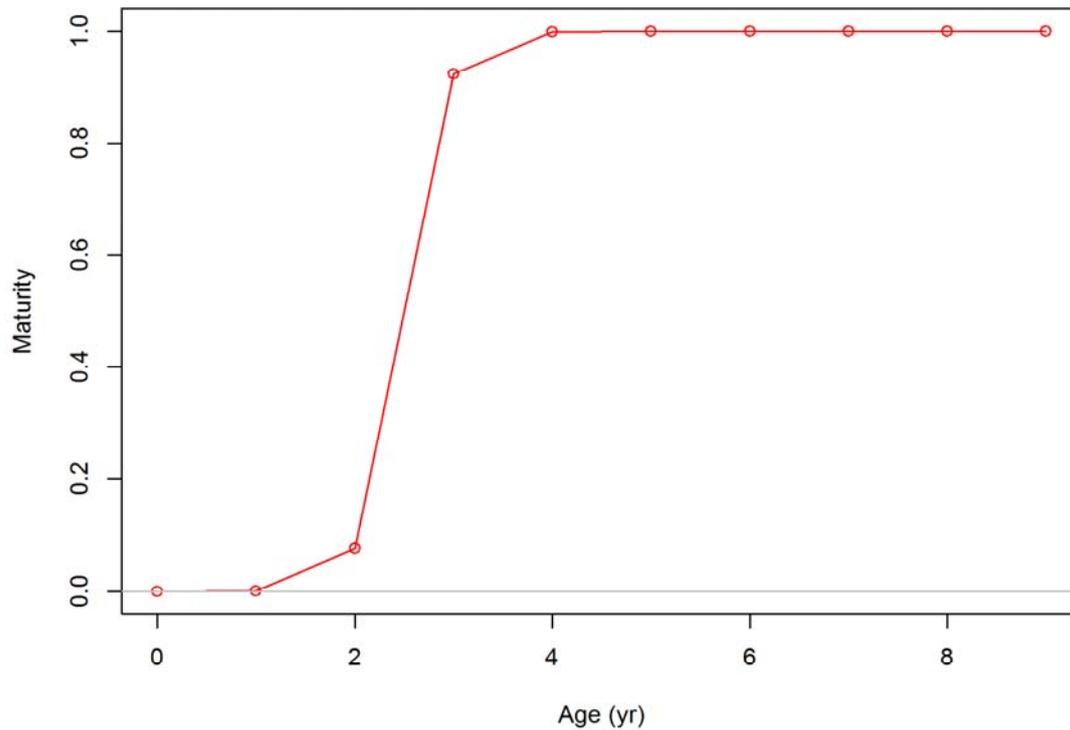


Figure 5-6. Model input relationship between age (years) and maturity (proportion) for female Sardine (expected age-at-maturity), represented by a logistic function with $A_{50} = 2.5$ (inflection point) and slope parameter = -5.

Figure 5-7 shows the base-case, model-derived estimates of spawning biomass exploitation rate between years 1992 and 2014 for the commercial fishery. These estimates reveal a small increase in exploitation rate in 1998-1999, when spawning biomass was estimated to be low, followed by a significant increase in exploitation rate between 2000 and 2005, when fishing intensity reached its peak, a trend commensurate with large increases in total catches during that period. Since that time (2006 to 2014) the exploitation rate of spawning biomass is estimated to have remained relatively steady between 15-25%.

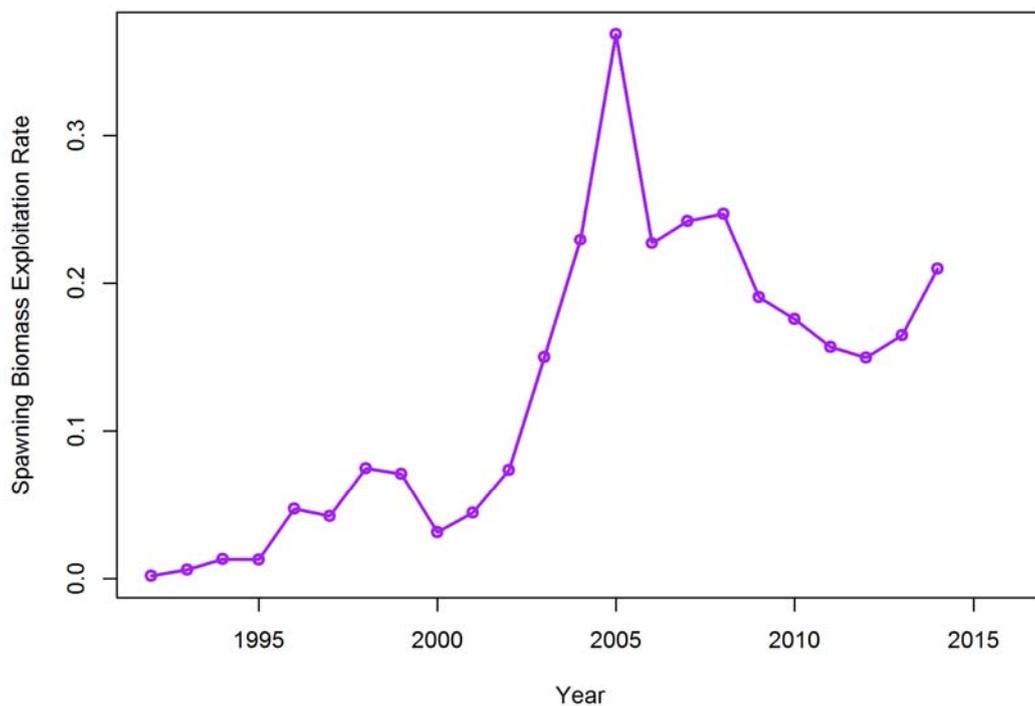


Figure 5-7. Model-derived estimates of spawning biomass exploitation rate, between years 1992 and 2014 for the commercial purse seine fishery.

The estimated time-series of recruitment for the base-case model (Figure 5-8) shows recruitment for the fishery is relatively constant, with no years with very low recruitment. There are several periods of high estimated recruitment, firstly from 1997 to 1999, following the mass mortality events of 1995 and 1998, and again from 2006 to 2009, when recruitment is estimated to have been highest for the time series. Annual estimates of recruitment from 2010 onwards are estimated to be below the long-term average.

