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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2014

T.M. Ward, A.R. Ivey and J. Earl

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Report to the Australian Fisheries Management Authority

T.M. Ward, A.R. Ivey and J. Earl

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EXECUTIVE SUMMARY

This report presents fishery statistics and synthesises existing stock assessment information for quota species of the Commonwealth Small Pelagic Fishery (SPF). The report is a requirement at Tiers 1 and 2 of the SPF Harvest Strategy 2008 (last revised April 2013).

Preliminary Daily Egg Production Method (DEPM) assessments for Blue Mackerel provided a mid-range best estimate of spawning biomass of ~56,000 t and 23,000 t for the West (2005 survey) and East (2004 survey) zone, respectively. Management Strategy Evaluation (MSE) suggested that the spawning biomass was higher than the DEPM estimate in each zone. For the East, the SPF Resource Assessment Group agreed to use a mid-range estimate of spawning biomass of 40,000 t for setting the Recommended Biological Catch (RBC), after a sensitivity analysis was done. Since 1997/98, Blue Mackerel catches in the East ranged from 309 – 1007 t, with 415 t taken in 2013/14. In the West, annual catch increased in 2005/06 and was 1,977 t in 2008/09. The estimate of total catch in the West for 2013/14 is confidential due to the low number of operators. The current maximum RBCs at Tier 2 for Blue Mackerel for the East and West are set at 3,000 t and 6,500 t, respectively. Recent annual catches have been well below the maximum RBC for each zone. All fish sampled from catches in the East and West during the late 2000s were above the estimated size at maturity. There is no evidence to suggest that recent catches of Blue Mackerel in either zone are not sustainable.

In 2014, the first dedicated application of the DEPM for Jack Mackerel off the east coast of Australia estimated a spawning biomass of ~157,800 t. This estimate is within the range of previous estimates of 114,900 – 169,000 t derived from surveys undertaken in 2002. Annual catches of Jack Mackerel in the East peaked at ~40,000 t in 1986/87, but have not exceeded ~3,000 t since 2003/04. In 2013/14, the total catch of 0.4 t was <1% of both the RBC (10,600 t) and spawning biomass estimate for the species in the East. Annual catches of Jack Mackerel in the West have not exceeded 500 t since 1997/98. The estimate of total catch in the West for 2013/14 is confidential, but below the current Tier 2 maximum RBC of 5,000 t. The abundance of older age classes in purse-seine catches off Tasmania declined between the mid-1980s and mid-1990s, suggesting a possible fishery impact on population structure. Coupled with large declines in historical catches, this situation gave rise to concern about the status of Jack Mackerel in the East. However, since the mid-1990s, fishing effort and catches have remained at relatively low levels. There is no evidence to suggest that recent low catches of Jack Mackerel in either Zone are not sustainable.

Yellowtail Scad is one of several permitted by-product species of the SPF. Historically high catches of Yellowtail Scad reported since 2009/10 have resulted from the entry of a number of new purse-seine vessels in New South Wales. The total catch in the East in 2013/14 was 487 t.

DEPM estimates for Redbait in the East (2005 and 2006 surveys) suggested a spawning biomass of ~70,000 t, implying that peak annual catches of ~7,000 t taken during the early 2000s were sustainable. This conclusion was supported by the outputs from the MSE. In 2013/14, no Redbait catches were reported for the West, while <0.1 t was landed in the East. There is no evidence to suggest that recent low catches of Redbait in either zone are not sustainable.

The best estimate of spawning biomass of Australian Sardine off eastern Australia was ~29,000 t in 2004. Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000 – 35,000 t. The MSE estimate of spawning biomass was similar to the DEPM estimate. Annual catches of Australian Sardine in the East were <1,000 t from 1997/98 to 2001/02 and gradually increased to 4,770 t in 2008/09. In 2013/14, total catch declined to 1,385 t, which is below the current RBC for the East of 3,000 t. The highest annual catch in the East (4,770 t) was ~17% of the best estimate of spawning biomass. There is no evidence that the recent low catches are not sustainable.

Increasingly long periods between DEPM surveys of individual stocks have begun to limit the understanding of the status of SPF quota species in both zones, with the exception of Jack Mackerel (East). There is no evidence to suggest that recent catch levels of any quota species are not sustainable. Surveys were undertaken in August 2014 to quantify the spawning biomasses of Australian Sardine and Blue Mackerel in the East Zone. The results of these surveys will be available in late 2015.

1 GENERAL INTRODUCTION

1.1 Overview

This assessment of the Commonwealth Small Pelagic Fishery (SPF) builds on previous fishery assessment reports in 2010, 2011, 2012 and 2013 (Ward *et al.* 2011; 2012; 2013; 2014). This report provides a synopsis of information available for key species of the SPF: Jack Mackerel (*Trachurus declivis*), Redbait (*Emmelichthys nitidus*), Blue Mackerel (*Scomber australasicus*), Australian Sardine (*Sardinops sagax*) and Yellowtail Scad (*Trachurus novaezelandiae*); and an assessment of the current status of the stocks of these species (except for Yellowtail Scad - a permitted SPF by-catch species) in waters around south-eastern Australia. The assessment is based on commercial catch and effort data up to 30 June 2014, and available biological information (size and age structures, reproduction, maturity) to inform stock structure. Biomass estimates and Management Strategy Evaluations (MSEs) are also included where available. This report satisfies the requirements of the SPF Harvest Strategy (AFMA 2008, revised in 2013).

1.2 Description of the Commonwealth Small Pelagic Fishery

The Commonwealth Small Pelagic Fishery (SPF) is a purse-seine and mid-water trawl fishery that operates in Commonwealth waters (3-200 nm) around southern Australia, from southern Queensland to latitude 31°S in Western Australia, including Tasmania. The fishery is divided into two zones (i.e. East and West) according to an east-west divide at longitude 146°30'E (Figure 1.1, AFMA 2009).

The four main target species of the SPF are Jack Mackerel, Redbait, Blue Mackerel and Australian Sardine. These species are also targeted by recreational fishers in some States (Henry and Lyle 2003), and by other Commonwealth and State-managed commercial fisheries, including the Southern and Eastern Scalefish and Shark Fishery, Western Tuna and Billfish Fishery and the Eastern Tuna and Billfish Fishery (SPF species primarily targeted for bait; Moore and Skirtun 2012). Yellowtail Scad is one of several permitted by-product species of the SPF. A brief history of the SPF is described in Moore and Skirtun (2012).

1.3 Management of the Fishery

The SPF is managed by the Australian Fisheries Management Authority (AFMA) in accordance with the *Small Pelagic Fishery Management Plan 2009*. The fishery is managed using a combination of input and output controls that include limited entry, zoning, mesh size restrictions and total allowable catch (TAC) limits for each target species (hereafter referred to as quota species) within each zone (AFMA 2008, reviewed in April 2013).

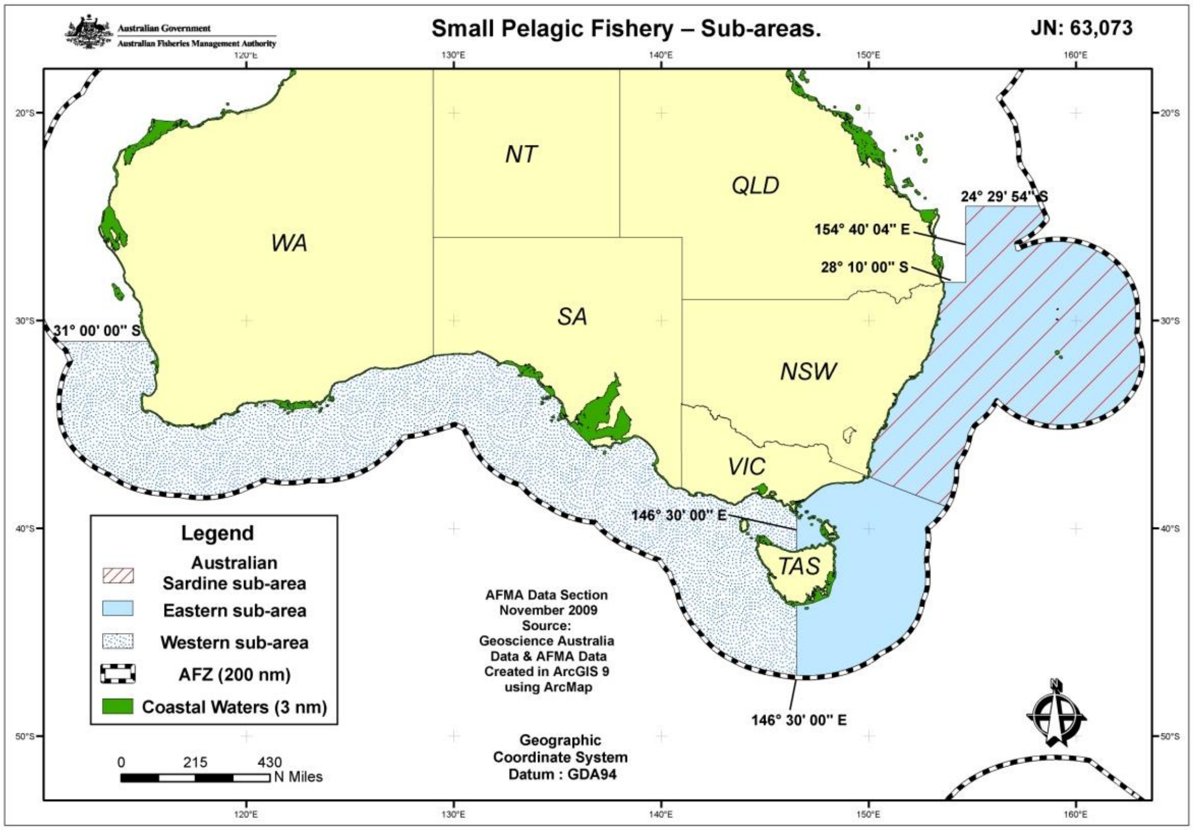

Figure 1.1 Management sub-areas of the SPF.

1.3.1 Harvest Strategy

In 2008, AFMA established a harvest strategy (HS) for the SPF which was updated in 2013 (AFMA 2008). The HS is a three tiered system used by the SPF Resource Assessment Group (SPFRAG) to develop advice on the Recommended Biological Catches (RBCs) for stocks (East and West) for each quota species. Stocks are allocated to a tier based upon the level of knowledge about stock size (spawning biomass), with Tier 1 representing the highest level of available information and Tier 3 the lowest (Moore and Skirtun 2012). Corresponding individual transferable quotas (ITQs) are established; Tier 1 stocks have the largest quota (by weight), and Tier 3 the smallest (Tracey *et al.* 2013). The tiered system was introduced to ensure that heavy exploitation only occurs in stocks where there is a high level of confidence that such exploitation can be sustained (Moore and Skirtun 2012). TACs for each quota species are determined by subtracting other sources of mortality (i.e. catches taken in other Commonwealth and State fisheries) from the corresponding RBCs.

A brief description of each tier and its requirements are provided below.

Tier 1: RBCs for each Tier 1 species in each zone are set at 10-20% of the median spawning biomass estimated using the Daily Egg Production Method (DEPM). The exploitation rate applied each season is determined by the SPFRAG based on the time period since the last DEPM (as outlined in the HS) and annual assessments of both catch/effort data and size/age structure of catches.

Tier 2: Maximum RBCs for each Tier 2 species in each zone are specified and based, where possible, on approximately 7.5% of the median spawning biomass estimate. RBCs are determined by the SPFRAG on the basis of old (>5 years) DEPM estimates and annual assessments of both catch/effort data and size/age structure of catches. Current Tier 2 RBCs for each zone/species are shown in Table 1.1.

Tier 3: Maximum RBCs for Tier 3 species in each zone may not exceed 500 t. RBCs are determined by SPFRAG on the basis of catch and effort data.

Table 1.1. Current Tier 2 maximum RBC values for the target species of the Commonwealth Small Pelagic Fishery in the West and East zones.

Species	Zone	Tier 2 maximum RBC (t)
Blue Mackerel	East	3,000
	West	6,500
Redbait	East	5,000
	West	5,000
Jack Mackerel	East	10,600
	West	5,000
Australian Sardine	East	3,000

1.4 Previous Assessments

DEPM surveys have been conducted for Blue Mackerel East and West (Ward and Rogers 2007; Ward *et al.* 2009), Australian Sardine East (Ward and Rogers 2007), Redbait East (Neira *et al.* 2008), Jack Mackerel East (Neira 2009) and Yellowtail Scad East (Neira 2011).

In January 2014, surveys were undertaken to determine the distribution and abundance of eggs and larvae of Jack Mackerel off Australia’s East Coast as part of the first dedicated application of the DEPM to Jack Mackerel (Ward *et al.* 2015). These surveys also examined the spawning habitat of Australian Sardine off eastern Australia during summer, which will ultimately be used to refine the application of DEPM for Sardine and provide updated estimates of spawning biomass for the species.

Management Strategy Evaluations (MSEs) have been conducted by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Giannini *et al.* 2010). A formal review of the HS for the Commonwealth SPF was completed in January 2015 (Smith *et al.* 2015). Results of the review by Smith *et al.* (2015) are not discussed in this assessment report.

1.5 Aims and Objectives

This report collates and presents recent catch/effort data for the SPF and available biological information for each of the quota species: Jack Mackerel, Redbait, Blue Mackerel and Australian Sardine; and an important by-catch species: Yellowtail Scad. Biomass estimates and MSEs are also included where available. This report satisfies the requirements of the SPF Harvest Strategy (AFMA 2009).

2 BLUE MACKEREL (*SCOMBER AUSTRALASICUS*)

2.1 Introduction

2.1.1 Background to Fishery

Large fisheries for *Scomber spp.* (i.e. annual catches between ~50,000 to 500,000 t per annum) are located off Japan, Peru, China, Korea, Russia, and the Ukraine (Ward et al. 2011). The largest fishery for Blue Mackerel is based in New Zealand where annual catches range between ~9,000 t and 14,000 t per annum. In Australia, Blue Mackerel is taken in several fisheries with annual catches typically less than 3,000 t (Ward et al. 2011).

The largest catches of Blue Mackerel in Australia are taken by the SPF, with smaller landings taken by the Great Australian Bight Trawl, Gillnet Hook and Trap, Western Tuna and Billfish, Eastern Tuna and Billfish and South East Trawl fisheries (Ward and Rogers 2007). Relatively small quantities of Blue Mackerel are taken in the South Australian Marine Scalefish Fishery and by a multi-species fishery off Western Australia using a variety of gear types (Ward and Rogers 2007).

The New South Wales commercial purse-seine fishery has targeted Yellowtail Scad and Blue Mackerel since the early 1980s (Stewart and Ferrell 2001). During that time, Blue Mackerel typically comprised ~38% of the total annual catches. The average annual catch of Blue Mackerel in Victorian waters between 1978/79 and 2004/05 was 49 t (±22.9 t) with catches ranging between 0.2 and 370.6 t per annum (Ward and Rogers 2007). Blue Mackerel is also an important target species for recreational fisheries in Australia (Henry and Lyle 2003).

The Tasmanian Purse-Seine Fishery has recorded catch and effort data since its inception in 1984. Logbooks contain a shot-by-shot record of fishing operations and species taken. The first reported landings of Blue Mackerel occurred in 1985/86, but limited species-specific information was recorded (Ward and Rogers 2007). From 1985/86 to 1989/90, Blue Mackerel represented <4% of the total annual catch. Species-specific information was not available for other years.

2.1.2 Taxonomy

Mackerels fall within the genus *Scomber* that has traditionally included three species: Blue Mackerel (*S. australasicus*), Chub Mackerel (*S. japonicus*), and Atlantic Mackerel (*S. scombrus*). However, Scoles *et al.* (1998) showed that *S. australasicus* and *S. japonicus* are more closely related to each other than to *S. scombrus*, and morphological and genetic differences in Atlantic and Indo-Pacific populations of *S. japonicus* may warrant recognition of two separate species. A separate species, *S. coli*, was identified through genetic analysis and replaces *S. japonicus* in the Atlantic Ocean (Infante *et al.* 2006). Under these definitions, there are two closely related species, *S. japonicus* and *S. australasicus,* in the Indian and Pacific Oceans, and *S. scombrus* and *S. coli* in the Atlantic Ocean.

2.1.3 Distribution

Blue Mackerel occur throughout the Pacific Ocean including South East Asia, Australia and New Zealand and in the northern Indian Ocean and Red Sea. In Australia, it is found mainly in southern temperate and subtropical waters between southern Queensland and Western Australia (Ward et al. 2001). Juveniles and small adults usually occur in inshore waters and larger adults form schools in depths of 40-200 m across the continental shelf (Kailola et al. 1993).

2.1.4 Stock Structure

The stock structure of Blue Mackerel in Australasian waters is uncertain. Significant differences in the morphology of monogenean parasites distinguished fish from Australia and New Zealand (Rohde 1987). However, Scoles *et al.* (1998) found no genetic differences between Blue Mackerel from Australia and New Zealand using mtDNA RFLP analysis and cytochrome *b* sequencing. A recent study into stock structure of Blue Mackerel (Ward and Rogers 2007) found populations across Australia were significantly different using both parasite and otolith analyses, with a small amount of overlap between adjacent sampling locations (WA and SA, SA and Qld) and less between distant locations (WA and Qld). Little is known about the movement patterns of Blue Mackerel.

2.1.5 Food and Feeding

Mackerel (*Scomber* spp.) have been found to alter their feeding behaviour and ingestion rates depending on prey size and density (Prokopchuk and Sentyabov 2006; Garrido et al. 2007). A recent dietary study of small pelagic fish off South Australia found Blue Mackerel feed on mainly krill and larval fish (Daley, SARDI Aquatic Sciences, unpublished data).

2.1.6 Age, Growth and Size

Like many other pelagic fishes, it is challenging to age Blue Mackerel using standard approaches, as the majority of otoliths are difficult to read, and these difficulties increase with fish age (Ward and Rogers 2007). Growth rates and trajectories of males and females from waters off South Australia are similar. Juveniles of both sexes grow rapidly, and reach ~250 mm fork length (FL) after ~2 years of life (Ward and Rogers 2007). Blue Mackerel reach sizes of up to 440 mm FL in the Great Australian Bight (GAB) and are estimated to attain ~8 years (Stevens *et* *al.*1984*).* Off eastern Australia, an opaque zone forms in the otoliths of one-year old fish during winter and is complete by early summer (Stewart et al. 1999). Commercial catches of Blue Mackerel taken off southern New South Wales comprised mostly 1 – 3 year old fish and included individuals up to 7 years old (Stewart and Ferrell 2001).

2.1.7 Reproduction

Approximately 50% of male and female Blue Mackerel are sexually mature at 237 and 287 mm FL, respectively. Blue Mackerel are serial spawners, and spawn multiple times over a prolonged spawning season (Ward and Rogers 2007; Rogers *et al.* 2009). Spawning in southern Australia occurs from summer to early autumn and late winter to spring in New South Wales (Ward and Rogers 2007). Mean spawning frequencies range from 2 to 11 days in southern Australia. Mean batch fecundity is ~70,000 oocytes per batch and 134 oocytes per gram of weight. Fecundity increases exponentially with fish length and weight. Most of the eggs collected off southern Australia have been obtained from the mid-shelf. High egg and larval densities are recorded at depths of 40–120 m with sea surface temperatures (SSTs) of 18–22^{o}C (Ward and Rogers 2007). The location of spawning off southern Australia appears to vary substantially between years. Results of an exploratory survey suggest that the western GAB is an important spawning area. However, this region has not yet been sampled intensively (Ward and Rogers 2007).

2.1.8 Early Life History and Recruitment

Blue Mackerel eggs are transparent and spherical, measure 1.05 – 1.35 mm in diameter, possess a smooth chorion and a prominent, unsegmented yolk with a single, 0.22-0.38 mm diameter oil globule (Ward and Rogers 2007). Blue Mackerel yolk-sack larvae are <3.2 mm total length (TL) at hatching (Neira *et al.* 1998) and metamorphose at lengths of ~23.3 mm TL.

2.1.9 Stock Assessment

An extensive study investigated the application of a range of egg-based stock assessment methods for Blue Mackerel and concluded that the species was amenable to assessment using the DEPM (Ward and Rogers 2007; Ward *et al.* 2009). Both the annual and daily egg production methods have been used to estimate the spawning biomass of Mackerel, *Scomber scombrus*, in the north-eastern Atlantic Ocean (Gonclaves *et al.* 2009).

2.1.10 Recreational fishing

Recreational fishers harvest Blue Mackerel using rod and line, hand line and troll lines (Ward and Rogers 2007) throughout the southern waters of Australia, including southern Queensland. The

Australian National Survey of Recreational and Indigenous Fishing (Henry and Lyle 2003) estimated that boat-based recreational fishers harvested 720,814 Blue Mackerel annually, with 21% of these being released back into the water. Of those Blue Mackerel retained, 75% were taken in New South Wales, and 14% and 8% taken in Western Australia and South Australia, respectively. Catches from Victoria, Tasmania and Queensland comprised the remaining 3% of the total recreational catch (Henry and Lyle 2003). Based on the length/weight key developed by Stewart and Ferrell (2001), the estimated weight of Blue Mackerel harvested annually by the recreational sector in Australia is 228 t (Ward and Rogers 2007).

2.2 Methods

2.2.1 Fishery Statistics

Fishery statistics were supplied by ABARES for the period from 1997/98 to 2010/11. From 2011/12 to 2013/14, all fishery statistics were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are in financial years. Estimates of monthly catch and effort supplied for Blue Mackerel in the East from July 1997 to June 2010 included data for oceanic and non-oceanic fishing operations. After this, all estimates only included oceanic fishing activity (purse-seine and mid-water trawling).

2.2.2 Biological Information

Samples of Blue Mackerel were collected from commercial purse-seine catches taken in New South Wales between 2006/07 and 2013/14 to inform about stock structure in the East. Size frequency data for these samples were supplied by New South Wales Department of Primary Industries (DPI).

Samples of Blue Mackerel from the West were obtained from catches taken in summer/early autumn by the commercial purse-seine fishery operating from Port Lincoln, South Australia between 2008/09 and 2010/11. Each fish was measured for fork length (FL) to the nearest millimetre (mm) and its otoliths were extracted, weighed and read to estimate age. Several reproductive indices were determined by Ward and Rogers (2007). No fine-scale spatial or temporal information was available for these samples.

2.2.3 Biomass Estimates and MSE

Preliminary biomass estimates for Blue Mackerel in each zone resulted from research efforts in 2003 and 2005 (Rogers and Ward 2007).

A MSE model was used to test a range of management/harvest scenarios under the SPF harvest strategy for all stocks in the SPF (Giannini *et al.* 2010). In most scenarios, the 30 year simulation period used in the MSE was sufficient for each stock to reach equilibrium, and generally this was well above 20% of virgin biomass levels (B_{20}). Sensitivities of the model to the various input parameters were also tested. The model was found to be most sensitive to the assumed stock-recruitment relationship and natural mortality. The model was re-examined in 2011 to address concerns about values used for number of recruits.

2.3 Results

2.3.1 Fishery statistics

Location of vessels

A total of 30 vessels landed Blue Mackerel in the East in 2013/14, most of which were based in New South Wales (57%) and Tasmania (37%) (Figure 2.1). In the West, a total of 4 vessels reported catches of Blue Mackerel in 2013/14 (Figure 2.2).

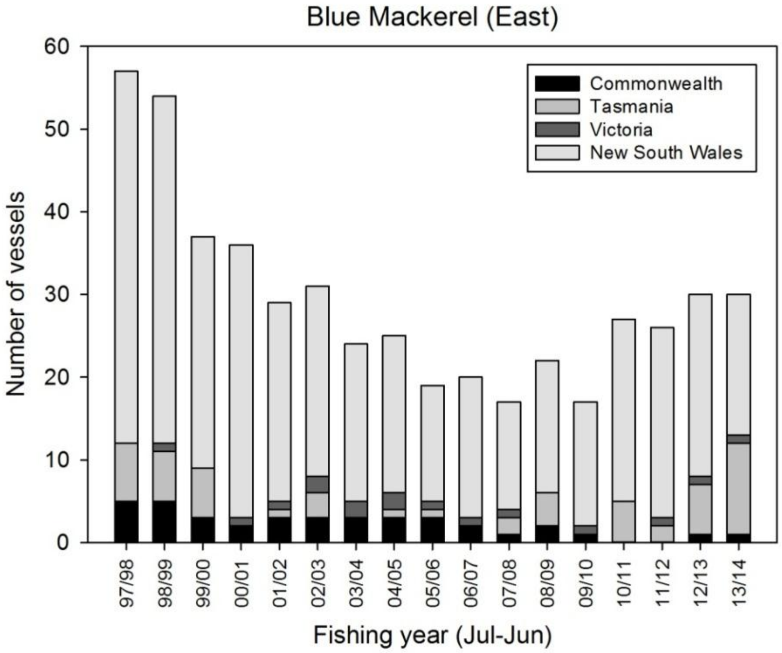

Figure 2.1. Number of vessels that landed Blue Mackerel in the East, from each of the four participating management jurisdictions for each financial year from 1997/98 – 2013/14.

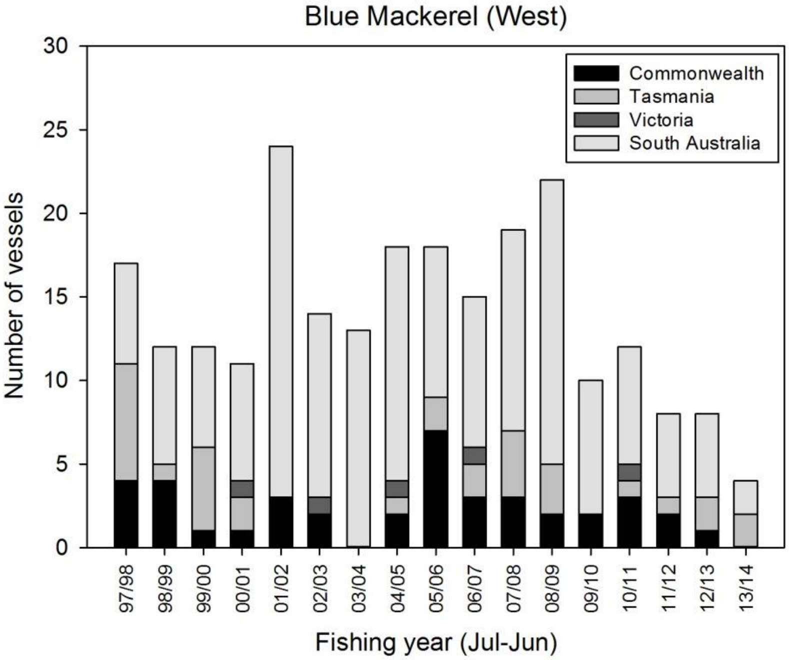

Figure 2.2. Number of vessels that landed Blue Mackerel in the West, from each of the four participating management jurisdictions for each financial year from 1997/98 – 2013/14.

Annual patterns – catch, effort and CPUE

Annual catches of Blue Mackerel in the East decreased from 1008 t in 2002/03 to a historic low of 298 t in 2010/11 and 2011/12 (Figure 2.3). Catch then increased to 478 t in 2012/13, before declining to 415 t in 2013/14. The historical trend in annual fishing effort was similar to annual catch, i.e. it was relatively high in the early 2000s (>1,600 vessel days), decreased to an historic low (559 vessel days) in 2011/12 and remained low (593 vessel days) in 2013/14 (Figure 2.3). Mean annual catch per unit effort (CPUE) increased from 0.23 t.vessel day^{-1} in 1997/98 to a peak of 0.72 t.vessel day^{-1} in 2004/05 (Figure 2.4). In 2007/08, CPUE declined to 0.3 t.vessel day^{-1}, before increasing to an historic peak of 0.78 t.vessel day^{-1} in 2012/13. In 2013/14, CPUE was 0.7 t.vessel day^{-1}, which was the third highest recorded in the fishery.

The estimated recreational catch of Blue Mackerel in the East in 2000/01 was 178 t, which was 22% of the total annual catch taken by the Commonwealth SPF.

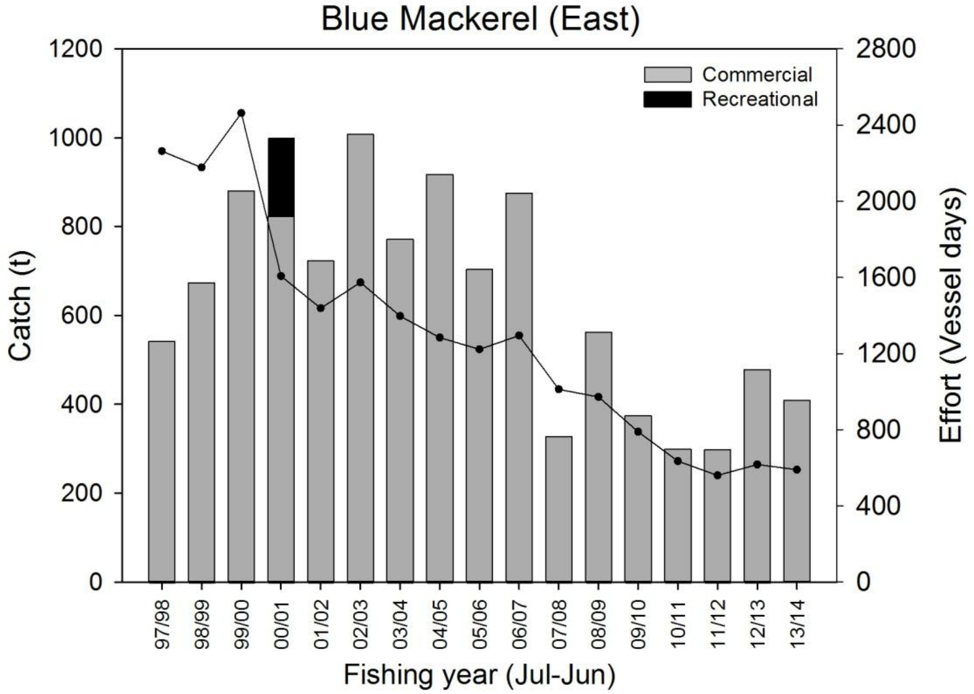

Figure 2.3. Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the East for each financial year from 1997/98 – 2013/14. Estimated catch for the recreational sector is also shown for 2000/01 and is based on catches taken in New South Wales, Victoria, Queensland and Tasmania.

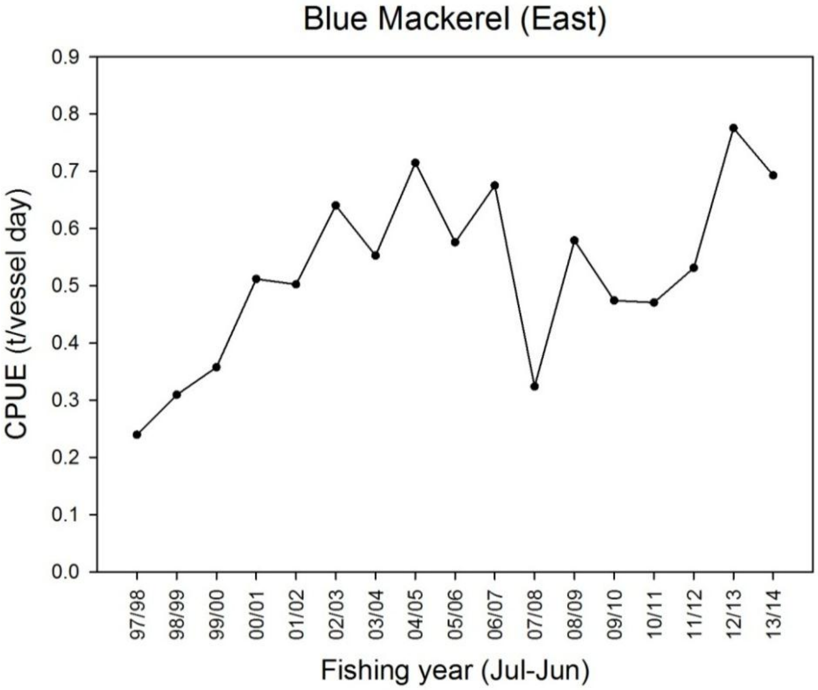

Figure 2.4. CPUE (t per vessel day) for Blue Mackerel in the East for each financial year from 1997/98 – 2013/14.

Annual catches of Blue Mackerel were more variable in the West than the East. From 1997/98 and 2003/04, annual catches were low and ranged from 0.8 t to 62 t. Catches continued to increase and averaged ~1,500 t.yr^{-1} from 2005/06 and 2008/09 and included a peak of 1,977 t in 2008/09 (Figure 2.5). Since then, catch declined in each year and was 2.3 t in 2012/13, which was among the lowest on record. Catch and effort data for 2013/14 are confidential, due to the low number (<5) of vessels reporting catch. The estimated recreational catch of Blue Mackerel in the West in 2000/01 was 49 t.

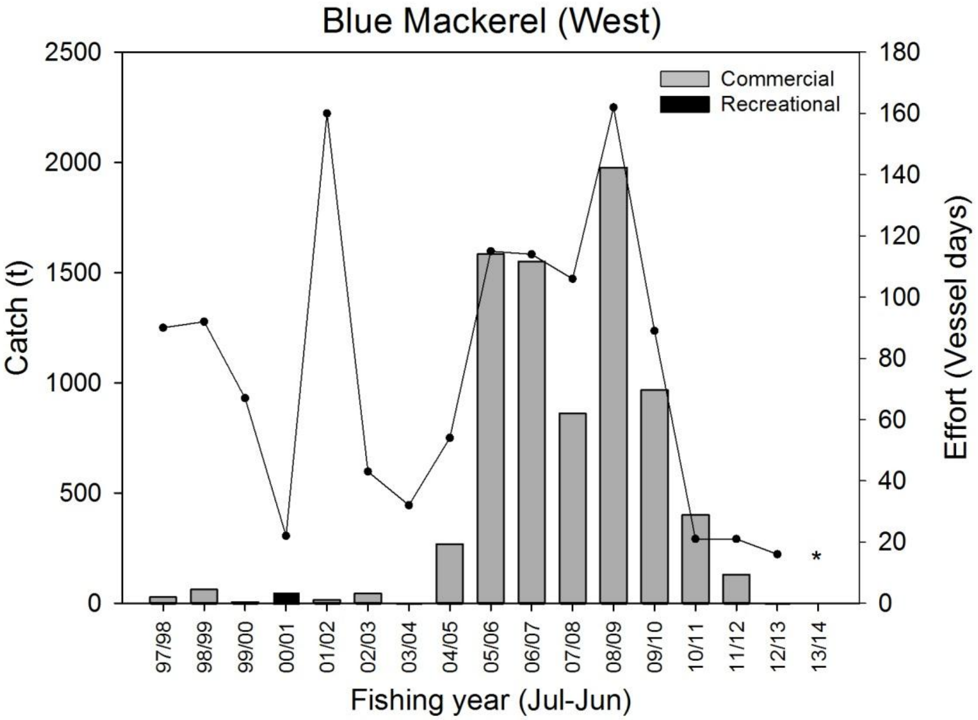

Figure 2.5. Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the West for each financial year from 1997/98 – 2013/14. Estimated catch for the recreational sector is shown for 2000/01 and is based on catches taken in South Australia and Western Australia. (*) indicates data confidentiality, where <5 license holders reported landings.

Since 1997/98, fishing effort for Blue Mackerel in the West has also been variable. It varied from 22 vessel days in 2000/01, increased to peaks of ~160 vessel days in 2001/02 and 2008/09, before decreasing to 16 vessel days in 2012/13 (Figure 2.5). The historical trend in annual CPUE was similar to annual catch, i.e. CPUE remained <1 t.vessel day^{-1} between 1997/98 and 2003/04, increased from 2005/06 to 2010/11 (averaged ~13 t.vessel day^{-1}) and then declined to 0.16 t.vessel day^{-1} in 2012/13 (Figure 2.6).

