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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2013

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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2013

Report to the Australian Fisheries Management Authority

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

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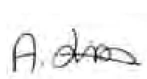
Signed: 

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EXECUTIVE SUMMARY

This report presents fishery statistics and synthesises existing stock assessment information for the key 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).

Due to the low number of fishing vessels operating in 2012/13, estimates of total catch were confidential for most SPF species. One exception was Blue Mackerel (*Scomber australasicus*), for which total catches in the East and West Zones were low in a historical context due to relatively low levels of fishing effort.

Preliminary Daily Egg Production Method (DEPM) assessments for Blue Mackerel provided a mid-range best estimate of spawning biomass of ~56,000 t in the West Zone (2005 survey). For the East Zone, 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 (AFMA 2014). Management Strategy Evaluation (MSE) suggested that the spawning biomass was higher than the DEPM estimate in each zone. Since 1997/98, Blue Mackerel catches in the East ranged from 309–1007 t, with 454 t taken in 2012/13. In the West, catches increased rapidly after 2004 and reached 1,977 t in 2008/09. Total catch in 2012/13 was 2.3 t. Recent annual catches have been well below the maximum RBC limit at Tier 2 for each zone (3,000 t in East; 6,500 t in West). All fish sampled from catches in the West Zone were above the estimated size at maturity; catches were dominated by 4 and 5 year old fish. There is no evidence to suggest that recent catches of Blue Mackerel in either zone are not sustainable.

Preliminary DEPM assessments of Jack Mackerel (*Trachurus declivis*) in the East Zone derived from samples collected in October 2002, estimated a spawning biomass of between 114,900 t and 169,000 t (median 141,500 t). Off Tasmania, catches peaked at ~40,000 t in 1986/87, but have not exceeded ~3,000 t since 2003/04. Estimates of total catch of Jack Mackerel in 2012/13 are confidential. Catches in the West have not exceeded 500 t in the period since 1997/98. The abundance of older age classes in purse-seine catches off Tasmania declined between the mid-1980s and mid-1990s, potentially indicating a 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.

Historically high catches of Yellowtail Scad (*Trachurus novaezelandiae*) reported since 2009/10 has resulted from the entry of a number of new purse seiners. Catch peaked at 727 t in 2010/11 and declined to 525 t and 477 t in 2011/12 and 2012/13, respectively.

DEPM estimates for Redbait (*Emmelichthys nitidus*) in the East suggest a spawning biomass in excess of 50,000 t, implying that peak annual catches of ~7,000 t during the early 2000s were sustainable. This conclusion was supported by the outputs from the MSE. No Redbait catches were reported for 2012/13 in either zone. 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 (*Sardinops sagax*) 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. Catches of Australian Sardine in the East remained below 1,000 t up to 2001, but have exceeded 2,000 t since 2004/05 and reached almost 5,000 in 2008/09. In 2012/13, the catch of Australian Sardine in the East was 2,022 t. In 2012/13, the number of vessels reporting catch declined by 40% and total catch declined to 1,097 t. The highest annual catch in the East (~5,000 t) was ~17% of the best estimate of spawning biomass (~29,000 t based on samples collected in 2004). There is no evidence to suggest that the recent catch level of Australian Sardine in the East is not sustainable.

There is no evidence to suggest that recent catch levels of any SPF quota species are not sustainable. However, all estimates of spawning biomass are five or more years old, with the exception of Jack Mackerel East that was undertaken in 2011. Consideration should be given to conducting DEPM assessments for all species in each zone. A survey of Jack Mackerel in the East Zone was undertaken in January 2014. The large size of the West Zone makes the stock assessment in that area difficult.

1 GENERAL INTRODUCTION

1.1 Background to Small Pelagic Fishery

The Commonwealth Small Pelagic Fishery (SPF), managed by the Australian Fisheries Management Authority (AFMA), is a purse-seine and mid-water trawl fishery extending from southern Queensland to southern Western Australia. There are currently 71 licences in the SPF which target several species including Jack Mackerel *Trachurus declivis*, Redbait *Emmelichthys nitidus*, Blue Mackerel *Scomber australasicus,* and Australian Sardine *Sardinops sagax.* Yellowtail Scad, *Trachurus novaezelandiae,* is taken as by-product. SPF species are also taken in several State and Commonwealth managed fisheries, including by the recreational fishing sector (Henry and Lyle 2003). Key events in the history of the SPF are listed in Woodhams *et al.* (2012).

1.2 Harvest Strategy

The SPF is managed by a combination of input and output controls that include limited entry, zoning, mesh size restrictions, and total allowable catch (TAC) limits (AFMA 2008, reviewed in April 2013; Woodhams *et al.* 2012). A new Management Plan was implemented in 2009 that established Eastern and Western management sub-areas (zones, hereafter referred to as East and West) rather than the previous four (Figure 1.1, AFMA 2009) and introduced some new controls such as Individual Transferable Quotas (ITQs).

There is a tiered Harvest Strategy (HS) with prescribed levels of research required at each Tier (AFMA 2008; Woodhams *et al.* 2012). Recommended Biological Catches (RBCs) are determined by the SPF Resource Assessment Group (SPFRAG).

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 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 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.