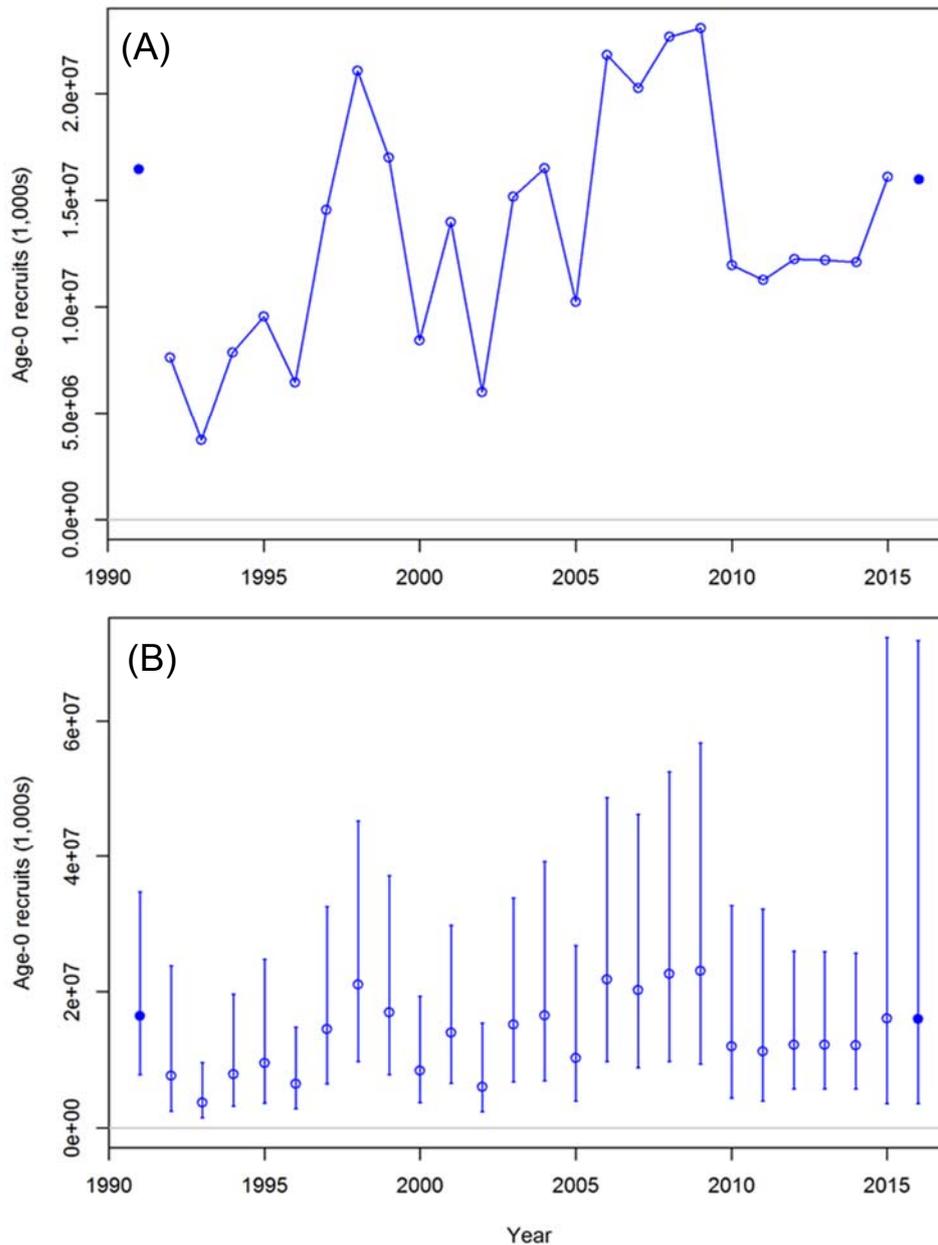


Figure 5-8. Model estimated recruitment series (A) from 1992 until 2014, including forecast recruitments (assumed to follow the underlying stock recruitment curve) for 2015 and 2016. Model-estimated recruitment series (B) with 95% confidence intervals.

5.3.5 Spawning biomass

Under the base-case assessment model, unfished equilibrium spawning biomass (prior to 1992) is estimated at approximately 249,000 t (Figure 5-9). Estimates of total spawning biomass fell to approximately 75,000 t and 58,000 t in 1996 and 1999 respectively, following the modelled mass mortality events of 1995 and 1999. Following those declines, the spawning stock is estimated to have recovered to a peak of approximately 196,000 t in 2002,

before declining to approximately 111,000 t in 2006 (Figure 5-9) and peaking in 2012 at approximately 227,000 t. Using the base-case model, the spawning biomass is assessed to be approximately 162,000 t at the beginning of 2014 and approximately 142,000 t at the beginning of 2015.

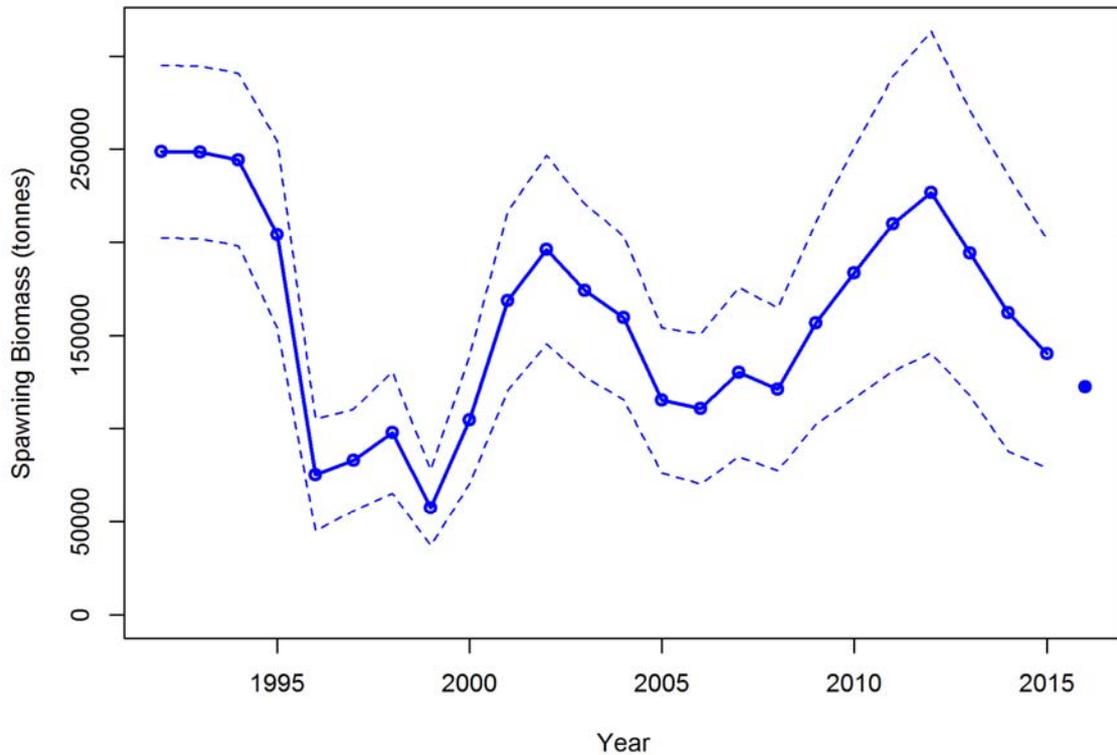


Figure 5-9. Time-series of model-estimated spawning biomass (solid blue line) with 95% confidence intervals (dashed blue lines), including current (2015) estimated biomass and 2016 forecast biomass.

5.3.2 Data weighting

The fit to the integrated data sources was balanced following a data weighting approach similar to that of Francis (2011). These methods resulted in the age composition data being down-weighted, such that the final multiplicative down-weighting value was set to 0.056. This low weighting factor reflects the inherent uncertainty in age determination and subsequent uncertainty of the age composition data. The survey-based index of spawning biomass was iteratively re-weighted using an additive term that affects the CV of each yearly point estimate. A final value of 0.145 was input for this additive variance.

5.3.3 Sensitivity analyses and model diagnostics

Figure 5-10 shows the results of a sensitivity analysis comparing the base-case model with alternative models that included fixed (rather than estimated) values of natural mortality (M). Setting the model to include fixed $M = 0.5$ and 0.7 (± 0.1 from the base-case maximum likelihood estimate of 0.6) had minimal effect on the model results. Similarly, changes to the assumed value of steepness for the stock recruitment curve (h) had minimal effect on model outputs, including the time-series of spawning biomass (Figure 5-11). The sensitivity to allowing for time-varying selectivity also produced estimates of spawning biomass that were very similar to the base-case model (Figure 5-12). Overall, model sensitivity tests indicate the main outputs of the base-case model are robust to changes in key parameters. Further base-case model diagnostics, including the results of likelihood profile analyses for natural mortality (M), steepness of the stock-recruitment relationship (h), and unfished equilibrium stock recruitment (R_0) are presented in the Appendix (Figure A-2). Results of the likelihood profile analyses confirm there is sufficient information in the data to estimate M and R_0 , with no significant conflicts among data sources in regards to the estimation of those parameters. Furthermore, the likelihood profile analysis of h supports the decision to fix that parameter at 0.9 .