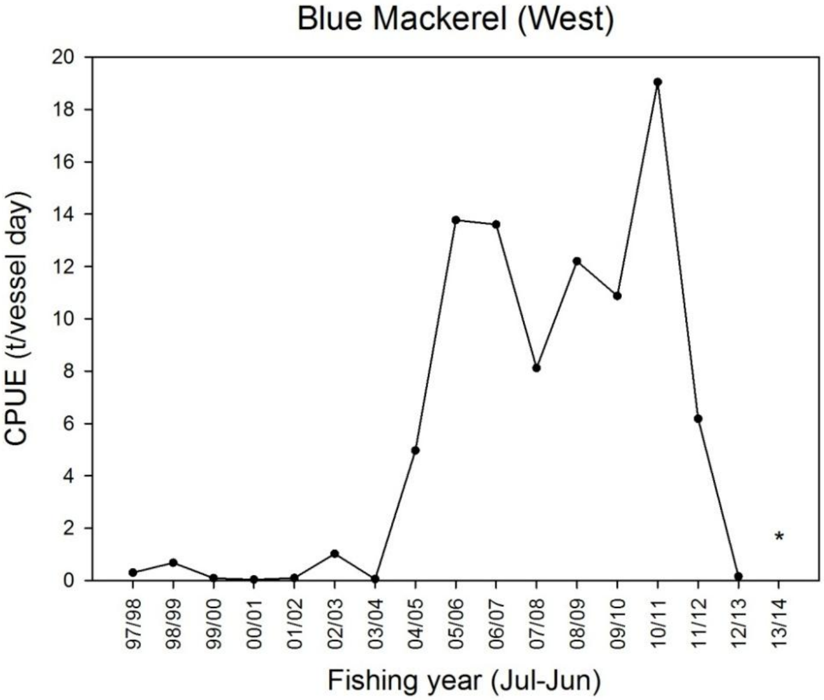

Figure 2.6. CPUE (t.vessel day^{-1}) for Blue Mackerel in the West for each financial year from 1997/98 – 2013/14. (*) indicates data confidentiality, where <5 license holders reported landings.

Intra-annual patterns - catch and effort

Estimates of monthly catch and effort for Blue Mackerel in the East from July 1997 to June 2010 included data for oceanic and non-oceanic (nearshore and estuarine) fishing operations. During that period, intra-annual patterns in catch and effort were highly variable with catches occurring in most months and annual peaks in catch were not consistent. From 2010/11, all estimates were for oceanic fishing activity only and substantially lower than previous years (Figure 2.7). Catches were typically <100 t in most months during this period. Exceptions occurred in February 2012 and March 2013, when catch increased to 213 t and 220 t, respectively. Monthly catch and effort data for Blue Mackerel in the West for most years were confidential (Figure 2.8).

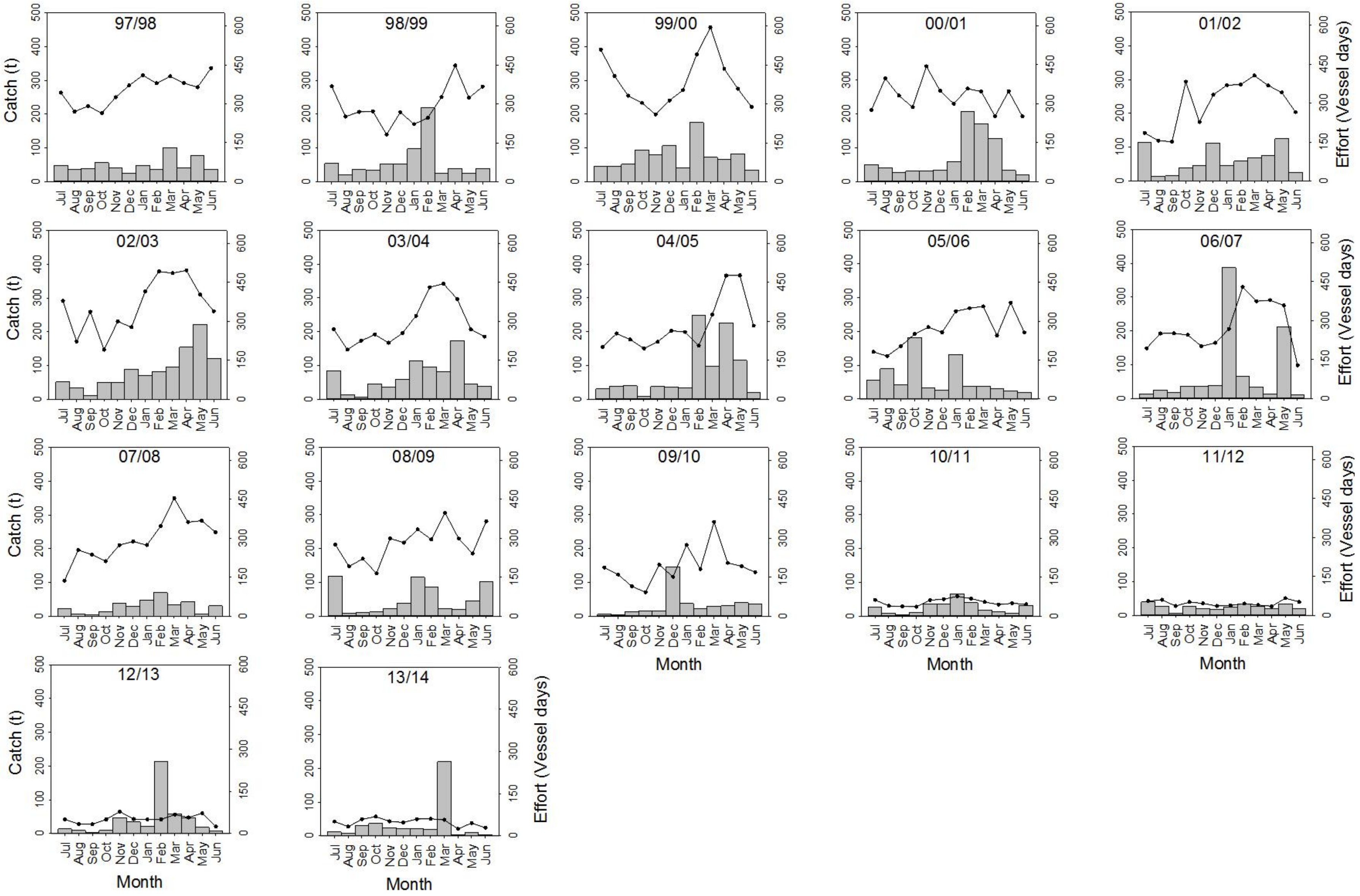

Figure 2.7. Intra-annual patterns of catch (tonnes, bars) and effort (vessel days, lines) for Blue Mackerel in the East for each financial year from 1997/98 - 2013/14. Catch and effort data for each year from 2010/11 - 2013/14 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders reported landings from individual month.

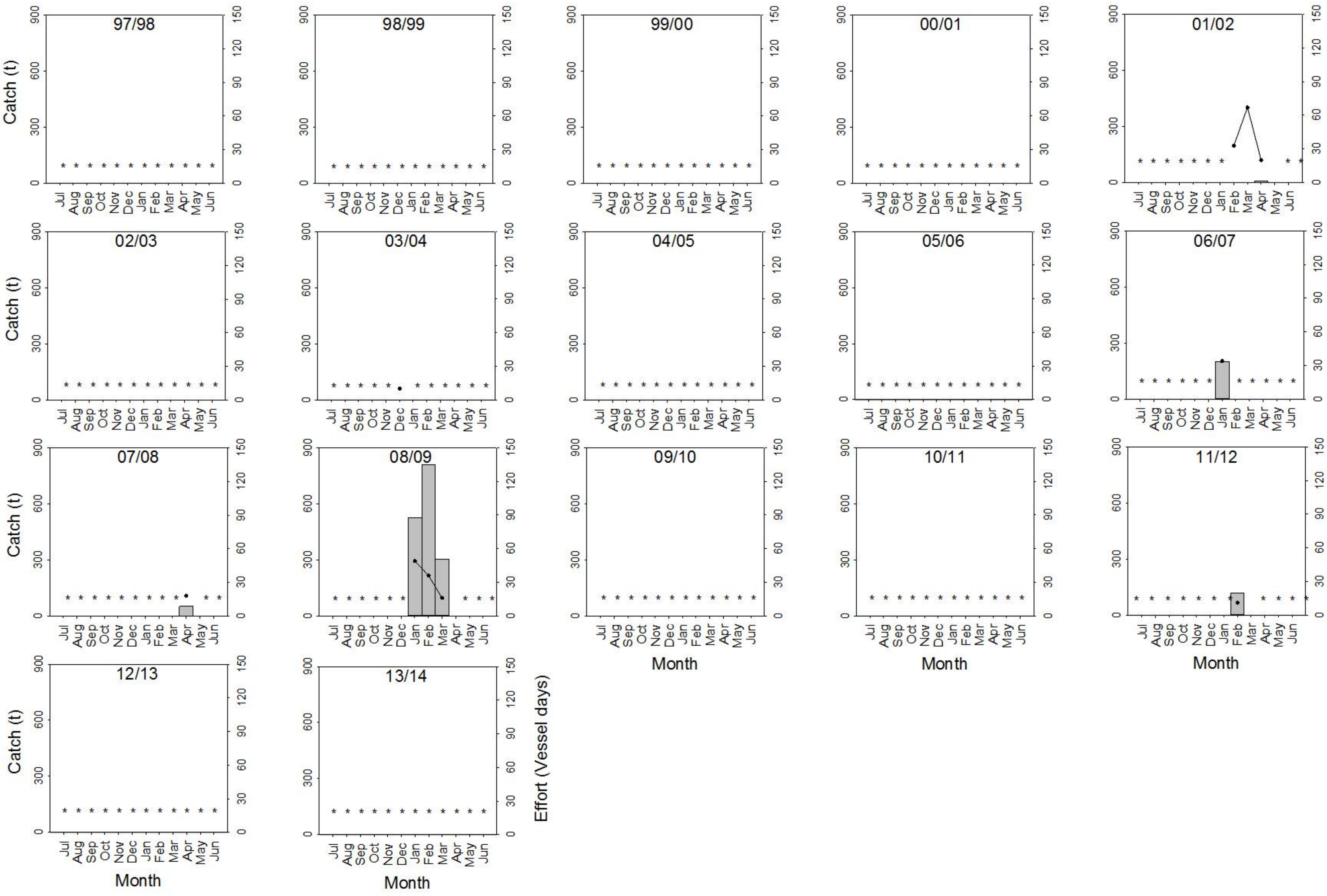

Figure 2.8. Intra-annual patterns in catch (tonnes, bars) and effort (vessel days, lines) for Blue Mackerel in the West for each financial year from 1997/98 – 2013/14. Catch and effort data for each year from 2010/11 - 2013/14 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders reported landings.

2.3.2 Biological Information

Sample Summary

For the East, fish length data were collected from a total of 5,250 Blue Mackerel sampled from commercial catches taken in New South Wales between 2006/07 and 2013/14 (Table 2.1). Information on the spatial and temporal coverage of these samples relative to fishery production in New South Wales was not available. No biological data were available from Victoria, which accounts for ~50% of the annual catch in the East. Therefore, the available biological samples from New South Wales alone may not be representative of the Blue Mackerel harvested by vessels in the southern areas of the East zone.

Table 2.1. Summary of the samples of Blue Mackerel (East) collected from commercial purse-seine net catches taken in New South Wales between 2006/07 and 2013/14 (data supplied by New South Wales DPI).

Season	No. of samples	No. of fish	Size range (fork length mm)
2006/07	23	1869	220 - 400
2007/08	13	1286	160 - 340
2011/12	13	810	180 - 390
2012/13	2	108	280 - 370
2013/14	11	1177	170 - 360

For the West, samples of Blue Mackerel for biological analysis were collected from commercial purse-seine net catches taken off Port Lincoln. Total fish sampled for three different collections were: 79 fish in 2008/09, 933 fish in 2009/10, and 245 fish in 2010/11. The male to female sex ratios for each year were 1:1, 0.9:1 and 0.9:1, respectively. As Blue Mackerel catches in the West from 2008/09 to 2010/11 were relatively small and limited to the summer/early autumn period, biological samples from these catches are likely a poor representation of the Blue Mackerel population in that zone. No samples were collected in 2011/12 and 2012/13, which reflected the low levels of fishing activity in the West during those years.

Size Frequency

For Blue Mackerel sampled from commercial catches in the East, there were substantial differences in the size distributions among years (Figure 2.9). Fish ranged from 160 to 400 mm FL (Table 2.1). Size distributions generally consisted of a single mode between 280 and 320 mm FL. One exception was the bimodal distribution for 2007/08 that involved modes at 240 mm FL and 280 mm FL. In 2013/14, the size distribution included fish from 170 to 360 mm FL, with a single mode at 260 mm FL.

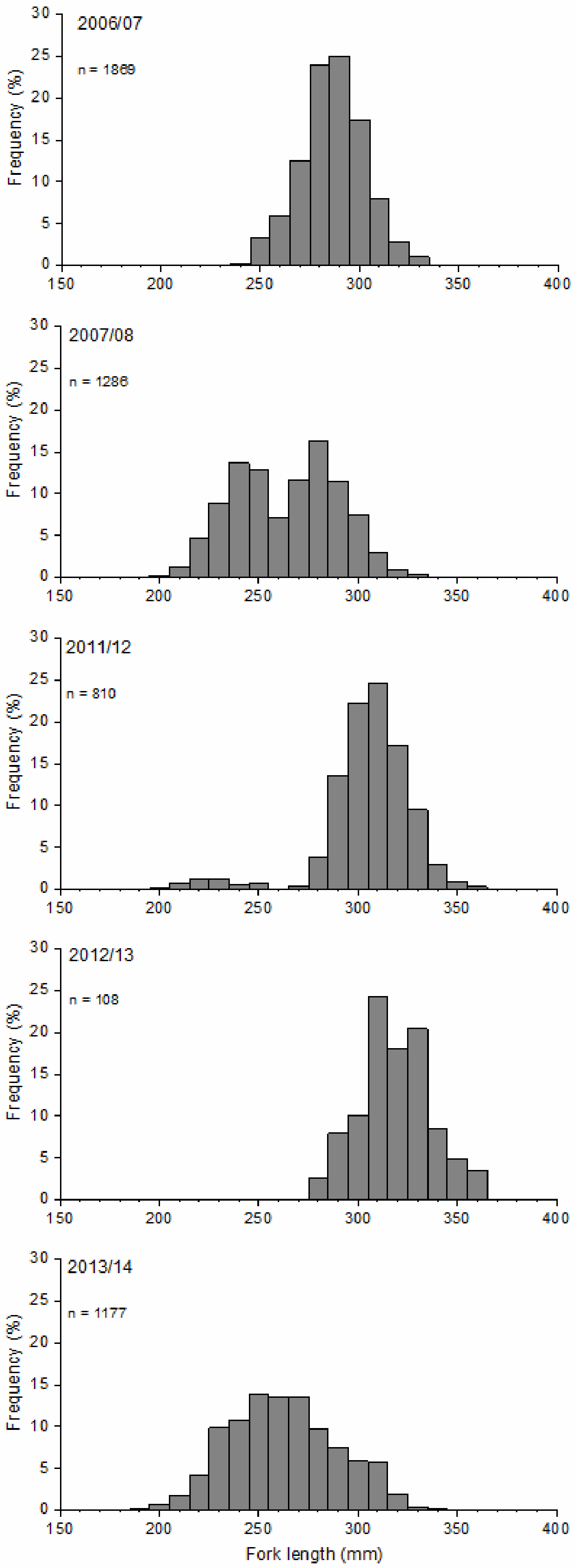

Figure 2.9. Length frequency (mm FL) of Blue Mackerel (East) from samples collected from commercial purse-seine shots in New South Wales from 2006/07 to 2013/14 (data supplied by New South Wales DPI).

Fish sampled in the West in 2008/09 ranged from 316 – 390 mm FL (Figure 2.10) and >50% of fish were between 340 and 370 mm FL. In 2009/10 and 2010/11, most fish ranged between 300 and 400 mm FL, whilst a small number of fish were between 260 and 299 mm TL.

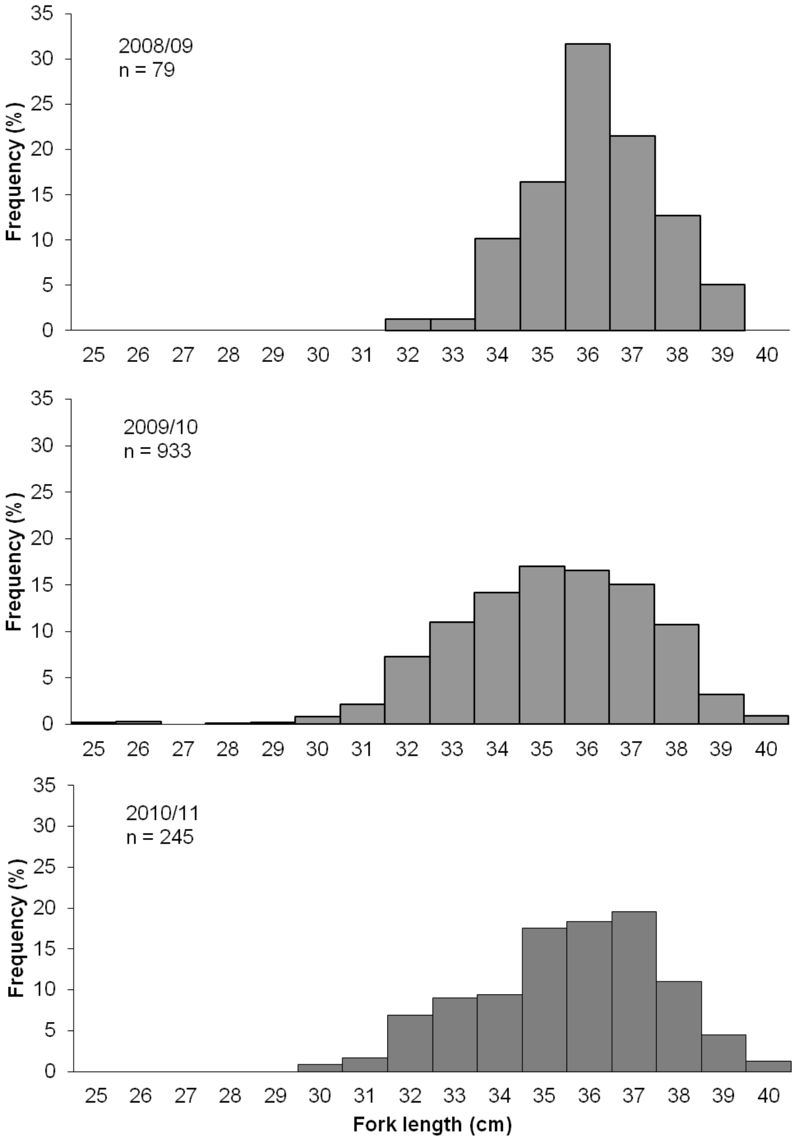

Figure 2.10. Length frequency (mm FL) of Blue Mackerel (West) from samples collected from commercial purse-seine shots in South Australia from 2008/09 to 2010/11.

Age Structure

The otolith weight-age algorithm developed by Ward and Rogers (2007) was used to estimate the ages of individual Blue Mackerel collected in the West (Port Lincoln) from 2008/09 – 2010/11. In 2008/09, ages ranged from 3 to 6 years (Figure 2.11) and 82% of fish were 4 and 5 years old. A similar age structure was identified in 2009/10 and 2010/11. However, a greater range of ages were involved, included fish up to 8 years of age. In all years, the majority of fish were older than three years.

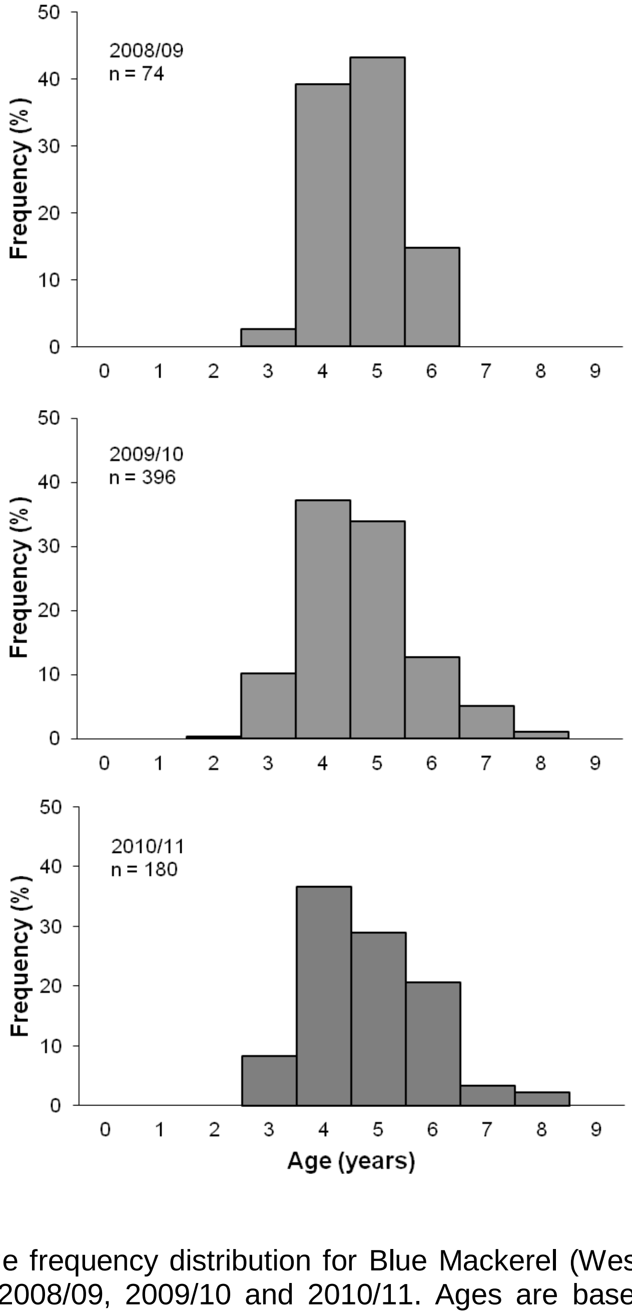

Figure 2.11. Age frequency distribution for Blue Mackerel (West) landed in Port Lincoln during 2008/09, 2009/10 and 2010/11. Ages are based on the otolith-weight, age relationship in Ward and Rogers (2007) for South Australia.

Gonad stages

In 2008/09, although the majority of fish sampled in the West were above the estimated size at maturity (Ward and Rogers 2007), approximately 50% and 31% of the males and females, respectively, were immature (Stage 1, Figure 2.12). Females were generally at a more advanced stage of gonad development than males with a higher proportion at Stage 2 and Stage 3 (53.8% and 15.4% (F) vs. 42.5% and 7.5% (M), respectively). A greater proportion of fish were at a more advanced stage of development in 2009/10 and 2010/11, with Stage 3 gonads dominating the sample for both males and females (Figure 2.12).

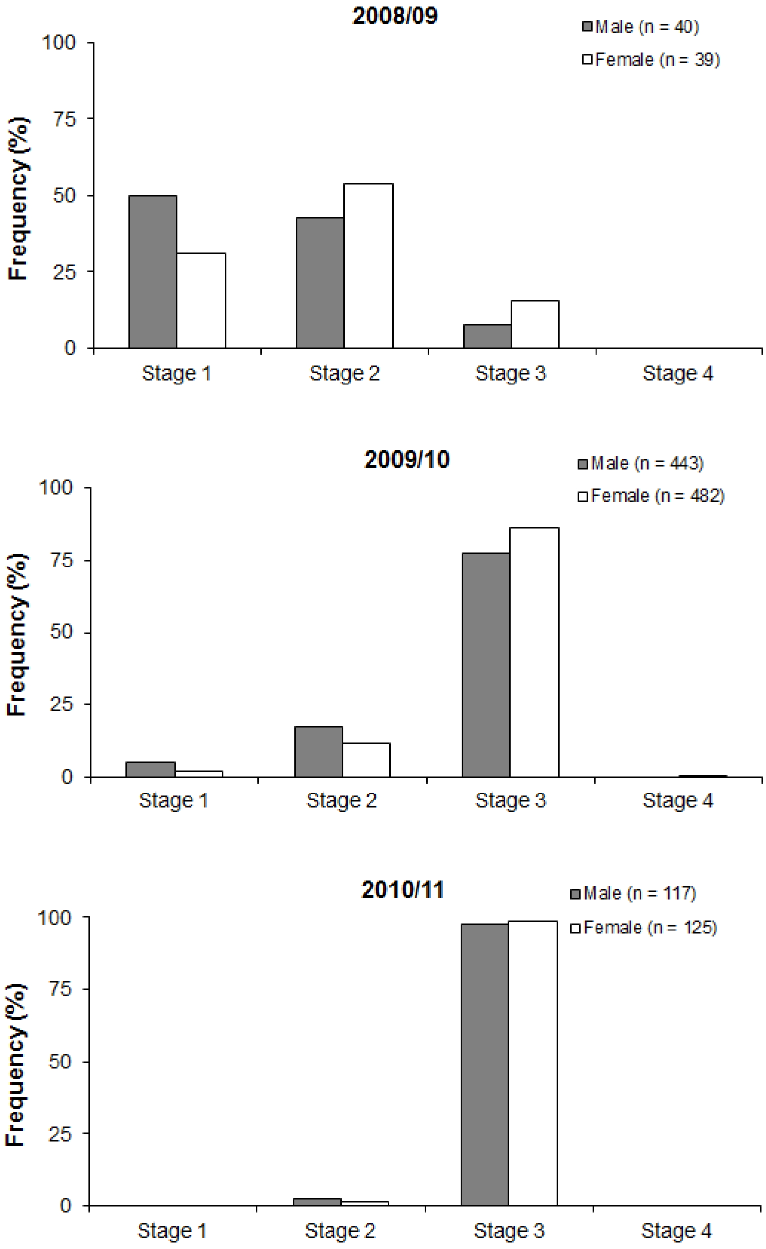

Figure 2.12. Distribution of gonad developmental stages (Stages 1 – 4) by sex for Blue Mackerel (West) landed in Port Lincoln during 2008/09, 2009/10 and 2010/11.

Size at maturity

An insufficient number and size range of Blue Mackerel were collected to estimate size at maturity for the species.

Gonadosomatic index (GSI)

Only annual summer GSI data were available for Blue Mackerel. In 2008/09, GSIs for males and females was 0.9% (Figure 2.13). In 2009/10, the GSI for both sexes increased to ~5% (Figure 2.13), before increasing again in 2010/11 to 7% (males) and 6% (females) (Figure 2.13).

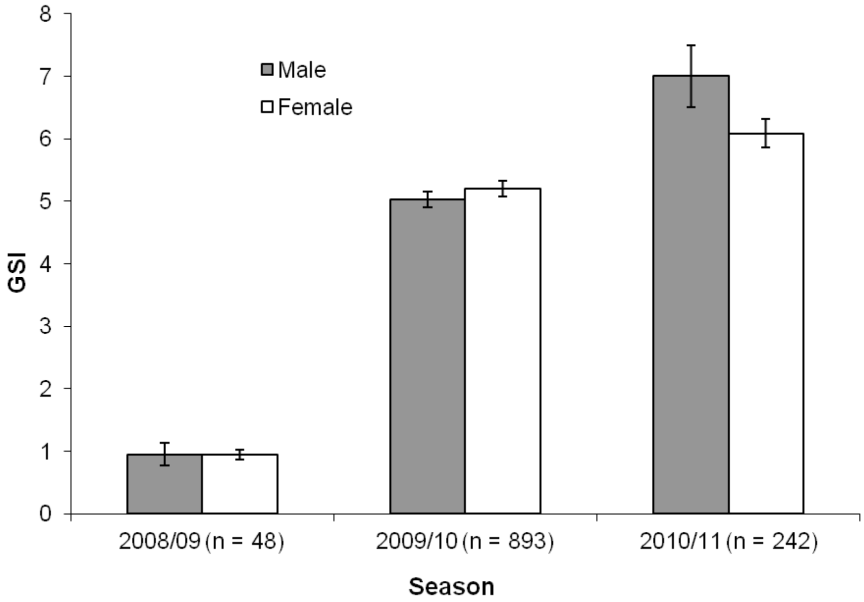

Figure 2.13. Mean summer gonadosomatic index (%) for mature Blue Mackerel (i.e. excluding Stage 1 fish) landed in Port Lincoln during 2008/09, 2009/10 and 2010/11. Error bars represent standard error.

DEPM

Preliminary estimates of the spawning biomass of Blue Mackerel in the West and East calculated from the ‘best’ estimate of each parameter were 56,228 t and 23,009 t, respectively (Ward and Rogers 2007). ‘Minimum’ and ‘maximum’ estimates ranged from 10,993 to 293,456 t in the West and 7,565 to 116,395 t in the East. The ‘best’ estimates of spawning biomass are conservative because the estimates of egg production on which they are based were obtained using the method of McGarvey and Kinloch (2001). This method typically provides lower estimates than the current internationally accepted method (i.e. linear version of exponential egg mortality model with application of a bias correction factor). In addition, there is evidence to suggest that spawning occurred outside the area surveyed in the West (i.e. in the western Great Australian Bight). Spawning may also have occurred outside the survey area in the East. Furthermore, the survey conducted off eastern Australia in

July 2004 may have been conducted outside the peak spawning season. Much higher estimates of egg production (23.01 – 33.00 eggs per m^2 per day) were obtained in October 2003 compared to July 2004, however, spawning biomass could not be estimated for the 2003 survey due to limitations in the sampling design (non-parallel transects). If egg production estimates for October 2003 were used to calculate spawning biomass for July 2004, the best estimate of spawning biomass for eastern Australia would have been 77,648 t (Ward and Rogers 2007). Previous studies have shown that egg production and spawning area are key determinants of spawning biomass (Ward *et. al.* 2009). Sensitivity analyses conducted in the study suggest estimates of spawning biomass were strongly affected by uncertainty in estimates of spawning fraction.

2.3.3 Biomass Estimates and MSE

For Blue Mackerel East, the “best” DEPM estimate of spawning biomass was 13% of the model calculated estimate of virgin biomass (Giannini *et al.* 2010). This is not an issue when investigating Tier 1 scenarios, as these are “relative” quantities determined as a percentage of the spawning biomass. Tier 1 scenarios all reached equilibrium at around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable. However, these should be treated with caution as these harvest quantities are “absolute” quantities and represent a much smaller proportion of the model calculated biomass than the DEPM estimate of biomass.

The results for Blue Mackerel West are similar to those for Blue Mackerel East (Giannini *et al.* 2010). In this case, the DEPM estimate of spawning biomass was 31% of the model calculated estimate of spawning biomass.

2.4 Summary and Conclusions

Preliminary assessments of spawning biomass for Blue Mackerel using the DEPM provided a mid-range best estimate of 23,009 t for the East and 56,228 t for the West (Ward and Rogers 2007). For each zone, the MSE suggested that spawning biomass was higher than the DEPM estimate. The SPFRAG noted that estimates of spawning biomass in the East and West are likely to be lower than the actual spawning biomass. As such, in 2008, the SPFRAG agreed to use a mid-range estimate of 40,000 t of spawning biomass for setting the RBC in the East, after a sensitivity analysis was completed (Woodhams *et al.* 2012; AFMA 2014).

In the East, catches peaked at 1,008 t in 2002/03 and declined to 298 t in 2011/12. In 2013/14, the total catch of 415 t was 14% of the RBC (3,000 t) and 2% of the DEPM biomass estimate (23,009 t). The long-term declining trend of catch was similar to the trend for fishing effort, which suggests that recent low catches relate to lower fishing effort rather than reductions in the size of the fishable biomass. Furthermore, catches in most years involved mainly individuals above the size at maturity (Ward and Rogers 2007).

In the West, catches of Blue Mackerel were relatively low (<65 $t.yr^{-1}$) from 1997/98 to 2003/04, before increasing to 1,977 t in 2008/09. In 2012/13, annual catch declined to 2.3 t which was <1% of both the RBC (6,500 t) and DEPM biomass estimate (56,228 t). This suggests that the impacts of the current level of fishing pressure on the spawning biomass in the West are low. Catch data for 2013/14 are confidential, due to the low number (<5) of vessels reporting catch. Similar to the East, recent low catches in the West likely relate to a lack of targeted fishing for Blue Mackerel. High catches taken in the West during the late 2000s were dominated by fish >4 years of age and involved mostly (99%) individuals above the size at maturity (Ward and Rogers 2007).

The most recent classification of stock status for Blue Mackerel in the East and West by Woodhams *et al.* (2012) suggested that the species was ‘not overfished’ and ‘not subject to overfishing’. The fishery-dependent and -independent data presented in this chapter suggest that recent low catches of Blue Mackerel in the East and West are sustainable. However, further DEPM assessments are required to provide updated estimates of spawning biomass for this species.

Using the definitions from the National Status of Key Australian Fish Stocks Report (Flood *et al.* 2014), the fishery for Blue Mackerel in the East and West are classified as sustainable.

3 JACK MACKEREL AND YELLOWTAIL SCAD (*TRACHURUS* SPP.)

3.1 Introduction

3.1.1 Background to Fishery

A major purse-seine fishery for small pelagic fishes was developed off Tasmania in the mid-1980s, with catches peaking at over 40,000 t in 1986/87. The majority of the catch consisted of Jack Mackerel (*Trachurus declivis*), with relatively low catches of Redbait (*Emmelichthys nitidus*) and Blue Mackerel (*Scomber australasicus*) taken as by-product. The fishery became the largest in Australia, by weight, before large reductions in catches in 1988/89 resulted in financial problems for the fishery (Kailola *et al.* 1993; Pullen 1994a). Large-scale purse-seine operations for Jack Mackerel continued through the 1990s. However, large inter-annual fluctuations and an overall downward trend in fishery production effectively resulted in purse-seine operations ceasing in 2000. The majority of the catch taken between the mid-1980s and 2000, was processed at plants in Triabunna (east coast of Tasmania) for fish meal and oil for aquaculture feed, with small quantities frozen for rock lobster bait, processed for human consumption or canned as pet food (Pullen 1994a).

In 2001/02, a 6-month fishing trial using a mid-water pair-trawl operation was established to target subsurface schools of Jack Mackerel. A total catch of over 5,000 t was taken between December 2001 and April 2002, of which 90% was Redbait. On the strength of this trial, a multi-purpose 50 m mid-water trawler was brought to Tasmania to target small pelagic species with fishing operations commencing in late 2002. By mid-2003, more than 7,000 t of small pelagic fish was landed and Redbait dominated the catch. More recent fishing for small pelagic fish by purse-seiners in Tasmanian State waters yielded 203 t of Jack Mackerel in 2007/08, 920 t in 2008/09 and 917 t in 2009/10 (Hartman and Lyle 2011).

3.1.2 Taxonomy

Jack Mackerel and Yellowtail Scad belong to the family Carangidae, which includes 140 species representing 32 genera (Nelson 2006). Carangids are found worldwide with most species occurring in tropical waters. There are 65 species in Australian waters, of which eight species from four genera inhabit southern temperate waters (Gomon *et al.* 2008). The genus *Trachurus* contains 13 species, three of which are found in Australia: *T. declivis, T. murphyi* and *T. novaezelandiae*.

3.1.3 Distribution

Jack Mackerel are widely distributed throughout coastal waters of southern Australia and New Zealand. In Australia, they occur along the southern coast from Shark Bay in Western Australia, to Wide Bay in Queensland, including the waters around Tasmania (Gomon *et al.* 2008). They are found down to depths of 500 m, but more commonly over the continental shelf to 200 m (Pullen 1994a).

Yellowtail Scad have a similar distribution to Jack Mackerel although their distribution extends further to the north on each side of the continent and are rare around Tasmania (Kailola *et al.* 1993; Gomon *et al.* 2008).

3.1.4 Stock Structure

There is some evidence to suggest that at least two populations of Jack Mackerel occur within Australian waters, whilst a third occurs in New Zealand. Analysis of morphometric measurements and meristic counts showed a significant difference between east Australian fish and those from the GAB (Lindholm and Maxwell 1988). Genetic studies have found no significant differences between southern New South Wales and eastern Tasmanian fish (Smolenski *et al.* 1994), but distinct differences between GAB and New Zealand fish (Richardson 1982). In an extensive review of available biological, environmental and fishery data, Bulman *et al.* (2008) concluded that Jack Mackerel from eastern Australia, including eastern Tasmania, were likely to be a separate sub-population to fish from west of Tasmania, including the GAB and Western Australia.