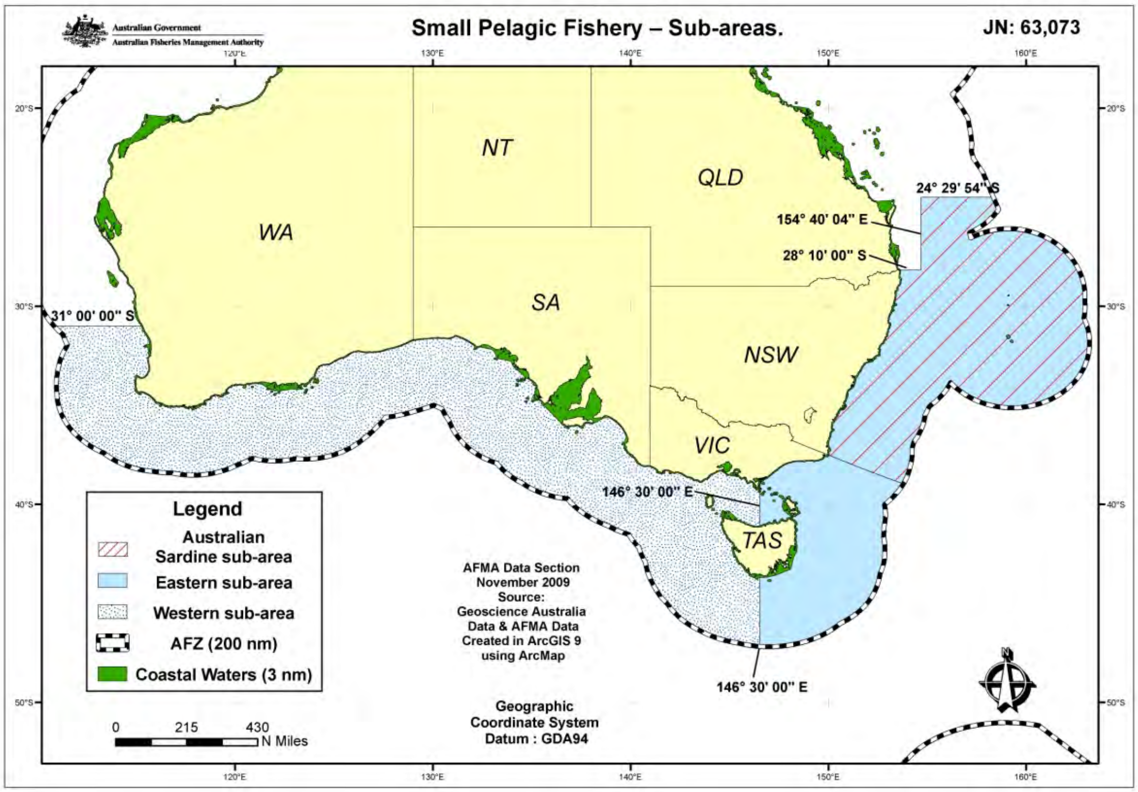

Figure 1.1 Management sub-areas of the Commonwealth Small Pelagic Fishery.

Table 1.1 Tier 2 maximum RBC values for the West and East Zones of the Small Pelagic Fishery (from AFMA 2014).

Species	West Zone (t)	East Zone (t)
Blue Mackerel	6,500	3,000
Jack Mackerel	5,000	10,600
Redbait	5,000	5,000
Australian Sardine	N/A	3,000

1.3 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 2011) and Yellowtail Scad East (Neira 2011). Management Strategy Evaluations (MSEs) have been conducted by Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Giannini *et al.* 2010). This assessment of the

Commonwealth SPF builds on previous annual assessment reports by Ward *et al.* 2010; 2011; 2012).

1.4 Aims and Objectives

This report collates and presents recent catch/effort and biological data for each of the quota species in the SPF and an important by-catch species, Yellowtail Scad. Biomass estimates and MSEs are also included where available. The report satisfies the requirements of the SPF Harvest Strategy (AFMA 2008).

2 BLUE MACKEREL (*SCOMBER AUSTRALASICUS*)

2.1 Introduction

2.1.1 Background to Fishery

Large fisheries for *Scomber spp.* (i.e. ~50,000 to 500,000 t per annum) are located off Japan, Peru, China, Korea, Russia, and the Ukraine (Ward *et al.* 2001). The largest fishery for Blue Mackerel is based in New Zealand where annual catches range between approximately 9,000 and 14,000 t per annum. Blue Mackerel is taken in several fisheries in Australia with total annual catches usually less than 3,000 t (Ward *et al.* 2001).

Blue Mackerel is predominately taken in the SPF but also in the Great Australian Bight Trawl (GAB), Gillnet Hook and Trap (GHT), Western Tuna and Billfish (WTBF), Eastern Tuna and Billfish (ETBF) and the South East Trawl (SET) fisheries (Ward and Rogers 2007). Relatively small quantities of Blue Mackerel are taken in South Australia by Marine Scalefish Fishery (MSF) licence holders using pole, hand-line, troll-line, long-line, gill-net, shark-net, bait-net and purse-seine nets (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 comprise ~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 contained a shot-by-shot record of fishing operations and species taken. The first reported landings of Blue Mackerel occurred during the 1985/86 fishing season, but limited species-specific information was recorded (Ward and Rogers 2007). From 1985/86 to 1989/90, Blue Mackerel represented <4% of catches. Species-specific information was not available for other years.

Blue Mackerel is taken in a multi-species fishery off Western Australia using a variety of gear types, including purse-seine, beach seine, trawl, gill and haul nets, fishing poles and drop lines (Ward and Rogers 2007).

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. australasicu*s and *S. japonicus* are more closely related to each other than to *S. scombrus*, and that morphological and genetic differences in Atlantic and Indo-Pacific populations of *S. japonicus* may warrant recognition of two separate species. Analyses by Infante *et al.* (2006) support this claim and a separate species, *S. coli*, has been established to replace *S. japonicus* in the Atlantic Ocean. 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. One study found significant differences between Australia and New Zealand in the morphology of monogenean parasites (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).