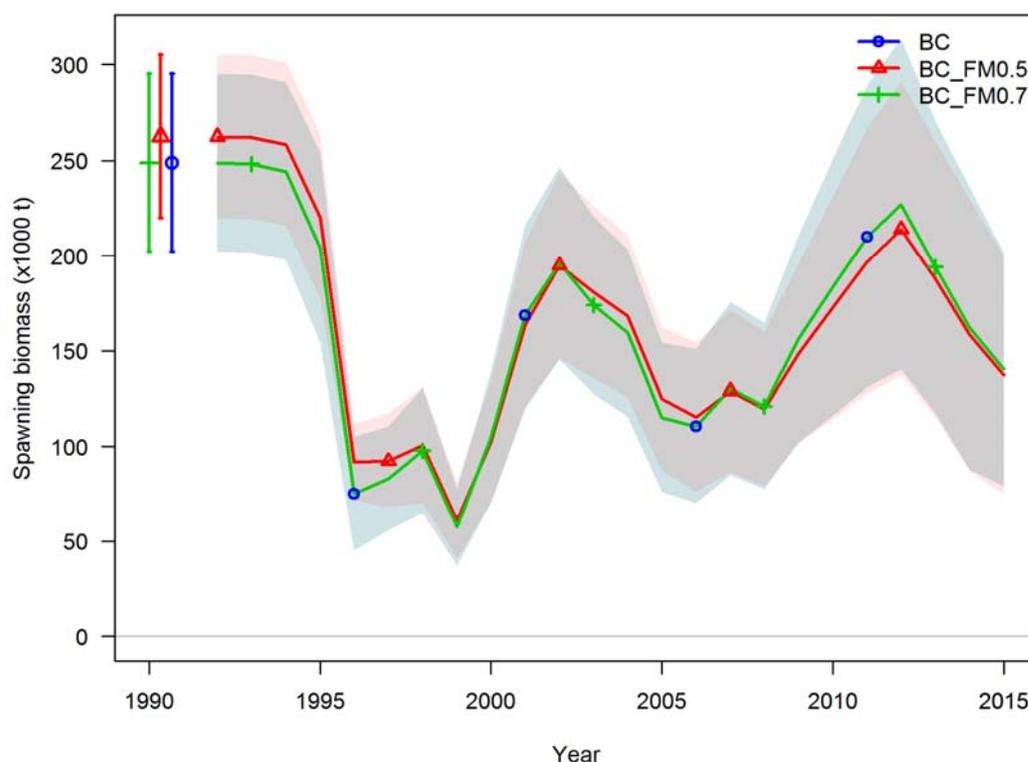


Figure 5-10. Time-series of estimated spawning biomass and 95% confidence intervals for the base-case model with estimated natural mortality, $M=0.6$ (blue line), compared to sensitivity tests with fixed natural mortality, $M = 0.5$ (red line), and $M = 0.7$ (green line).

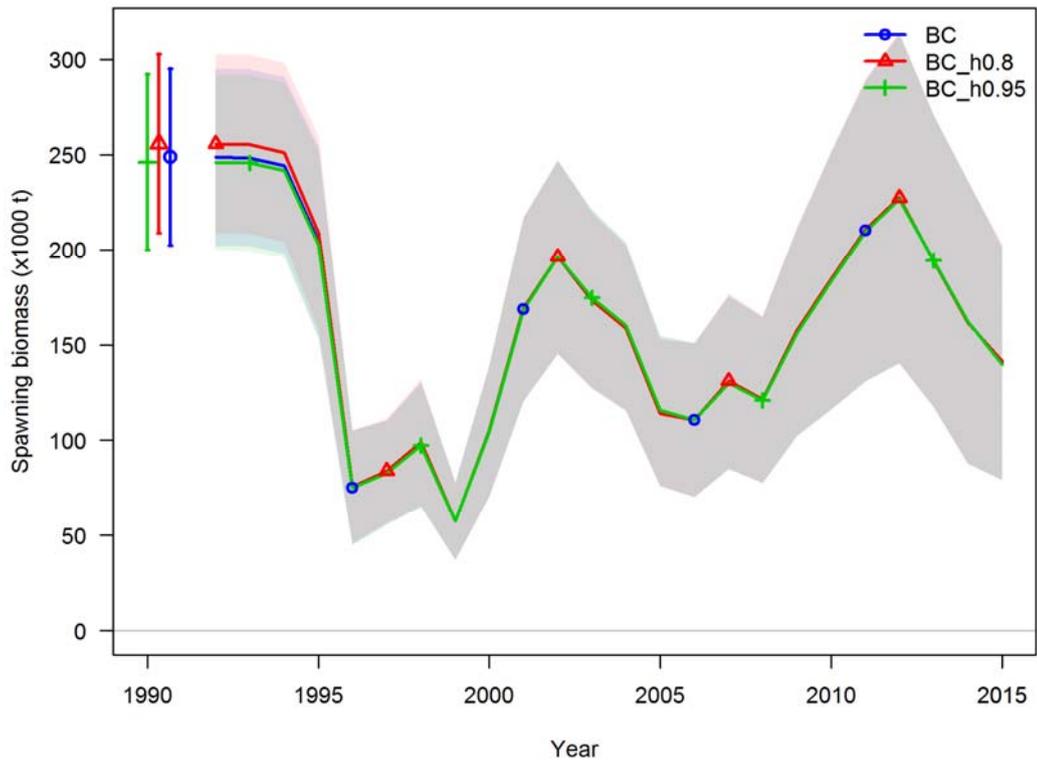


Figure 5-11. Time-series of estimated spawning biomass and 95% confidence intervals for the base-case model with fixed steepness ($h = 0.9$) of the stock-recruitment curve (blue line), compared to sensitivity tests with fixed $h = 0.8$ (red line), and $h = 0.95$ (green line).

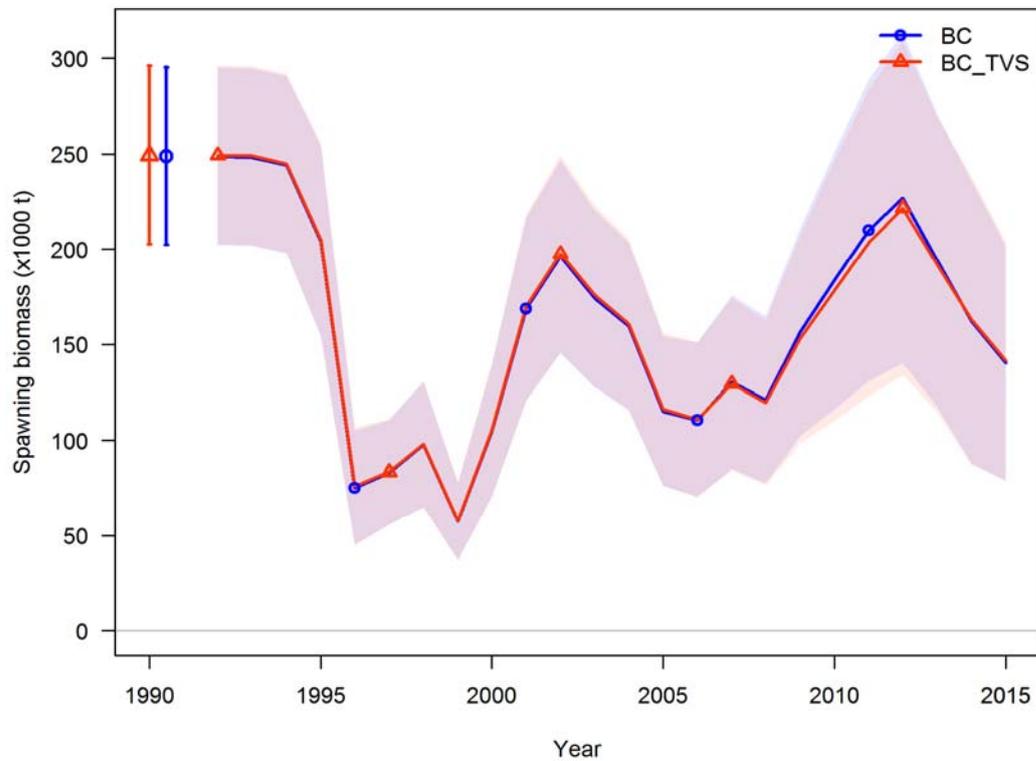


Figure 5-12. Time-series of estimated spawning biomass and 95% confidence intervals for the base-case model with constant selectivity (blue line), compared to sensitivity test with time varying selectivity (selectivity change in 2011-2014, red line).

5.3.6 Long-term stock projections

Figure 5-13 shows the results of a sensitivity analysis comparing projected spawning biomass levels under different total catches for the projected period. Ten-year model projections with an assumed annual TACC of 38,000 t, suggest the population will have an average long-term spawning biomass of approximately 147,000 t under future recruitment scenarios consistent with the model-estimated stock recruitment relationship. The average long-term spawning biomass is estimated to be approximately 168,000 t with a TACC of 30,000 t and 119,000 t with a TACC of 47,500 t.