Little is known of the stock structure of Yellowtail Scad in Australian waters.

3.1.5 Movement

No specific studies have examined the movement of Jack Mackerel or Yellowtail Scad. However, a correlation between size and depth is evident, with smaller fish generally found inshore and larger fish offshore (Shuntov 1969; Stevens *et al.* 1984; Kailola *et al.* 1993; Pullen 1994). Such size-dependent distribution suggests offshore movement with increasing size.

3.1.6 Food and Feeding

Jack Mackerel feed primarily on aquatic crustaceans, particularly euphasiids (krill) and copepods (Shuntov 1969; Stevens *et al.* 1984; McLeod 2005; Bulman *et al.* 2008). Krill, in particular *Nyctiphanes australis*, are the most common dietary item for Jack Mackerel throughout its distribution, and on average account for 44% of the diet in fish from eastern Tasmania (Webb 1976; Williams and Pullen 1993; McLeod

2005). Fish that occur in deeper waters also consume mesopelagic fish (Maxwell 1979; Blaber and Bulman 1987). In addition, Jack Mackerel eat a variety of other prey items in minor quantities including ostracods, gastropods, amphipods, isopods, polychaetes and echinoderms (Stevens *et al.* 1984; Blaber and Bulman 1987; McLeod 2005). Dietary composition has also been shown to vary seasonally (Bulman *et al.* 2008).

Studies in the GAB found that Jack Mackerel generally feed during the day with fish in offshore waters feeding mostly on krill and fish in inshore waters consuming mainly copepods (Shuntov 1969; Stevens *et al.* 1984). Prey size has been shown to be dependent on fish size, with larger prey items taken by larger fish (Stevens *et al.* 1984).

3.1.7 Age, Growth and Size

Jack Mackerel reach a maximum of 470 mm TL, 1 kg in weight and 17 years of age (Last *et al.* 1983; Williams and Pullen 1986; Lyle *et al.* 2000; Browne 2005). Multiple studies have investigated the age and growth of Jack Mackerel: (whole otoliths: Stevens and Hausfeld 1982, Jordan 1994; whole otoliths: and Lyle *et al.* 2000, Browne 2005). The annual formation of increments in otoliths has been validated using marginal increment analysis (Lyle *et al.* 2000). In Tasmania, Jack Mackerel grow quickly at a young age, reaching 270 mm TL within their first 4 years and 335 mm TL by the time they reach 10 years, with no significant difference in growth between males and females (Lyle *et al.* 2000).

Growth of Yellowtail Scad is variable, with individuals reaching ~200 mm between 2 and 4 years of age (Stewart and Ferrell 2001). The maximum size of Yellowtail Scad is 330 mm TL (Kailola *et al.* 1993), while individuals to 14 years of age have been recorded (Stewart and Ferrell 2001).

3.1.8 Reproduction

Jack Mackerel are serial spawners, although spawning frequency has not been determined in Australian waters (Marshall *et al.* 1993; Neira 2011). Mean batch fecundity was estimated to be ~63,000 eggs for fish from eastern Tasmania (Neira 2011). Females have been shown to reach sexual maturity (SAM_{50}) at ~315 mm TL (Marshall *et al.* 1993). Spawning is thought to occur in spring along most of the New South Wales coastline (Maxwell 1979; Keane 2009) and during summer in the southern regions from Eden (New South Wales) to St. Helens off Tasmania and in the GAB (Stevens *et al.* 1984; Marshall *et al.* 1993; Jordan *et al.* 1995; Ward *et al.* 2015). Mean GSI values for females off eastern Tasmania increase substantially in

November and remain high until January, before declining in February (Williams *et al.* 1986). Back-calculation of birthdates based on otolith microstructure of larval fish otoliths indicated that spawning occurs between mid-December and mid-February (Jordan 1994). Spawning activity follows a semi-lunar cycle with peaks associated with both full and new moons.

The reproductive biology of Yellowtail Scad is not fully understood for the Australian population (Neira 2009). Mean batch fecundity was estimated to be ~39,000 eggs based on published eggs.g^{-1} values applied to mean female weight from commercial catch data (Neira 2009). Female and male Yellowtail Scad reach sexual maturity (SAM_{50}) at 200 mm and 220 mm FL, respectively (Kailola *et al.* 1993).

3.1.9 Early Life History and Recruitment

Jack Mackerel eggs are positively buoyant and 0.97-1.03 mm in diameter (Neira 2011). Larvae have been described by Trnski (1998). Larvae have been collected off southern New South Wales during spring, and off eastern Tasmania, in Bass Strait and the GAB during summer (Stevens *et al.* 1984; Keane 2009). Yellowtail Scad eggs are morphologically similar to Jack Mackerel eggs but slightly smaller (0.78-0.88 mm; Neira 2009).

3.1.10 Stock Assessment

During the late 1980s and early 1990s, considerable research effort was directed at describing the fisheries biology of Jack Mackerel. Projects were initiated to (1) evaluate tools for assessment of the Jack Mackerel stocks; (2) describe factors contributing to inter-annual variability in the availability of Jack Mackerel; and (3) collect information on early life history and reproductive biology of the species (Jordan *et al.* 1992; 1995). Research outputs included greater understanding of interactions between local oceanography and availability of surface schools of Jack Mackerel (Harris *et al.* 1992; Williams and Pullen 1993), and data on the reproductive biology and early life history of Jack Mackerel (Harris *et al.* 1992; Young and Davis 1992; Marshall *et al.* 1993; Williams and Pullen 1993; Jordan 1994; Jordan *et al.* 1995). The abundance of surface schools of Jack Mackerel off eastern Tasmania was found to have a close relationship with oceanographic changes (Young *et al.* 1993). However, no successful method of assessing the size of the Jack Mackerel resource was developed, despite attempts to use a combination of aerial surveys of surface schooling fish, and hydro-acoustic surveys of surface and sub-surface schools on the shelf break (Jordan *et al.* 1992).

The first dedicated application of the DEPM to Jack Mackerel off the south-east coast of Australia (i.e. the key spawning area off eastern Australia) was undertaken in 2014 (Ward *et al.* 2015). As part of the study, large numbers of samples of eggs and adults were collected concurrently during what has previously been identified as the main spawning period for the species (Marshall *et al.* 1993; Jordan *et al.* 1995). The study established an effective method for sampling adult Jack Mackerel and provided the first estimates of the adult reproductive parameters required for application of the DEPM for this species (Ward *et al.* 2015).

Prior to the 2014 study, the DEPM was applied to Jack Mackerel in 2011 using samples collected off south-eastern Australia in 2002 during a survey of Blue Mackerel (Neira 2011). Adult parameters for the DEPM were derived from Tasmanian trawl samples and published data. More recently, ecosystem modelling of south east Australian waters indicated that the spawning biomass of Jack Mackerel was likely to be in the vicinity of 130,000 to 170,000 t (Fulton 2013), which is consistent with the estimates provided by Neira (2011).

There have been limited stock assessments of Yellowtail Scad in Australia. A provisional DEPM spawning biomass estimate (Neira 2009) suggested a biomass of between 2,900 and 5,900 t depending on the model used to estimate daily egg production. This estimate was based on samples collected during a survey in October 2002 directed at Blue Mackerel. There is significant uncertainty around both egg identification and some adult parameters, so this result must be viewed with caution.

3.1.11 Management

This small pelagic fishery has changed dramatically since the commencement of large scale fishing operations in the mid-1980s. Between the late 1980s and prior to the implementation of the Commonwealth Small Pelagic Fishery Management Plan in 2009, the Tasmanian component (Zone A) of the fishery was managed using a combination of input and output controls, principal among these being a TAC. A combined species TAC for Zone A was initially set at 42,000 t in 1988/89 and was based on the highest annual catch from the purse-seine fishery (Jordan *et al.* 1992). The TAC was decreased to 34,000 t in 2002/03 with the renewed interest in small pelagic fish and commencement of mid-water trawl operations. Despite catches not approaching this level, the TAC was applied in subsequent fishing seasons up until 2008/09 at which time the SPF was split into East and West Zones and, under the SPF harvest strategy framework (AFMA 2008), species and zone specific TACs were established. For the 2013/14 season, the recommended TAC for Jack Mackerel was

10,230 t in the East and 5,000 t in the West. Both East and West Zones are currently managed at the Tier 2 level. The DEPM spawning biomass estimates provided by Neira (2011) were used to set the Tier 2 maximum RBC for Jack Mackerel East at 10,600 t (AFMA 2008).

Yellowtail Scad is classed as a permitted by-catch species in the SPF.

3.1.12 Recreational fishing

In Australia, recreational fishers target Jack Mackerel and multiple species of scad using rod and line, and troll lines in New South Wales, Queensland, South Australia, Western Australia and Tasmania. The Australian National Survey of Recreational and Indigenous Fishing (Henry and Lyle 2003) estimated that boat-based recreational fishers harvested 740,260 Jack Mackerel and Scads (combined) in 2000/01, with 37% of these being released back into the water. Of those fish retained, 46% were landed by fishers in New South Wales, 26% in Western Australia and 19% in Queensland. Catches from the other States comprised the remaining 8% of the total recreational catch (Henry and Lyle 2003). Based on the mean length/weight key developed by Stewart and Ferrell (2001), the estimated weight of Jack Mackerel/Yellowtail Scad harvested by the recreational sector annually in Australia was ~94 t (Ward and Rogers 2007). This catch information is not presented in this report, as estimates of catch for individual species were not available.

3.2 Methods

3.2.1 Fishery Statistics

Fishery statistics were supplied by ABARES for the period from 1997/98 to 2010/11. From 2011/12 to 2013/14, all fishery statistics were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are in financial years.

Estimates of monthly catch and effort supplied for Jack Mackerel and Yellowtail Scad in the East from July 1997 to June 2010 included data for oceanic and non-oceanic fishing operations. After this, all estimates were for oceanic purse-seine and mid-water trawling fishing operations only.

3.2.2 Biological Information

Jack Mackerel

For Jack Mackerel, fishery-dependent length frequency and biological data were collected between 1984 and 1993 as part of a monitoring program of the Jack

Mackerel Purse-Seine Fishery off Tasmania. Samples collected during demersal research trawling, conducted by CSIRO and the Tasmanian fisheries agency between 1985 and 1990, supplied some biological information. Between 1994 and 2001, the level of catch sampling of the purse-seine fishery was limited.

Biological data were collected by AFMA observers on a small proportion of trips during the 2001/02 pair-trawl fishing trials undertaken off Tasmania. As such, data for 2001/02 are limited and may not be representative of the catch. Following the commencement of mid-water trawl operations in 2002, the Tasmanian Aquaculture and Fisheries Institute (TAFI) commenced an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length frequency data collected from 2002 to 2008.

Purse-seine operations for small pelagic fish resumed in Tasmanian State waters in 2008/09, with Redbait and Jack Mackerel the main species targeted. Catch sampling of mid-water trawl and purse-seine operations adjacent to Tasmania was implemented in 2009 as part of the SPF monitoring program under the SPF Harvest Strategy framework (AFMA 2008).

For available samples, biological data were collected from individual fish and included FL (to the nearest mm), total weight (to the nearest gram), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall *et al.* 1993) and gonad weight (to the nearest 0.1 g). For some individuals, their otoliths were also extracted and used for age estimation and growth modelling.

Commercial logbook information, length frequency and biological data collected between 1984/85 and 2009/10 were also included in this assessment. Age, growth and reproductive data for Jack Mackerel were available from previous studies by Jordan *et al.* (1992), Lyle *et al.* (2000) and Browne (2005). In addition, specimens from 2009/10 mid-water trawl and purse-seine fishing operations were analysed to provide recent size and age composition estimates of the catch. No catch sampling was undertaken for Jack Mackerel from 2010/11 to 2012/13 due to limited activity in the fishery. However, length frequency data were available for Jack Mackerel from research (demersal trawl net) sampling undertaken between St. Helens (Tasmania) and Eden (New South Wales) in January 2014 (Ward *et al.* 2015).

Yellowtail Scad

Annual length frequency data for Yellowtail Scad sampled from commercial catches taken in New South Wales were supplied by New South Wales DPI for the period from 2000/01 to 2013/14. Samples collected between 2010/11 and 2012/13 were sub-sampled, and otoliths of these fish were extracted and used for age estimation.

3.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Jack Mackerel was obtained for the East using samples collected during a study in 2002 (Neira 2011). Ecosystem modelling conducted by Fulton (2013) provided biomass ranges for Jack Mackerel in the East. A targeted DEPM survey for Jack mackerel was conducted in the East during January 2014 (Ward *et al.* 2015).

No reliable biomass estimates are available for Yellowtail Scad.

3.3 Results

3.3.1 Fishery Statistics

Number of vessels

The number of vessels that reported landings of Jack Mackerel in the East declined from a peak of 52 vessels in 1998/99 to five vessels in 2011/12 (Figure 3.1). In 2013/14, a total of seven vessels landed Jack Mackerel in the East, with six from Tasmania and one from Victoria (Figure 3.1). Similarly in the West, the number of vessels landing Jack Mackerel has declined over the last 15 years. Only one vessel from Tasmania reported catches of Jack Mackerel in the West in 2013/14 (Figure 3.2).

The number of vessels that reported landings of Yellowtail Scad in the East declined from a peak of 46 vessels in 1997/98 to 16 vessels in 2009/10 (Figure 3.3). On average, 98% of the vessels reporting catch in each year are from New South Wales. In 2013/14, a total of 19 vessels reported landings of Yellowtail Scad, all of which were from New South Wales waters (Figure 3.3).

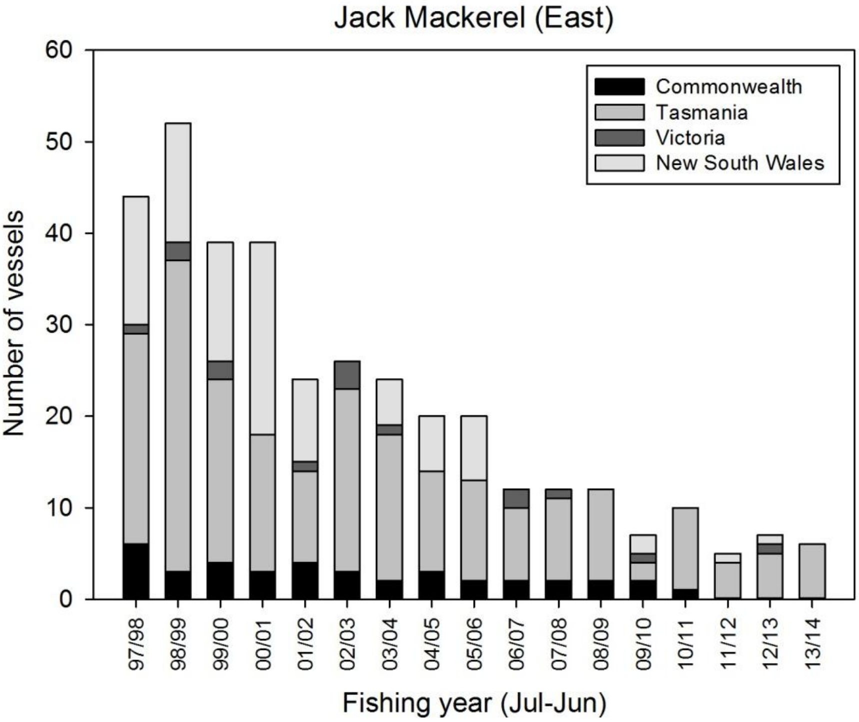

Figure 3.1. Number of vessels that landed Jack Mackerel (East) in each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

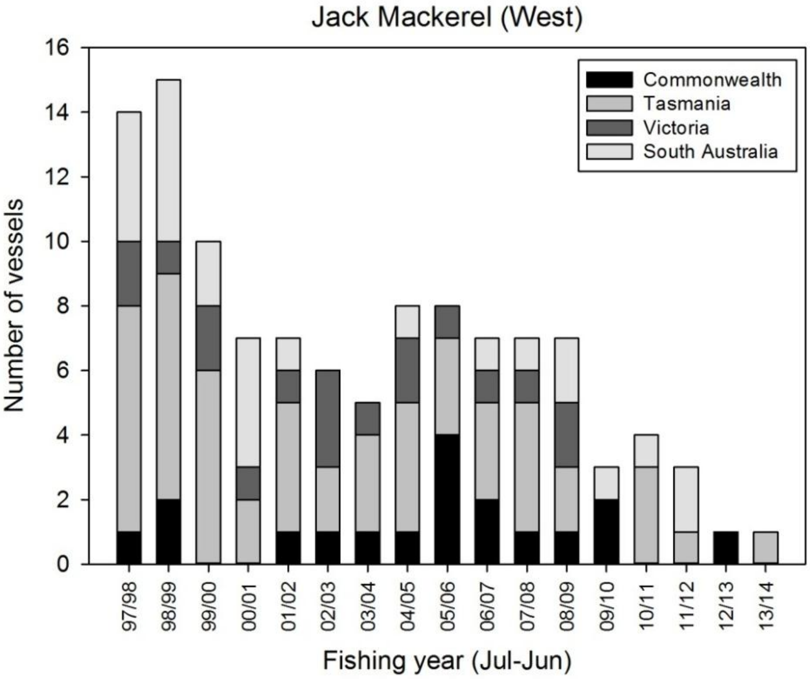

Figure 3.2. Number of vessels that landed Jack Mackerel (West) in each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

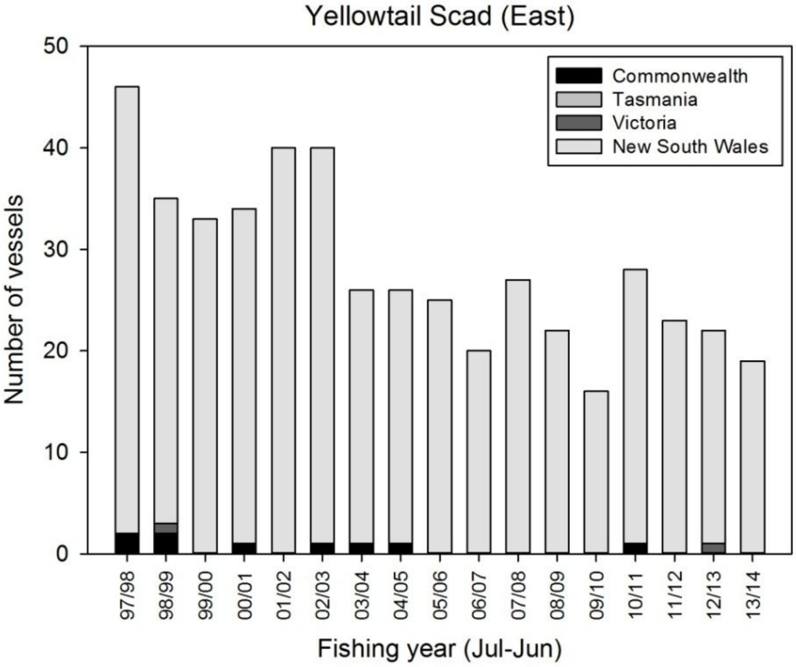

Figure 3.3. Number of vessels which landed Yellowtail Scad in the East, from each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

Annual Patterns – catch, effort and CPUE

Total catches of Jack Mackerel for the East declined from 9,620 t in 1997/98 to 102 t in 2000/01 (Figure 3.4). Landings then increased to 3,340 t in 2003/04, before decreasing to 56 t in 2011/12. In 2012/13 and 2013/14, annual catches did not exceed 0.8 t. Historically, annual estimates of effort have trended downwards from a peak of 905 vessel days in 1998/99 to eight vessel days in 2013/14 (Figure 3.4). Over the same period, CPUE fluctuated considerably between 0.03 and 13.9 t.vessel day^{-1} but also trended downwards (Figure 3.5).

Historically, Jack Mackerel catches in the West have been lower than those in the East (Figure 3.6). Annual catches peaked at 463 t in 2006/07. With the exception of 2005/06 (338 t), all other non-confidential catches have been <153 t (Figure 3.6). The peak catches in the mid-2000s coincided with years when effort was relatively high (Figure 3.6). Annual catch and effort data from 2009/10 to 2013/14 are confidential due to the low number (<5) of vessels reporting catch. Annual CPUE from 1997/98 to 2004/05 did not exceed 2 t per vessel day^{-1} (Figure 3.7). CPUE increased to >4.6 t.vessel day^{-1} from 2005/06 to 2008/09, and annual estimates since then are confidential.

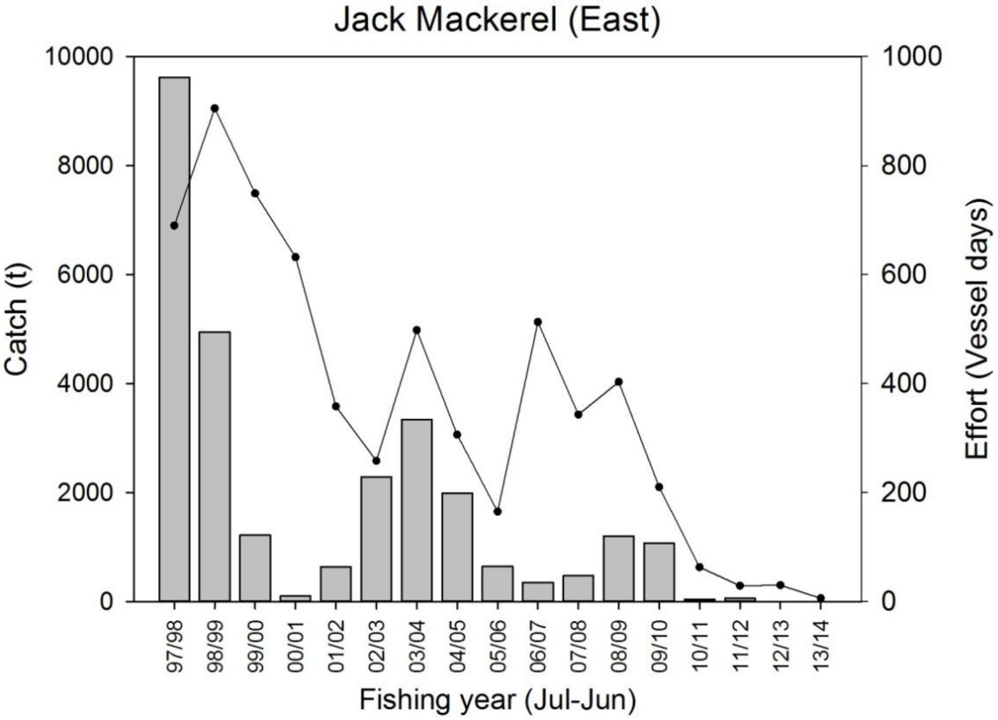

Figure 3.4. Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel (East) for each financial year from 1997/98 – 2013/14. (*) indicates data confidentiality, where <5 license holders reported landings.

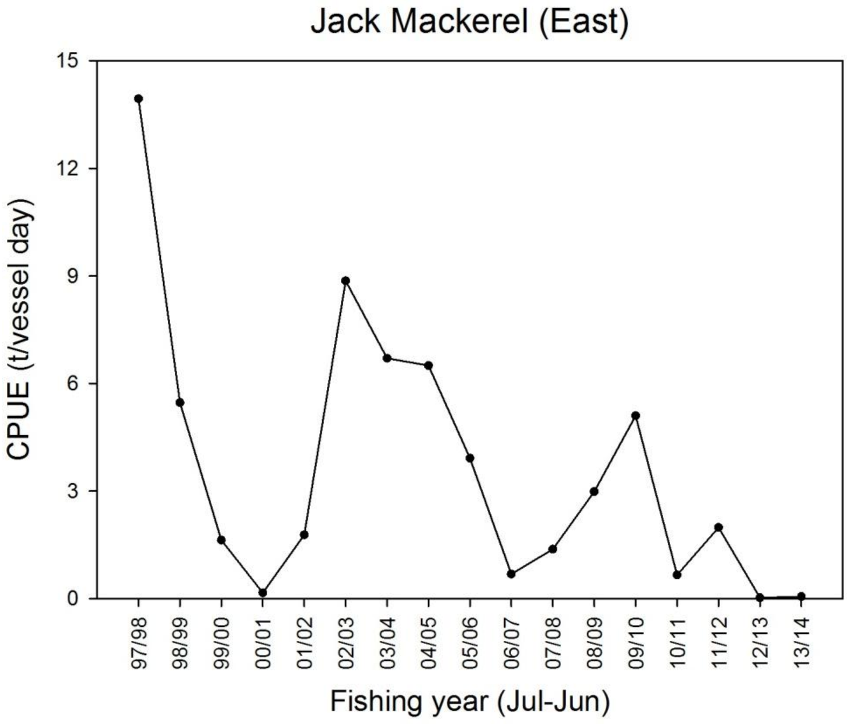

Figure 3.5. CPUE (t per vessel day) for Jack Mackerel (East) for each financial year from 1997/98 – 2013/14. (*) indicates data confidentiality, where <5 license holders reported landings.

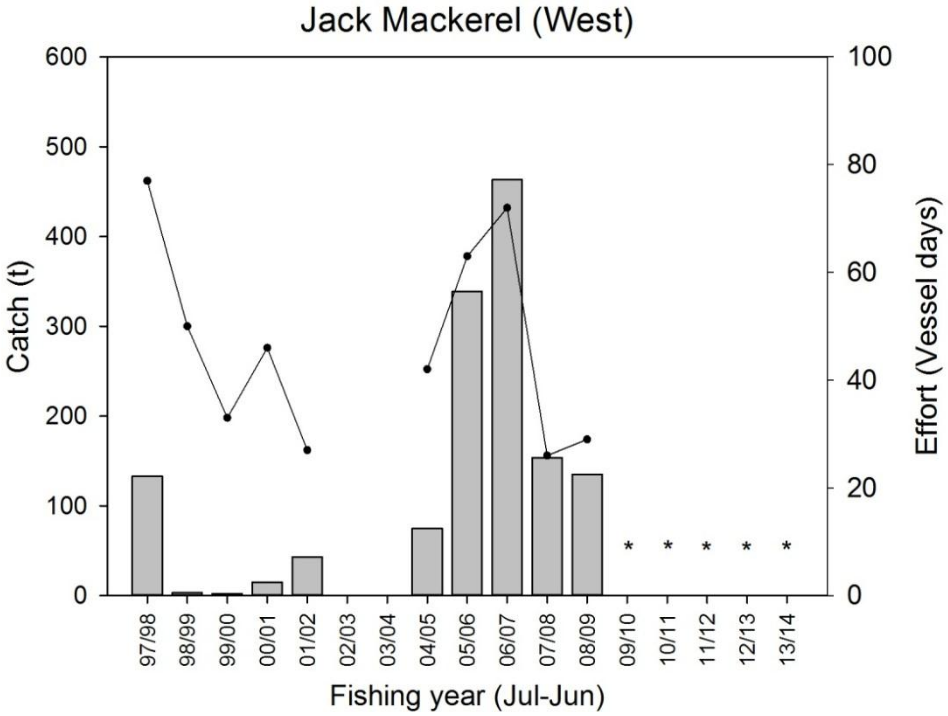

Figure 3.6. Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel (West) for each financial year from 1997/98 – 2013/14 (no data was provided for 2002/03 and 2003/04). (*) indicates data confidentiality, where <5 license holders reported landings.

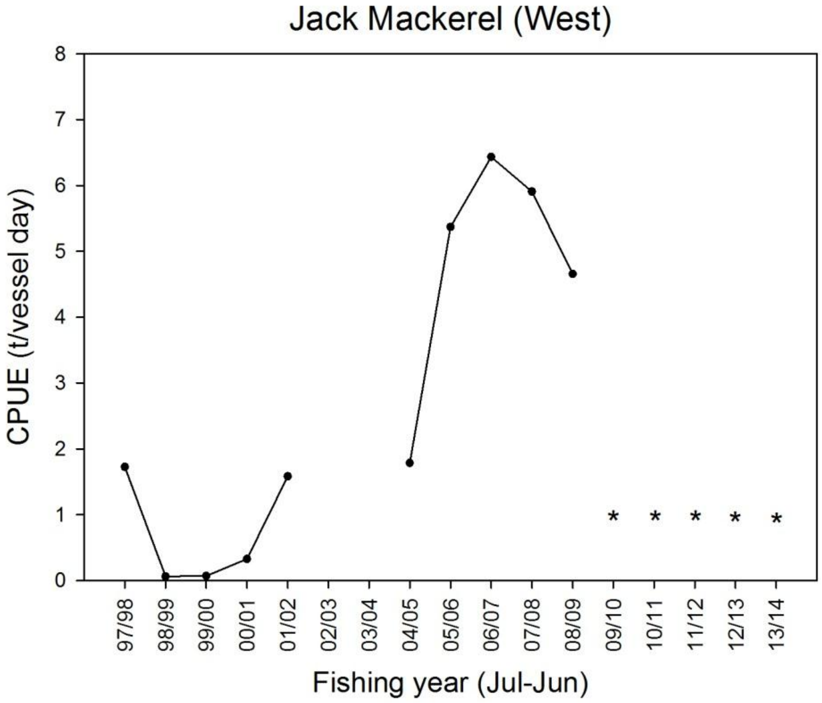

Figure 3.7. CPUE (t per vessel day) for Jack Mackerel (West) for each financial year from 1997/98 – 2013/14 (no data was provided for 2002/03 and 2003/04). (*) indicates data confidentiality, where <5 license holders reported landings.

Yellowtail Scad catches in the East were ~450 t in 1997/98 and gradually trended down to 177 t in 2009/10 (Figure 3.8). Catch increased to 401 t in 2010/11 and remained relatively high in 2012/13 (507 t) and 2013/14 (487 t). Annual fishing effort also followed a downward trend between 1997/98 - 2008/09, although unlike catch, this declining trend continued in subsequent years to 2013/14 (Figure 3.8). The recent divergent trends for catch and effort were reflected in estimates of CPUE which indicated a significant increase in catch rate from <0.25 t.vessel day^{-1} between 1997/98 and 2009/10, to ~0.54 t.vessel day^{-1} in 2012/13 and 2013/14 (Figure 3.9).

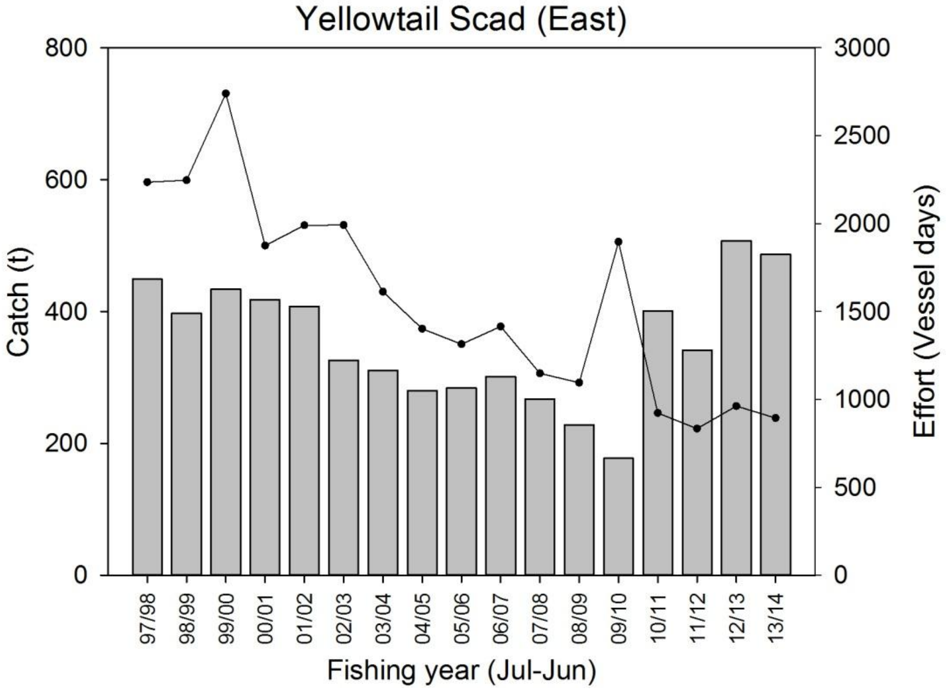

Figure 3.8. Total landed catch (t, bars) and effort (vessel days, line) for Yellowtail Scad (East) for each financial year from 1997/98 – 2013/14.

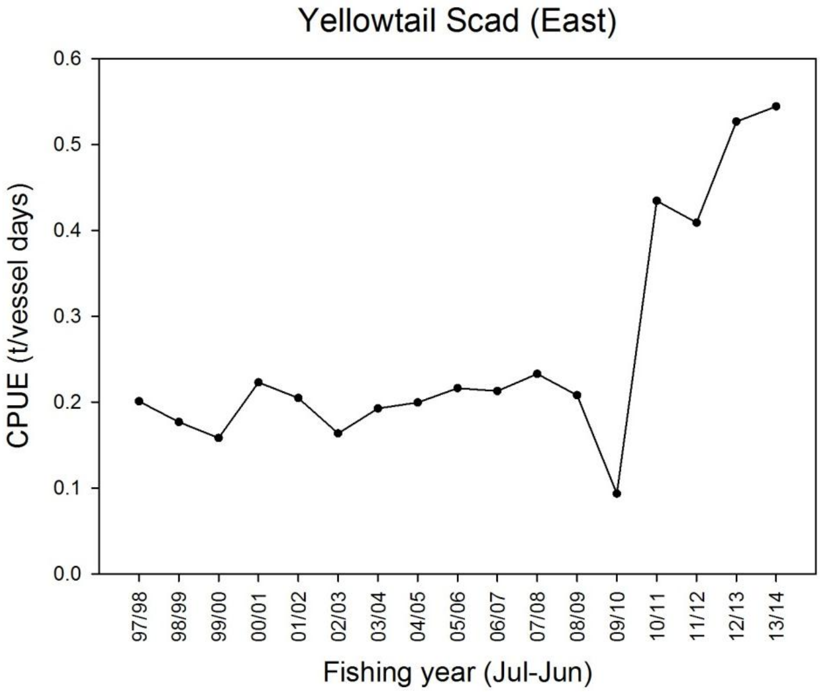

Figure 3.9. CPUE (t per vessel day) for Yellowtail Scad (East) for each financial year from 1997/98 – 2013/14.

Intra-annual Patterns - catch and effort

Presentation and interpretation of intra-annual catch and effort data for Jack Mackerel for the East were affected by confidentiality issues arising from the small number of vessels participating in the fishery. Between 1997/98 and 1999/2000, most of the catch was taken during the summer months (Figure 3.10). No data were presented for Jack Mackerel from the West due to confidentiality issues.

For Yellowtail Scad in the East, no consistent long-term intra-annual patterns in catch and/or effort were evident. Since 2010/11, monthly catches were typically highest during summer and early autumn (Figure 3.11).