2.1.5 Movement

Little is known about the movement patterns of Blue Mackerel in Australian waters.

2.1.6 Food and Feeding

Mackerel (*Scomber* spp.) have been found to alter their feeding behaviour and ingestion rates depending on prey size and density and to consume their own larvae (Prokopchuk and Sentyabov 2006; Garrido *et al.* 2007). A recent study of the diet of small pelagic fish off South

Australia found the diet of Blue Mackerel to be dominated by krill and larval fish (Daley, SARDI Aquatic Sciences, unpublished data).

2.1.7 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. Stevens *et al.* (1984) found that Blue Mackerel attained sizes of up to 440 mm FL in the Great Australian Bight (GAB) and estimated that fish were aged up to ~8 years. Stewart *et al.* (1999) showed that off eastern Australia an opaque zone is deposited during winter in the otoliths of one-year old Blue Mackerel, and that zones became visible in early summer (Stewart *et al.* 1999). Stewart and Ferrell (2001) estimated the ages and growth rates of Blue Mackerel taken off southern New South Wales in commercial purse-seine operations and in a fishery-independent sampling program. Most fish in the commercial catches were 1–3 years old and the maximum age was ~7 years.

2.1.8 Reproduction

Approximately 50% of male and female Blue Mackerel are sexually mature at 237 and 287 mm FL, respectively. Blue Mackerel are serial spawners, spawning 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°C. 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).

2.1.9 Early Life History and Recruitment

Blue Mackerel eggs are transparent and spherical, measure 0.80-1.35 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.

2.1.10 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 Daily Egg Production Method (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).

2.1.11 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). Comparisons of the estimated total recreational catch of Blue Mackerel to the total commercial catch for the Commonwealth SPF for 2000/01 is presented for the East and West Zones in Figure 2.3 and Figure 2.5, respectively.

2.2 Methods

2.2.1 Fishery Statistics

Fishery statistics were supplied by the ABARES for the period from 1997/98 to 2010/11. Since then, data are supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported by 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 were for oceanic fishing activity only.

2.2.2 Biological Information

Samples of Blue Mackerel from the West were obtained from catches from the commercial purse-seine fishery operating from Port Lincoln, South Australia between 2008/09 and 2010/11. No fine-scale spatial or temporal information was available for these samples, although the fish were caught in summer/early autumn. Fish were dissected and otoliths were weighed and read (ring count and a readability index assigned) at SARDI Aquatic Sciences. Reproductive indices were determined after Ward and Rogers (2007). Size frequency data for samples collected from commercial purse-seine fishing operations in New South Wales in 2011/12 and 2012/13 were supplied by New South Wales DPI.

2.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Blue Mackerel was obtained for each zone during a study between 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

2.3.1.1 Location of vessels

A total of 31 vessels landed Blue Mackerel in the East in 2012/13, of which 68% were based in New South Wales (Figure 2.1). In the West, a total of 8 vessels reported catches of Blue Mackerel (Figure 2.2).

2.3.1.2 Annual patterns – catch, effort and catch per unit effort

Annual catches of Blue Mackerel in the East decreased from 1008 t in 2002/03 to an historic low of 293 t in 2010/11 (Figure 2.3). In 2012/13 catch increased to 454 t. The historical trend in annual fishing effort was similar to annual catch, i.e. it was relatively high in the late 1990s and early 2000s (>2000 vessel days) and decreased to <700 fisher days in 2011/12 and 2012/13 (Figure 2.3). 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. 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 0.74 t.vessel day^{-1} in 2012/13.

Annual catches of Blue Mackerel were more variable in the West than the East with landings of <65 t.yr^{-1} from 1997/98 and 2003/04, before an increase to >1,500 t in 2005/06 and 2006/07 and a peak of 1977 t in 2008/09 (Figure 2.5). After this, catch declined in each year and was 2.3 t in 2012/13, which was among the lowest on record. The estimated recreational catch of Blue Mackerel in the West in 2000/01 was 49 t. Over the last 15 years, fishing effort has also been highly variable. It ranged from 22 vessel days in 2000/01 to 162 vessel days in 2008/09, before decreasing to 30 vessel days in 2012/13 (Figure 2.5). CPUE remained <1 t.vessel day^{-1} between 1997/98 and 2003/04 and increased to ~14 t.vessel day^{-1} in 2005/06 (Figure 2.6). Subsequent catch rates remained relatively high in most years to 2010/11, before decreasing to 0.08 t.vessel day-1 in 2012/13.

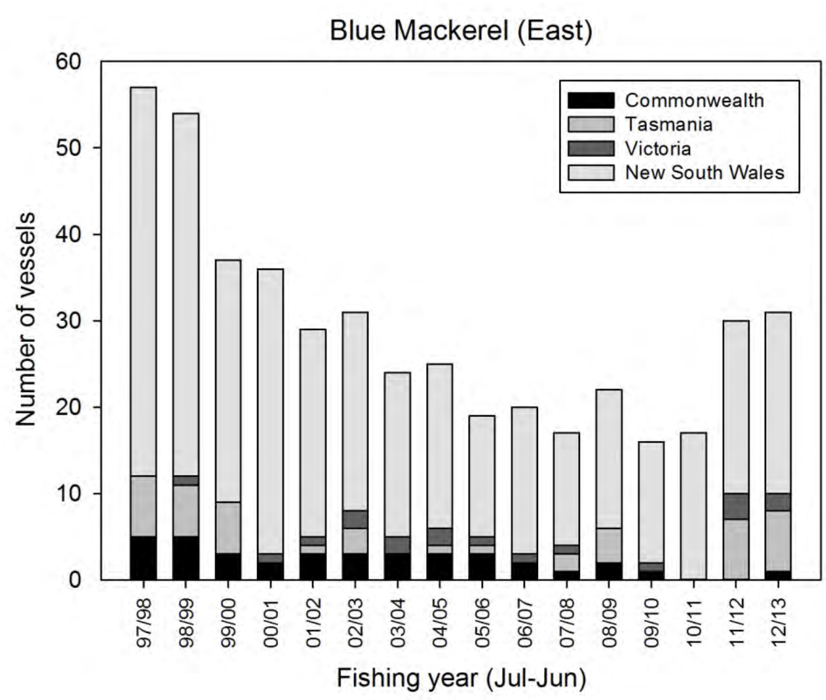

Figure 2.1 Number of vessels which landed Blue Mackerel in the East, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