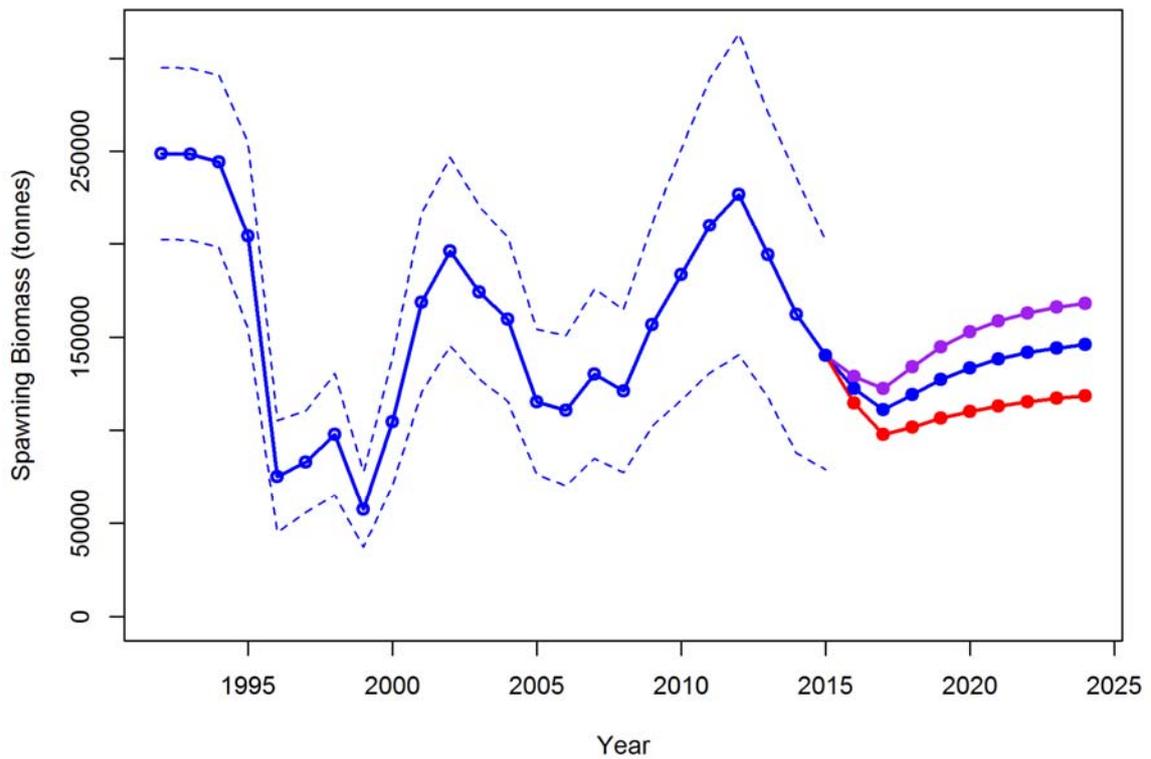


Figure 5-13. Ten year model predictions of future spawning biomass assuming a TACC of 38,000 t (blue line), 30,000 t (purple line) and 47,500 t (red line).

5.4 Discussion

The overall base-case model fits relatively well to the catch-at-age data and spawning biomass estimates from fishery-independent surveys. It is likely that the model fits could be improved by adding time-varying natural mortality parameters to account for juvenile mortality in 1995 and 1998. Future assessments should also account for changes in fishing practices over time. For example, the spatial management arrangements in the new Harvest Strategy have resulted in a higher proportion of larger (older) fish being taken in catches. The base-case model assumed a constant selectivity curve that does not account for these sorts of changes. Hence, it is likely that recruitment is underestimated for 2012 onwards. These issues could be addressed by further exploring the implementation of time-varying selectivity to reflect changes in the 'availability' of both younger and older fish over time. The model could also be modified to be spatially explicit (i.e. recognize zones) or, more simply, to use the areas-as-fleets approach (Waterhouse *et al.* 2014; Hurtado Ferro *et al.* 2014), and model catch and age composition data from different spatial zones separately and with different selectivity curves.

The stock projections presented in this chapter should be viewed with caution. For example, the projection that the spawning biomass in 2015 is estimated to be 142,000 t (i.e. below the target reference point) may reflect the low levels of model estimated recruitment for after 2012 that resulted from the increased abundance of large fish in catches during those year, and reflected the implementation of spatial management and increased targeting of large fish. This interpretation is supported by the longer term projections based on the average historical recruitment level that suggest spawning biomass may stabilize at ~147,000 t (i.e. close to the target reference point) over ten years with a TACC of 38,000 t. Further testing and development of the model is required.

6.0 GENERAL DISCUSSION

6.1 Stock status and uncertainty

This assessment of the status of the South Australian Sardine Fishery analyses a large quantity and wide range of high-quality, fishery-dependent and fishery-independent data and synthesises these data using a dynamic, age-structured population model. The implications of some of the key uncertainties in the data, assumptions and estimates upon which the model is based are explicitly tested by conducting sensitivity analyses. We consider that the information available and approach taken in this report provides a sound basis for assessing the status of the South Australian Sardine stock. The key limitations of the assessment are associated with: 1) imprecision in the estimates of spawning biomass; 2) uncertainties in estimates of fish age resulting from difficulties associated with reading annuli in Sardine otoliths; and 3) assumptions of the model that may bias outputs (e.g. the assumption of constant age and size selectivity of fishing operations among years).

Data and model outputs presented in this report suggest that the spawning stock on which the SASF is based is in a sound position. Firstly, the mean size of fish taken in catches from Spencer Gulf has increased since 2012, when it reached a low of 128 mm, and was 147 and 139 mm in 2013 and 2014, respectively. The mean length of Sardine taken from Spencer Gulf during 1 January to 30 June 2015 was 144 mm (SARDI, unpublished data), which is above the upper target reference point for mean size of 142 mm specified in the harvest strategy (PIRSA 2014). Secondly, the estimate of spawning biomass obtained in the DEPM survey undertaken in February-March 2014 was above the target reference point for spawning biomass of 150,000 t (PIRSA 2014). Thirdly, outputs from the preliminary age structured population model developed for the fishery suggests that the spawning biomass was above the target reference point. Fourthly, model projections based on average historical recruitment levels suggest that the spawning biomass is likely to remain close to the target reference point over the next 10 years under TACCs of 38,000 t. The only issue of potential concern in this assessment is the model projected decline in spawning biomass in 2015 to 142,000 t under a TACC of 38,000 t. However, this finding is likely to reflect the low and highly uncertain model estimates of recruitment after 2012 resulting from the increase of large fish in catches due to i) the increase in the proportion of catches taken from outside Spencer Gulf, and ii) increased targeting of large fish in the gulf. Further testing and development of the model is required to ensure the model structure and assumptions are appropriate; this should include further investigation of the effects of changes in fishing patterns on estimates of recruitment and projections of future spawning biomasses.

Based on the evidence presented in this report SASF is classified as **sustainable**.

6.2 Management implications and future research needs

The harvest strategy in the new management plan (PIRSA 2014) responds to the key issue of concern raised in the previous stock assessment report for the SASF (Ward *et al.* 2012), which was the reduction in the mean size of fish taken from Spencer Gulf during 2009 to 2012. The inclusion in the new harvest strategy of a size-based decision rule that controls the level of fishing effort in Spencer Gulf, based on the mean size of fish taken in catches, is an important step forward for the SASF. This decision rule represents a pragmatic approach to mitigating the potential for growth overfishing to occur, regardless of whether the reduction in the abundance of target sized-fish on key fishing grounds results from environmental factors, recruitment variability and/or fishing pressure. The increase in the mean size of fish taken from Spencer Gulf since 2012 is likely to reflect, at least in part, the success of the industry-based program for monitoring fish size and disseminating spatial catch information to the fleet that was established after the 2012 season to assist fishers avoid the capture of small fish.

Smith *et al.* (2015) suggested that target and limit reference points for small pelagic fishes in Australian waters, including Sardine, of 50% (B_{50}) and 20% (B_{20}) of the unfished spawning biomass, respectively, are “safe from an ecosystem perspective and provide reasonable levels of yield”. Both the target (150,000 t) and limit (75,000 t) reference points in the new harvest strategy for the SASF are more conservative than those recommended by Smith *et al.* (2015) as they equate to B_{60} and B_{30} , respectively. Similarly, the range of exploitation rates that can be applied under the new harvest strategy (i.e. 10-25%) are conservative compared to the maximum level (33%) that Smith *et al.* (2015) suggest is likely to maintain the median spawning biomass of Sardine above B_{50} and the chance of falling below B_{20} at less than 10%.

Preliminary model outputs presented in this report suggest that the new harvest strategy for the SASF will maintain stocks close to the conservative target reference point for spawning biomass of 150,000 t over the next decade under a TACC of 38,000 t. The model projection that the spawning biomass in 2015 may fall to 142,000 t under a TACC of 38,000 t should be treated with caution because it is likely to reflect low model estimates of recruitment after 2012 caused by increased catches of large fish through the introduction of zoning and changes in targeting practices. This estimate is above the level which Smith *et al.* (2015) suggest is safe from an ecosystem perspective (i.e. B_{50} or 125,000 t).