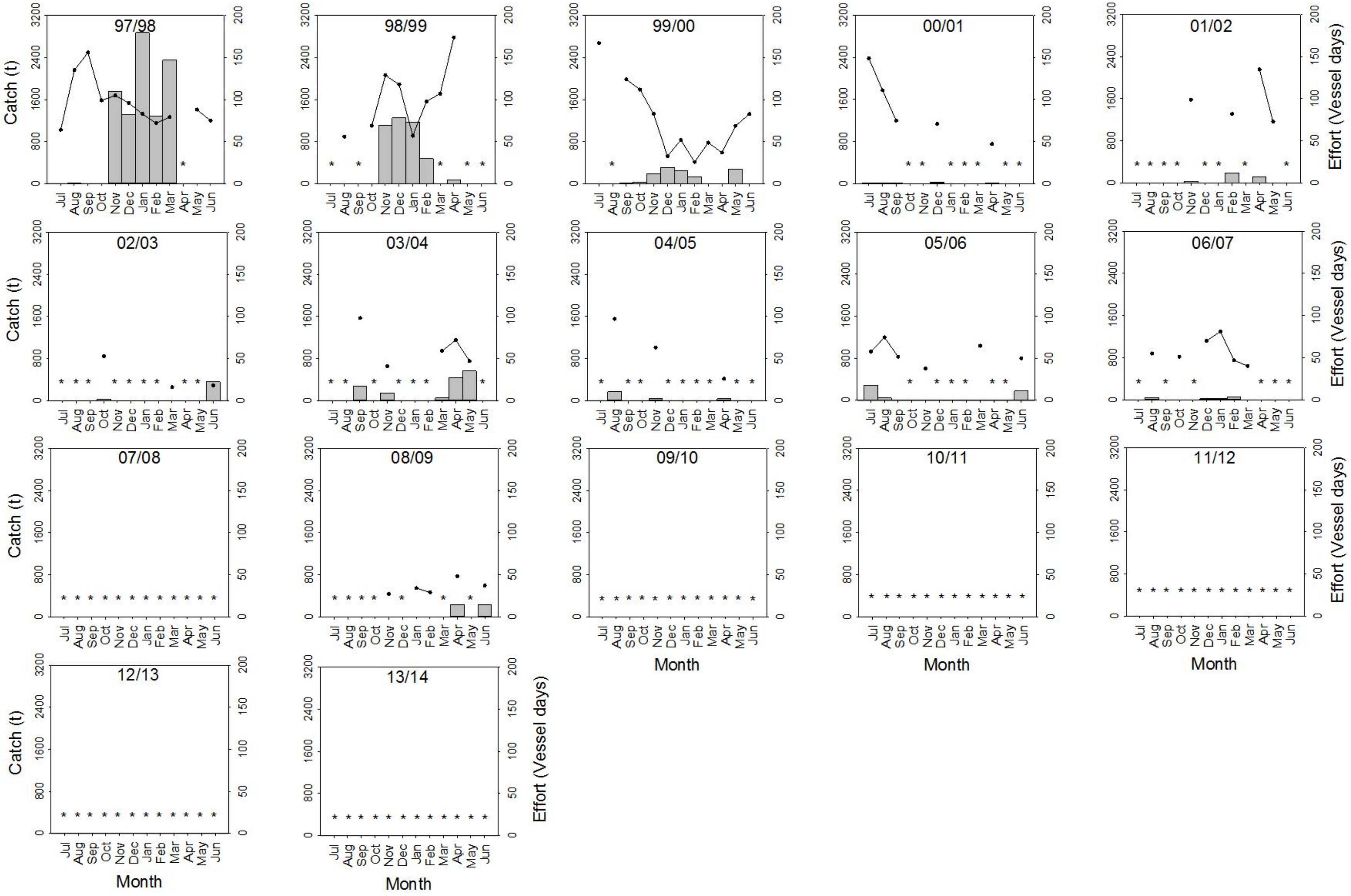

Figure 3.10. Intra-annual patterns of catch (bars) and effort (line) for Jack Mackerel (East) for each financial year from 1997/98 – 2013/14. Catch and effort data for each year from 2010/11 – 2013/14 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders reported landings.

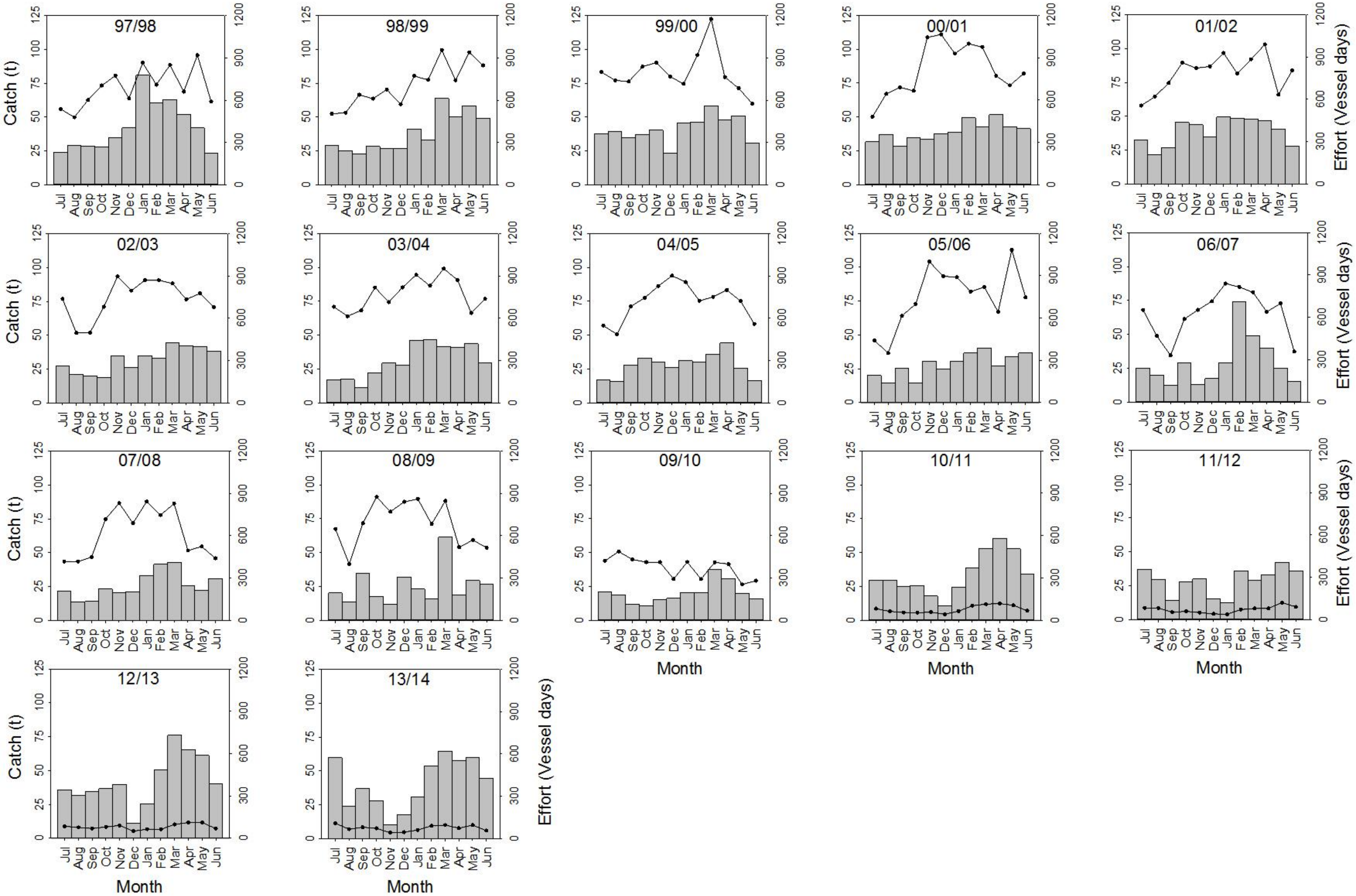

Figure 3.11. Intra-annual patterns of catch (bar) and effort (line) for Yellowtail Scad (East) for each financial year from 1997/98 – 2013/14. Catch and effort data for each year from 2010/11 – 2013/14 excludes non-oceanic fishing activity.

3.3.2 Biological Information

Due to the limited commercial fishing for Jack Mackerel, catch sampling has been limited since 2010/11. In January 2014, ten samples (n = 1,759) of Jack Mackerel were collected from catches taken as part of the DEPM research (demersal trawl net) surveys undertaken off eastern Victoria/southern New South Wales (Ward *et al.* 2015). An additional seven samples (n = 947) were collected from catches taken from waters off the north-eastern coast of Tasmania (Ward *et al.* 2015). No age information was collected from these samples.

For Yellowtail Scad in the East, length data were collected from a total of 27,532 fish sampled from commercial catches taken in New South Wales between 2000/01 and 2013/14 (Table 3.1). Information on the spatial and temporal coverage of these samples, relative to fishery production in New South Wales was not available, although between 8 and 47 catch samples of Yellowtail Scad were taken in each year. Of the Yellowtail Scad sampled in 2011/12 and 2012/13, otoliths were removed for ageing from 119 and 60 individuals, respectively. These data were supplied by New South Wales DPI.

Table 3.1. Summary of Yellowtail Scad (East) samples of collected from commercial purse-seine net catches taken in New South Wales between 2000/01 and 2013/14 (data supplied by New South Wales DPI).

Season	No. of samples	No. of fish	Size range (FL mm)
2000/01	41	5,078	80 – 330
2001/02	47	4,996	80 – 330
2003/04	7	1,400	220 – 325
2004/05	20	1,499	100 – 320
2005/06	31	2,661	110 – 320
2006/07	25	3,048	190 – 310
2007/08	18	2,429	80 – 310
2008/09	8	1,328	100 – 310
2011/12	17	2,040	120 – 290
2012/13	8	916	180 – 290
2013/14	19	2,137	170 - 300

Size Structure

The purse-seine fishery: 1984/85 - 2000/01

Purse-seine catches of Jack Mackerel landed between 1984/85 and 1995/96 off eastern Tasmania comprised mostly fish between 210 and 350 mm FL, and included individuals up to 440 mm FL (Figure 3.12). The size structure for catches taken in 1984/85 was bimodal and comprised fish between 240 and 360 mm FL. From

1985/86 to 1988/89, catches were dominated by a single mode, with most fish in the 250 – 350 mm FL size range and evidence for a slight shift in size structure toward larger fish. A second cohort of small fish (<250 mm FL) was first evident in 1988/89, and by 1989/90 the size distribution was bimodal, with peaks at 240 mm FL and 320 – 330 mm FL.

A bimodal size structure was evident in the following three years with the position and relative heights of the modes varying between years. The annual size structures from 1993/94 – 1995/96 were unimodal and showed evidence of a general shift to larger fish.

Mid-water trawl fishery: 2001/02 - 2005/06

Jack Mackerel caught by mid-water trawl operations off eastern Tasmania after 2001 were considerably smaller than those caught by the earlier purse-seine operations, with specimens mostly between 200 and 300 mm FL (Figures 3.13, 3.14).

East coast catches were characterised by an increase in modal length, from 240 to 270 mm FL between 2002/03 and 2004/05, and only a small proportion of the catch comprised fish >300 mm FL (Figure 3.13). By contrast, catches from south-western Tasmania were mostly between 250 and 370 mm FL, with an overall modal length of 290 mm FL (Figure 3.14).

Mid-water trawl and purse-seine operations: 2009/10-2010/11

Overall 1,862 Jack Mackerel were sampled from 21 mid-water trawl and purse-seine catches between July 2009 and June 2010. All but one sample were from catches taken off eastern Tasmania (Table 3.2).

The size composition of east coast mid-water trawl and purse-seine catches were similar with each dominated by fish between 180 and 240 mm FL (Figure 3.15). Overall, these fish were smaller than those taken by mid-water trawl during the early 2000s and were relatively small in comparison with the purse-seine catches of the 1980s and 1990s. The single mid-water trawl catch sample from south-western Tasmania comprised fish of similar sizes to catches from eastern Tasmania (Table 3.1) and these were substantially smaller than fish taken by mid-water trawl during the early 2000s.

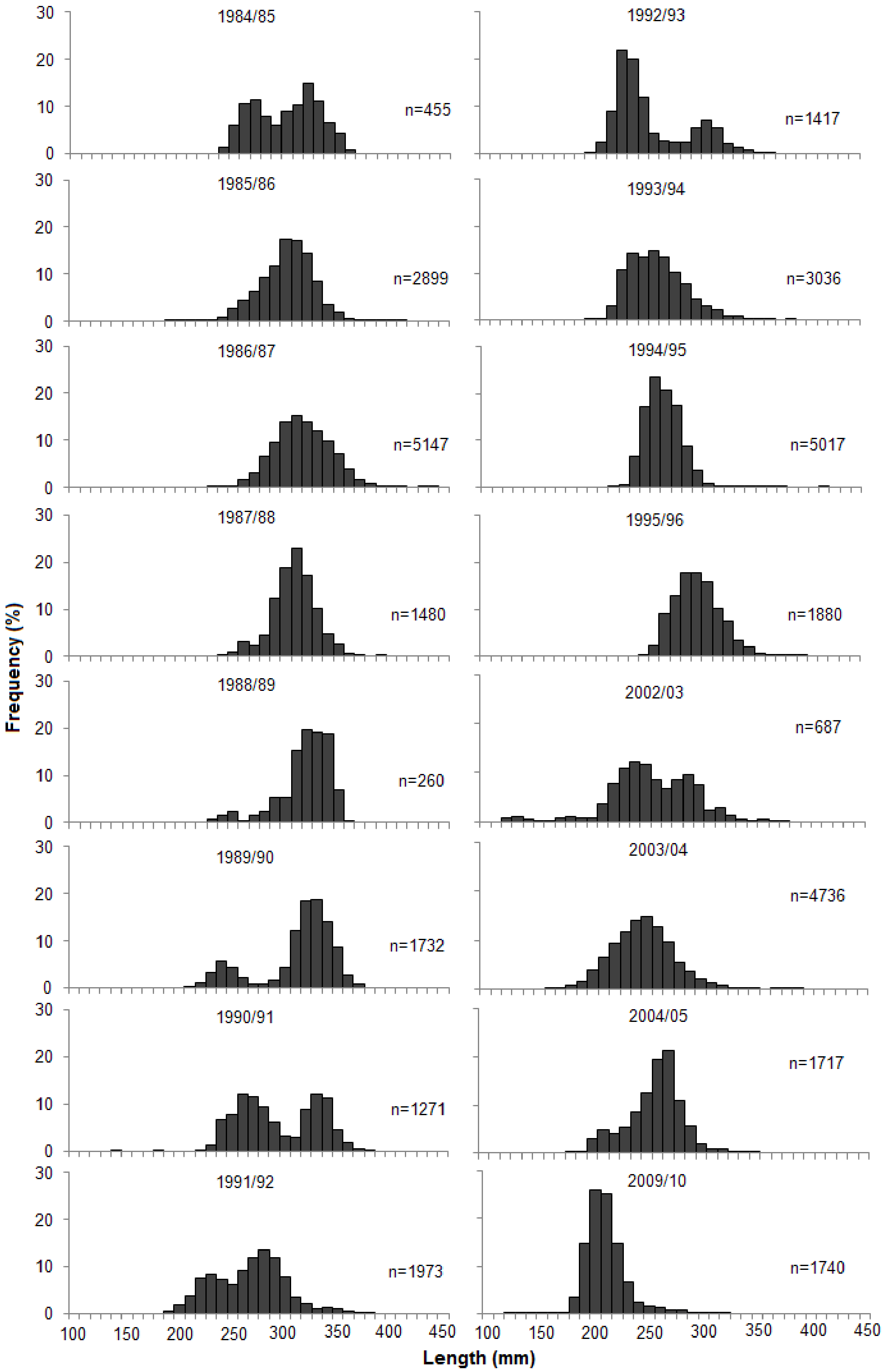

Figure 3.12. Length frequency distributions of Jack Mackerel caught in the SPF by purse-seine (1984/85 – 1995/96), mid-water trawl (2002/03 – 2005/06) and both fishing methods combined (2009/10) off eastern Tasmania between 1984/85 and 2010/11. No data were available between 1997/98 and 2001/02. n = sample size.

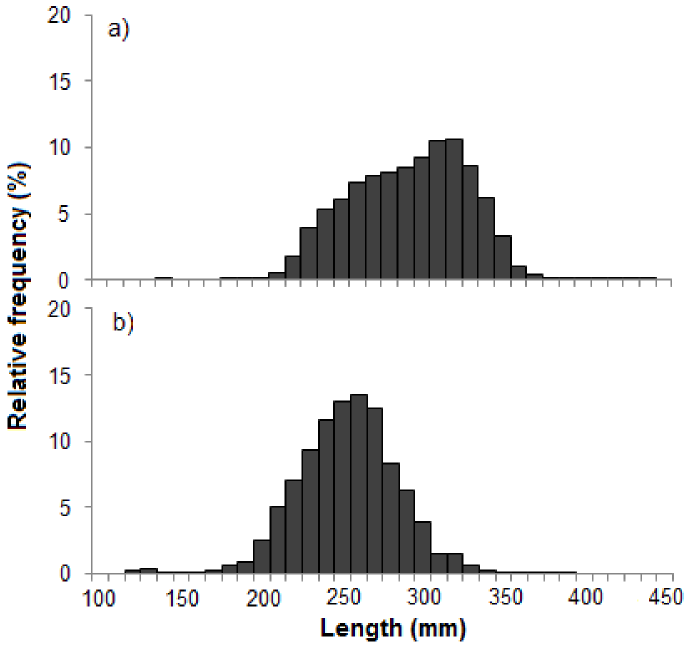

Figure 3.13. Length frequency distributions (mm FL) of Jack Mackerel caught in the SPF off eastern Tasmania from (a) purse-seine operations (1984/85 – 1996/97), and (b) mid-water trawl operations (2002/03 – 2005/06).

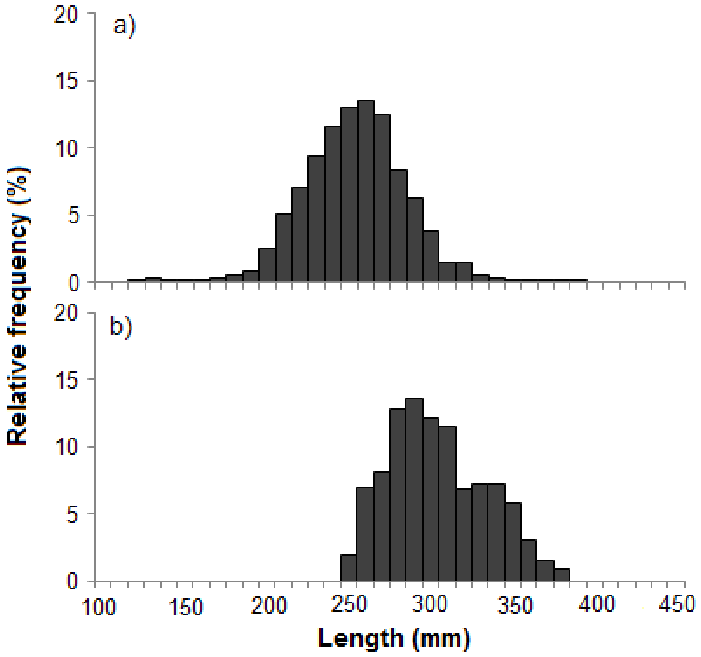

Figure 3.14. Length frequency distributions (mm FL) of Jack Mackerel caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2002/03 and 2005/06.

Table 3.2. Summary of shots sampled in the SPF off Tasmania for Jack Mackerel length-frequency data during 2009/10 and 2010/11. Also shown is the number of individuals (n), size range (mm FL) and mode (mm FL) of each length-frequency distribution.

Sampling month	**No. of samples**	**Location**	**Gear type**	**n**	**Size range (mm)**	**Mode (mm)**
Jul-09	1	South-west	Midwater trawl	132	160 – 220	190
Aug-09	3	East coast	Midwater trawl	248	150 – 290	200
Sep-09	2	East coast	Midwater trawl	70	210 – 250	220
Oct-09	1	East coast	Purse-seine	204	160 – 230	200
Dec-09	1	East coast	Purse-seine	87	190 – 320	220
Jan-09	1	East coast	Purse-seine	62	200 – 250	220
Feb-10	6	East coast	Purse-seine	602	170 – 320	210
Mar-10	2	East coast	Purse-seine	181	120 – 290	210
May-10	1	East coast	Purse-seine	48	140 – 250	200
Jun-10	3	East coast	Purse-seine	228	150 – 300	210

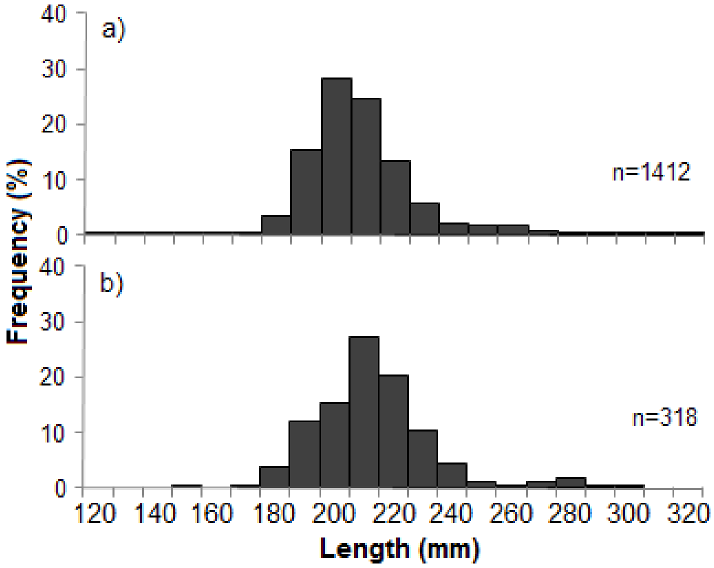

Figure 3.15. Length frequency distribution (mm FL) of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawl operations during 2009/10. n = sample size.

Research (demersal trawl net) surveys: 2014

The size structure for research samples of Jack Mackerel collected off eastern Victoria/southern New South Wales comprised mostly fish between 240 - 310 mm FL, with a mode at 250 mm FL (Figure 3.16). Similarly, the size structure for research samples from off north-eastern Tasmania comprised mostly fish between 250 - 310 mm FL, although with a narrower mode at 280 mm FL (Figure 3.16).

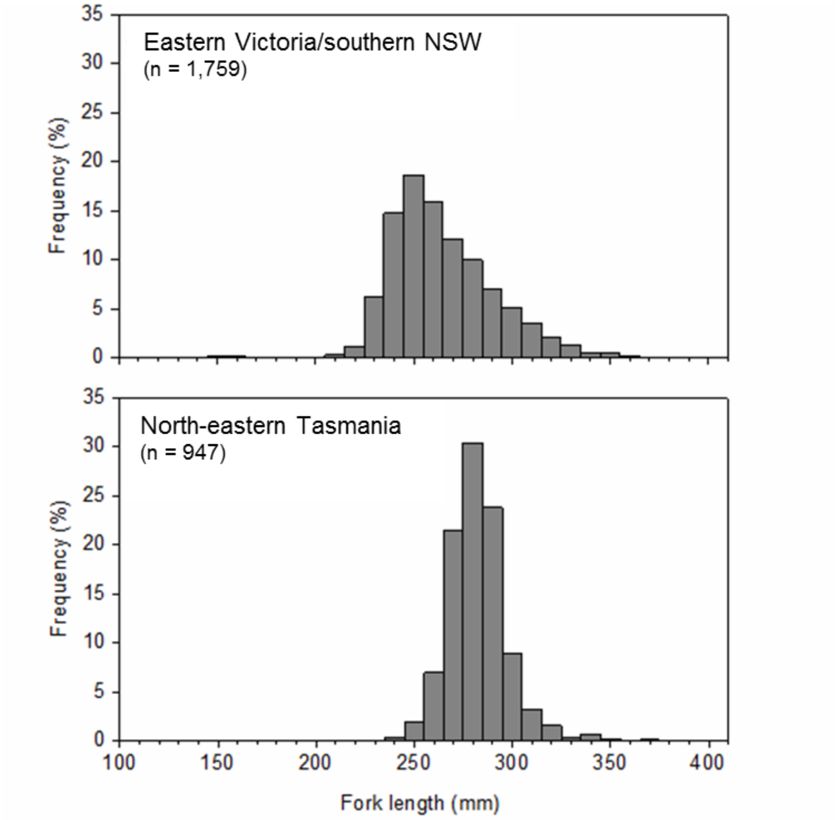

Figure 3.16. Length frequency (mm FL) for Jack Mackerel from research (demersal trawl net) sampling undertaken between St. Helens, Tasmania and Eden, New South Wales in January 2014. Top: off eastern Victoria/southern New South Wales, above 39° latitude; bottom: off north-eastern Tasmania, below 39°latitude.

Commercial purse-seine fishing operations: New South Wales only

Annual size structures for Yellowtail Scad taken by commercial purse seiners in New South Wales between 2000/01 and 2013/14 mainly contained fish between 200 and 280 mm FL (Figure 3.17). The size structures were relatively consistent among years, with each comprising a narrow dominant mode and varying between 220 and 260 mm FL. For some years, the size structure also included a secondary mode at ~150 mm FL.

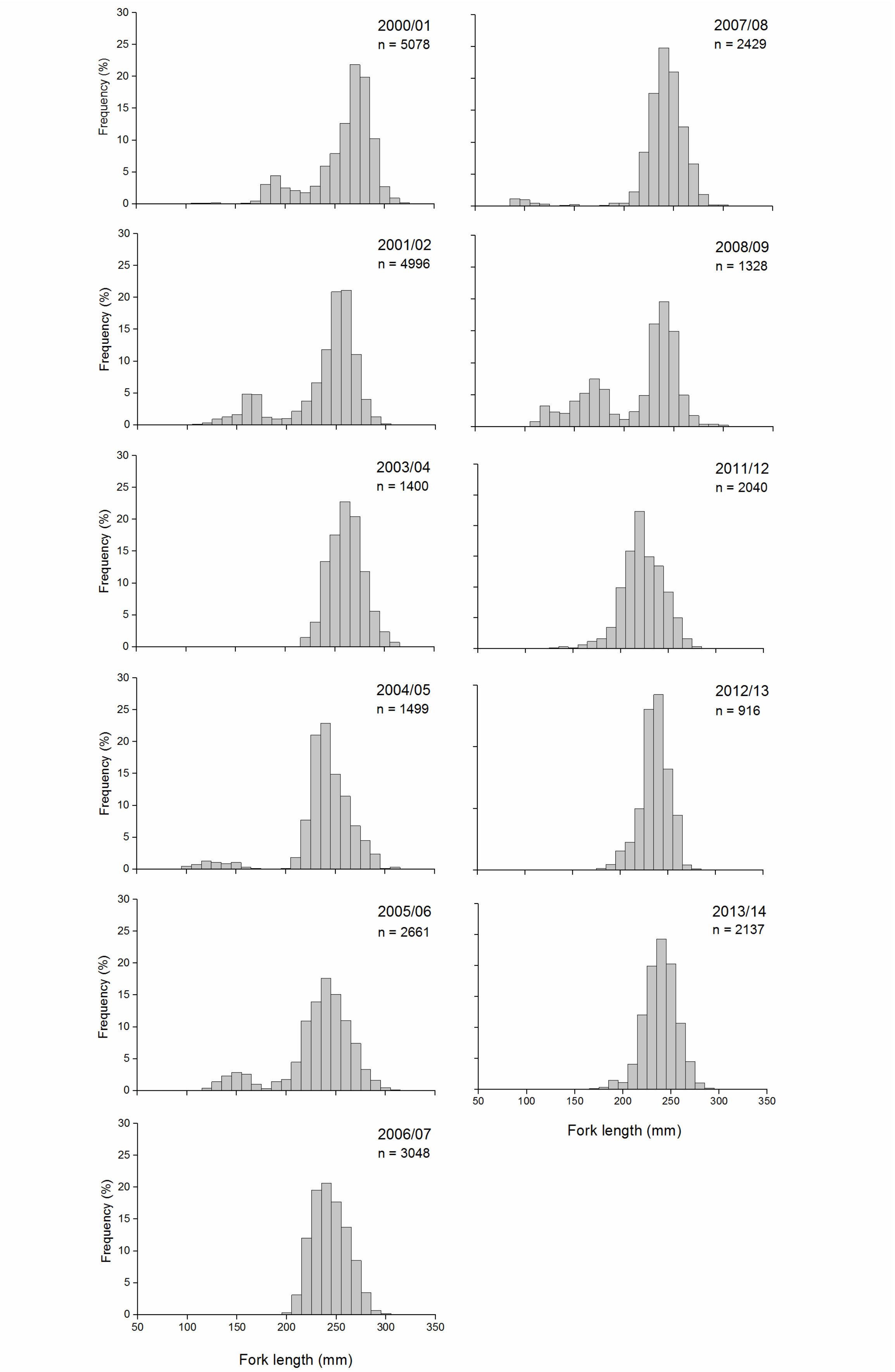

Figure 3.17. Length frequency (mm FL) of Yellowtail Scad collected from commercial purse-seine shots in New South Wales from 2000/01 to 2013/14 (data supplied by New South Wales DPI).

Age Structure

The purse-seine fishery: 1984/85 – 2000/01

The age structure of Jack Mackerel caught in Zone A of the SPF was estimated using age-length keys based on age data pooled from 1985/86, 1989/90, 1993/94 and 1994/95. Jack Mackerel taken by the purse-seine fishery were generally 3-10 years old (Figure 3.18). Catches between 1984/85 and 1990/91 were dominated by 4 and 5 year olds with fish up to 9 years also well represented. Between 1991/92 and 1994/95, few fish older than 6 years were taken, with 3-5 year olds the dominant age groups. The 1995/96 age structure was similar to that of the mid 1980s suggesting the relative scarcity of older fish evident in the intervening years may not have been solely due to impact of fishing on population age structure. However, it should be noted that the application of a pooled age-length key rather than annual age data appears to have had a smoothing effect on age composition, in particular when representing the older age groups.

Mid-water trawl fishery: 2001/02 – 2008/09

Jack Mackerel mid-water trawl catches off eastern Tasmanian between 2001/02 and 2004/05 consisted of mainly fish aged 2-5 years old, with a modal age of 3-4 years (Figure 3.19). By contrast, the age structure of catches from south-western Tasmania were characterised by a higher proportion of fish older than 5 years, and a mode at 4-5 years in each of the years sampled.

Mid-water trawl and purse-seine operations: 2009/10

A total of 377 Jack Mackerel (107 mid-water trawl and 270 purse-seine caught) were aged during 2009/10 (Table 3.3; Figure 3.20) using an age-length key. Mid-water trawl and purse-seine catches from eastern Tasmania were dominated by 2-3 year old fish (Figure 3.20). In comparison with catches from earlier years, these findings indicate a shift towards younger age groups. The age structure of the single catch monitored from south-west Tasmania also showed a high proportion of 2 year old fish, representing an estimated 70% of the distribution.

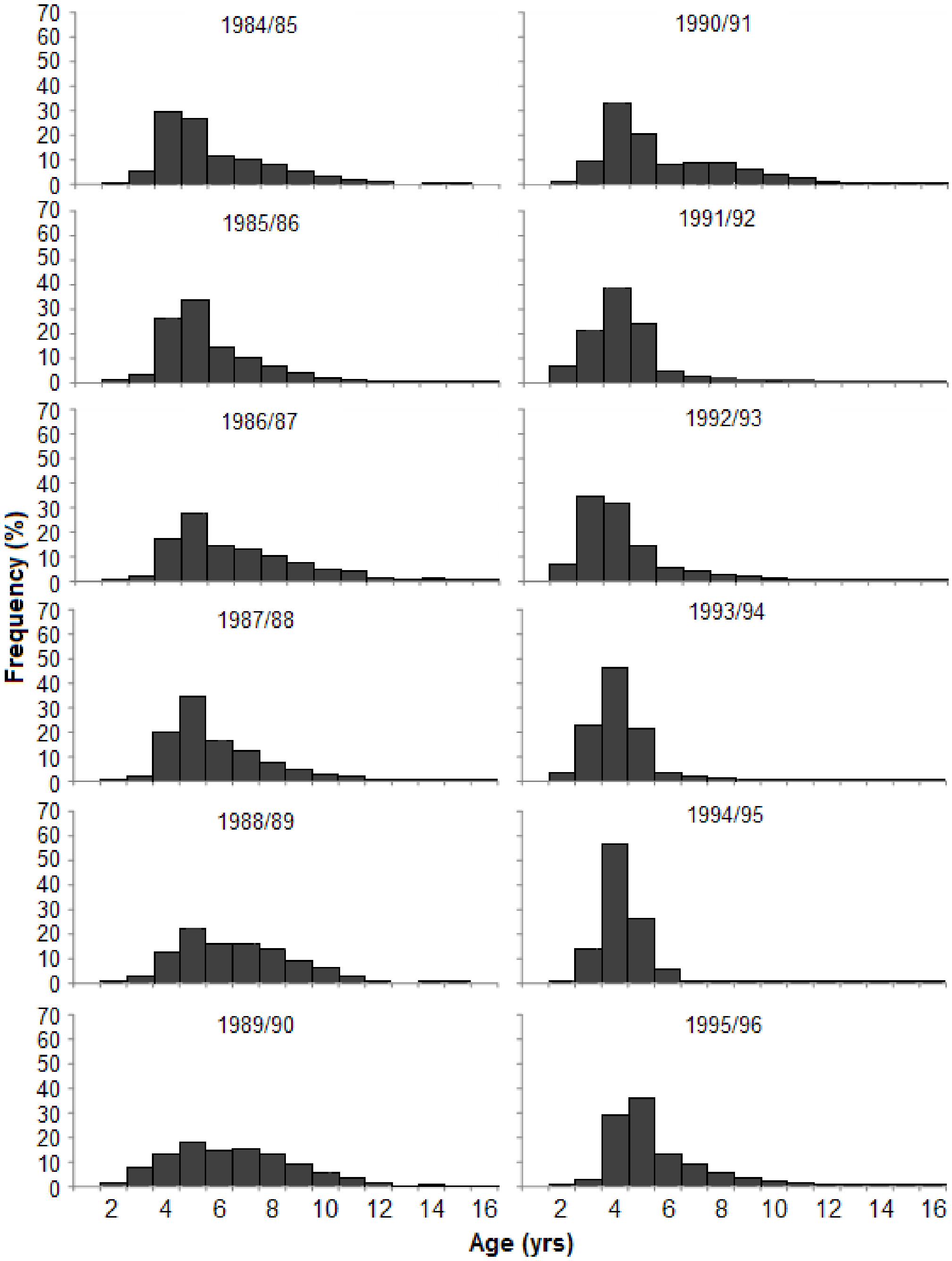

Figure 3.18. Age structure of Jack Mackerel from catch sampling from eastern Tasmania between 1984/85 and 1995/96.

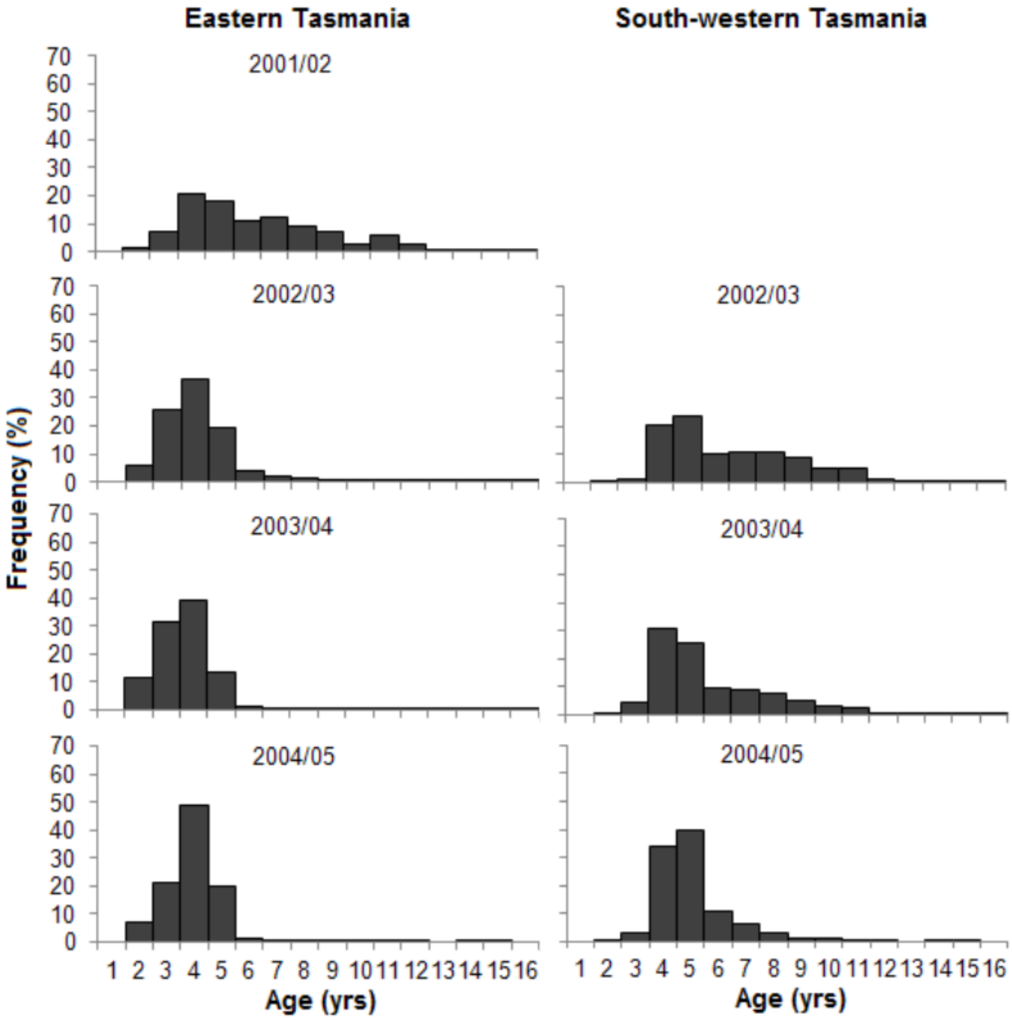

Figure 3.19. Age structure of Jack Mackerel from catch sampling from eastern and south-western Tasmania between 2001/02 and 2004/05. Data were not available from south-western Tasmania for 2001/02.