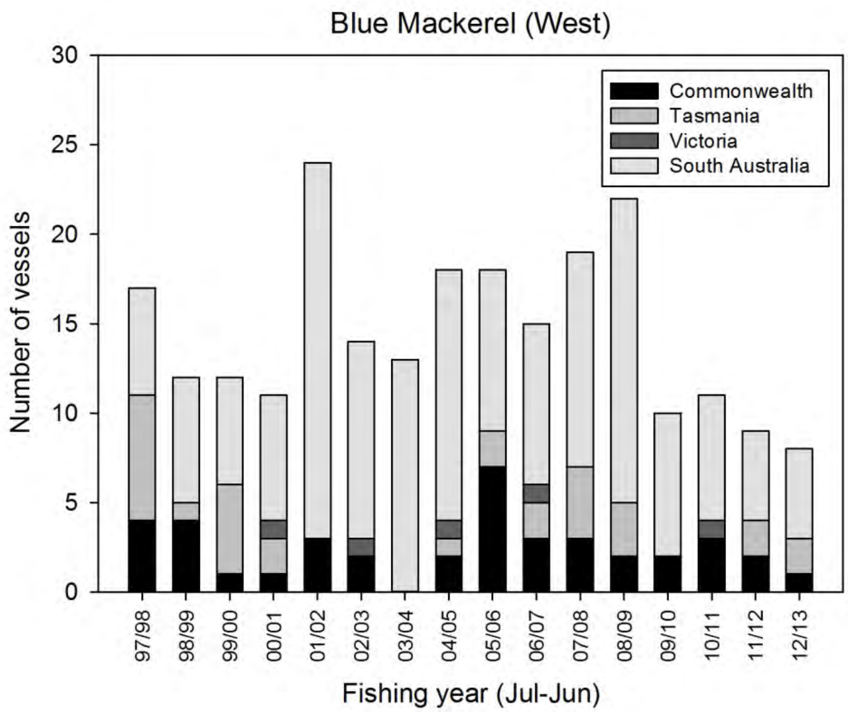

Figure 2.2 Number of vessels which landed Blue Mackerel in the West, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

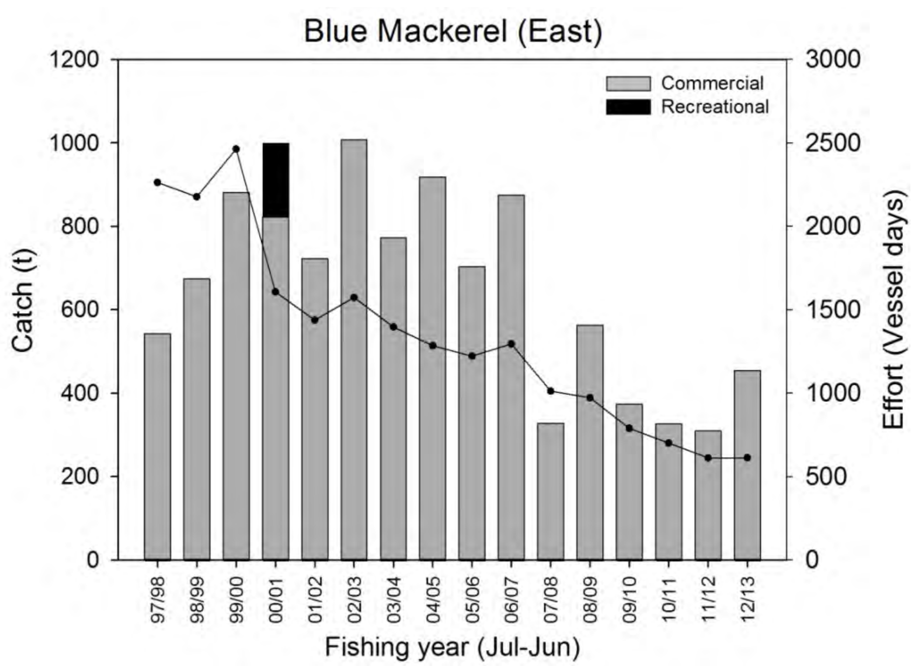

Figure 2.3 Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the East for each financial year from 1997/98–2012/13. Estimated catch for the recreational sector is also shown for 2000/01 and is based on catches taken in New South Wales, Victoria, Queensland and Tasmania.