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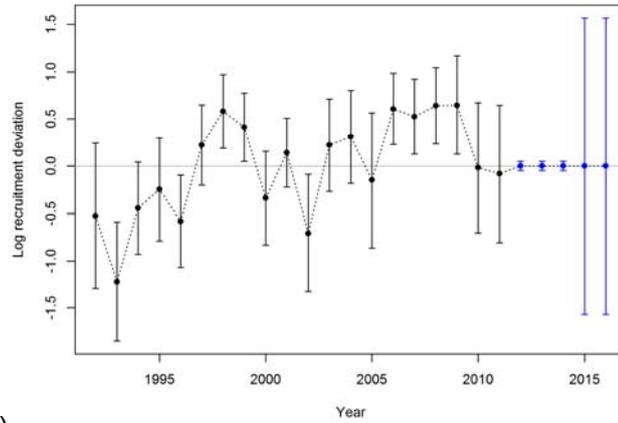
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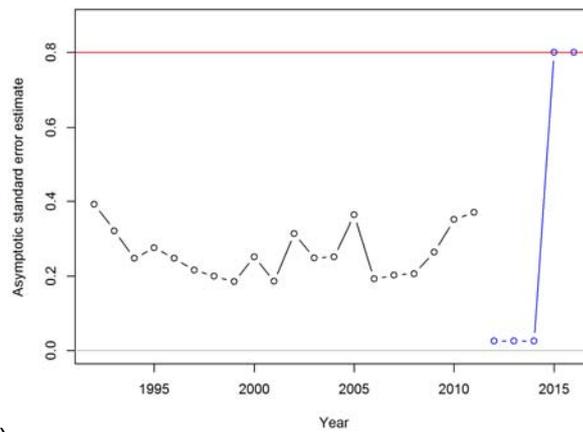
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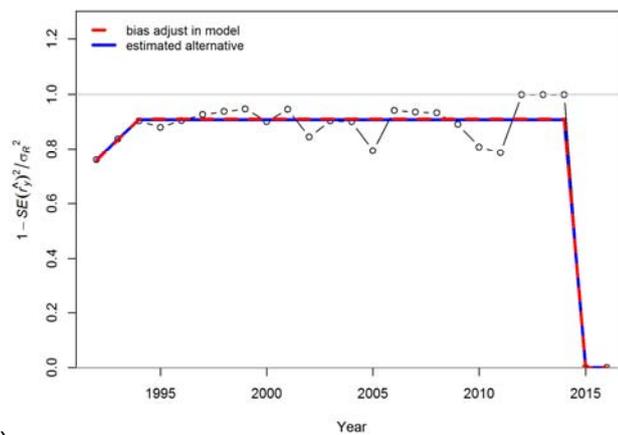
APPENDIX A: MODEL DIAGNOSTICS AND STOCK SYNTHESIS INPUT FILES



(A)



(B)



(C)

Figure A-1. Diagnostic plots for recruitment estimates from the base-case model: (A) recruitment deviations from stock-recruitment curve with standard errors; (B) asymptotic standard errors for recruitment deviation estimates (black lines/points) and for forecast recruitments (blue line/points); and (C) recruitment bias adjustment ramp.

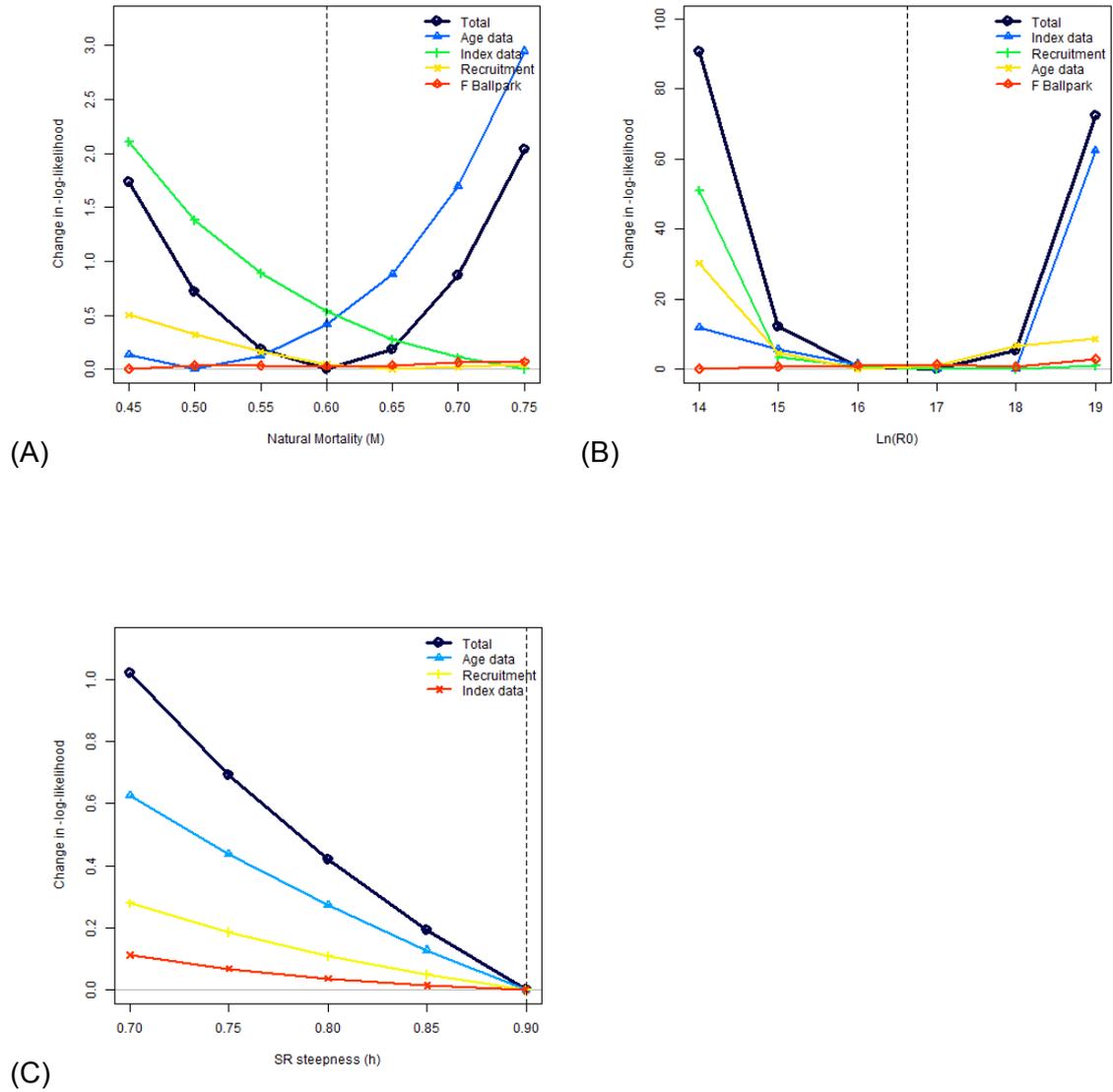


Figure A-2. Results of likelihood profile analyses for the base case model: (A) for natural mortality (M) between values of 0.45 and 0.75; (B) for unfished equilibrium stock recruitment (R_0) between values of 14 and 19 (natural log of R_0); and (C) steepness of the stock-recruitment relationship (h) between values of 0.7 and 0.9.

Supplement A-1. SS3 input files for the base-case model.

STARTER.SS

```

# SSV3.24S
# Starter File
# South Australian Sardine Fishery, 2015
# Athol Whitten, SARDI, athol.whitten@sa.gov.au
sardine.dat
sardine.ctl
0      # 0=use init values in control file; 1=use ss3.par
2      # run display detail (0,1,2)
1      # detailed age-structured reports in REPORT.SSO (0,1)
0      # write detailed checkup.sso file (0,1)
0      # write parm values to ParmTrace.sso (0=no,1=good,active; 2=good,all; 3=every_iter,all_parms; 4=every,active)
0      # write to cumreport.sso (0=no,1=like&timeseries; 2=add survey fits)
0      # Include prior_like for non-estimated parameters (0,1)
1      # Use Soft Boundaries to aid convergence (0,1) (recommended)
0      # Number of bootstrap datafiles to produce
5      # Turn off estimation for parameters entering after this phase
0      # MCMC burn interval
0      # MCMC thin interval
0      # jitter initial parm value by this fraction
-1     # min yr for sdreport outputs (-1 for styr)
-2     # max yr for sdreport outputs (-1 for endyr; -2 for endyr+Nforecastyrs)
0      # N individual STD years
0.0001 # final convergence criteria (e.g. 1.0e-04)
0      # retrospective year relative to end year (e.g. -4)
0      # min age for calc of summary biomass
1      # Depletion basis: denom is: 0=skip; 1=rel X*B0; 2=rel X*Bmsy; 3=rel X*B_styr
1      # Fraction (X) for Depletion denominator (e.g. 0.4)
4      # (1-SPR)_reporting: 0=skip; 1=rel(1-SPR); 2=rel(1-SPR_MSX); 3=rel(1-SPR_Btarget); 4=notrel
1      # F_std reporting: 0=skip; 1=exploit(Bio); 2=exploit(Num); 3=sum(frates)
0      # F_report_basis: 0=raw; 1=rel Fspr; 2=rel Fmsy ; 3=rel Fbtgt
999 # check value for end of file