Table 3.3. Summary of shots sampled in the SPF off Tasmania for Jack Mackerel age data during 2009/10. The number of individuals (n) aged is indicated along with the age range and average.

Sampling month	Location	Gear type	n	Age range (years)	Average age (years)
Jul-09	South-west	Midwater trawl	20	1-3	2.2
Aug-09	East coast	Midwater trawl	47	2-4	2.7
Sep-09	East coast	Midwater trawl	40	2-7	2.5
Oct-09	East coast	Purse-seine	20	2-3	2.3
Dec-09	East coast	Purse-seine	20	2-6	3.1
Jan-09	East coast	Purse-seine	20	2-4	2.5
Feb-10	East coast	Purse-seine	80	2-7	2.4
Mar-10	East coast	Purse-seine	40	1-6	3.0
May-10	East coast	Purse-seine	20	2-4	3.0
Jun-10	East coast	Purse-seine	70	2-5	3.3

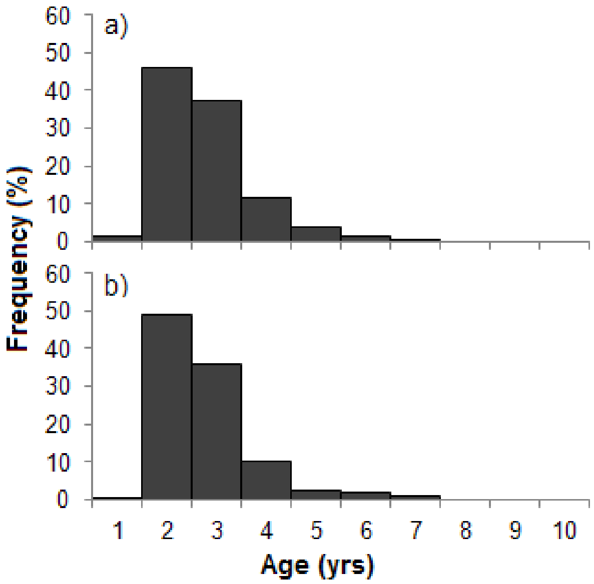

Figure 3.20. Age distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

Purse-seine operations: 2011/12 – 2013/14

The ages of Yellowtail Scad collected from commercial catches from the south central New South Wales coast in 2011/12 and 2012/13 ranged from 2 to 14 years, with >58% of the annual samples between 4 and 5 years (Figure 3.21).

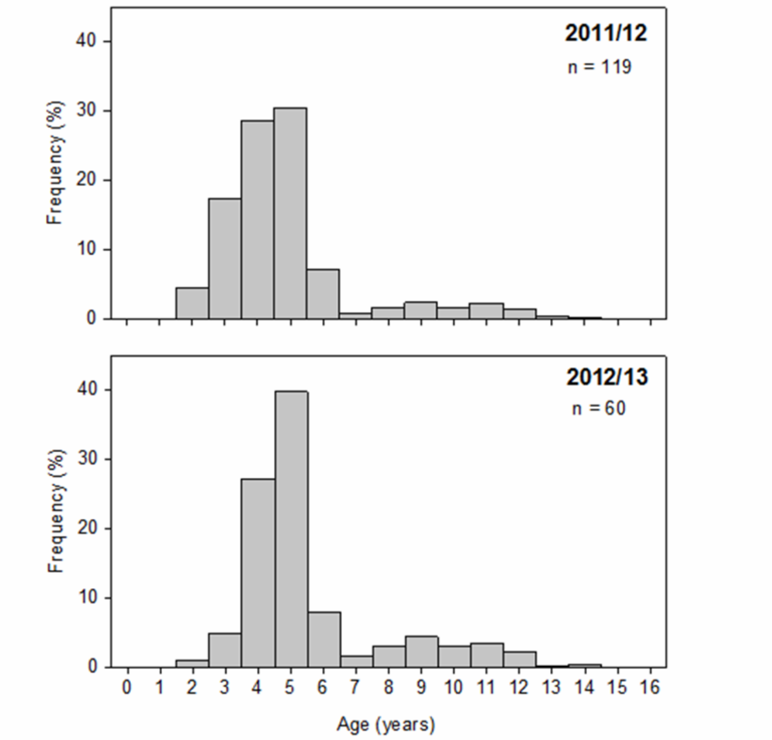

Figure 3.21. Age frequency distribution for commercial catches (purse-seine) of Yellowtail Scad taken between 2011/12 and 2012/13 from the northern and southern regions of New South Wales combined (data supplied by New South Wales DPI).

Growth

Growth of male and female Jack Mackerel from eastern Tasmania was described using the von Bertalanffy growth function (VBGF) (Table 3.3, Figure 3.22). Growth was rapid within the first few years of life, with individuals reaching a mean length in excess of 230 mm FL, i.e. approximately 64% of L_∞, in the first three years, slowing thereafter. Maximum assigned ages for females and males were 15 and 16 years, respectively.

Table 3.3. Summary of von Bertalanffy growth function parameters for Jack Mackerel off eastern Tasmania. Pooled data includes males, females and unsexed/unknown individuals.

		VBGF parameters		
Sex	**n**	**L_∞**	**K**	**t_0**
Male	534	364.0	0.27	-0.92
Female	763	360.3	0.29	-0.63
Pooled	2,143	362.8	0.29	-0.81

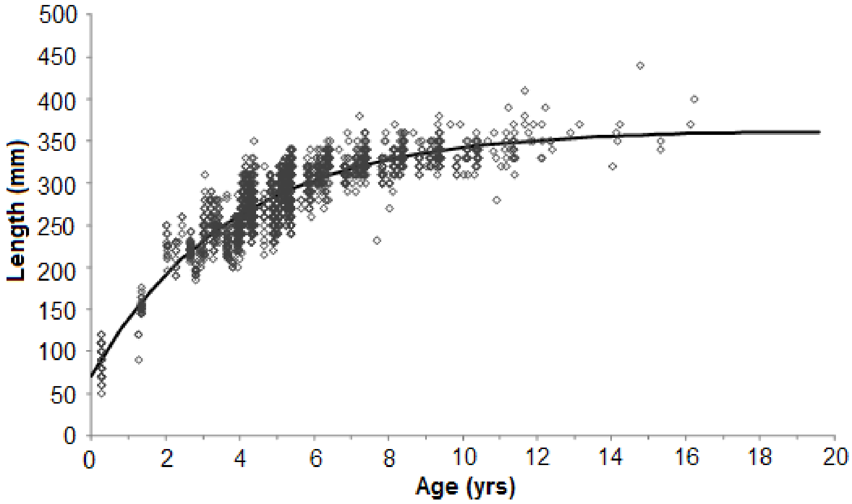

Figure 3.22. Length (mm FL) at age (years) data for Jack Mackerel from eastern Tasmania. The black line represents the von Bertalanffy growth function.

Reproduction

Gonadosomatic Index (GSI) and gonad stages

Trends in male and female GSI and female macroscopic staging indicated that Jack Mackerel have a discrete spawning season that extends over a three month period from late spring to mid-summer (Figures 3.23, 3.24). GSI for both sexes rose sharply in November with a maximum of 2.6% recorded in January. After this, GSI declined rapidly and remained low through to June (Figure 3.23). Fish with hydrated oocytes and/or running ripe, and/or spent gonads (Stages IV-VI) were first evident in November and became more abundant during December-January (Figure 3.24).

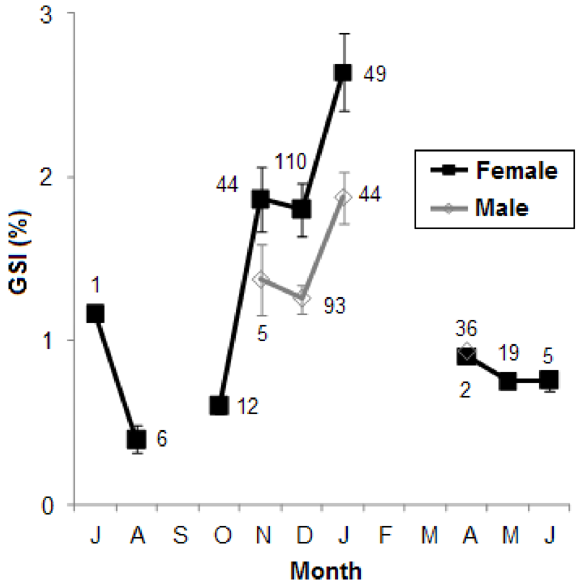

Figure 3.23. Monthly mean GSIs of Jack Mackerel, by sex from eastern Tasmania. Numbers associated with data points represent sample size (±SE).

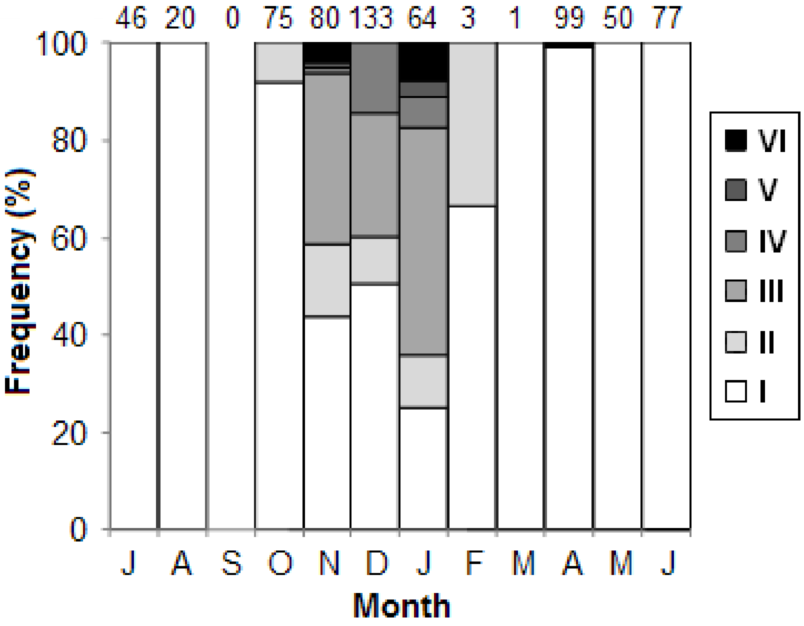

Figure 3.24. Monthly distribution of macroscopic gonad stages from female Jack Mackerel from eastern Tasmania. Top numbers represent sample sizes.

Size at maturity

Fifty percent maturity was estimated at 268 mm FL for females and 291 mm FL for males with small differences between sexes (Table 3.4, Figure 3.25). All fish larger than 360 mm FL were mature.

Table 3.4. Size at sexual maturity logistic parameters and 50% maturity (L_{50}) values of Jack Mackerel, by sex, off eastern Tasmania.

			Size at maturity		
Region	**Sex**	**N**	**a**	**b**	**L_{50} (mm)**
Eastern Tasmania	female	333	-8.40	0.031	268
	male	309	-6.40	0.022	291

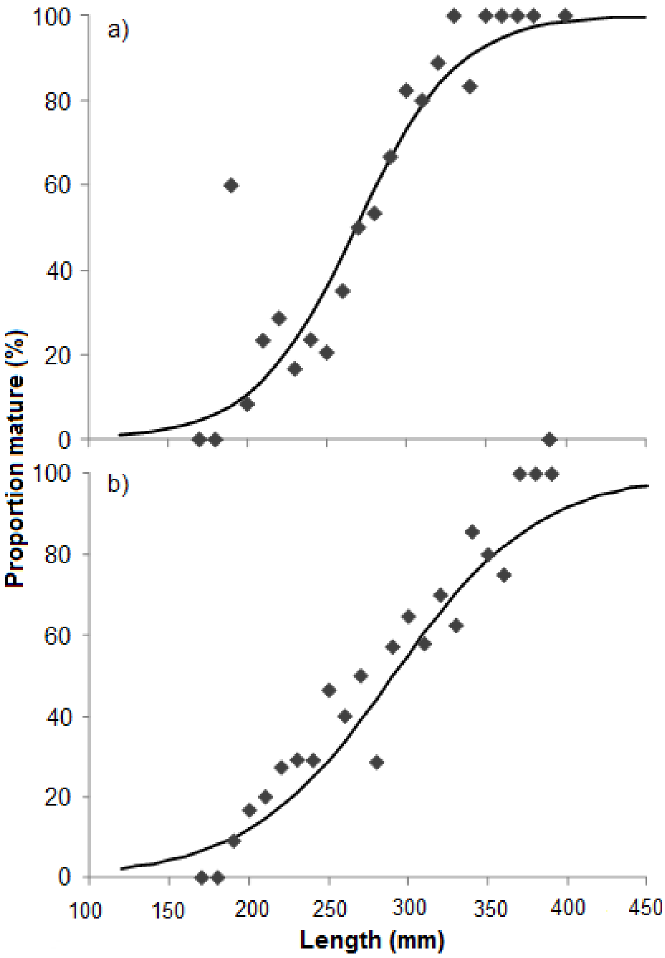

Figure 3.25. Proportion of mature female (a) and male (b) Jack Mackerel by length class (mm FL) fitted with logistic ogives.

3.3.3 Biomass Estimate and MSE

Preliminary DEPM analysis by Neira (2011) estimated the spawning biomass of Jack Mackerel between Sugarloaf Point and Cape Howe (East) during October 2002 to be 114,000 – 169,000 t. This estimate is considered imprecise due to lack of locally collected species-specific reproductive parameters and lack of a validated temperature-dependent incubation model to age eggs. The estimate is also considered to be conservative (negatively biased) as the surveys did not cover the entire spawning area.

The first dedicated application of the DEPM for estimating spawning biomass of Jack Mackerel off eastern Australia based on concurrent sampling of both eggs and adults was undertaken in January 2014 (Ward *et al.* 2015). The estimated spawning area for Jack Mackerel off south-eastern Australia was 23,553 km^2, comprising 38% of the total area sampled (63,355 km^2) (Ward *et al.* 2015). A total of 3,530 live Jack Mackerel eggs were collected from 117 of the 292 sampling stations. Eggs were collected from waters between Eden and Triabunna where SSTs ranged between 15 and 22°C. The highest densities of eggs occurred in waters off north-eastern Tasmania and Bass Strait with SSTs in the range of 16.5 – 20°C and water depths of 40 – 80 m.

The estimates of egg production (28.9 eggs.day^{-1}.m^{-2}) and spawning fraction (0.056) obtained by Ward *et al.* (2015) are both low compared to the estimates of these parameters obtained in other studies (e.g. 78 eggs.day^{-1}.m^{-2} from Neira (2011) and 0.2 (spawning fraction) for *T. Trachurus* from Karlou-Riga and Economidis 1997). However, there is evidence that estimates of both parameters obtained in the 2014 study are reliable (Ward *et al.* 2015).

The estimate of Jack Mackerel spawning biomass calculated using data from the 2014 survey was 157,805 t (95% CI = 59,570 – 358,731) (Ward *et al.* 2015). This estimate is within the range of estimates of spawning biomass for Jack Mackerel off eastern Australia provided by Neira (2011) of 114,900 to 169,000 t and within the range of plausible estimates of biomass suggested for the ecosystem by Fulton (2013) of 130,000 to 170,000 t.

The MSE was used to test a range of management/harvest scenarios under the harvest strategy for all stocks in the SPF (Giannini *et al.* 2010). Only one stock was modelled for Jack Mackerel. As there were no DEPM survey estimates for spawning biomass to differentiate the stocks (at the time of assessment), model conditions were the same for both East and West stocks. The Tier 1 scenarios investigated using the MSE all reached equilibrium at around B_{40} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable. However, these should be treated with caution as harvest quantities are “absolute” values and were done without a DEPM estimate of spawning biomass to provide a benchmark.

3.4 Summary and Conclusions

Application of the DEPM for Jack Mackerel off the east coast of Australia in 2014 estimated a spawning biomass of ~157,800 t. This estimate is within the range of previous estimates by Neira *et al.* (2011) of 114,900 – 169,000 t derived from surveys undertaken in 2002. Annual catches of Jack Mackerel in the East peaked at ~40,000 t in 1986/87, but have not exceeded ~3,000 t since 2003/04. The total catch of 0.4 t in 2013/14, was <1% of both the RBC and spawning biomass estimates for the species in the East (Ward *et al.* 2015). In the West, annual catches have not exceeded 200 t since 1997/98. The estimate of total catch for the West in 2013/14 is confidential, but is <1% of both the RBC and biomass estimate.

The long term trend in production levels throughout the history of the fishery for Jack Mackerel is likely the result of a combination of changes in fish availability/abundance and market/economic factors. However, the potential effects of fishing on abundance and population structure are poorly understood. Several authors have documented large inter-annual variability in oceanographic conditions in the southern part of the east Australia current (e.g. Harris *et al.* 1992; Young *et al.* 1993; McLeod *et al.* 2012), which may contribute to changes in relative abundance of surface schools of small pelagic species such as Jack Mackerel and their availability to the fishery. It has been suggested that the apparent shift from Jack Mackerel to Redbait as the dominant small pelagic fish in this region during the 1990s, was a result of a decline in the abundance of surface schools of Jack Mackerel due to environmentally-mediated changes in the composition of the plankton assemblage (food availability) (Harris *et al.* 1992; Young *et al.* 1993; McLeod *et al.* 2012).

The development of mid-water trawling for small pelagic fish in the early 2000s was replaced by the resumption of small-scale purse-seine operations in the late 2000s. Fish processors in Tasmania have reported difficulty in selling Jack Mackerel since 2003/04 and the species tends to be avoided by fishers due to relatively high catch rates of Australian Sardine that must be currently discarded in waters off Tasmania. However, the low market value of the species, reduced demand for fish meal, and a recent moratorium on the operation of large-scale factory trawlers (>130 m) has meant that fishing activity has been minimal in recent years.

Between 1984/85 and 1990/91, purse-seine catches of Jack Mackerel were dominated by 4 and 5 year old fish, with over 90% of the catch being over 3 years of age. By contrast, between 1991/92 and 2004/05, the catches were increasingly dominated by 3 and 4 year olds and in 2009/10, 2 and 3 year olds were the dominant age classes in both purse-seine and mid-water trawl catches. While fishery impacts are plausible in the early stages of the fishery due to high catch levels (i.e. ~40,000 t in mid-1980s), annual catches have been at historically low levels (i.e. <100 t) in recent years and may therefore reflect recruitment variability and/or targeting practices. The paucity of biological information collected for Jack Mackerel over recent years is due mainly to the low levels of fishing effort.

The most recent classification of stock status for Jack Mackerel by Flood *et al.* (2014) suggested that the biological stocks in the East and West are sustainable. The fishery-dependent and -independent data presented in this chapter suggest that the current levels of fishing pressure on Jack Mackerel in the East and West are unlikely to cause the stocks to become recruitment overfished.

Using the definitions from the National Status of Key Australian Fish Stocks Report (Flood *et al.* 2014), the fishery for Jack Mackerel in the East and West are classified as sustainable.

Although recent annual catches of Yellowtail Scad (East) by the SPF are among the highest recorded in the fishery, assessment of stock status for this species is currently limited by the lack of biological and demographic data.

4 REDBAIT (*EMMELICHTHYS NITIDUS*)

4.1 Introduction

4.1.1 Background to Fishery

Redbait represented a key by-product species taken by the purse-seine fishery for Jack Mackerel (*Trachurus declivis*) that developed off Tasmania in the mid-1980s, with catches of small pelagic fish peaking at over 40,000 t in 1986/87. During that period, Redbait rarely exceeded 5% by weight of the landed catch of Jack Mackerel in any year, but the high volume of production meant that annual landings in the order of 1,500 t were taken between the mid-1980s and early 1990s.

In 2001/02, a 6-month fishing trial involving a mid-water, pair-trawl operation was established to target subsurface schools of Jack Mackerel (Welsford and Lyle 2003). A total catch of over 5,000 t was taken between December 2001 and April 2002, nearly 90% of which was Redbait. On the strength of this trial, a multipurpose 50 m mid-water trawler was brought to Tasmania to target small pelagic species, in particular Redbait, with fishing operations commencing in late 2002. Catches of Redbait from mid-water trawling were nearly 7,000 t in 2002/03 and comprised up to 94% of the total catch.

More recent fishing for small pelagic fish by purse-seine in Tasmanian State waters yielded 300 t of Redbait in 2007/08, 521 t in 2008/09 and 122 t in 2009/10 (Hartmann and Lyle 2011). There were no Redbait catches in Tasmania in 2010/11, 2011/12 and 2012/13. Redbait are primarily frozen whole for use as feed for farmed Southern Bluefin Tuna (*Thunnus maccoyii*), and are also used along with Jack Mackerel in the production of fish meal for use in the aquaculture industry.

4.1.2 Taxonomy

Redbait (*Emmelichthys nitidus,* Richardson 1845) belong to the family Emmelichthyidae, of which there are 3 genera and 15 species (Nelson 2006). Emmelichthyids are widespread, found throughout tropical and temperate waters around the globe. They are generally found in schools over continental shelf breaks, seamounts and submarine ridges. They inhabit depths from the surface to >800 m, though are mostly recorded from mid-water trawls in 100-400 m water (Heemstra and Randall 1977; Smith and Heemstra 1986; Mel'nikov and Ivanin 1995). Redbait are one of two species of emmelichthyid found off southern Australia, the other being the rubyfish (*Plagiogeneion rubiginosum*) (Last *et al.* 1983; May and Maxwell 1986; Gomon *et al.* 2008).

4.1.3 Distribution

Redbait are widely distributed throughout the southern hemisphere, with the species reported from Tristan da Cunha in the southern Atlantic, the south-western coast of South Africa, St Paul and Amsterdam Islands, mid-oceanic ridges and seamounts through the Indian Ocean, Australia, New Zealand, submarine ridges in the south-eastern Pacific, and the southern coast of Chile (Markina and Boldryev 1980; Meléndez and Céspedes 1986; Parin *et al.* 1997). Within Australian waters, their range extends from mid New South Wales to south-west Western Australia, including Tasmania (Gomon *et al.* 2008).

4.1.4 Stock Structure

There have been no studies on the stock structure of Redbait in Australia. However, Bulman *et al.* (2008) concluded that Redbait from eastern Australia were likely to be a single stock. The situation for western Tasmania and the GAB is less clear, but the observation that fish off eastern and south-western Tasmania exhibit some biological differences (Neira *et al.* 2008), provides some evidence for separation into eastern and western stocks around Tasmania.

No studies have investigated Redbait movement.

4.1.5 Food and Feeding

A study of the diet of Redbait in South African coastal waters indicated that the smaller size classes (136-280 mm) feed exclusively on small planktonic crustaceans, with euphausiids (*Nyctiphanes* and *Euphausia* spp.), hyperiid amphipods (primarily *Themisto gaudichaudi*), mysids and large copepods comprising the entire diet (Meyer and Smale 1991). Larger individuals (281-493 mm) may also feed for the most part on small planktonic crustaceans, but nekton such as cephalopods, carid shrimp, and small fishes including myctophids, also constituted a component of the diet (Meyer and Smale 1991). Redbait of unspecified size captured on the shelf off eastern Victoria had a varied diet, dominated by pelagic crustaceans and other pelagic invertebrates including gelatinous zooplankton (Bulman *et al.* 2000; 2001). Similarly, Redbait captured off eastern Tasmania in 2003 and 2004 had a diet dominated by pelagic crustaceans, with krill (*Nyctiphanes australis*) and copepods comprising 66% and 33% of the diet, respectively (McLeod, 2005).

The diet of Redbait is similar to that of Jack Mackerel (*T. declivis*) from Tasmania, with krill *N. australis* representing the dominant prey item on the continental shelf (Young *et al.* 1993; McLeod 2005). Since Redbait and Jack Mackerel form mixed species schools in Tasmanian waters (Williams and Pullen 1993) it is likely that these species also feed on similar prey items.

4.1.6 Age, Growth and Size

The maximum reported size for female and male Redbait from Tasmania is 317 and 304 mm FL, respectively (Neira *et al.* 2008), and is considerably smaller than for the species in other areas. Redbait grow to 335 mm FL off eastern Victoria (Furlani *et al.* 2000), 344 mm standard length (SL) off the coast of Chile (Meléndez and Céspedes 1986) and individuals of 493 mm TL have been caught in South African waters (Heemstra and Randall 1977; Meyer and Smale 1991). Redbait are observed to school by size, and also stratify by water depth, with larger (>200 mm FL) individuals often found deeper and closer to the seafloor (Markina and Boldryev 1980).

Estimates of growth for Redbait derived from either interpretation of structure in whole otoliths (Williams *et al.* 1987) and sectioned otoliths (Neira *et al.* 2008), suggest that growth is rapid in the first years of life. On average, Redbait off Tasmania reached >200 mm FL in the first three years, with growth slowing thereafter (Neira *et al.* 2008). The maximum estimated age for Redbait based on sectioned otoliths is 21 and 18 years for females and males, respectively (Neira *et al.* 2008). The larger Redbait reported from Africa (e.g. Meyer and Smale 1991) suggest that maximum age may be higher than reported for Tasmanian fish, or that growth is highly variable regionally. Ageing of rubyfish in New Zealand, using otolith sections, has produced age estimates in of up to 100 years for fish over 400 mm (Paul *et al.* 2000; Horn *et al.* 2012), indicating that some emmelichthyids may be long-lived.

4.1.7 Reproduction

Redbait is an asynchronous batch spawner with indeterminate fecundity. Annual trends in GSI and macroscopic gonad stages indicated that Redbait from eastern Tasmania spawn between September and November, with a peak in activity during September and October (Ewing and Lyle 2009). There are regional differences in size and age at sexual maturity for Redbait. Males and females from south-western Tasmania mature approximately 100 mm larger and two years older compared to Redbait from eastern Tasmania (157 and 146 mm FL, respectively; Ewing and Lyle 2009). Spawning occurs along a 2.5 nautical mile (nm) corridor either side of the shelf break when mid-water temperatures are 12 – 15.2°C (Neira *et al.* 2008).

4.1.8 Early Life History and Recruitment

Redbait eggs are positively buoyant and hatch approximately 2-4 days after fertilisation depending on temperature (Neira *et al.* 2008). Newly hatched yolk sac larvae range from 1.9 – 3.3 mm TL. Little is known about the early life history of Redbait post-hatching, although spawning areas (eggs and larvae) have been described by Neira *et al.* (2008).

4.1.9 Stock Assessment

Spawning habitat of Redbait was described from egg, larval and environmental data collected over shelf waters between north-eastern Bass Strait and lower south-western Tasmania in 2005 and 2006 (Neira *et al.* 2008). The daily egg production method (DEPM) was subsequently applied to estimate the spawning biomass of Redbait within this region (Neira *et al.* 2008; Neira and Lyle 2011).

4.1.10 Management

A DEPM assessment has been conducted for the East Zone. The fishery is managed at the Tier 2 level and as such conservative TACs have been set based on the rules outlined by the SPF Harvest Strategy. For the 2013/14 season, Tier 2 maximum RBC for Redbait in both the East and West was 5,000 t (AFMA 2014).

4.1.11 Recreational fishing

There is no known recreational fishery for Redbait in Australia.

4.2 Methods

4.2.1 Fishery Statistics

Commercial operators participating in the Zone A Jack Mackerel Purse-Seine Fishery were required to complete logbooks recording catch and effort from the inception of the fishery (1984). The initial logbook comprised a shot-by-shot record of fishing operations and included species breakdown. This was replaced for the 1990/91 fishing year with a trip catch return, in which catch composition was not routinely reported, just total landings of small pelagic fish. Trawl operations since 2001/02 have been reported in the Commonwealth South East Fishery trawl logbook, providing a shot-by-shot record of catch and effort and includes catch composition. When purse-seine operations targeting small pelagic fish resumed in Tasmanian

State waters, shot by shot catch and effort data were recorded in the Tasmanian General Fishery Logbook.

Since 1997/98, the number of vessels reporting catches of Redbait in the East and West has not exceeded four. As such, only aggregated catch data can be presented for this species.

4.2.2 Biological Information

Fishery dependent length frequency and biological data for Redbait were collected between 1984/85 and 1993/94 as part of a monitoring program of the Jack Mackerel purse-seine fishery. Some biological information was also collected from samples of Redbait collected from demersal research trawling conducted by CSIRO and the relevant Tasmanian fisheries agency between 1985/86 and 1990/91. Between 1994/95 and 2001/02 the level of catch sampling of the purse-seine fishery was limited and targeted mainly at Jack Mackerel.

Collection of biological data during pair-trawl fishing trials in 2001/02 was undertaken by AFMA observers on a small proportion of trips, so data are limited and may not be representative of the catch. Following the commencement of mid-water trawl operations in 2002, the TAFI commenced an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length frequency data collected from 2002-2008.

Purse-seine operations for small pelagic fish resumed in Tasmanian State waters during 2008/09, with Redbait and Jack Mackerel being the main species targeted. Catch sampling of mid-water trawl and purse-seine operations adjacent to Tasmania was implemented in 2009/10 as part of the SPF monitoring program under the SPF Harvest Strategy framework (AFMA 2008).

Biological data were collected from individual specimens and included FL (to the nearest mm), total weight (to the nearest g), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall *et al.* 1993) and gonad weight (to the nearest 0.1 g). Otoliths were also extracted and used for age estimation and growth modelling (Williams *et al.* 1987).

Commercial logbook information, length frequency and biological data collected between 1984 and 2010 were available for the present review. Age growth and reproductive data for Redbait were available from previous studies by Welsford and Lyle (2003) and Neira *et al.* (2008). In addition, specimens from 2009/10 mid-water trawl and purse-seine fishing operations have been analysed to provide size and age composition estimates of the catch. No biological information has been supplied since 2009/10.

4.2.3 Biomass Estimates and MSE

A detailed study on the early life history, reproduction and stock assessment of Redbait was conducted between 2004 and 2006, with spawning biomass estimated using the DEPM from egg and adult reproductive data collected off eastern Tasmania during October 2005 and 2006 (Neira *et al.* 2008).

4.3 Results

4.3.1 Fishery Statistics East / West

Number of vessels

In 2013/14, one fishing vessel reported catches of Redbait in the East (Figure 4.1), while no catches were reported for the West (Figure 4.2).

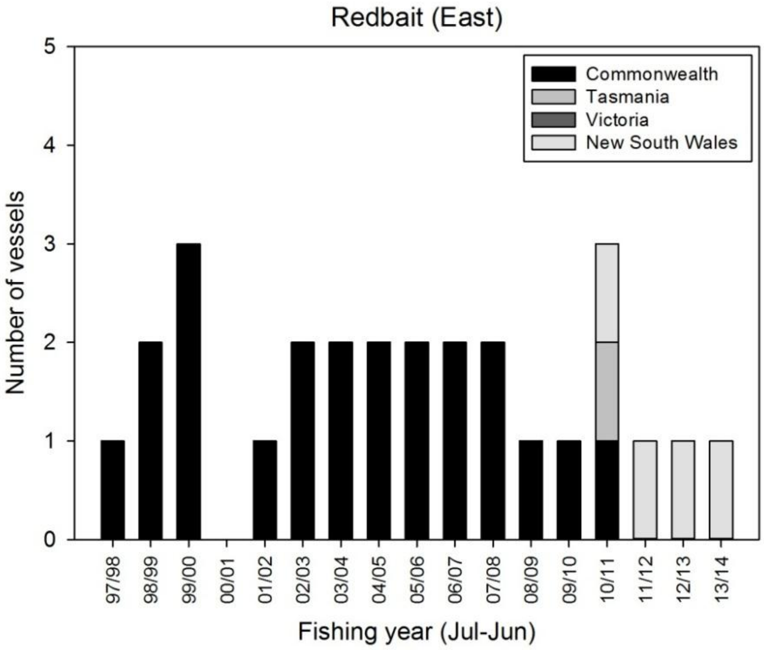

Figure 4.1. Number of vessels which landed Redbait in the East, from each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

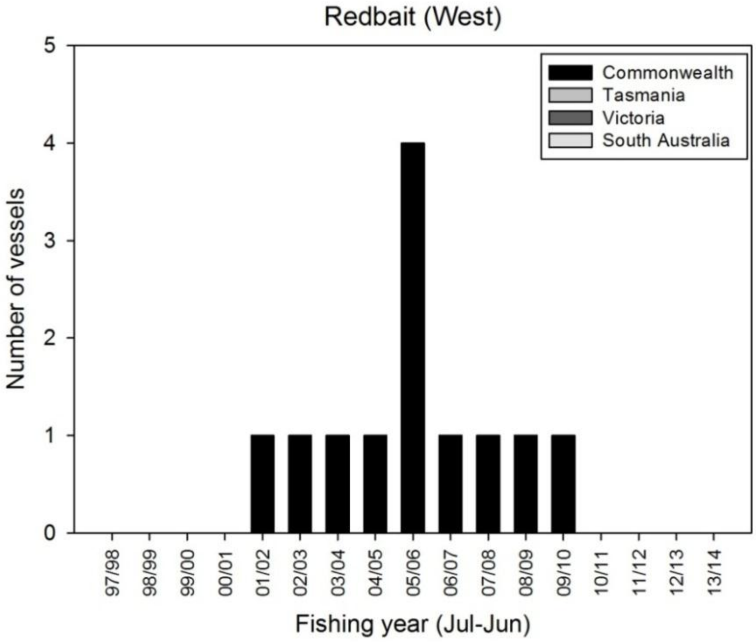

Figure 4.2. Number of vessels that landed Redbait in the West, from each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

Annual patterns – catch

From 1997/98 to 2000/01, Redbait catches in the East did not exceed 315 t (Figure 4.3). Catches increased to ~3,550 t in 2001/02 and 2002/03 and peaked at ~6,660 t in 2003/04. From then, annual catches progressively declined to 28 t in 2010/11 (Figure 4.3) and were less than 0.1 t in 2011/12, 2012/13 and 2013/14.

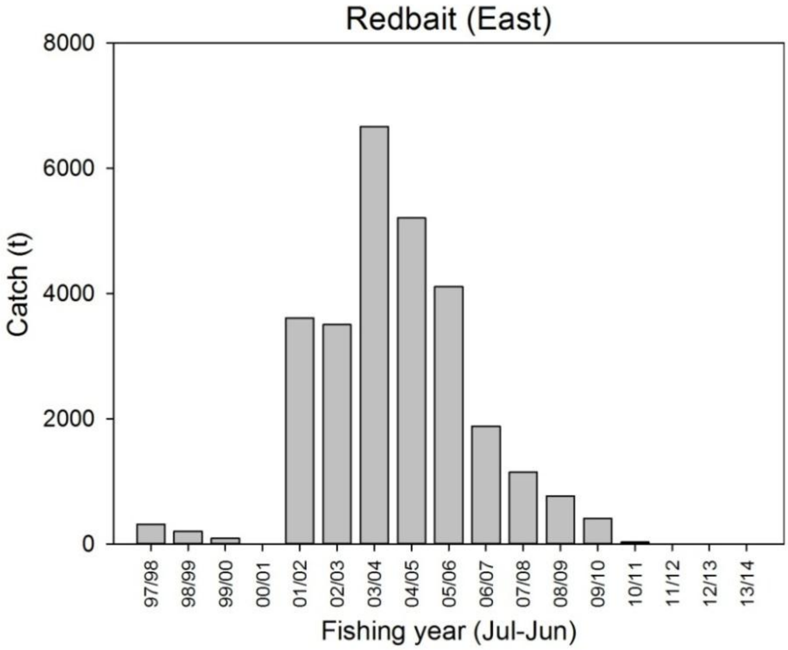

Figure 4.3. Total landed catch (t, bars) for Redbait (East) for each financial year from 1997/98 – 2013/14.