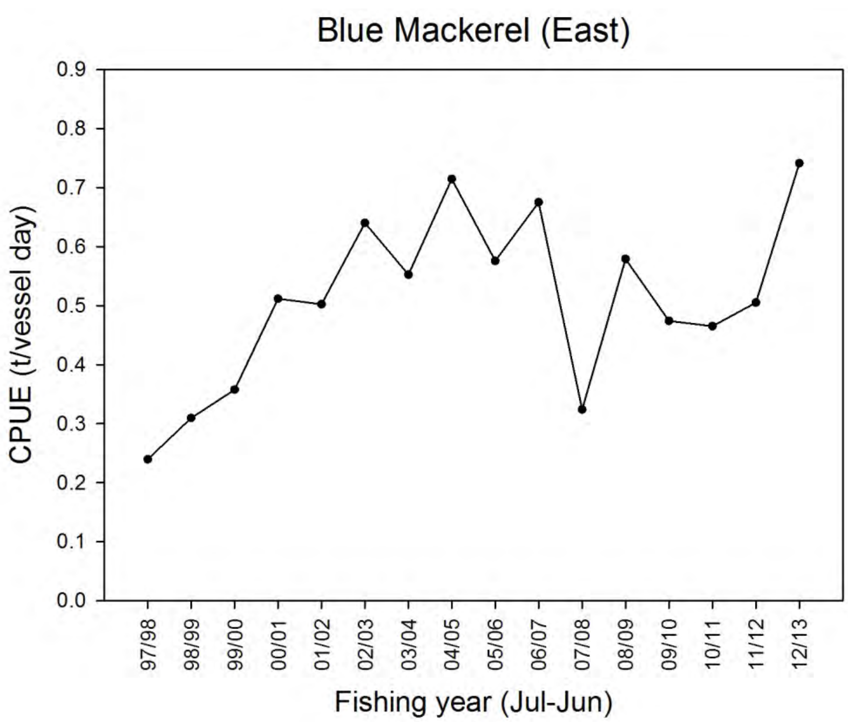

Figure 2.4 CPUE (t per vessel day) for Blue Mackerel in the East for each financial year from 1997/98–2012/13.

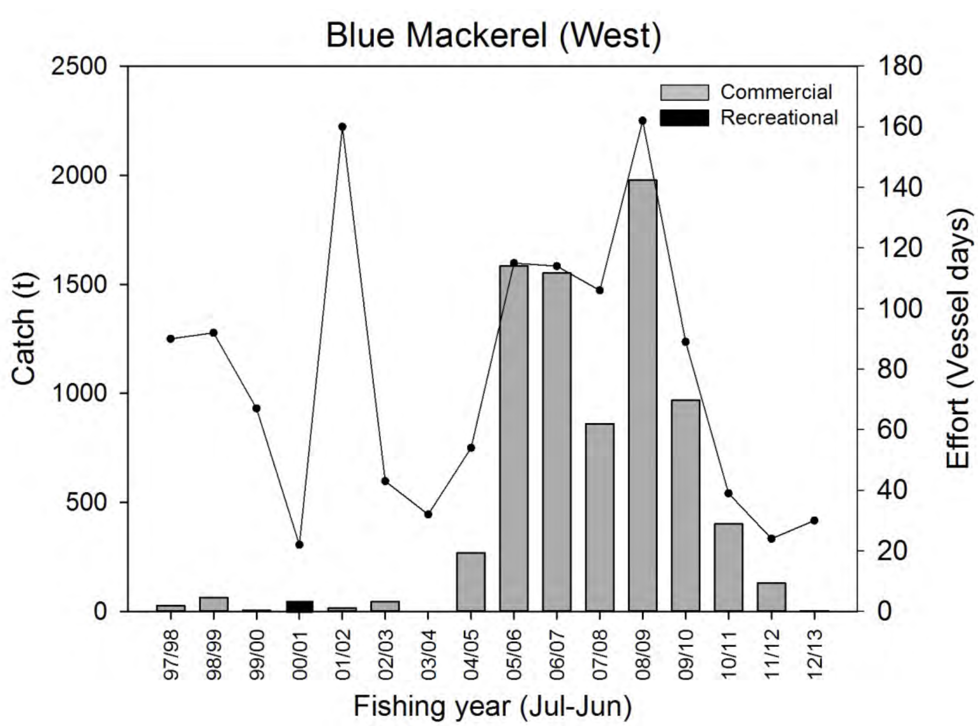

Figure 2.5 Total landed catch (t, bars) and effort (vessel days, line) for Blue Mackerel in the West for each financial year from 1997/98–2012/13. Estimated catch for the recreational sector is also shown for 2000/01 and is based on catches taken in South Australia and Western Australia.

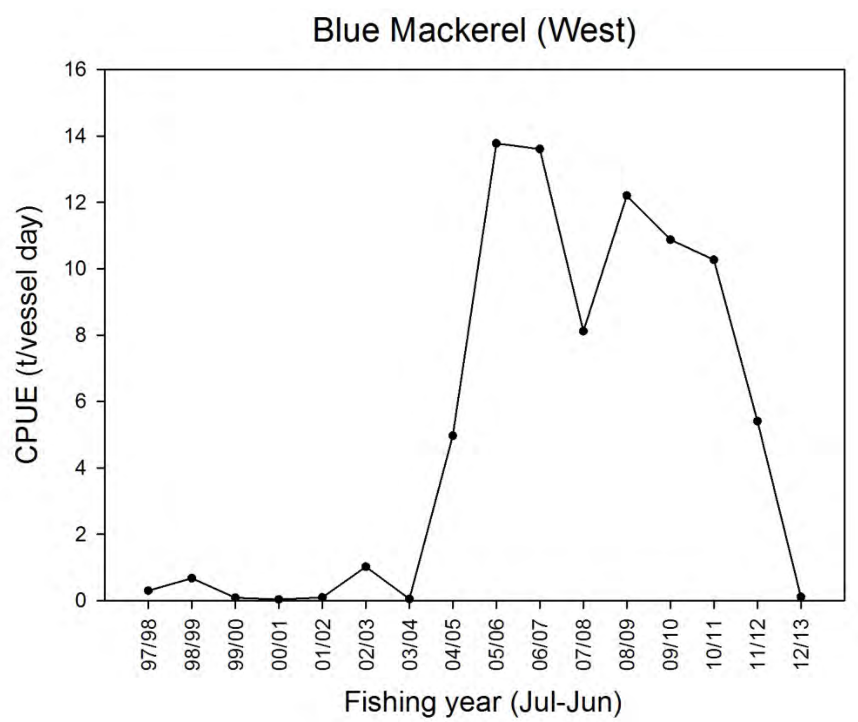

Figure 2.6 CPUE (t/vessel day) for Blue Mackerel in the West for each financial year from 1997/98–2012/13.