```

CONTROL FILE 'SARDINE.CTL'

```

# SSV3.24S
# Control File
# South Australian Sardine Fishery, 2015
# Athol Whitten, SARDI, athol.whitten@sa.gov.au

1 #_N_Growth_Patterns
1 #_N_Morphs_Within_GrowthPattern

1 #_Nblock_Designs
2 # Number of blocks per design
# Beginning and ending years of blocks:
1995 1995 1998 1998

# Biological specifications
0.54 #_Fracfemale
1 #_NatM_type:_0=1Parm; 1=N_breakpoints;_2=Lorenzen;_3=agespecific;_4=agespec_withseasinterpolate
2 #_Number of breakpoints
# Age at each breakpoint
2.5 3.0

1 #_GrowthModel: 1=vonBert with L1&L2; 2=Richards with L1&L2; 3=age_speciific_K; 4=not implemented
1 #_Growth_Age_for_L1
999 #_Growth_Age_for_L2 (999 to use as Linf)
0 #_SD_add_to_LAA (set to 0.1 for SS2 V1.x compatibility)
0 #_CV_Growth_Pattern: 0 CV=f(LAA); 1 CV=F(A); 2 SD=F(LAA); 3 SD=F(A); 4 logSD=F(A)
2 #_maturity_option: 1=length logistic; 2=age logistic; 3=read age-maturity matrix by growth_pattern; 4=read age-fecundity;
5=read fec and wt from wtatage.ss
1 #_First_Mature_Age
1 #_Fecundity_option:(1)eggs=Wt*(a+b*Wt);(2)eggs=a*L^b;(3)eggs=a*Wt^b; (4)eggs=a+b*L; (5)eggs=a+b*W
0 #_Hermaphroditism_option: 0=none; 1=age-specific fxn
3 #_Parameter_offset_approach (1=none, 2= M, G, CV_G as offset from female-GP1, 3= M and CV old offset to young same sex (as per
SS2 V1.x)
1 #_Env/block/dev_adjust_method (1=standard; 2=logistic transform keeps in base parm bounds; 3=standard w/ no bound check)

```

```

# Mortality and growth parameters
# Lo Hi  Init Prior Prior  Prior Param Env Use Dev  Dev  Dev  Block  Block
# bnd bnd  value mean  type  SD   phase var dev minyr maxyr SD  design func
0.40 0.80 0.60 0   -1   0.8    2    0  0  0    0    0.5  0    0    # M at age <=2.5
0.00 1.00 0.00 0   -1   0.8   -2    0  0  0    0    0.5  1    2    # M at age >=3.0 (exp offset)
6    10    8    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Lmin
18   22   20.5 0   -1   0.8   -2    0  0  0    0    0.5  0    0    # Lmax
0.27 0.35 0.31 0   -1   0.8   -3    0  0  0    0    0.5  0    0    # VBK
0.01 0.20 0.1  0   -1   0.8   -3    0  0  0    0    0.5  0    0    # CV young
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # CV old: exp offset to CV young

# Males (Offset to females)
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # M at age <=2.5: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  1    2    # M at age >=3.0: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Lmin: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -2    0  0  0    0    0.5  0    0    # Lmax: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # VBK: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -4    0  0  0    0    0.5  0    0    # CV young: exp offset to GP 1 (female)
-3   3    0    0   -1   0.8   -4    0  0  0    0    0.5  0    0    # CV old: exp offset to CV young (male)

# Weight-length and maturity parameters (L in cm, W in kg)
# Females
# Lo Hi  Init Prior Prior  Prior Param Env Use Dev  Dev  Dev  Block  Block
# bnd bnd  value mean  type  SD   phase var dev minyr maxyr SD  design function
-3   3    5.03e-6 0   -1   0.8   -3    0  0  0    0    0.5  0    0    # W-L scale (Female) (Parameter A in W=A*L^B, Weight
in kg)
 3   4    3.26    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # W-L power (Female) (Parameter B in W=A*L^B, Weight
in kg)
 0   3    2.5    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Age at 50% maturity (Logistic curve inflection
point)
-6   3    -5    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Maturity slope (Logistic curve slope, must have a
negative value)
-3   3    1    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Fecundity: Intercept eggs/gm
-3   3    0    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # Fecundity: Slope eggs/gm

-3   3    4.94e-6 0   -1   0.8   -3    0  0  0    0    0.5  0    0    # W-L scale (Male) (Parameter A in W=A*L^B, Weight
in kg)
 1   4    3.27    0   -1   0.8   -3    0  0  0    0    0.5  0    0    # W-L power (Male) (Parameter B in W=A*L^B, Weight
in kg)

# Distribute recruitment among growth pattern x area x season
-4   4    0    0   -1   99   -3    0  0  0    0    0.5  0    0    # RecrDist_GP_1
-4   4    0    0   -1   99   -3    0  0  0    0    0.5  0    0    # RecrDist_Area_1

```

```

-4  4  0  0  -1  99  -3  0  0  0  0  0.5  0  0  # RecrDist_Seas_1

# Cohort growth (K) deviation parameter
1  1  1  1  -1  99  -5  0  0  0  0  0.5  0  0  # CohortGrowDev

# Cond: MG time-block setup:
1  #(0=Read one line apply all, 1=read one line each parameter)
# Block parameters for M:
0.0  2.00  0.90  0  -1  99  -3  #Nat_M_Breakpoint Block 1, 1995 Mass Mortality (Females)
0.0  2.00  0.90  0  -1  99  -3  #Nat_M_Breakpoint Block 1, 1998 Mass Mortality (Females)
0.0  2.00  0.90  0  -1  99  -3  #Nat_M_Breakpoint Block 1, 1995 Mass Mortality (Males)
0.0  2.00  0.90  0  -1  99  -3  #Nat_M_Breakpoint Block 1, 1998 Mass Mortality (Males)

# Seasonal_effects_on_biology_parms
#_femwtlen1, femwtlen2, mat1, mat2, fec1, fec2, Malewtlen1, malewtlen2, L1, K
0 0 0 0 0 0 0 0 0 0

# Spawner-recruit parameters
3 #_SR_function: 2=Ricker; 3=std_B-H; 4=SCAA; 5=Hockey; 6=B-H_flattop; 7=survival_3Parm
# Lo  Hi  Init  Prior  Prior  Prior  Param
# bnd  bnd  value  mean  type  SD  phase
10  20  15  0  -1  10  1  # Ln(R0)      # SR_R0
0.2  1  0.9  0  -1  0.5  -2  # Steepness  # SR_steep
0  2  0.8  0  -1  0.8  -3  # Sigma R    # SR_sigmaR
-5  5  0.0  0  -1  1  -3  # Environmental link coefficient  # SR_envlink
-5  5  0.0  0  -1  1  -4  # Initial equilibrium offset to virgin  # SR_R1_offset
0.0  0.5  0.0  0  -1  99  -2  #_Reserve for future autocorrelation  # SR_autocorr

# Spawner-recruit set-up
0  #_SR_env_link
0  #_SR_env_target_0=none;1=devs;_2=R0;_3=steepness
1  # do_recr_dev: 0=none; 1=devvector; 2=simple deviations
1992 # first year of main recr_devs; early devs can precede this era
2011 # last year of main recr_devs; forecast devs start in following year
3  #_recdev phase
1  # (0/1) to read 13 advanced options
0  #_recdev_early_start (0=none; neg value makes relative to recdev_start)
-1 #_recdev_early_phase
0  #_forecast_recruitment phase (incl. late recr) (0 value resets to maxphase+1)
1000 #_lambda for prior_fore_recrr occurring before endyr+1
1982 #_last_early_yr_nobias_adj_in_MPD
1994 #_first_yr_fullbias_adj_in_MPD
2014 #_last_yr_fullbias_adj_in_MPD