Annual catches of Redbait in the West were typically lower than the East but followed a similar temporal trend (Figure 4.4). No Redbait was landed by the SPF between 1997/98 to 2000/01. Catches were first reported in 2001/02, when a total of 1,100 t were landed. Catch increased to a peak of 3,430 t in 2005/06, remained high (2,923 t) in 2006/07, and then progressively declined to 120 t in 2009/10. No catches were recorded from 2010/11 to 2013/14. Since 1997/98, the trend in catch for the East and West has reflected the trend in annual fishing effort.

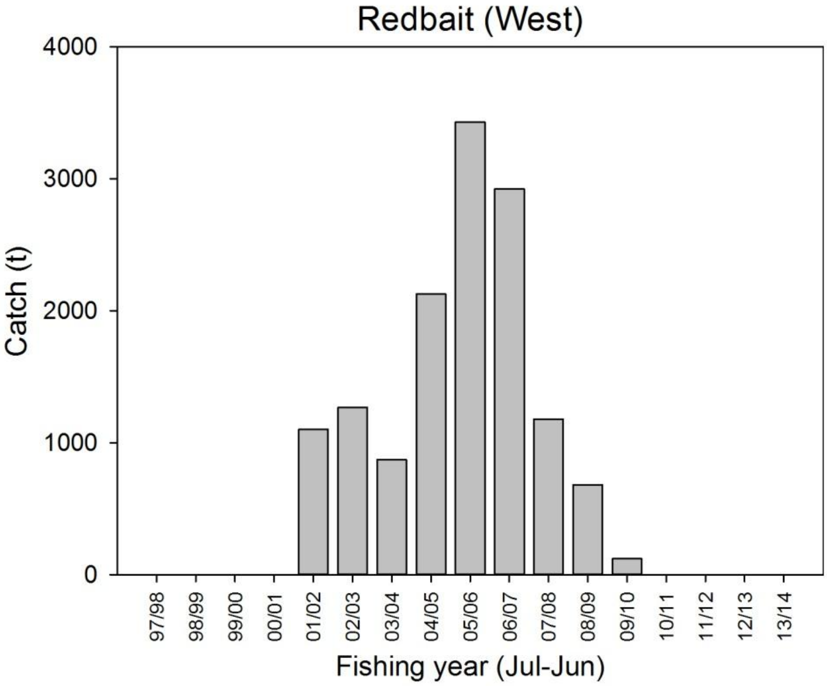

Figure 4.4. Total landed catch (t, bars) for Redbait (West) for each financial year from 1997/98 – 2013/14.

4.3.2 Biological Information

All biological data for Redbait in the East and West Zones were collected between 1984/85 to 2009/10 off eastern and south-western Tasmania, respectively, (i.e. the most productive fishing area for Redbait for the SPF). Prior to 2002, biological data were collected opportunistically and the number of samples collected in each year was highly variable. Limited data were collected on a small proportion of fishing trips in most years and may not be representative of the catch. From 2002 to 2006, an intensive biological monitoring program increased the temporal resolution of sampling. However, due to reductions in fishing effort, no biological samples have been collected since 2010.

Size Structure

The purse-seine fishery: 1984/85 – 2009/10

Redbait caught in the Jack Mackerel Purse-Seine Fishery between 1984/85 and 1994/95 off eastern Tasmania were mostly between 140-290 mm FL, with individuals up to 320 mm FL recorded (Figure 4.5). Catches between 1984/85 and 1987/88 were dominated by fish from 200 – 300 mm FL, with only a few small fish (100 – 140 mm FL) caught in 1985/86. A strong mode (cohort) of smaller fish (120 – 170 mm FL) was present in the size structure for 1988/89, and this cohort accounted for most of the catch the following year. Between 1989/90 and 2009/10, smaller fish (<200 mm FL) dominated the catch (Figure 4.5). No data was collected between 2010/11 and 2013/14.

Mid-water trawl fishery: 2001/02 – 2008/09

Redbait caught by mid-water trawl operations between 2001/02 and 2008/09 off eastern Tasmania were considerably smaller than those caught by the earlier purse-seine operations, with specimens mostly between 100 and 210 mm FL (Figures 4.5; 4.6). East coast catches comprised a high proportion of small fish with modes varying between 140 and 210 mm FL (Figure 4.6). Only a small proportion of the catch was made up of fish larger than 200 mm FL. By contrast Redbait caught by mid-water trawl operations off south-western Tasmania were mostly between 130 and 280 mm FL (Figures 4.6). 6. Overall, the size structure of Redbait catches from south-western Tasmania was bi-modal with peaks at around 140 and 200 mm FL (Figure 4.6).

Mid-water trawl and purse-seine operations: 2009/10

Overall, 887 Redbait were sampled from the catches of 12 purse-seine and mid-water trawl operations off eastern Tasmania between August 2009 and June 2010 (Table 4.1). Mid-water trawl catches from eastern Tasmania were dominated by fish from 190 – 240 mm FL (Figure 4.7). In contrast, purse-seine catches comprised fish between 180 and 200 mm FL, while individuals >210 mm FL were rare. The size structure of purse-seine catch was more typical of mid-water trawl catches from eastern Tasmania during the early 2000s than that for the recent mid-water trawl landings. A single catch (taken in early 2009) from south-western Tasmania comprised fish between 210 and 310 mm FL (mode 240 mm). This was consistent with the size range from previous years from that region (Table 4.1).

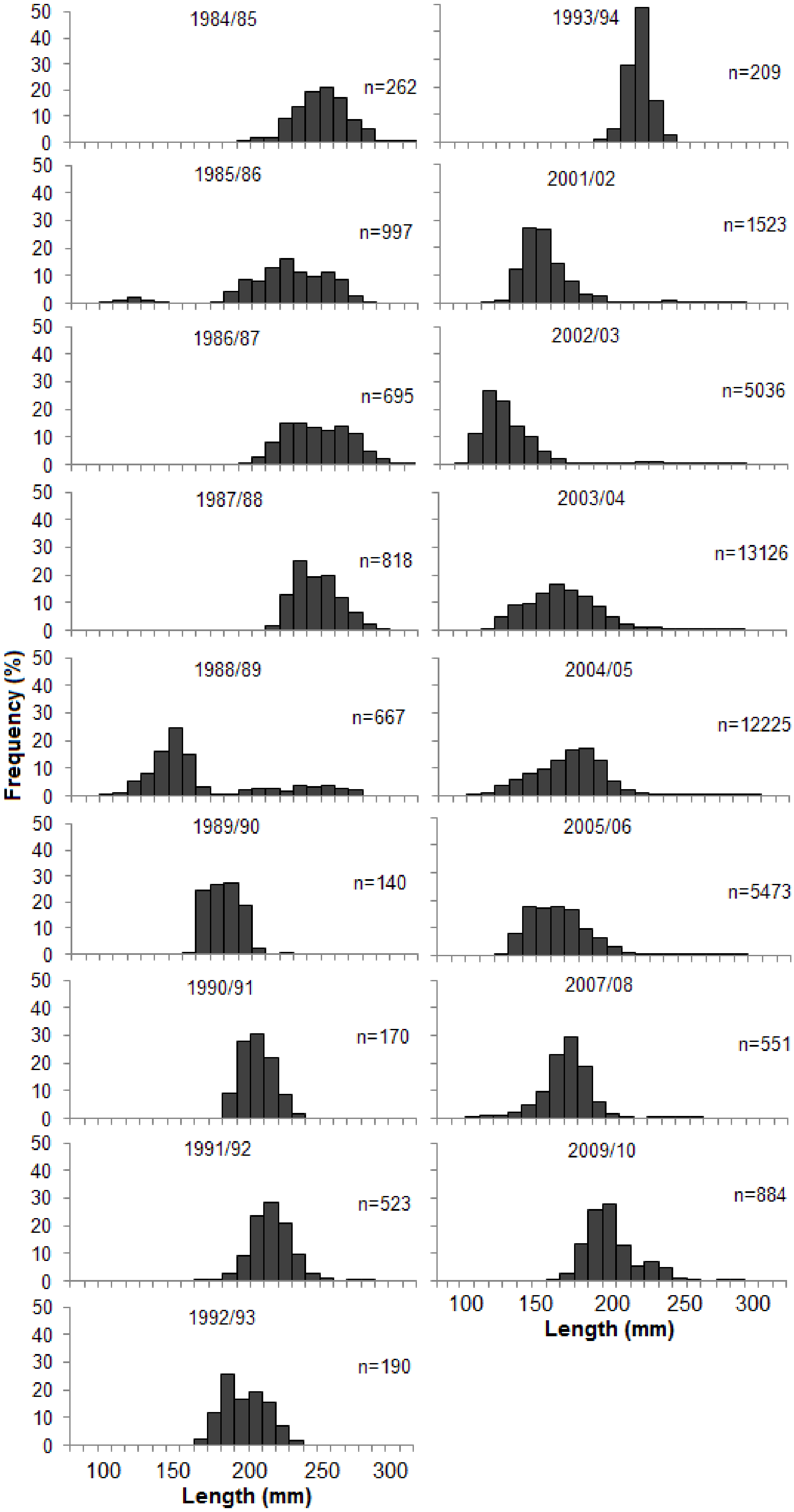

Figure 4.5. Length frequency distributions (mm FL) of Redbait caught in the SPF by purse-seine operations off eastern Tasmania from 1984/85 – 2009/10.

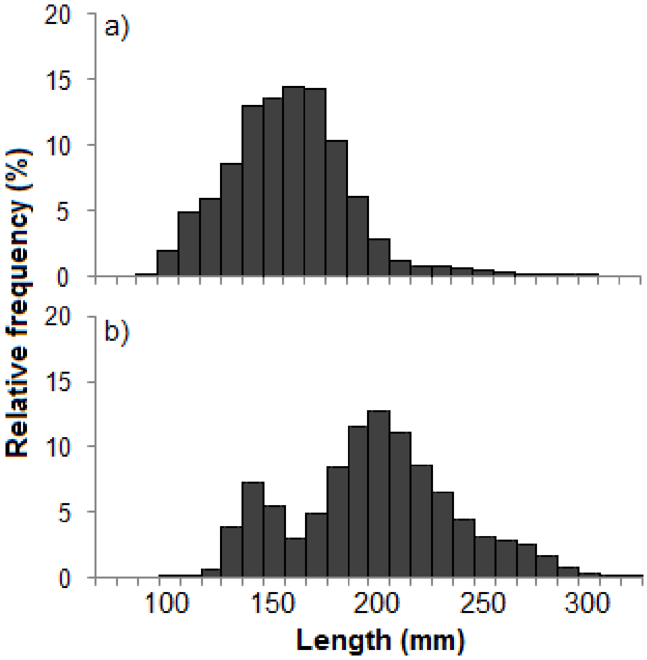

Figure 4.6. Year-weighted length frequency distributions (mm FL) of Redbait caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2001/02 and 2008/09.

Table 4.1 Summary of shots sampled in the SPF off Tasmania for Redbait length-frequency data between Feb-09 and Jun-10. The number of individuals (n) for which length-frequency data was collected along with the size range and modal length are indicated.

Sampling month	No. of shots	Location	Gear type	n	Size range (mm FL)	Mode (mm FL)
Feb-09	1	South-west	Midwater trawl	77	210-310	240
Aug-09	2	East coast	Midwater trawl	129	180-240	210
Sep-09	3	East coast	Midwater trawl	200	170-270	210
Jan-10	1	East coast	Purse-seine	20	190-230	200
Feb-10	2	East coast	Purse-seine	157	170-230	200
May-10	1	East coast	Purse-seine	75	180-220	200
Jun-10	1	East coast	Midwater trawl	64	210-300	240
Jun-10	2	East coast	Purse-seine	242	170-220	200

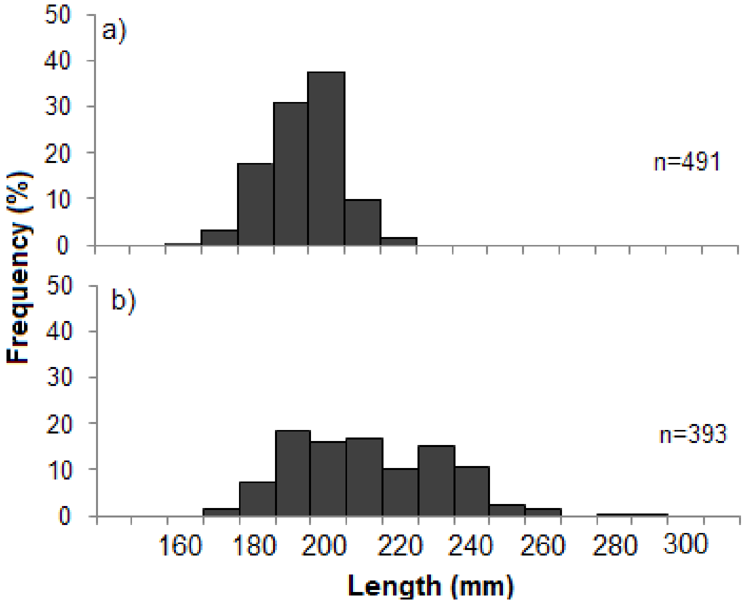

Figure 4.7. Length frequency distribution (mm FL) of Redbait caught in the SPF eastern Tasmania by purse-seine (a) and mid-water trawling (b) operations during 2009/10. n is sample size.

Age and growth

Growth of male and female Redbait from eastern and south-western Tasmania (pooled) was described using the VBGF (Table 4.2, Figure 4.8). On average, growth was rapid within the first years of life with individuals reaching ~200 mm FL in the first three years, with growth slowing thereafter. The maximum age for females and males Redbait was 21 and 18 years, respectively.

Table 4.2. Summary of von Bertalanffy growth function parameters by sex and region for Redbait sampled off the east (EC) and south-west (SW) coasts of Tasmania. (*) = eastern Tasmanian samples with juveniles excluded (based on Neira *et al.* 2008).

		VBGF parameters		
Region/Sex	**n**	**L_∞**	**K**	**t_0**
EC ♂	326	279.3	0.27	-1.45
EC ♂*	209	282.4	0.23	-2.27
EC ♀	503	297.2	0.22	-1.76
EC ♀*	386	346.1	0.11	-4.56
SW ♂	173	306.6	0.13	-5.49
SW ♀	294	304.8	0.16	-4.46
Pooled	1265	284.1	0.27	-1.54

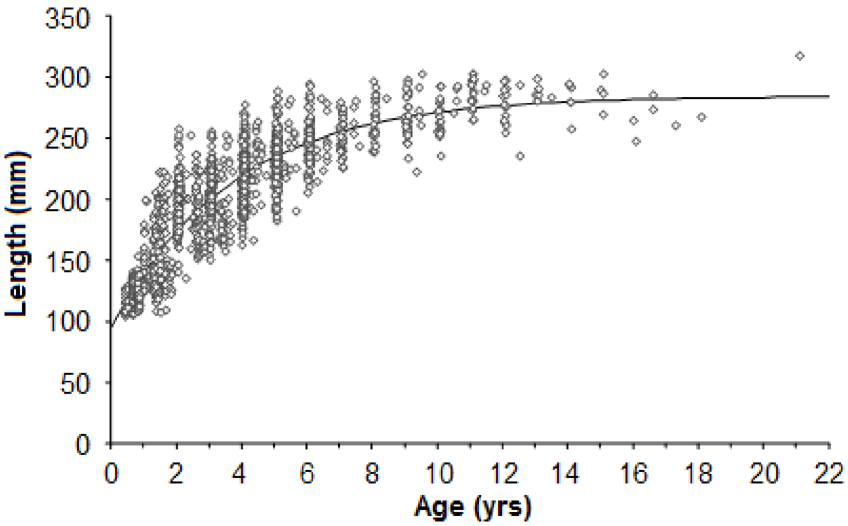

Figure 4.8. Length (mm FL) at age (years) data for Redbait sampled off the east and south-west coasts of Tasmania (regions pooled). The grey line represents the von Bertalanffy growth function.

Age Structure

Mid-water trawl fishery: 2001/02 – 2005/06

The age structure of Redbait caught in the SPF was estimated using age-length keys based on age data pooled between 2001/02 to 2005/06 (Figure 4.9). Catches from Eastern Tasmania comprised mostly fish between 1 and 5 years. These catches were generally dominated by 2 year olds, except during the 2002/03 season when 1 year olds accounted for 64% of the catch. The proportion of fish aged 2 years and under varied between 40% (2004/05) and 94% (2002/03), with few fish (<4%) above 5 years of age. The age structure of the south-west Tasmanian catches showed a higher proportion of older fish, with catches comprising mostly 2 and 8 year olds. A strong cohort of 2 year old fish dominated catches in 2003/04; this cohort subsequently dominated catches as 3 year olds in 2004/05 and 4 year olds in 2005/06.

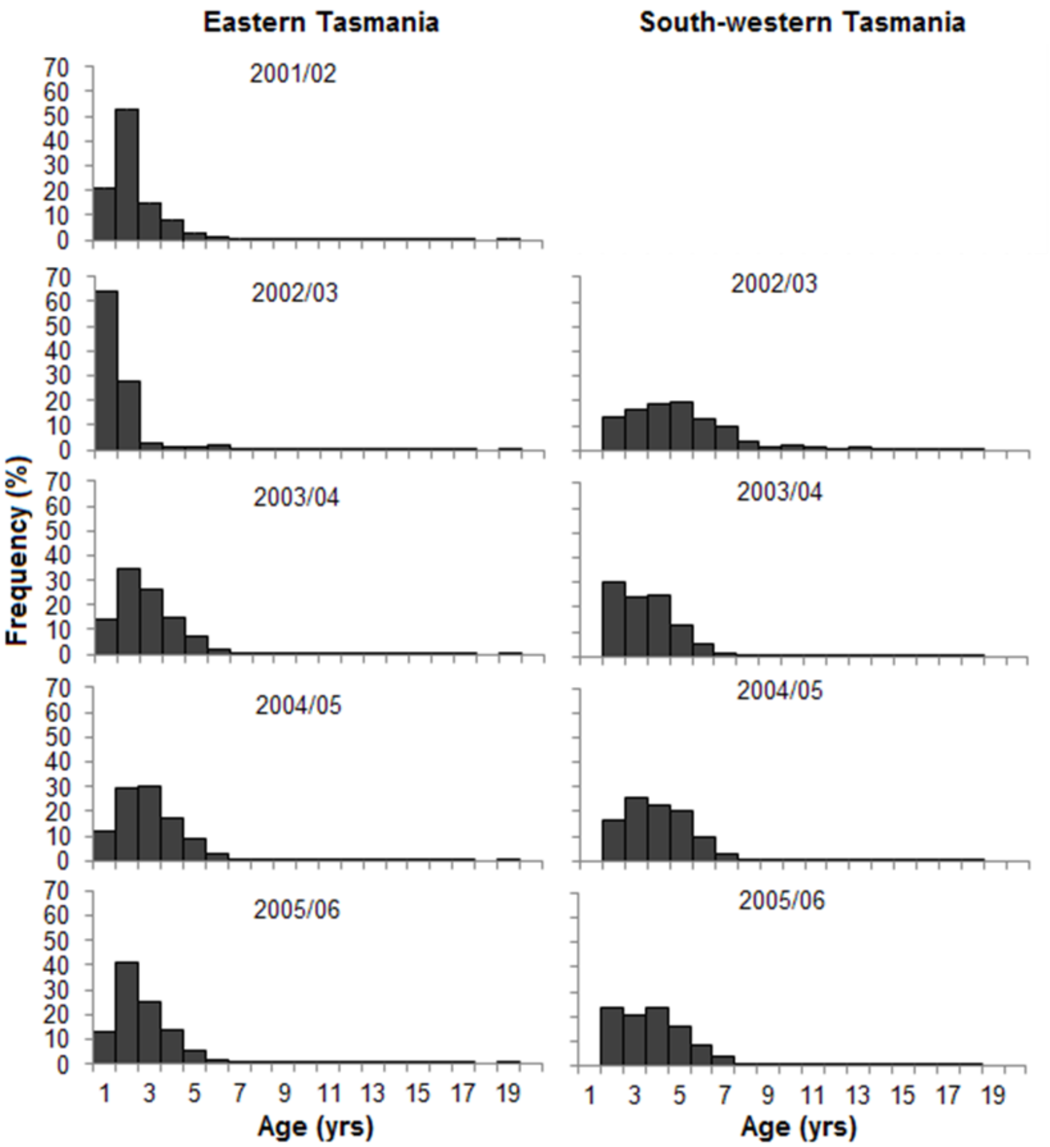

Figure 4.9. Age structure of Redbait catch samples from eastern and south-western Tasmania from 2001/02 to 2005/06 (No data were available off south-western Tasmania during 2001/02).

Mid-water trawl and purse-seine operations: 2009/10

A total of 280 Redbait (160 mid-water trawl and 120 purse-seine caught) were aged during 2009/10 (Table 4.3) using an age-length key. The age composition of the mid-water catch from eastern Tasmania was similar to previous years, with fish mostly between 2 and 3 years of age (Figure 4.10). Purse-seine catches were also dominated by 2 – 3 year old fish, with 2 year olds accounting for over half of the catch (Figure 4.10).

The single sample of Redbait from south-western Tasmania included individuals that were substantially older than those sampled from east coast catches, with 90% of fish estimated to be over 4 years of age.

Table 4.3. Summary of shots sampled in the SPF off Tasmania for Redbait age data during 2009/10. The number of individuals (n) aged is indicated along with the age range and average age.

Sampling month	Location	Gear type	n	Age range (years)	Average age (years)
Feb-09	South-west	Midwater trawl	20	2-13	6.2
August-09	East coast	Midwater trawl	40	2-7	2.7
Sep-09	East coast	Midwater trawl	70	1-9	3.3
Jan-10	East coast	Purse-seine	20	1-5	2.5
Feb-10	East coast	Purse-seine	40	1-2	1.3
May-10	East coast	Purse-seine	20	1-3	2.5
Jun-10	East coast	Midwater trawl	30	3-7	4.0
Jun-10	East coast	Purse-seine	40	2-3	2.4

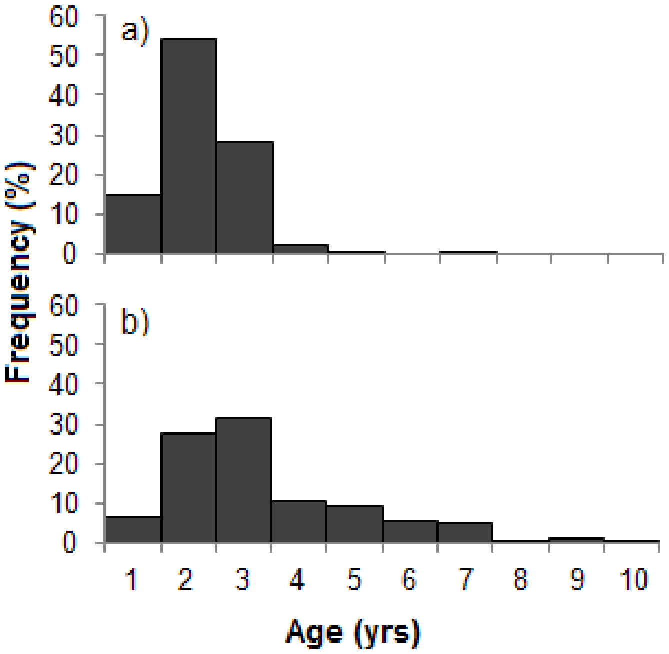

Figure 4.10. Age distribution of Redbait caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

<u>Gonadosomatic index</u>

Trends in male and female GSIs indicate that Redbait have a discrete spawning season that extends over a 2-3 month period during spring. GSIs for Redbait from the east coast rose sharply in August, peaking in September/October, before declining to resting levels by January (Figure 4.11). A similar pattern was evident for south-western Tasmania, although the peak occurred between October and November, i.e. one month later.

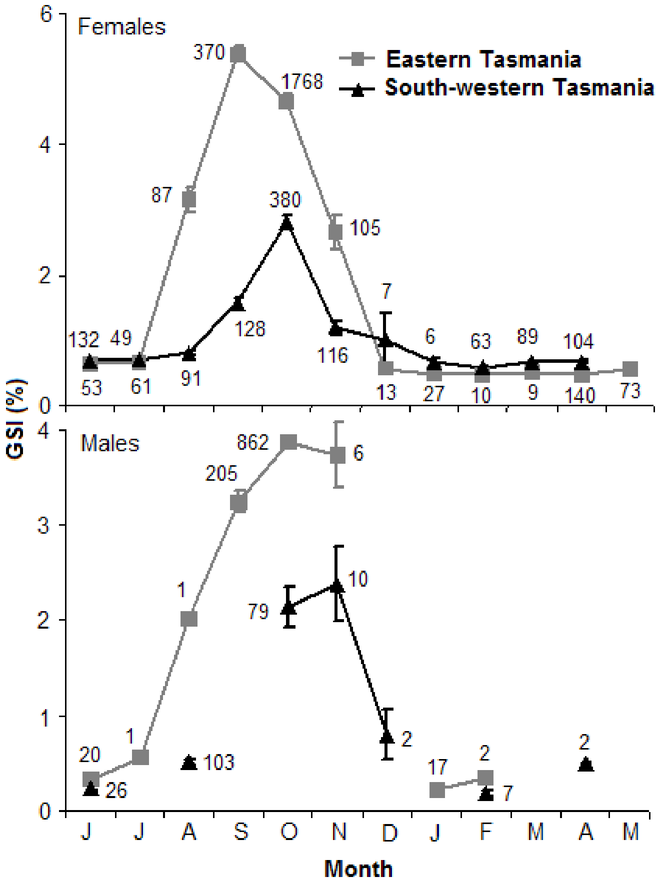

Figure 4.11. Monthly distribution of mean GSI (% ± SE), by sex and region. Numbers represent sample size. Based on Neira *et al.* (2008).

Gonad stages

Macroscopic staging of females confirmed that the seasonal increase in GSIs was attributed to reproductive activity. Fish with maturing gonads (Stage III) dominated east coast samples in August, and by September over half of the fish examined had hydrated oocytes (Stage IV) (Figure 4.12). Fish with hydrated oocytes were present through to November and spent fish (Stage VI) were evident between November and January, implying that limited spawning activity occurred December and January. Samples collected between January and August were dominated by fish with undeveloped or resting gonads (>90%). A similar pattern of gonad stage development was evident off south-western Tasmania. GSIs during the spawning season for south-western Tasmania were consistently lower than those for fish from eastern Tasmania, presumably due to the lower proportion of actively spawning fish (≥ Stage III) (Figure 4.12).

The occurrence of oocyte atresia in histological sections from fish sampled off eastern Tasmania during 2004/05 increased from 11% in fish sampled in late

October to 36% of the fish sampled in November. These observations support macroscopic staging by implying that peak spawning activity had passed by mid-November.

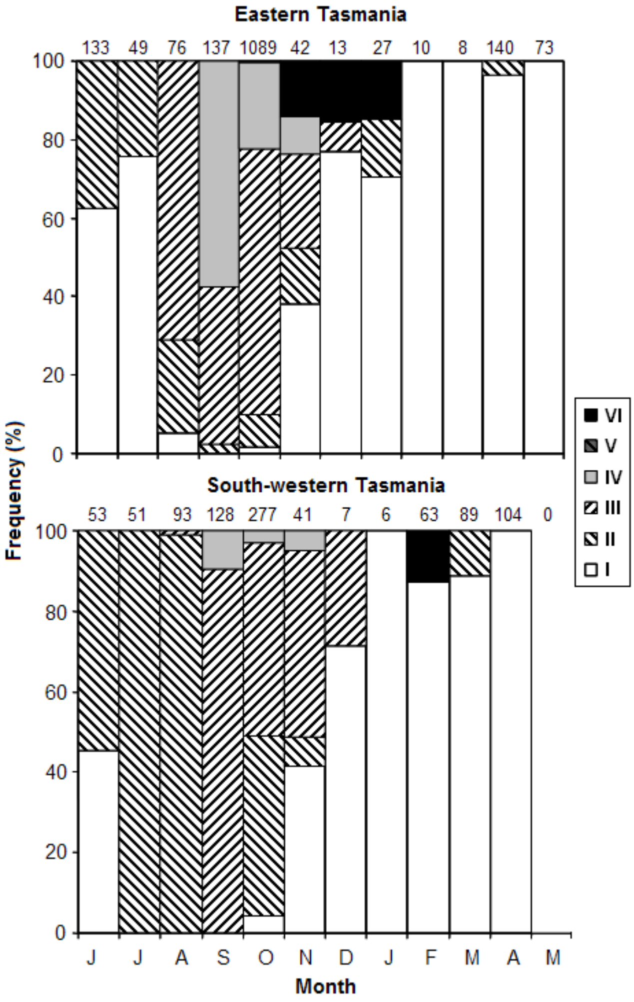

Figure 4.12. Monthly distribution of female macroscopic gonad stages (I – VI) by region. Numbers represent sample sizes. Based on Neira *et al.* (2008).

Size and age at maturity

Logistic growth models indicated that the female Redbait population attained sexual maturity at larger sizes than males in both eastern and south-western Tasmania, although age at maturity was generally similar between the sexes within a given region (Table 4.4, Figures 4.13; 4.14). There were, however, marked differences in size and age at maturity between the regions, with both sexes maturing at ~100 mm larger and 2 years older off south-western Tasmania compared with eastern Tasmania. The size (age) at 50% sexual maturity was 147 and 244 mm (4.8 and 2 years) for males, and 157 and 261 mm (4.1 and 2.0 years) for females, from eastern and south-western Tasmania, respectively.

Table 4.4. Parameters for logistic ogives fitted to size (mm FL) and age (years) data to determine L_{50} and A_{50} for Redbait by sex and region, based on Neira *et al.* (2008).

Region	**Sex**	**Size at maturity**				**Age at maturity**			
		N	**a**	**b**	**L_{50} (mm)**	**N**	**a**	**b**	**A_{50} (yrs)**
Eastern Tasmania	female	60	-16.81	0.11	157	141	-3.29	1.66	2.0
	male	594	-13.58	0.09	147	170	-3.20	1.58	2.0
South-western Tasmania	female	654	-12.68	0.05	261	133	-2.09	0.52	4.1
	male	128	-12.47	0.05	244	111	-3.00	0.62	4.8

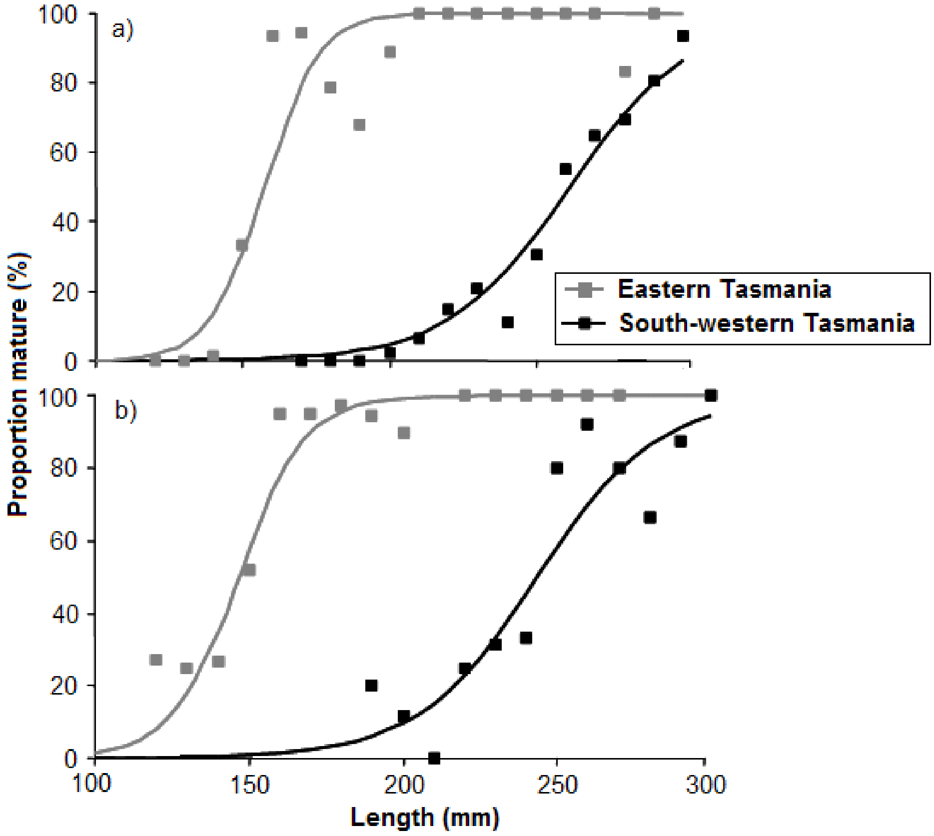

Figure 4.13. Proportion of mature female (a) and male (b) Redbait by length class (mm FL) and region, fitted with logistic ogives. Based on Neira *et al.* (2008).

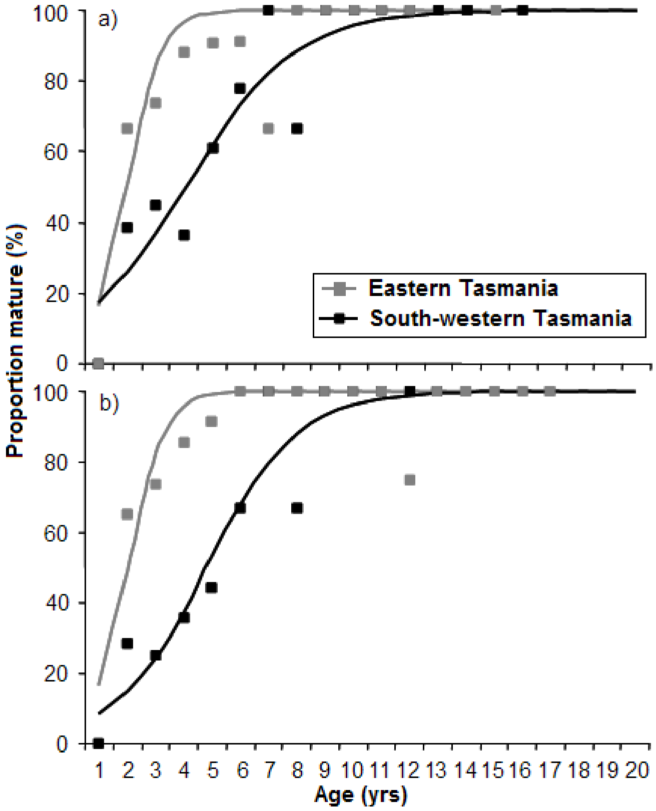

Figure 4.14. Proportion of mature female (a) and male (b) Redbait by age class (years) and region, fitted with logistic ogives. Based on Neira *et al.* 2008.

4.3.3 Biomass Estimates and MSE

DEPM

Estimates of egg production, spawning area, mean female weight, batch fecundity, sex ratio and spawning fraction of Redbait were calculated from data obtained from concurrent ichthyoplankton surveys and commercial trawl operations in 2005 and 2006 (Neira *et al.* 2008). Mean daily egg production (P_0) was estimated using two models; non-linear least-squares regression (NLS) and a generalised linear model (GLM), and was based on two data scenarios: all eggs and a data set with extremes omitted. Extremes included eggs ≤4 hours old and eggs ≥98% of incubation time.

Main spawning areas within the surveyed area off the east coast of Tasmania were identified between north-eastern Bass Strait (38.8°S) and south of the Tasman Peninsula (43.5°S) in 2005 (13,220 km^2), and between Cape Barren Island (40.5°S) and the same southern boundary in 2006 (8,695 km^2). Redbait spawning biomass computed using DEPM estimates derived from NLS and GLM model fits varied from 66,000 – 143,000 t in 2005 and 43,000 – 58,000 t in 2006.