2.3.1.3 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 (near shore 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 were substantially lower than previous years (Figure 2.7). Catches were typically <100 t in most months during this period. One exception occurred in March 2012, when catch was 213 t. Monthly catch and effort data for Blue Mackerel in the West for most years were confidential as they represent the fishing activities of less than five fishing vessels (Figure 2.8).

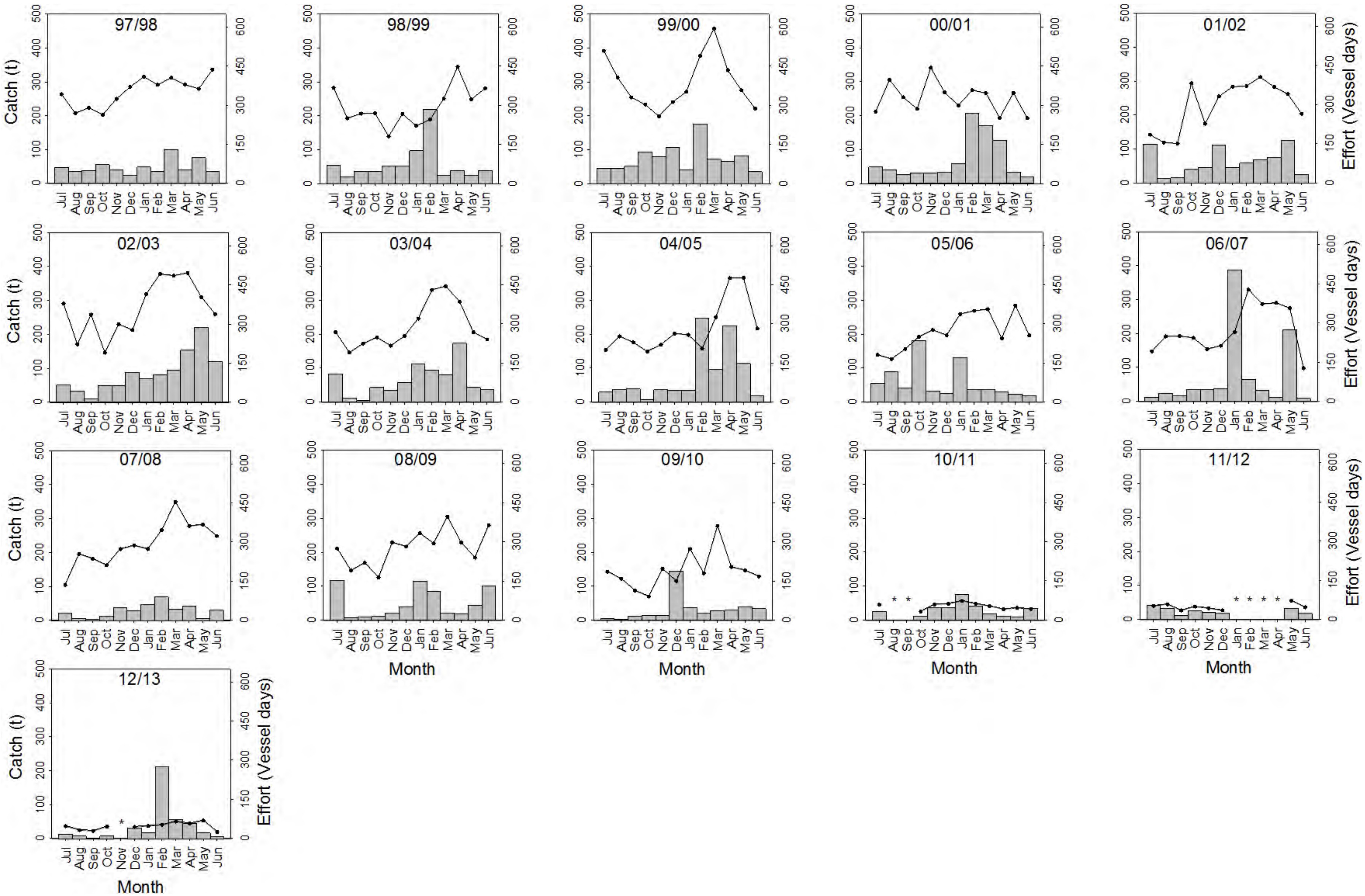

Figure 2.7 Intra-annual patterns of catch (bars) and effort (lines) for Blue Mackerel in the East for each financial year from 1997/98 - 2012/13. Catch and effort data for each year from 2010/11 - 2012/13 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