```

```

2015 #_first_recent_yr_nobias_adj_in_MPD
0.91 #_max_bias_adj_in_MPD
0.0 # period for recruitment cycles - use only if modelling seasons as years
-15 # min_rec_dev
15 # max_rec_dev
0 #_read_recdevs
# End of advanced SR options

#Fishing Mortality info
0.2 # F ballpark for tuning early phases
2000 # F ballpark year (neg value to disable)
3 # F_Method: 1=Pope; 2=instan. F; 3=hybrid (hybrid is recommended)
4 # max F or harvest rate, depends on F_Method
4 # N iterations for tuning F in hybrid method (recommend 3 to 7)

# Initial_F_parms
# Lo Hi Init Prior Prior Prior Param
# bnd bnd value mean type SD phase
0.00 1 0.00 0 -1 99 -1 # Commercial_PS

# Catchability Q_setup
# Q_type options: <0=mirror, 0=float_nobiasadj, 1=float_biasadj, 2=parm_nobiasadj, 3=parm_w_random_dev, 4=parm_w_randwalk,
5=mean_unbiased_float_assign_to_parm
0 0 0 0 # 1 Commercial_PS
0 0 0 2 # 2 Spawn_Survey

# Q parameters
# Lo Hi Init Prior Prior Prior Param
# bnd bnd value mean type SD phase
-2 2 0 0 -1 99 -2 # Fix Q=1, such that index is assumed to be absolute abundance.

# Size_selex_types
# Discard_options:_0=none;_1=define_retention;_2=retention&mortality;_3=all_discarded_dead
# Pattern, Discard, Male, Special
0 0 0 0 # 1 Commercial_PS # Set commercial size selectivity = 1.0 for all sizes (and use age-based selectivity)
30 0 0 0 # 2 Spawn_Survey # Set special selectivity 30, expected survey abundance equal to spawning biomass

# Age_selex_types
# Pattern, Discard, Male, Special
20 0 0 0 # 1 Commercial_PS # Double normal
10 0 0 0 # 2 Spawn_Survey # Age selectivity = 1.0 for all ages, (special selex defined in size-selex section)

```

```

# Age_selex_parms
# Lo  Hi  Init  Prior Prior  Prior Param Env Use Dev  Dev  Dev  Block  Block
# bnd bnd  value mean  type  SD    phase var dev minyr maxyr SD   design function

# Age_Selex_Parms 1: Commercial_PS (Double normal)
 0.0  9.9   3.0  0   -1    99    2    0  0  0    0    0.5  0    0    # 1 Peak3
-10.0 3.0  -5.0  0   -1    99    3    0  0  0    0    0.5  0    0    # 2 Top
-4.0 12.0  2.5  0   -1    99    3    0  0  0    0    0.5  0    0    # 3 Asc - width
-2.0  6.0   2.0  0   -1    99    3    0  0  0    0    0.5  0    0    # 4 Desc - width
-15.0 5.0  -10.0 0   -1    99    4    0  0  0    0    0.5  0    0    # 5 Init
-15.0 5.0  -10.0 0   -1    99    4    0  0  0    0    0.5  0    0    # 6 Final

# Cond: Custom_sel-env_setup
# Cond: 2 2 0 0 -1 99 -2 #_placeholder when no enviro fxns
# Cond: Selex time-block setup:
# 1 #(0=Read one line apply all, 1=read one line each parameter)
# Tag loss and tag reporting
0 # 0=no read; 1=read if tags exist

### Likelihood related quantities ###
# Variance adjustments to input values
1 #_Variance_adjustments_to_input_values (1/0 on/off)
# One column for each fleet/survey
0.000 0.145 # constant added to survey CV
0.000 0.000 # constant added to discard SD
0.000 0.000 # constant added to body weight SD
1.000 1.000 # multiplicative scalar for length comps
0.056 1.000 # multiplicative scalar for agecomps
1.000 1.000 # multiplicative scalar for length at age obs

5 # Max number of lambda phases: read this number of values for each component below
0 # SD offset (CPUE, discard, mean body weight, recruitment devs): 0=omit log(s) term, 1=include
2 # number of changes to make to default Lambdas (default value is 1.0)
# Like_comp codes: 1=surv; 2=disc; 3=mnwt; 4=length; 5=age; 6=SizeFreq; 7=sizeage; 8=catch;
# 9=init_equ_catch; 10=recrdev; 11=parm_prior; 12=parm_dev; 13=CrashPen; 14=Morphcomp; 15=Tag-comp; 16=Tag-negbin
#like_comp fleet/survey phase value sizefreq_method
# Lamba value for survey index:
1 2 1 1 1
# Lambda value for age data:
5 1 1 1 1

0 # (0/1) read specs for more stddev reporting
999 # EOF

```

DATA FILE 'SARDINE.DAT'

```

# SSV3.24S
# Data File
# South Australian Sardine Fishery, 2015
# Athol Whitten, SARDI, athol.whitten@sa.gov.au

1992  #_styr
2014  #_endyr
1     #_nseas
12    #_months/season
1     #_spawn_seas
1     #_Nfleet
1     #_Nsurvey
1     #_N_areas

Commercial_PS%Spawn_Survey
#1    2
0.35 0.20 # Timing_in_season (sardine fishing peaks Mar-Jun, spawning and survey occur Feb-Mar)
1    1    # Area_assignments_for_each_fishery_and_survey
1    # Units of catch: 1=bio; 2=number
0.05 # SE of log(catch) only used for init_eq_catch and for Fmethod 2 and 3

2    # Nsexes (females (1), then males (2))
9    # Accumulator age (+group, must be older than oldest age data)
0    # Init_equil_catch_for_each_fishery

23 # Number of years of catch data
# Value   Year   Season
464.883   1992   1
1435.404  1993   1
3241.230  1994   1
2597.000  1995   1
3531.000  1996   1
3500.000  1997   1
7312.000  1998   1
4080.000  1999   1
3290.000  2000   1
7507.000  2001   1
14450.000 2002   1
26137.000 2003   1
36631.000 2004   1
42475.000 2005   1

```

```

25137.000  2006  1
31577.110  2007  1
29922.050  2008  1
29854.605  2009  1
32253.646  2010  1
32969.512  2011  1
33990.205  2012  1
31981.276  2013  1
33972.196  2014  1

```

```

17 # Number of Abundance indices
# Fleet Unit ErrType (-1=Norm, 0=Lognorm)
1   1   0   #Commercial_PS (no data)
2   1   0   #Spawn_Survey

```

```

# Observations: (NOTE THESE OBSERVATIONS FOR ESTIMATES OF FEMALE-ONLY SPAWNING BIOMASS)

```

```

# Year Seas Survey Value SE of Log(Value)
1995  1   2   89100   0.37 #0.10 #0.55
1996  1   2   19980   0.31 #0.10 #0.47
1997  1   2   42120   0.25 #0.10 #0.39
1998  1   2   91603   0.36 #0.10 #0.55
1999  1   2   12372   0.36 #0.10 #0.55
2000  1   2   60673   0.29 #0.10 #0.45
2001  1   2   40072   0.27 #0.10 #0.41
2002  1   2   97625   0.38 #0.10 #0.58
2003  1   2   91778   0.34 #0.10 #0.51
2004  1   2   91372   0.32 #0.10 #0.48
2005  1   2   82116   0.31 #0.10 #0.46
2006  1   2   109423  0.36 #0.10 #0.55
2007  1   2   142015  0.31 #0.10 #0.46
2009  1   2   92627   0.22 #0.10 #0.34
2011  1   2   104334  0.22 #0.10 #0.34
2013  1   2   87828   0.31 #0.10 #0.47
2014  1   2   131720  0.31 #0.10 #0.47

```

```

# Discard biomass
0 # Number fleets with discard
0 # Number of discard observations

```

```

# Mean body weight
0 # No. Mean-body weight observations
0 # Degree of freedom for mean body weight T-distribution likelihood