The 2005 NLS-based estimates were 25-65% higher than GLM-based estimates depending on data scenario. By contrast, 2006 estimates were more similar in magnitude between models and data scenarios, although the GLM-based estimates tended to be slightly higher. Regardless of year or data scenario, the GLMs proved to be a better fit to the data, returning lower coefficients of variation (see Neria *et al.* 2008). Overall, the GLM that omitted eggs with assigned ages <4 hours and >98% of incubation time provided the best fit and was adopted as the preferred model. Biomass estimates were 86,990 t in 2005 and 50,782 t in 2006. For 2012/13, an average of these two DEPM values was used to set the RBC for Redbait (East) at 6,900 t (Tier 1 assessment). The RBC for the West was set at the Tier 2 maximum of 5,000 t based on available information including historic catches, information on stocks and life history characteristics.

<u>MSE</u>

For Redbait East, the DEPM estimate of spawning biomass was 23% of the model calculated estimate of spawning biomass. This is not an issue when investigating Tier 1 scenarios, as these are “relative” quantities determined as a percentage of the spawning biomass. The Tier 1 scenarios investigated using the MSE all reached equilibrium at around B_{40} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are conservative and sustainable. However, these should be treated with caution as these harvest quantities are “absolute” quantities and represent a much smaller proportion of the model calculated biomass than the DEPM estimate of biomass.

The results for Redbait West are similar to those of Redbait East. In this case there was no DEPM estimate of spawning biomass.

4.4 Summary and Conclusions

The most recent application of the DEPM for Redbait in the East (2005 and 2006 surveys) estimated a spawning biomass of ~70,000 t (Neira *et al.* 2008). This suggests that annual catches of Redbait by the SPF since 2009/10 of <15 t, have been sustainable. This evaluation is supported by the MSE. However, there is insufficient fishery catch and effort data and biological information available for recent years to confidently determine the status of the Redbait stocks in the East and West, due to low levels of fishing effort and outdated DEPM-based estimates of spawning biomass.

In 2012, the eastern stock was classified as not overfished (Woodhams *et al.* 2012). No estimates of spawning biomass are available for the western stock, thus it remains ‘uncertain’ whether or not this stock is overfished (Woodhams *et al.* 2012). However, biological sampling has revealed no obvious impact on size or age composition over the recent history of the fishery. In 2013/14, the total catch of Redbait in the East of <0.1 t was <1% of both the RBC and the most recent DEPM biomass estimate from 2006. There were no reported landings of Redbait in the West in 2013/14.

Using the definitions from the National Status of Key Australian Fish Stocks Report (Flood *et al.* 2014), the fishery for Redbait in the East and West are classified as sustainable.

5 AUSTRALIAN SARDINE (*SARDINOPS SAGAX*)

5.1 Introduction

5.1.1 Background to Fishery

Sardines (*Sardinops* spp.) form the basis of some of the world's largest fisheries (Schwartzlose *et al.* 1999) and have been the focus of extensive research where they are commercially important (Stratoudakis *et al.* 2006). Australian Sardine (*Sardinops sagax*) occurs in temperate waters from southern Queensland to Western Australia (Ward and Staunton-Smith 2002), where they support several commercial fisheries.

Exploitation of Sardine in Australia has occurred since the 1800s (Kailola *et al.* 1993), but combined national catches did not exceed 1,000 t until the 1970s, when several purse-seine fisheries were developed in south-western Western Australia. From then, annual catch in Western Australia increased steadily to ~8,000 t in 1990 (Kailola *et al.* 1993). In 1991, a Sardine fishery was established in South Australia to provide fodder for the tuna mariculture industry (Ward and Staunton-Smith 2002). Between 1993 and 2003, catches in this fishery ranged between 3,500 and 6,500 t. In 1995 and 1998, two mass mortality events affected all Australian Sardine populations and reduced the biomass in South Australia by 75% and 70%, respectively (Ward *et al.* 2001a). The Sardine fishery in Western Australia has not fully recovered since these mortality events with catches remaining below 2,000 t since 1999, including 1,999 t in 2013 (Fletcher and Santoro 2008; Ward *et al.* 2014a). The South Australian fishery, however, appeared to recover relatively quickly with a catch of ~21,000 t in 2002/03 and annual catches above 28,000 t since that time (Knight and Tsolos 2012). In 2013, the total catch by the South Australian fishery was 31,981 t (Ward *et al.* 2014a). Sardine catches from southern Queensland prior to 1996 were minimal as only small quantities were taken by beach seine nets for bait purposes (Ward and Staunton-Smith 2002). In 1996, a 3-year developmental fishery permit was issued for a single purse-seine vessel to take 600 t of four small pelagic fish species, including Sardine (Ward and Staunton-Smith 2002). In 2000, purse-seine fishing was prohibited in Queensland. In New South Wales, the annual catch of Sardines has increased rapidly in recent years from historical averages of 30-40 t to almost 5,000 t in 2008/09, but declined to 352 t in 2013 as a result of a reduction in fishing effort (Ward *et al.* 2014a).

5.1.2 Taxonomy and distribution

The Australian Sardine (*Sardinops sagax*, Jenyns 1842) belongs to the order Clupeiformes which is primarily composed of small, stream-lined schooling fishes. Commonly known as herrings, this order of fishes comprises approximately 300 species in seven families including Clupeidae (sardines, shads, pilchards) and Engraulidae (anchovies) (Froese and Pauly 2012). Clupeidae, of which the Australian Sardine is a member, are mostly marine forage fishes that are characterised by a compressed, silvery body shape with no obvious lateral line and weakly attached cycloid scales (Gomon *et al.* 2008). Worldwide, there are more than 50 genera and at least 210 species of clupeids. Of these genera, 6 occur in waters off southern Australia with each represented by one species (Gomon *et al.* 2008). The Australian Sardine belongs to the genus *Sardinops*.

Australian Sardine is found in waters off Australia, Japan, North and South America, Africa and New Zealand. In Australia, it occurs throughout temperate waters between Rockhampton (Queensland) and Shark Bay (Western Australia), including northern Tasmania (Gomon *et al.* 2008).

5.1.3 Stock Structure

There is a high level of genetic heterogeneity within the Australian stock of Sardine, but no evidence of spatially consistent stock structure (Okazaki *et al.* 1996; Ward *et al.* 1998). The existence of separate eastern and western stocks has been proposed for the species, with Bass Strait suggested as a significant barrier to gene flow (Izzo *et al.* 2012). However, no studies of stock structure have been undertaken across the distribution of Australian Sardine to confirm this.

Information on the movement rates of Australian Sardine across its distribution would assist future management. The most suitable approach to addressing questions of stock structure and movement rates would be in the context of an Australia-wide study that concurrently utilises genetic, parasite and otolith-based approaches that have recently been applied to several species of scombrids (see Buckworth *et al.* 2006; Ward and Rogers 2007).

5.1.4 Movement

Sardines are known to undergo extensive migrations. For example, schools of Sardines migrate north into waters off southern Queensland during winter-spring to spawn (Ward and Staunton Smith 2002). Similarly, off Africa, Sardines migrate north and south along the coast to access conditions that are favourable for spawning and the survival of recruits (van der Lingen and Huggett 2003). The movement patterns of

Sardines in Australian waters are poorly understood, although there is evidence of an ontogenetic shift in distribution in South Australia with larger, older fish most commonly found in shelf waters and small, younger fish mainly found in embayments including Spencer Gulf (Rogers and Ward 2007).

5.1.5 Food and Feeding

Sardine has two feeding modes: filter-feeding on micro-zooplankton and phytoplankton, and particulate-feeding on macro-zooplankton. Sardines switch between these two modes depending on relative prey density (van der Lingen 1994; Louw *et al.* 1998). 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 most to the diet (Daly 2007). Krill occurred in greater numbers (65.3%) than crustaceans (27%). Crab zoea, other decapods, copepods, polychaetes, fish eggs and larvae, and gelatinous zooplankton were also present.

5.1.6 Age, Growth and Size

Age determination studies of sardine have involved counting growth increments in scales (Blackburn 1950) and sagittae (Butler *et al.* 1996; Fletcher and Blight 1996), and modelling the formation of marginal increments (Kerstan 2000). Several methodological approaches have been used to show that translucent zones form annually in the sagittae of 1+ year old fish off South Africa (Waldron 1998), ≤ 2+ year olds off North America (Barnes *et al.* 1992) and ≥ 4+ year olds off Western Australia (Fletcher and Blight 1996). Despite this, the use of sectioned sagittae for ageing sardine from southern Australia has proven to be problematic due to difficulties associated with interpreting and counting opaque and translucent zones (Rogers and Ward 2007).

Growth rates and maximum size of Australian Sardine vary in response to localised variation in food availability and environmental conditions (Ward and Staunton-Smith 2002). In southern Australia, Australian Sardines rarely exceed 250 mm FL after 6 to 8 years (Rogers and Ward 2007). Larval and juvenile Sardines in southern Australian waters have growth rates of approximately 1.2 and 0.4 mm.day^{-1}, respectively (Rogers and Ward 2007). Rogers and Ward (2007) showed that the growth rates of Sardines were higher in South Australian waters than off other parts of the Australian coastline, yet lower than those in more productive boundary current ecosystems, such as the Benguela, Agulhas and Californian systems. A notable finding of the study was that fish in commercial catches were younger (and smaller) than those obtained in fishery-independent samples.

5.1.7 Reproduction

In Australia, Sardines usually spawn in open waters between the coast and shelf break (Blackburn 1950; Fletcher and Tregonning 1992; Fletcher *et al.* 1994). They are serial/batch spawners with asynchronous oocyte development and indeterminate fecundity, i.e. they release numerous batches of pelagic eggs throughout an extended spawning season. The number of eggs released in a batch (batch fecundity) is correlated with female size and varies among locations and years (Lasker 1985). In South Australia, females spawn batches of 4,000 – 35,000 pelagic eggs approximately once per week during the extended spawning season (Ward *et al.* 2012; 2014b). In most locations there is one spawning season per year, but off Albany in Western Australia there are two (Fletcher 1990).

The peak spawning season is variable across the Australian distribution of Sardines. For example, in South Australia spawning occurs during the summer-autumn upwelling from January to April (Ward *et al.* 2001b; Ward and Staunton Smith 2002). Similarly, along the south coast of Western Australia spawning peaks between January and June (Gaugan *et al.* 2002), while Sardines off Fremantle reached a maximum GSI during June (Murling *et al.* 2008). Along the east coast of Australia in Victoria, Sardine reach peak GSI from spring to early summer (Hoedt and Dimlitch 1995; Neira *et al.* 1999), while in southern Queensland peak GSI occurs in winter to early spring (Ward and Staunton-Smith 2002). Off southern New South Wales, peak GSI occurs between July and December (Stewart *et al.* 2010). Between 1989 and 1991, Sardine larvae were collected off Sydney during all months, except March (Gray and Miskiewicz 2002).

The size and age at which sardine reach sexual maturity vary between locations, and range from 100 to 180 mm FL, and 1.8 to 2.8 years, respectively (Blackburn 1950; Joseph 1981; Fletcher 1990). In South Australia, approximately 50% of males and females reach sexual maturity (L_{50}) at 146 and 150 mm FL, respectively (Ward and Staunton-Smith 2002).

5.1.8 Early Life History and Recruitment

Sardine has a relatively long larval phase: eggs hatch approximately two days after fertilization and yolk-sac larvae are ~2.2 to 2.5 mm TL and at lengths of 35–40 mm TL (Neira *et al.* 1998). Survival rates of sardine eggs and larvae strongly affect recruitment success (Louw *et al.* 1998). Larvae are known to undertake vertical migrations that may reduce passive transport away from regions with environmental conditions that are favourable for survival (Watanabe *et al.* 1996; Logerwell *et al.* 2001; Curtis 2004).

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 (Galindo Cortes 2010), but there has been less consideration of the effects of egg and larval predation on recruitment success.

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 of the eastern and central Great Australian Bight (Ward *et al.* 2014b), while juveniles occupy nursery areas that include shallow embayments and semi-protected waters. The factors affecting recruitment success of Sardines are poorly understood.

5.1.9 Stock Assessment

The DEPM was developed to assess the status of northern anchovy *E. mordax* stocks off the coast of California (Lasker 1985; Parker 1980) and is the preferred fishery-independent method of assessing spawning-stock biomass of sardine worldwide (see review in Barange *et al.* 2009), i.e. Atlanto-Iberian Sardine (*Sardina pilchardus*) (Bernal *et al.* 2011a; 2011b). The advantage of this approach is that it provides direct estimates of spawning biomass on which to base management decisions. DEPM has been used extensively to estimate the spawning biomass of Australian Sardine in South Australia since 1995 (Ward *et al.* 2014b).

As part of a project to evaluate the use of the DEPM to estimate spawning biomass of Blue Mackerel in southern and eastern Australia (Ward and Rogers 2007), ichthyoplankton surveys were conducted along the east coast from 2002 to 2004. Existing data and published parameter estimates were combined with information obtained from samples collected during these surveys for the application of the DEPM for Australian Sardine on the east coast in July 2004. The results of this study provided the first estimate of the spawning biomass for Australian Sardine along Australia’s east coast.

The first dedicated application of the DEPM to Australian Sardine off the south-east coast of Australia was undertaken in January 2014 (Ward *et al.* 2015). It identified a significant spawning area off northern Tasmania and in Bass Strait during this period. However, estimates of adult parameters were only available from South Australia as no adult samples were collected during the study by Ward *et al.* (2015). As such, the estimate of spawning biomass for Australian Sardine off eastern Australia during January 2014 should be treated with caution.

It is important to note that the biomass estimate provided in the study by Ward *et al.* (2015) was not an estimate of the total adult biomass of Australian Sardine off eastern Australia, rather it was an estimate of the portion of the population that was spawning in that part of the species range in summer 2014. Nonetheless, it provides insights into the catch limits that may be set for any developmental fishery that may be established in the region. Another DEPM survey, with targets including Australian Sardine, has been conducted between southern New South Wales and southern Queensland in August / September 2014. Results of this survey are expected in late 2015.

5.1.10 Management

A DEPM assessment was conducted for the East Zone in 2004. As such, the SPF for Australian Sardine is currently managed at the Tier 2 level (Table 1.1).

5.1.11 Recreational fishing

Information on the magnitude of recreational catches of Sardine is not available. The most recent National stock status report indicated that recreational and indigenous catches of Australian Sardine are likely to be negligible (Ward *et al.* 2014a).

5.2 Methods

5.2.1 Fishery Statistics

Fishery statistics were supplied by ABARES for the period from 1997/98 to 2010/11. From 2011/12 to 2013/14, all fishery statistics were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are in financial years.

Estimates of monthly catch and effort supplied for Australian Sardine in the East Zone from July 1997 to June 2010 included data for oceanic and non-oceanic (near shore and estuarine) fishing operations. After this, all estimates were for oceanic fishing activity only (purse-seine and mid-water trawling).

5.2.2 Biological Information

Annual length frequency data for Australian Sardine sampled from commercial catches taken in New South Wales were supplied by New South Wales DPI for the period from 2004/05 and 2013/14. Additional samples were collected from commercial catches taken from the north (Iluka) and south-central (Eden) coast of New South Wales between March 2009 and January 2010 for biological analysis. These fish were dissected and morphometric data collected by New South Wales DPI, while otoliths were interpreted for age by SARDI Aquatic Sciences using the methods of Rogers and Ward (2007).

AFMA observers collected biological samples of Sardine during trips in September 2012 and August 2013 which were supplied to SARDI Aquatic Sciences. These fish were measured for total fork length (mm), and some were retained for ageing. Australian Sardines were also sampled from commercial catches taken in New South Wales between July 2013 and July 2014 to determine population size and age structures and monitor reproductive activity.

5.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Australian Sardine in the East Zone was conducted in 2007 using ichthyoplankton samples collected in July 2004 (Rogers and Ward 2007). Existing data and published parameter estimates were combined to provide best, minimum and maximum estimates of spawning biomass using the DEPM. Egg data were obtained from an ichthyoplankton survey conducted between Bundaberg and Newcastle during July 2004 as part of a study of Blue Mackerel. New South Wales DPI provided some reproductive data for Australian Sardine off southern New South Wales. Other adult parameter estimates were collated from previous Australian studies of this species. The model was re-examined in 2011 to address concerns about values used for number of recruits.

5.3 Results

5.3.1 Fishery Statistics

Location of vessels

In 1997/98, a total of 42 vessels reported landings of Australian Sardine in the East, of which approximately 88% were from New South Wales (Figure 5.1). Since then, the number has gradually declined and in 2013/14, only eight commercial vessels reported catches of Sardine.

Annual Patterns – catch, effort and catch per unit effort

From 1997/98 to 2001/02, annual catches of Australian Sardine in the East Zone were relatively low and ranged from 72 t to 575 t (Figure 5.2). From then, catch increased to a peak of 4,768 t in 2008/09, before declining to 1,115 t in 2012/13. In 2013/14, catch increased to 1,385 t. Fishing effort has been highly variable among years since 1997/98 when it was 1573 vessel days (Figure 5.2). Fishing effort declined to <250 vessel days in 2001/02, increased to >960 vessel days through the mid-to-late 2000s, before decreasing to 170 vessel days in 2012/13. In 2013/14, effort increased to 243 fishing days.

CPUE increased from 0.35 t.vessel day^{-1} in 1997/98 to a historical peak of 12.96 t.vessel day^{-1} in 2010/11 (Figure 5.3). From then, catch rate decreased annually and in 2013/14 was 5.7 t.vessel day^{-1}.

Intra-annual Patterns - catch and effort

Intra-annual patterns of catch and effort have been highly variable across the data period with catches occurring in all months (Figure 5.4). Since 2009/10, presentation and interpretation of monthly data are limited due to confidentiality issues arising from the small number of vessels participating in the fishery.

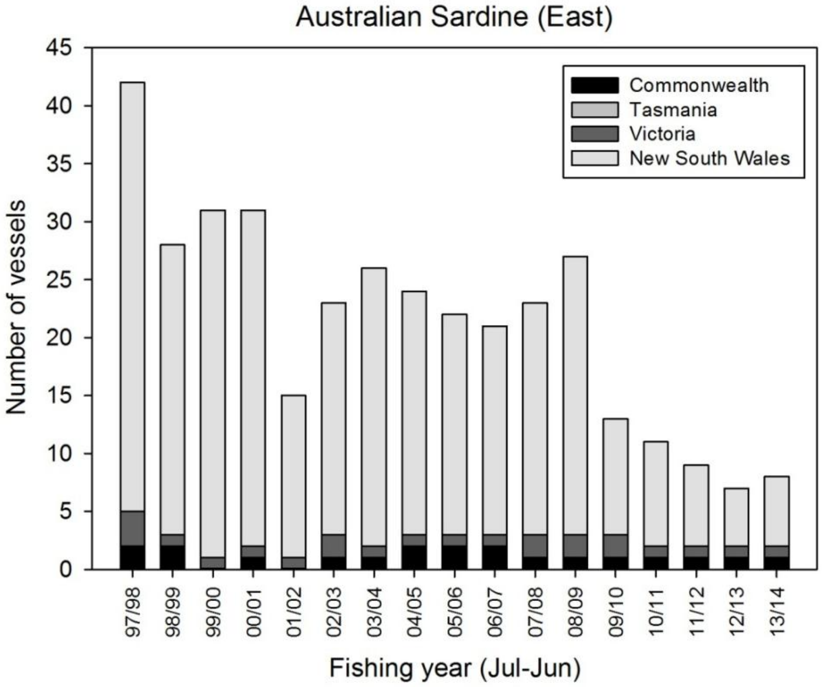

Figure 5.1. Number of vessels that reported landings of Australian Sardine in the East, from each of the participating management jurisdictions for each financial year from 1997/98 – 2013/14.

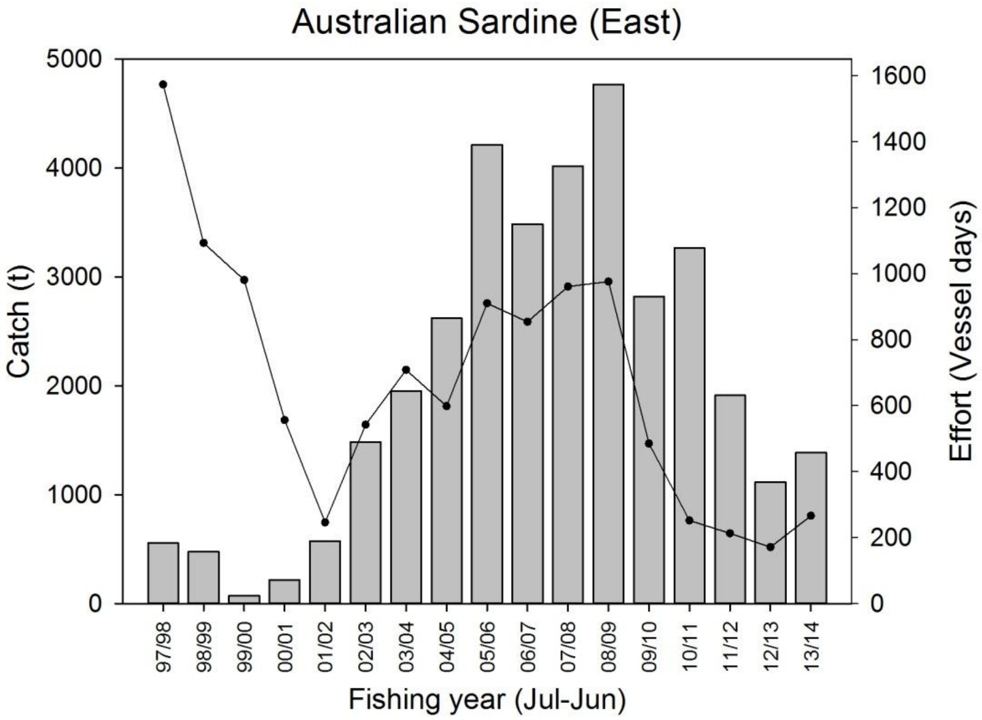

Figure 5.2. Total landed catch (t, bars) and effort (vessel days, line) for the East for each financial year from 1997/98 – 2013/14.

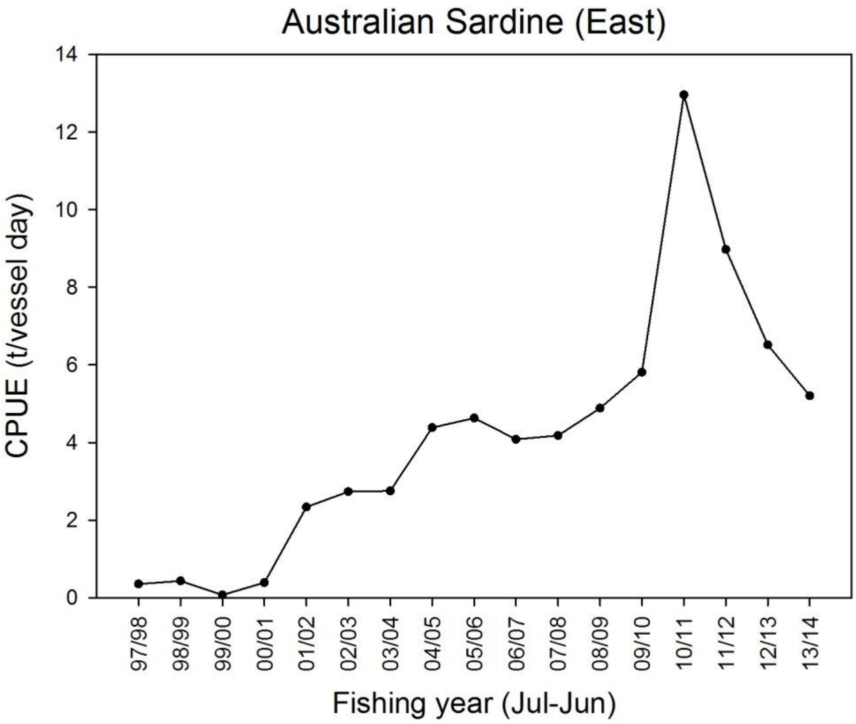

Figure 5.3. CPUE (t per vessel day) for the East for each financial year from 1997/98 –2013/14.

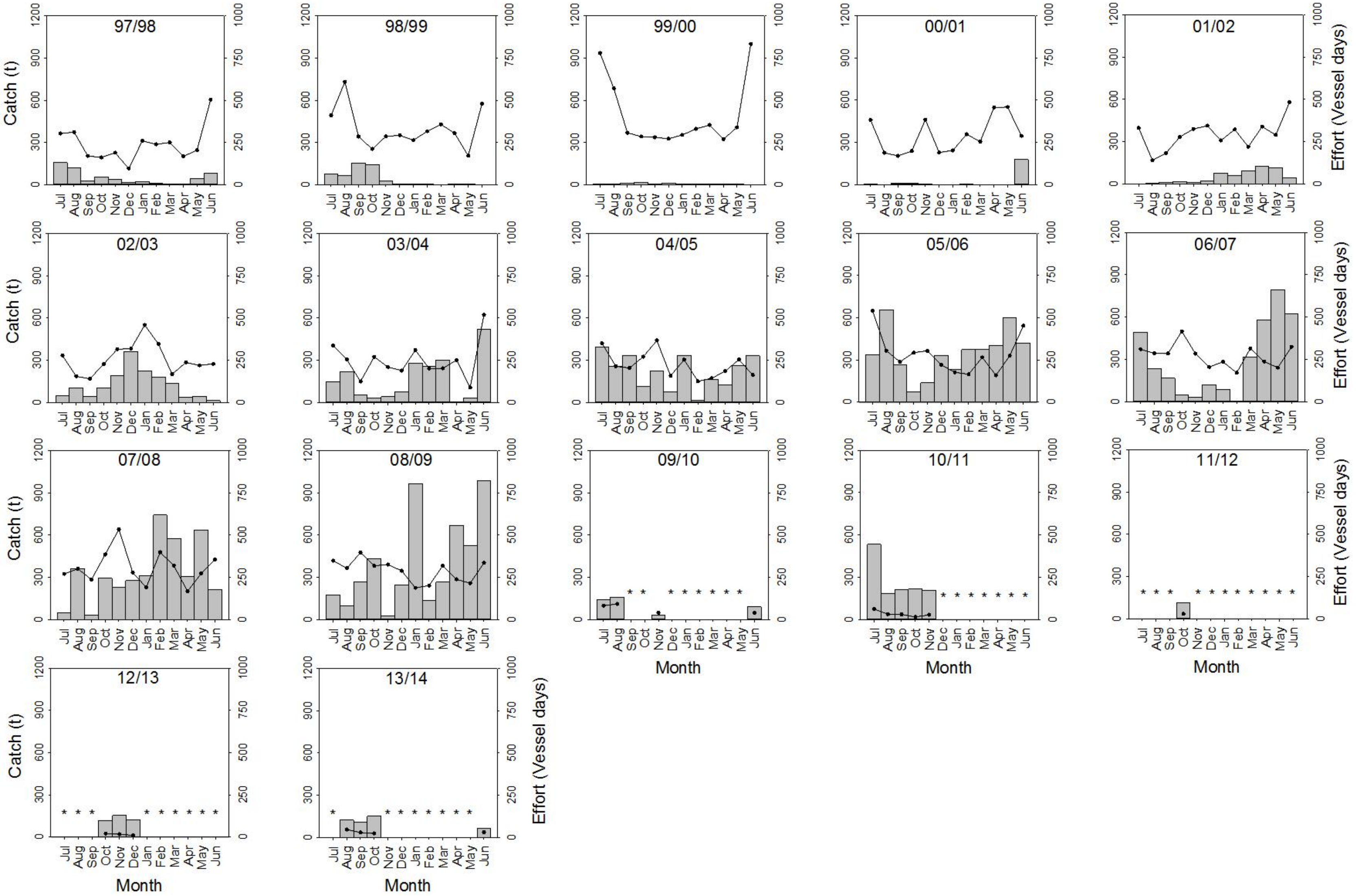

Figure 5.4. Intra-annual patterns of catch (bars) and effort (line) for Australian Sardine for the East for each financial year from 1997/98 – 2013/14. Catch and effort data for each year from 2010/11 - 2013/14 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders reported landings.

5.3.2 Biological Information

Sample Summary

Annual length frequency data for Australian Sardine sampled from commercial catches taken in New South Wales between 2004/05 and 2013/14 were supplied by New South Wales DPI (Table 5.1). The number of samples collected in each financial year ranged between 2 (2004/05) and 54 (2009/10). In 2013/14, 2,075 fish were collected from 30 sampling events.

Table 5.1. Summary of the samples of Australian Sardine collected from commercial purse-seine net catches taken in New South Wales between 2004/05 and 2013/14 (data supplied by New South Wales DPI).

Season	No. of samples	No. of fish	Size range (mm FL)
2004/05	2	249	90 – 210
2005/06	7	592	80 – 240
2006/07	31	3,098	70 – 230
2007/08	12	1,209	90 – 230
2008/09	8	860	110 – 210
2009/10	54	5,579	50 – 230
2010/11	5	473	100 – 220
2011/12	6	691	100 – 200
2012/13	4	538	100 – 180
2013/14	30	2,075	120 - 190

A total of 1,028 Australian Sardine were collected from commercial fishers in New South Wales for biological analysis during 2009 and 2010, with 240 fish captured from the north coast (Iluka) and 788 from the south central coast (Eden). These samples were collected over a period of three months from the north coast and eight months from the south central coast (Table 5.2). An additional 2,945 Australian Sardines were sampled from commercial catches taken in New South Wales between July 2013 and July 2014 to determine population size and age structures and monitor reproductive activity (Table 5.2).

Length data for 1,188 Australian Sardine, measured by AFMA observers in September 2012 (n = 208) and August 2013 (n = 980), were provided to SARDI (Table 5.3). From these samples, a total of 32 and 246 fish in 2012 and 2013, respectively, were retained for ageing.

In the context of the magnitude of catches of Australian Sardine in the East since the mid-1990s, the number and spatial and temporal coverage of the biological samples collected are limited and unlikely to provide a good representation of the catch.

Table 5.2. Summary of the number of Australian Sardines supplied to SARDI for biological analysis from the north coast and south central coast of New South Wales from March 2009 to January 2010.

Month	**North coast**	**South Central coast**
Mar-09	-	8
Jun-09	-	70
Jul-09	120	160
Aug-09	80	100
Sep-09	40	151
Oct-09	-	120
Nov-09	-	79
Jan-10	-	100

Table 5.3. Summary of the samples of Australian Sardine collected from commercial purse-seine net catches taken in New South Wales from July 2013 to July 2014 (data supplied by SARDI).

Month	**No. of samples**	**No. of fish**	**Size range (mm FL)**
July-13	5	250	124 – 173
Aug-13	16	734	131 – 178
Sep-13	14	576	68 – 179
Oct-13	4	229	133 – 177
Nov-13	1	52	139 – 168
May-14	8	377	127 – 185
Jun-14	16	727	124 – 193
Jul-14	7	322	130 - 194

Size Structure

Annual size structures for Australian Sardines sampled from commercial catches taken in New South Wales between 2004/05 and 2013/14 comprised mostly fish between 100 and 200 mm FL, although the modal size varied among years (Figure 5.5). For some years (i.e. 2004/05 to 2006/07, 2011/12), the size structure was bimodal with a dominant mode at ~140-150 mm FL (i.e. the approximate size at sexual maturity for Australian Sardine) and a smaller mode at ~180-200 mm FL. However, the size structures for all other years comprised a single dominant mode between 140 and 170 mm FL. For 2012/13 and 2013/14, the lengths of fish sampled were narrowly distributed around dominant modes at ~140 mm FL.

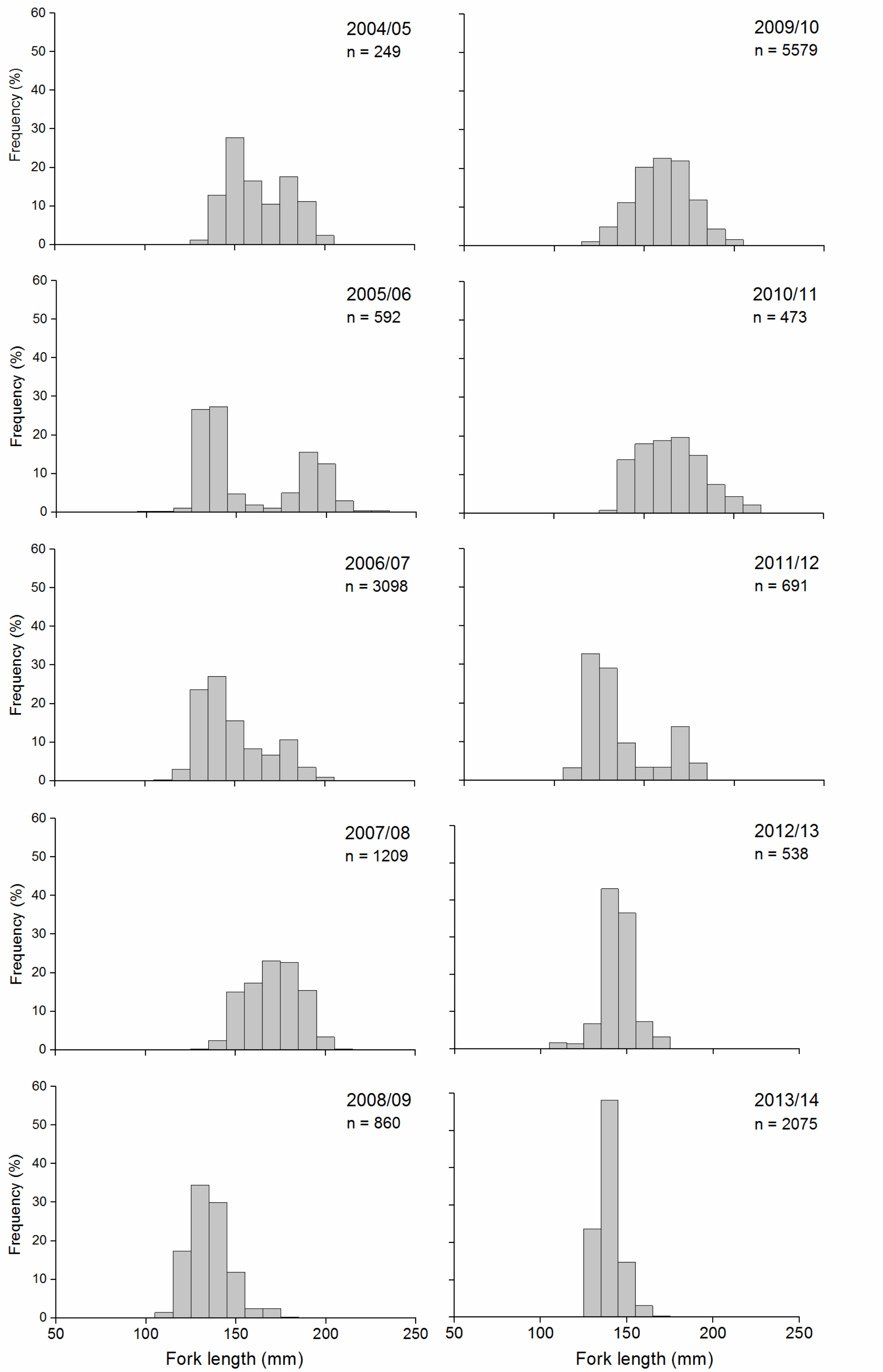

Figure 5.5. Annual length frequencies (mm FL) for Australian Sardine sampled from commercial catches taken in the northern (since 2008/09) and southern regions of New South Wales (combined) from 2004/05 to 2013/14. Data supplied by New South Wales DPI.

Monthly size structures for Australian Sardines taken by commercial purse-seine vessels in New South Wales from March 2009 to January 2010 comprised mainly fish between 120 and 200 mm FL (Figures 5.6, 5.7). For the north coast of New South Wales in July, August and September, the size structures had a single dominant mode at ~170 mm FL (Figure 5.6). Size structures for the south central region were more variable between months. The modal length of fish sampled in each month increased gradually from ~145 mm FL in March 2009 to ~185 mm FL in January 2010.