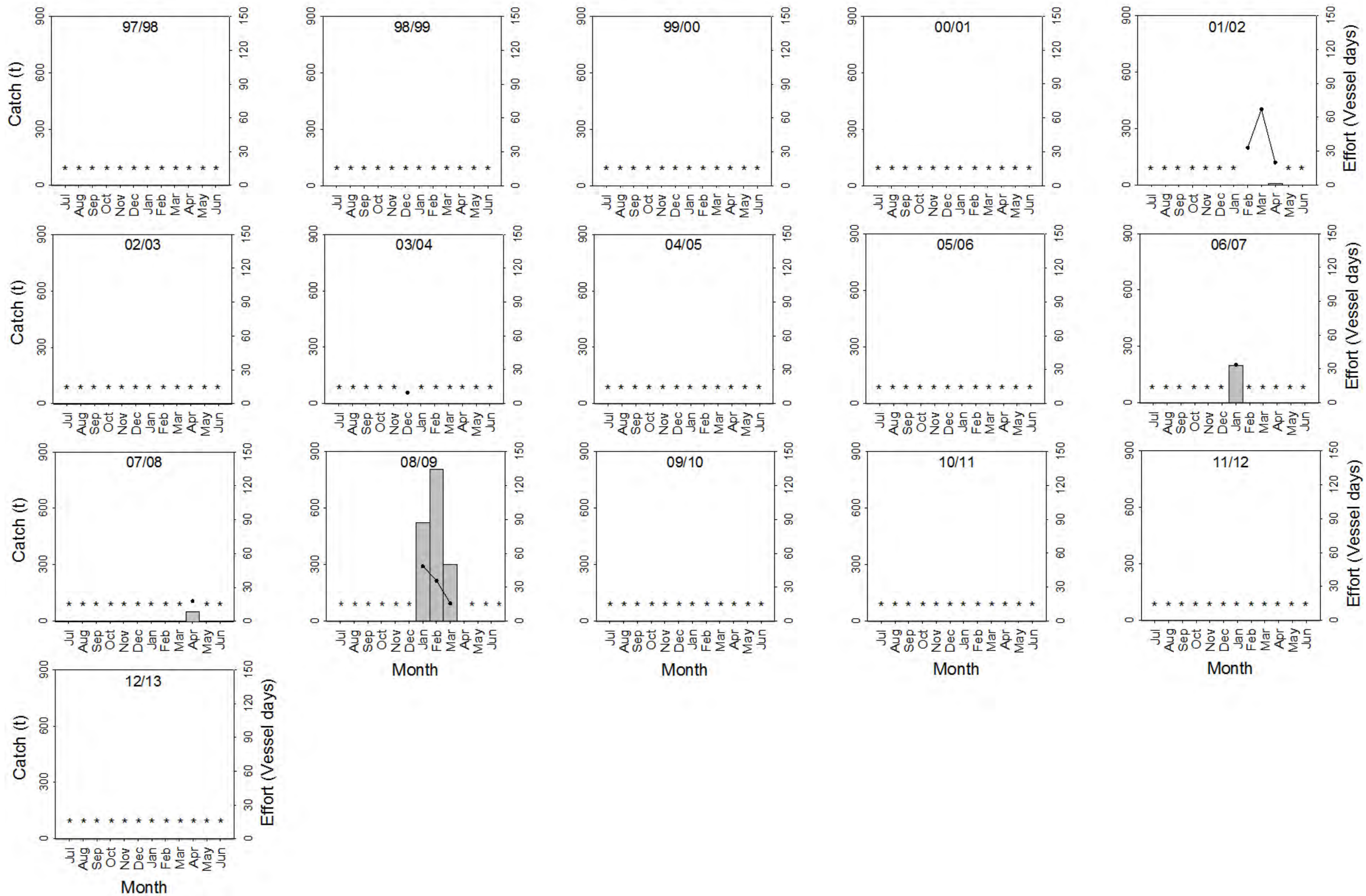

Figure 2.8 Intra-annual patterns in catch (bars) and effort (lines) for Blue Mackerel in the West for each financial year from 1997/98–2012/13. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

2.3.2 Biological Information

2.3.2.1 Sample Summary

For the West, a total of 79 Blue Mackerel collected in 2008/09 (1 sample), 933 in 2009/10 (1 sample) and 245 in 2010/11 (1 sample) were sampled from commercial purse-seine net catches taken off Port Lincoln (West) for biological analysis. 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 temporally limited, 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.

For the East, a total of 736 and 108 Blue Mackerel were collected from commercial purse-seine fishing activities in New South Wales in 2011/12 (12 samples) and 2012/13 (1 sample), respectively. Sex ratios were not available for these samples. Information on the spatial and temporal coverage of these samples relative to fishery production in New South Wales was not available. However, given the relatively high contribution (~53%, 228 t) of catches from Victorian vessels to the total annual catch for 2012/13, the small sample of fish provided from New South Wales is unlikely to provide an adequate representation of fish harvested by the fishery in that year.

2.3.2.2 Size Frequency

Fish sampled in the West (South Australia) in 2008/09 ranged from 316 – 390 mm FL (Figure 2.9) 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. Nonetheless, >99% of all fish were larger than the size at maturity reported in Ward and Rogers (2007, 237 and 287 mm FL for males and females, respectively).

Blue Mackerel sampled from commercial purse-seine fishing vessels in the East (New South Wales) in 2011/12 and 2012/13 were between 251 and 382 mm FL, with >50% of fish between 300 and 320 mm FL (Figure 2.10).