```

```

# Population length bins:
# These define the resolution at which the mean weight-at-length, maturity-at-length and size-selectivity are based.
# Calculations use the mid-length of the population bins.
2      # Length bin method: 1=use databins; 2=generate from binwidth, min, max below; 3=read vector
2      # Binwidth for population size comp
4.0    # Minimum size in the population (lower edge of first bin and size at age 0.00)
22.0   # Maximum size in the population (lower edge of last bin)

# Length composition
-1     # Comp_tail_compression
1e-007 # Add_to_comp
0      # Combine males into females at or below this bin number
2      # N_LengthBins

# Lower edge of each length data bin (in cm)
8 16 # (Need at least two length bins and some numbers here for model to run, but these values are inconsequential to model when
length data not used)

0 # Number of length observations
# Yr Seas Flt Sex Part Nsamp datavector(female-male)

# Age composition
9 # No. Age Bins

# Age Bin Vector - Lower age of each bin (first and last are accumulator bins)
0 1 2 3 4 5 6 7 8

1 # Number of ageing error matrices
-1 -1 -1 -1 -1 -1 -1 -1 -1
#0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001 0.001
0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5

19 # Number of age observations
1 # Length (at age) bin range method: 2 means value refers to length data bin index
0 # Combine males and females below this age bin number

# Age Composition Data
#YEAR SEASON FLEET SEX PARTITION AGE_ERR LBIN_LO LBIN_HI N_SAMPLES 0 1 2 3 4 5 6
7 8 V1 V2 V3 V4 V5 V6 V7 V8 V9
1995 1 1 0 2 1 -1 -1 684 0.0015 0.0424 0.2588 0.2339 0.2222 0.1389 0.0746 0.0219 0.0058 0
0 0 0 0 0 0 0 2 1 -1 -1 626 0.0815 0.2796 0.2061 0.0911 0.1486 0.1166 0.0623 0.0144 0.0000 0
1996 1 1 0 2 1 -1 -1 626 0.0815 0.2796 0.2061 0.0911 0.1486 0.1166 0.0623 0.0144 0.0000 0
0 0 0 0 0 0 0 2 1 -1 -1 626 0.0815 0.2796 0.2061 0.0911 0.1486 0.1166 0.0623 0.0144 0.0000 0

```

1997	1	1	0	2	1	-1	-1	481	0.0000	0.0748	0.5530	0.2516	0.0520	0.0270	0.0312	0.0083	0.0021	0
0	0	0	0	0	0	0	0											
1998	1	1	0	2	1	-1	-1	965	0.0000	0.0922	0.3472	0.2332	0.1803	0.0943	0.0373	0.0124	0.0031	0
0	0	0	0	0	0	0	0											
1999	1	1	0	2	1	-1	-1	788	0.0025	0.2081	0.4086	0.1599	0.1231	0.0698	0.0203	0.0076	0.0000	0
0	0	0	0	0	0	0	0											
2000	1	1	0	2	1	-1	-1	269	0.0037	0.0781	0.3978	0.4164	0.1004	0.0037	0.0000	0.0000	0.0000	0
0	0	0	0	0	0	0	0											
2001	1	1	0	2	1	-1	-1	1334	0.0015	0.0382	0.3081	0.3771	0.1957	0.0690	0.0090	0.0015	0.0000	0
0	0	0	0	0	0	0	0											
2002	1	1	0	2	1	-1	-1	1374	0.0000	0.0058	0.0917	0.3501	0.4032	0.1150	0.0313	0.0029	0.0000	0
0	0	0	0	0	0	0	0											
2003	1	1	0	2	1	-1	-1	1654	0.0260	0.0804	0.1693	0.2727	0.2582	0.1505	0.0369	0.0060	0.0000	0
0	0	0	0	0	0	0	0											
2004	1	1	0	2	1	-1	-1	1546	0.0543	0.0485	0.0847	0.3855	0.2898	0.1022	0.0278	0.0071	0.0000	0
0	0	0	0	0	0	0	0											
2005	1	1	0	2	1	-1	-1	879	0.0000	0.0159	0.3686	0.3402	0.1718	0.0796	0.0239	0.0000	0.0000	0
0	0	0	0	0	0	0	0											
2006	1	1	0	2	1	-1	-1	528	0.0019	0.0682	0.3239	0.3220	0.1648	0.0890	0.0208	0.0095	0.0000	0
0	0	0	0	0	0	0	0											
2008	1	1	0	2	1	-1	-1	655	0.0000	0.0504	0.4336	0.2931	0.1939	0.0260	0.0015	0.0015	0.0000	0
0	0	0	0	0	0	0	0											
2009	1	1	0	2	1	-1	-1	1509	0.0040	0.0179	0.4023	0.4042	0.1418	0.0265	0.0033	0.0000	0.0000	0
0	0	0	0	0	0	0	0											
2010	1	1	0	2	1	-1	-1	2252	0.0000	0.0058	0.4076	0.3326	0.1674	0.0608	0.0218	0.0036	0.0004	0
0	0	0	0	0	0	0	0											
2011	1	1	0	2	1	-1	-1	543	0.0000	0.0221	0.4401	0.3168	0.1492	0.0552	0.0129	0.0037	0.0000	0
0	0	0	0	0	0	0	0											
2012	1	1	0	2	1	-1	-1	359	0.0000	0.0167	0.3482	0.3148	0.1476	0.1365	0.0334	0.0028	0.0000	0
0	0	0	0	0	0	0	0											
2013	1	1	0	2	1	-1	-1	479	0.0000	0.0042	0.1336	0.3549	0.2881	0.1566	0.0585	0.0042	0.0000	0
0	0	0	0	0	0	0	0											
2014	1	1	0	2	1	-1	-1	538	0.0000	0.0167	0.2472	0.4498	0.0874	0.1152	0.0595	0.0186	0.0056	0
0	0	0	0	0	0	0	0											

```

0 #_N_MeanSize-at-Age_obs
1 #_N_environ_variables
0 #_N_environ_obs
0 # N sizefreq methods to read
0 # no tag data
0 # no morphcomp data

```

999 # EOF

FORECAST.SS

```

# SSV3.24S
# Forecast File
# South Australian Sardine Fishery, 2015
# Athol Whitten, SARDI, athol.whitten@sa.gov.au

# For all year entries except rebuild; enter either: actual year, -999 for styr, 0 for endyr, neg number for rel. endyr
1 # Benchmarks: 0=skip; 1=calc F_spr,F_btgt,F_msy
2 # MSY: 1= set to F(SPR); 2=calc F(MSY); 3=set to F(Btgt); 4=set to F(endyr)
0.40 # SPR target (e.g. 0.40)
0.40 # Biomass target (e.g. 0.40)

#_Bmark_years: beg_bio, end_bio, beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel.
endyr)
0 0 0 0 0 0
1 # Bmark_relF_Basis: 1 = use year range; 2 = set relF same as forecast below

1 # Forecast: 0=none; 1=F(SPR); 2=F(MSY) 3=F(Btgt); 4=Ave F (uses first-last relF yrs); 5=input annual F scalar
2 # N forecast years
0 # F scalar (only used for Do_Forecast==5)

#_Fcast_years: beg_selex, end_selex, beg_relF, end_relF (enter actual year, or values of 0 or -integer to be rel. endyr)
0 0 0 0
1 # Control rule method (1=catch=f(SSB) west coast; 2=F=f(SSB) )
0.40 # Control rule Biomass level for constant F (as frac of Bzero, e.g. 0.40); (Must be > the no F level below)
0.1 # Control rule Biomass level for no F (as frac of Bzero, e.g. 0.10)
1 # Control rule target as fraction of Flimit (e.g. 0.75)
3 #_N forecast loops (1=OFL only; 2=ABC; 3=get F from forecast ABC catch with allocations applied)
3 #_First forecast loop with stochastic recruitment
0 #_Forecast loop control #3 (reserved for future bells&whistles)
0 #_Forecast loop control #4 (reserved for future bells&whistles)
0 #_Forecast loop control #5 (reserved for future bells&whistles)
2017 # FirstYear for caps and allocations (should be after years with fixed inputs)
0 # stddev of log(realized catch/target catch) in forecast (set value>0.0 to cause active impl_error)
0 # Do West Coast gfish rebuild; output (0/1)
0 # Rebuilder: first year catch could have been set to zero (Ydecl)(-1 to set to 1999)
0 # Rebuilder: year for current age structure (Yinit) (-1 to set to endyear+1)
1 # Fleet relative F: 1=use first-last alloc year; 2=read seas(row) x fleet(col) below
# Note that fleet allocation is used directly as average F if Do_Forecast=4
2 # Basis for fcast catch tuning and for fcast catch caps and allocation (2=deadbio; 3=retainbio; 5=deadnum; 6=retainnum)
# Max totalcatch by fleet (-1 to have no max) must enter value for each fleet
-1

```

```
# Max totalcatch by area (-1 to have no max); must enter value for each fleet
-1
# Fleet assignment to allocation group (enter group ID# for each fleet, 0 for not included in an alloc group)
0
# Conditional on >1 allocation group
# Allocation fraction for each of: 0 allocation groups
# No allocation groups
2 # Number of forecast catch levels to input (else calc catch from forecast F)
2 # basis for input Fcast catch: 2=dead catch; 3=retained catch; 99=input Hrate(F) (units are from fleetunits; note new codes in
SSV3.20)
# Input fixed catch values
#Year Seas Fleet Catch(or_F)
2015 1 1 38000
2016 1 1 38000
#
999 # End of file.
```