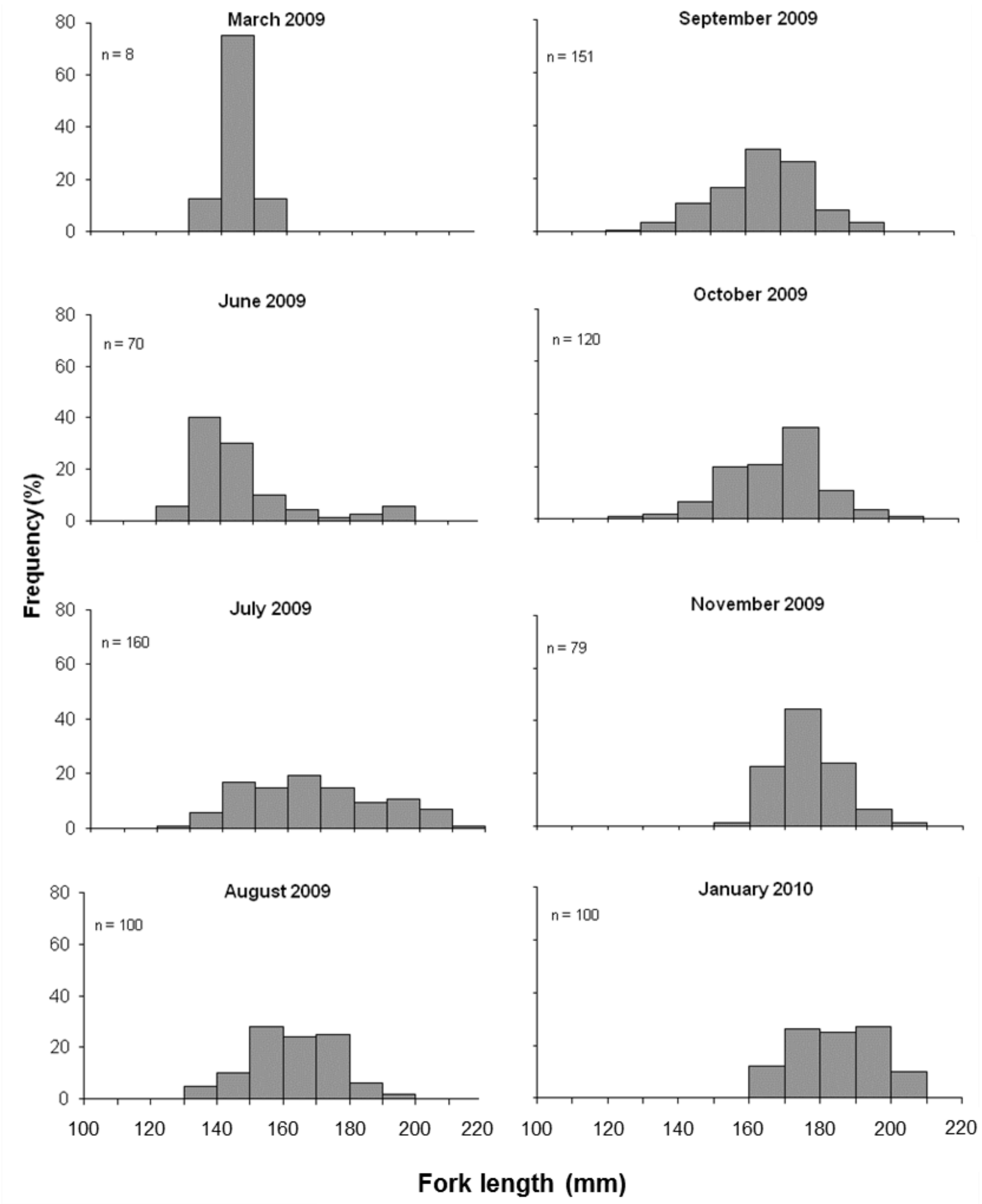

Figure 5.6. Length frequency histograms (mm FL) for Australian Sardine samples from commercial catches from the south-central coast of New South Wales in 2009 and 2010.

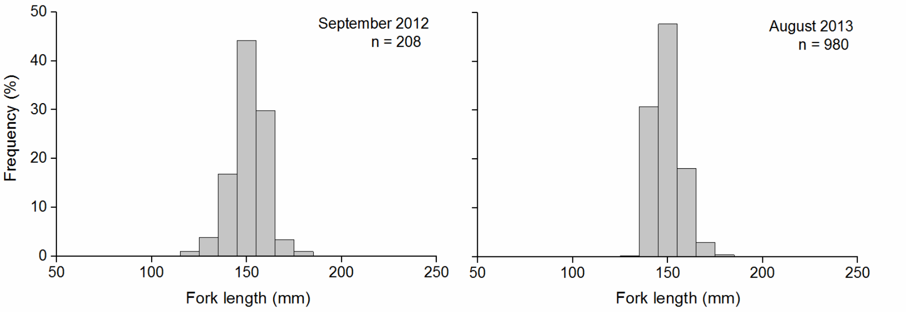

Figure 5.7. Length frequency histograms (mm FL) for Australian Sardine samples collected by AFMA observers aboard commercial fishing vessels in September 2012 and August 2013 on the north coast of New South Wales.

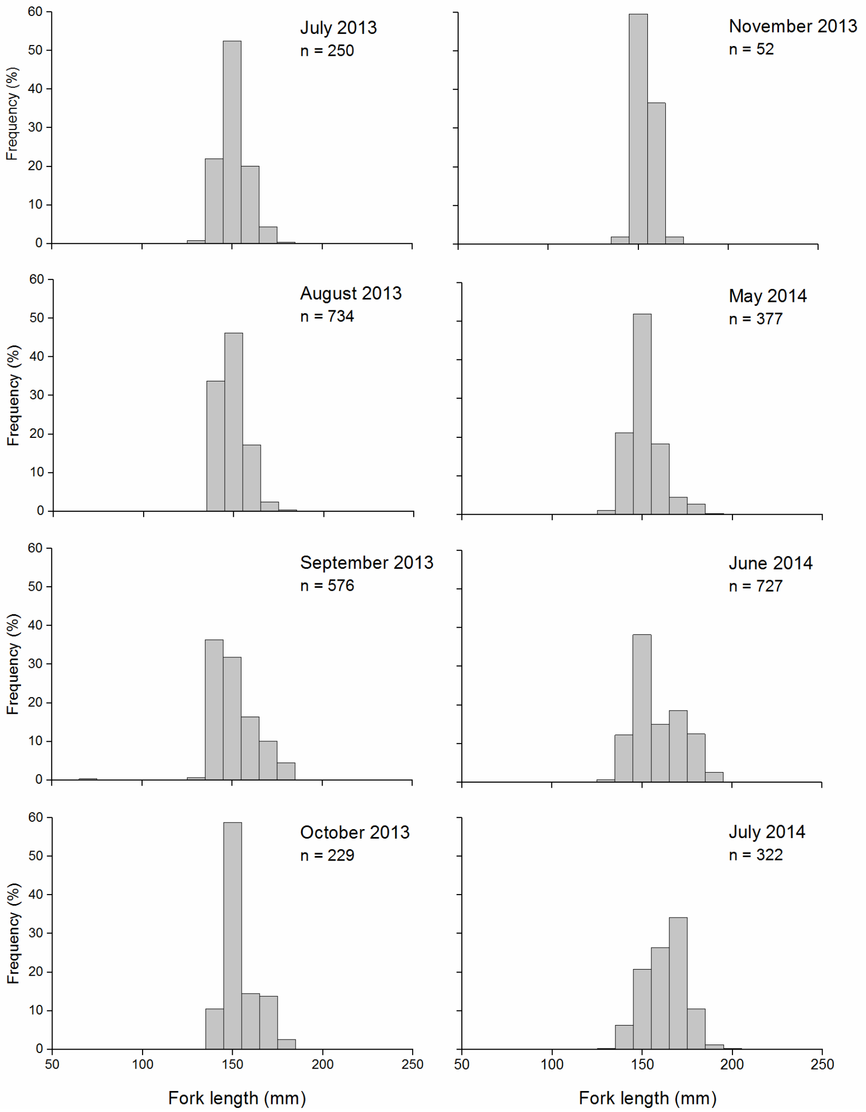

Figure 5.8. Monthly length frequency histograms (mm FL) for Australian Sardine sampled from commercial catches taken in the northern (since 2008/09) and southern regions of New South Wales (combined) from July 2013 to July 2014. Data supplied by SARDI Aquatic Sciences.

Age structure

The ages of Australian Sardine collected from commercial catches from the south central New South Wales coast in 2009 ranged from 0+ to 5 years, whereas catches from the northern region consisted of individuals from 0+ to 3 years (Figure 5.9). Commercial samples from northern New South Wales in September 2012 and August 2013 comprised mostly 2 year old fish (Figure 5.10).

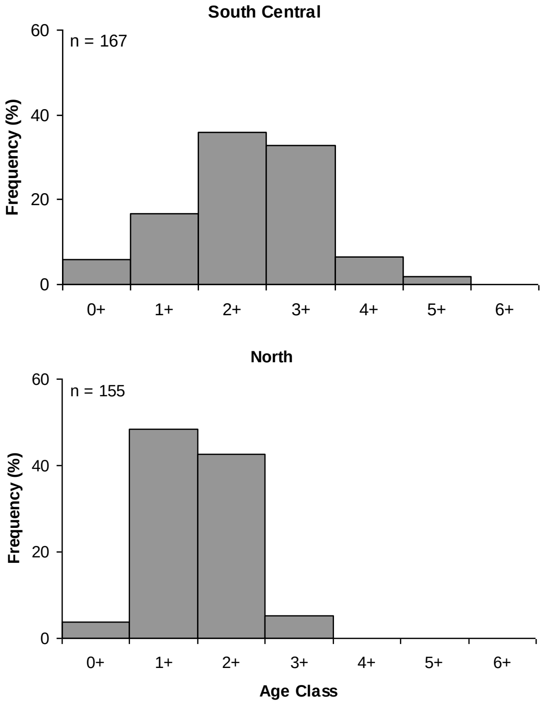

Figure 5.9. Age frequency histograms for Australian Sardine samples from commercial catches from the south central and north coast of New South Wales in 2009. Data derived from otolith ring counts. Otoliths with poor readability were omitted.

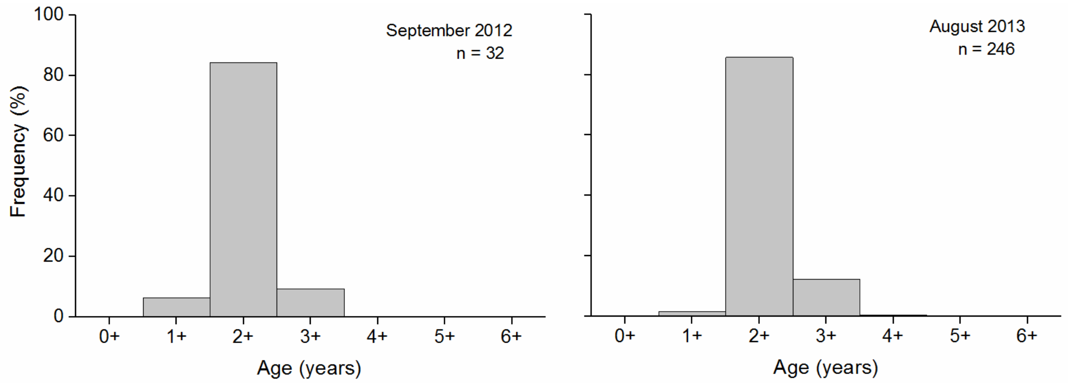

Figure 5.10. Age frequency histogram for Australian Sardine collected from commercial vessels on the north coast of New South Wales in September 2012 and August 2013. Ages are derived from the otolith weights using the South Australian commercial catch relationship (Rogers and Ward 2007).

Commercial samples collected monthly from northern New South Wales between July 2013 and July 2014 comprised mostly 2 and 3 year old fish, although fish up to 6 years were recorded in May 2014 (Figure 5.11).

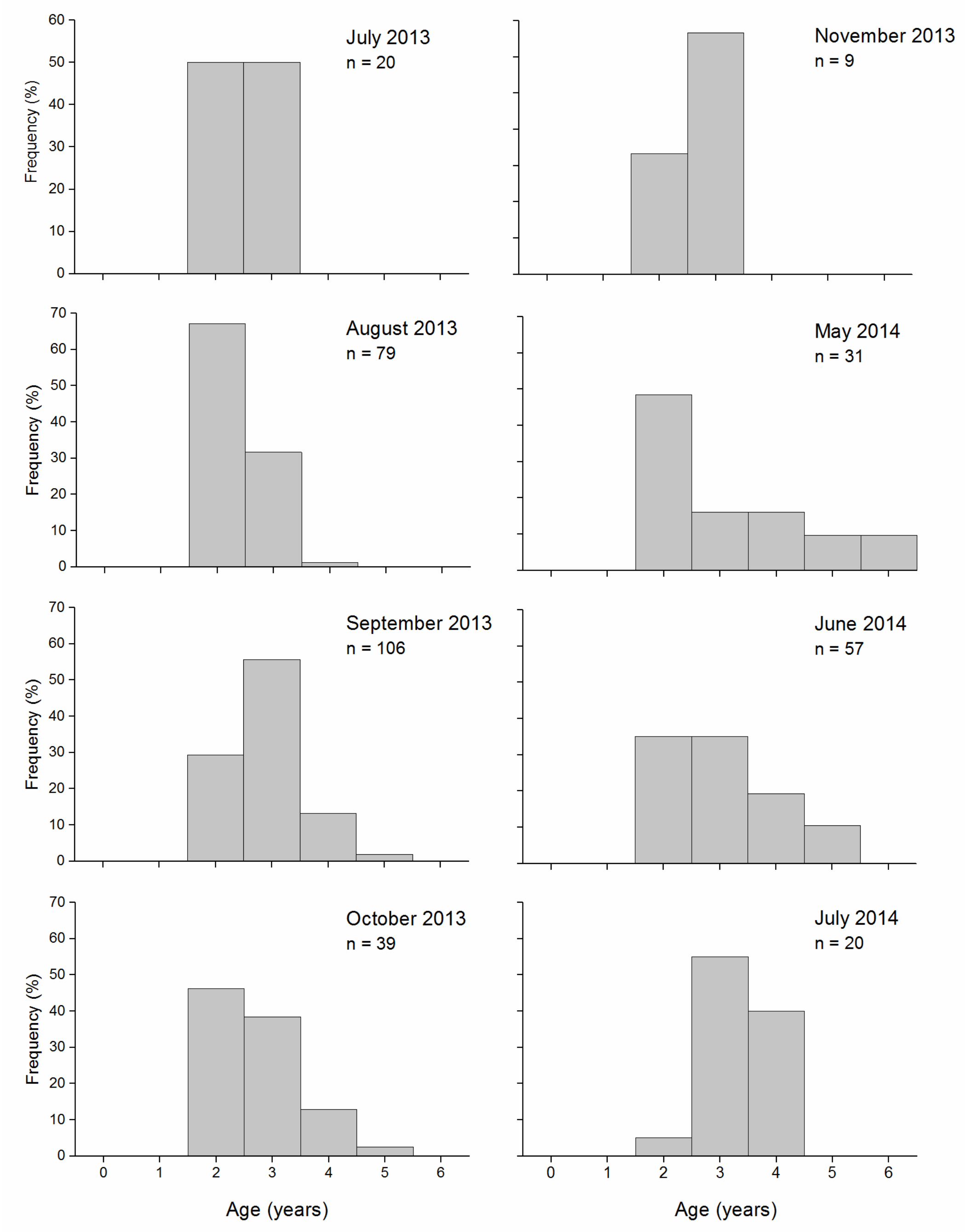

Figure 5.11. Monthly age frequencies for Australian Sardine sampled from commercial catches taken in the northern (since 2008/09) and southern regions of New South Wales (combined) from July 2013 to July 2014. Data supplied by SARDI Aquatic Sciences. Otoliths with poor readability were omitted.

Growth

The growth patterns for Australian Sardines collected from the North and South Central coasts of New South Wales were similar (Figure 5.10). Samples from both regions exhibited considerable variation in size for each of the age classes.

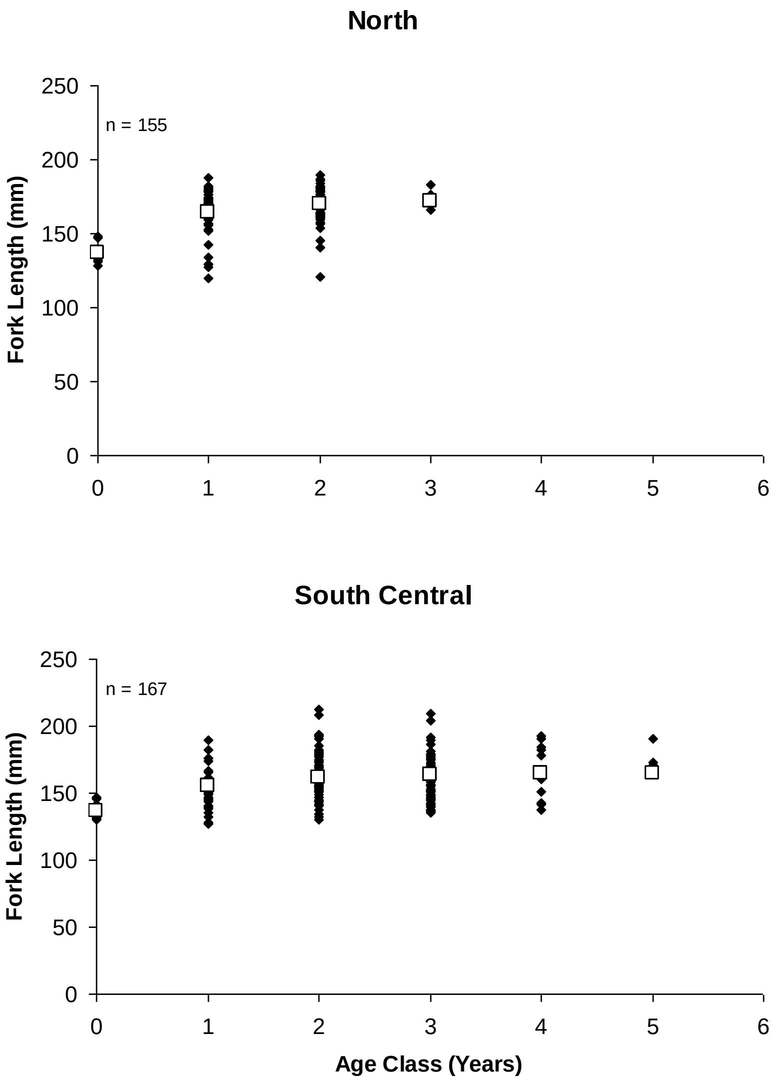

Figure 5.12. Growth patterns for Australian Sardines collected from commercial catches from the north and south central coast of New South Wales in 2009. Ages were derived from ring count analysis; otoliths with poor readability (readability index 4 and 5) were omitted. Open squares generated from the VGBF.

Gonad stages

Samples from the north and south central New South Wales coast comprised mainly of mature fish (≥ Stage 2) across the sampling period (Figure 5.13). Insufficient numbers of immature fish were collected to facilitate an estimate of size at maturity. Actively spawning females (Stage 4) were collected from the north coast in all months sampled (July, August and September) and in June, July and August on the south central coast.

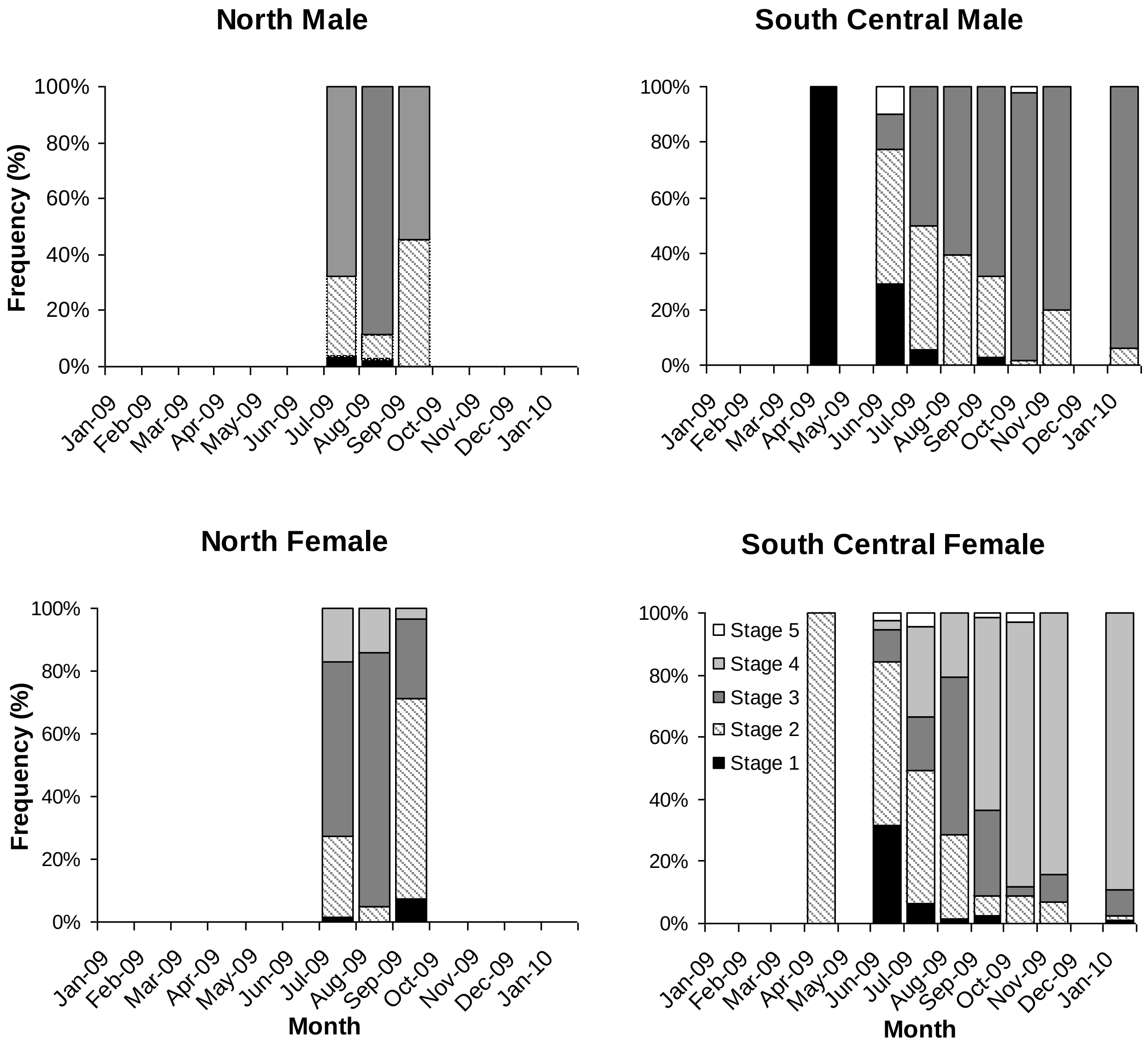

Figure 5.13. Frequency of occurrence of each stage of gonad development (Stage 1-5)for monthly sampling of Australian Sardine from both the north and south central coast of New South Wales. Sample sizes for each month are shown in Table 5.3.

Sex ratio

In 2009/10, the sex ratios of samples of Australian Sardine collected in all months and regions were biased towards females (Table 5.4). The sex ratios of samples collected in 2013 were variable, with a bias toward males in July, August and October and a bias toward females in September and November (Table 5.5). In contrast, all samples collected in 2014 comprised slightly more females than males.

Table 5.4. Sex ratio (R) of Australian Sardine samples taken in 2009/10.

	South Central			**North**		
Month	**Female**	**Male**	**R**	**Female**	**Male**	**R**
March 2009	6	2	0.75			
June 2009	38	31	0.55			
July 2009	108	52	0.68	70	50	0.58
August 2009	67	33	0.67	43	35	0.55
September 2009	80	70	0.53	28	11	0.72
October 2009	68	52	0.57			
November 2009	44	35	0.56			
January 2010	83	17	0.83			
Total	494	292	0.63	141	96	0.59

Table 5.5. Sex ratio (R) of Australian Sardine samples taken from July 2013 to July 2014.

Month	**Female**	**Male**	**R**
July-13	109	141	1.29
Aug-13	299	435	1.46
Sep-13	312	262	0.84
Oct-13	113	116	1.02
Nov-13	38	13	0.34
May-14	191	186	0.97
Jun-14	377	349	0.93
Jul-14	166	156	0.94

Gonadosomatic index

GSI estimates were used to describe the timing and duration of gonad development for Australian Sardine from New South Wales. For the north coast in 2009, a lack of samples limited the analysis of temporal variation in GSIs, although the estimated values for both sexes were relatively high in August (Figure 5.14). For the south central coast, GSIs for females were lowest in April and June and increased gradually to the annual maximum in November. Similarly, GSIs for males were low in June and increased through the winter and spring months to a maximum in mid-summer (January 2010).

For Australian Sardines from New South Wales from July 2013 to July 2014, GSIs for both sexes were relatively high during July and August 2013, gradually decreased from September to November, remained low until May 2014 and then increased to a peak in July 2014 (Figure 5.15).This suggests that spawning most likely occurred during the winter months.

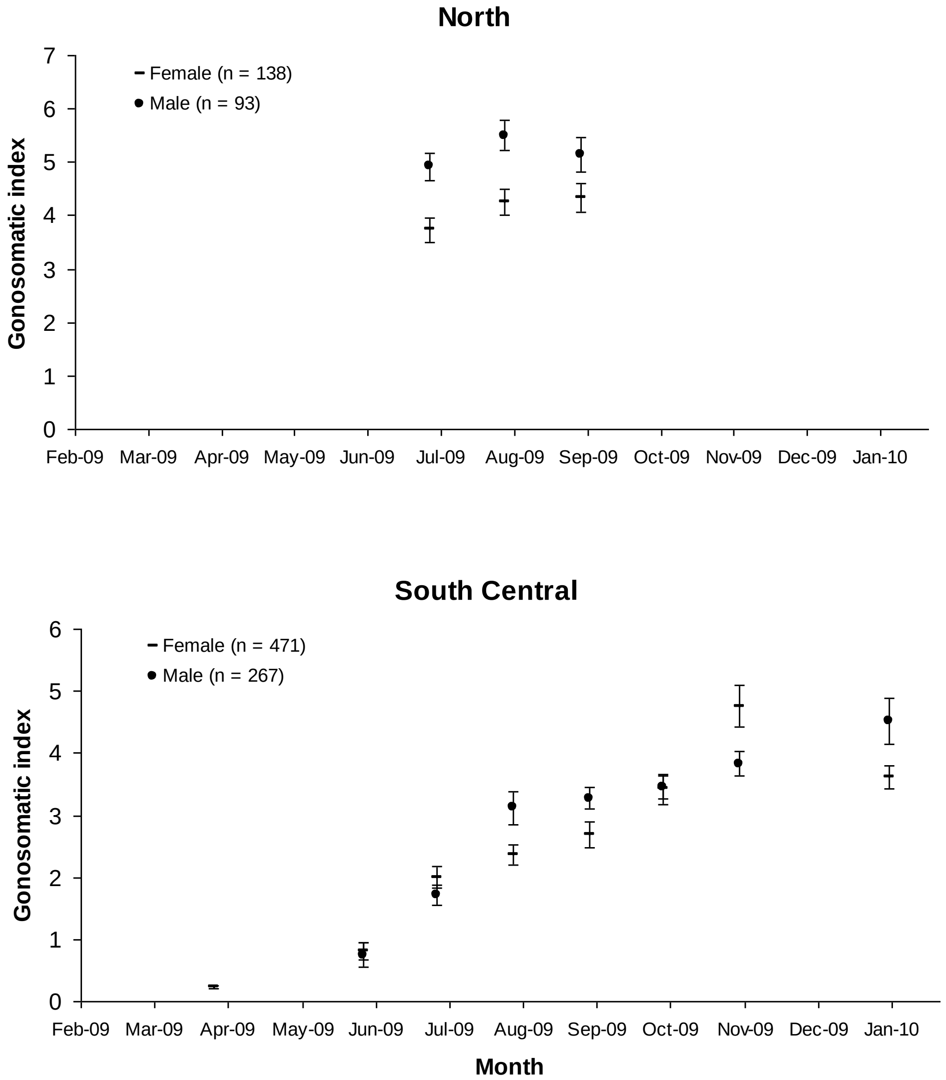

Figure 5.14. Monthly GSIs (% ± SE) for Australian Sardine from the north and south central coast of New South Wales between February 2009 to January 2010.

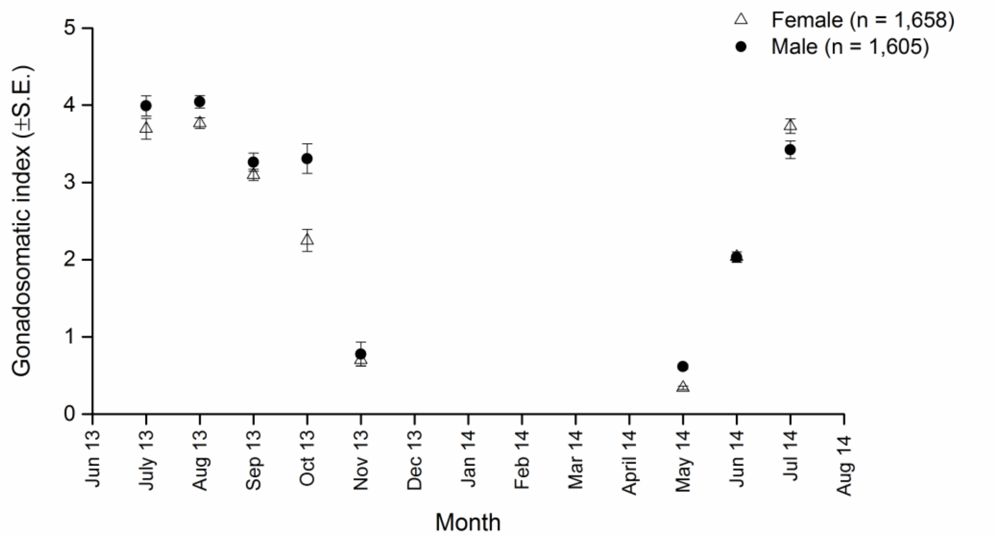

Figure 5.15. Monthly GSIs (% ± SE) for Australian Sardine from New South Wales between July 2013 and July 2014. Error bars are standard error. Immature fish (stage 1) have been omitted from data.

5.3.3 Biomass Estimates and MSE

DEPM

The total area sampled during the 2004 ichthyoplankton survey was ~41,585 km^2 (Ward and Rogers 2007). Overall, a total of 2,441 Australian Sardine eggs were collected from 85 stations. High densities of eggs were recorded between Cape Byron and Newcastle.

The best estimate of spawning biomass off eastern Australia during July 2004 was 28,809 t. Minimum and maximum estimates were 9,161 and 58,673 t, respectively. Spawning biomass estimates were relatively insensitive to variations in spawning area, female weight, sex ratio and batch fecundity. Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000–35,000 t. This estimate is conservative and likely negatively biased as spawning season and area varies temporally and spatially on the East coast of Australia (Ward and Staunton-Smith 2002), and it is unlikely that the entire spawning area was sampled in peak spawning season.

Estimates of spawning biomass provide a context for assessing the suitability of recent catch levels for Australian Sardine (Ward and Staunton-Smith 2002). The highest annual catch of ~4,800 t (2008/09) is ~16.6% of the best estimate of spawning biomass, suggesting that fishing is being conducted within sustainable limits.

Based on surveys undertaken in January 2014 by Ward *et al.* (2015), the estimated spawning area for Australian Sardine off south-eastern Australia was 11,906 km^2. It is important to note that this not an estimate of the total adult biomass of Australian Sardine off eastern Australia, it is only an estimate of the portion of the population that was spawning in this part of the range during that period, as the main spawning area for Australian Sardine off eastern Australia occurs off northern New South Wales and southern Queensland during late winter and early spring (Ward and Staunton-Smith 2002). Overall, a total of 1,429 live Sardine eggs were collected from 59 of the 292 sampling stations, most of which were off north-eastern Tasmania and in Bass Strait where SSTs were between 16 – 21°C (Ward *et al.* 2015). The estimate of spawning biomass for this region was 10,962 t. The study by Ward *et al.* (2015) provides unequivocal evidence that Australian Sardine occurs in this area at least in some years and provides insights into the quantum of catches that may be suitable for any developmental fishery that may be established in the region.

MSE

For Australian Sardine in the East Zone, the DEPM estimate of spawning biomass based on surveys in 2004, was 96% of the model calculated estimate of spawning biomass. The Tier 1 scenarios investigated using the MSE, all reached equilibrium at around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels are also sustainable. Given that the DEPM survey estimate of spawning biomass is close to the model calculated estimate, these conclusions can be considered with greater certainty.

5.4 Summary and Conclusions

The best estimate of spawning biomass of Australian Sardine off eastern Australia is 28,809 t (2004 survey; Ward and Rogers 2007). Only unlikely values of mean daily egg production and spawning fraction produced estimates outside the range of 25,000 – 35,000 t. However, as the entire spawning area was not surveyed, the spawning biomass may have been under estimated. Annual catches of Australian Sardine in the East were <1000 t from 1997/98 – 2001/02, but exceeded 2,000 t from 2004/05 – 2011/12, including 4,768 t in 2008/09. Catch declined to 1,114 t in 2012/13. In 2013/14, the total catch of 1,385 t was 4.7% of the best estimate of spawning biomass (28,809 t) and 46% of the current RBC (3,000 t) for the stock. These estimates of annual total catch represent the cumulative annual catch from fisheries managed separately by three jurisdictions (i.e. New South Wales, Victoria and the Commonwealth).

The reduction in fishing effort for Australian Sardine in the East since 2008/09 reflects a significant reduction in the size of the fishing fleet, with only eight commercial vessels reporting catch in 2013/14, compared to >25 vessels in some years during the 2000s. Other factors that may have also contributed to the reduction in effort include a fire in a major fish processing factory in Eden (southern New South Wales) and movement of Sardines from inshore to offshore waters (AFMA 2014).

On the basis of the information presented in this chapter and using the definitions from the National Status of Key Australian Fish Stocks Report (Flood *et al.* 2014), the Australian Sardine stock in the East is classified as sustainable. This is consistent with the most recent classification of stock status for Australian Sardine by Ward *et al.* (2014a).

Results from a DEPM survey conducted off northern New South Wales and southern Queensland during September 2014 will provide an estimate of the spawning biomass of adult Australian Sardine off eastern Australia.

6 GENERAL SUMMARY AND CONCLUSIONS

Available evidence suggests that recent catch levels of all SPF quota species are sustainable. In 2013/14, catches of Blue Mackerel, Jack Mackerel and Redbait were relatively low and well below the Tier 2 maximum RBCs for each species for both the West and East zones of the SPF. There is no evidence to suggest that the recent low catches for these species relates to a depleted stock biomass. Rather the reductions in fishing effort and catch appear to be driven by economic constraints. The most recent classification of stock status for Jack Mackerel suggested that the biological stocks in the East and West are sustainable (Flood *et al.* 2014). Blue Mackerel and Redbait were classified as ‘not over-fished’ in both zones (Woodhams *et al.* 2012). One exception was for Redbait in the West, which was classified as ‘uncertain’ (Woodhams *et al.* 2012). The evidence presented in this report suggests that the current catch levels of Blue Mackerel, Jack Mackerel and Redbait in the East and West zones are sustainable.

The total catch of Australian Sardine of 1,385 t in 2013/14 was well below the RBC for this species. The evidence presented in this report suggests that the current catch level of Australian Sardine (East) is sustainable.

With the exception of Jack Mackerel in the East, the current understanding of the status of SPF species in both zones is limited by the increasingly long period since DEPM surveys have been conducted for individual stocks. Research surveys were undertaken in August 2014 to estimate the spawning biomasses of Australian Sardine and Blue Mackerel in the East Zone. The report on these surveys will be completed in 2015.

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