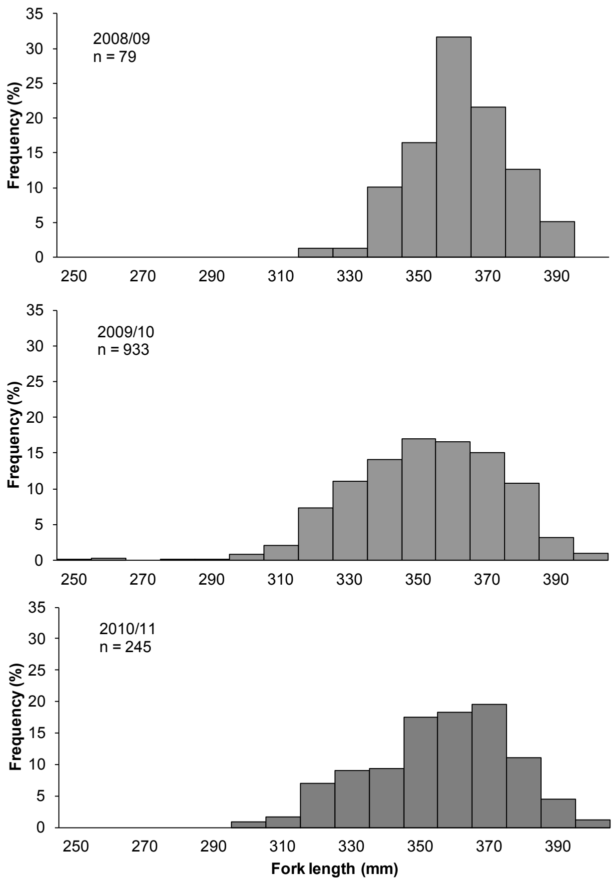

Figure 2.9 Size frequency of Blue Mackerel from samples collected from commercial purse-seine shots in South Australia from 2008/09 to 2010/11.

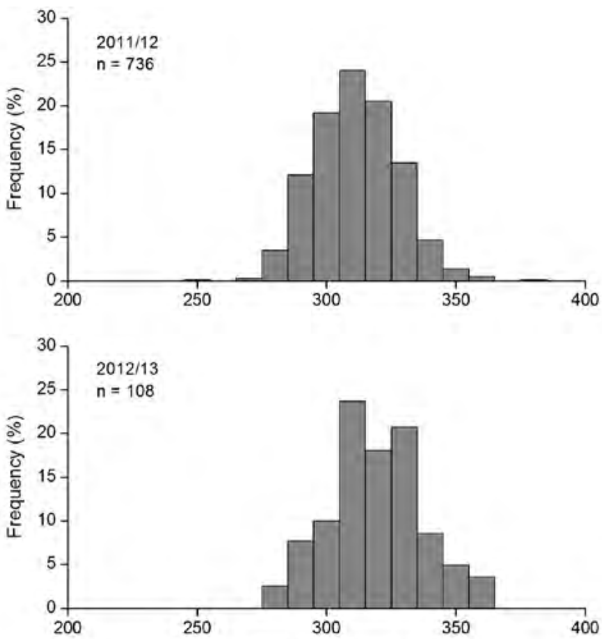

Figure 2.10 Size frequency of Blue Mackerel from samples collected from commercial purse-seine shots in New South Wales from 2011/12 to 2012/13.

2.3.2.3 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 fish of a greater range of ages were collected, including fish up to 8 years of age. In all years the majority of fish were greater than three years old.

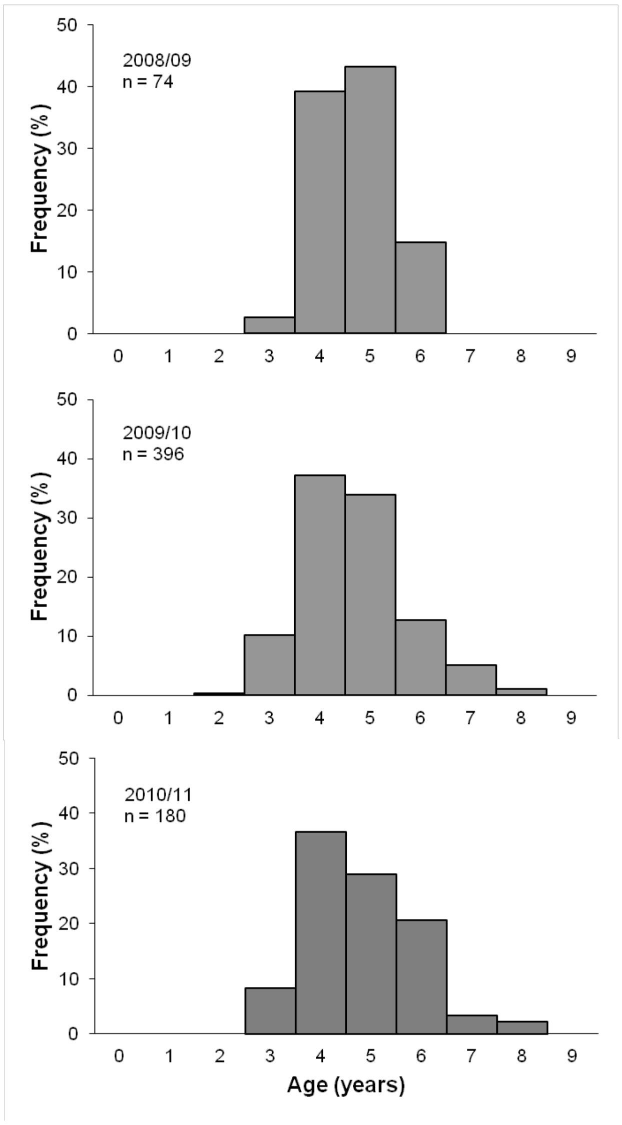

Figure 2.11 Age frequency distribution for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11, based on the otolith weight, age relationship in Ward and Rogers (2007) for South Australia.

2.3.2.4 Gonad stages

In 2008/09, although the majority of fish sampled in the West (Port Lincoln) were below the size at maturity reported by 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% vs. 42.5% and 7.5%, 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).

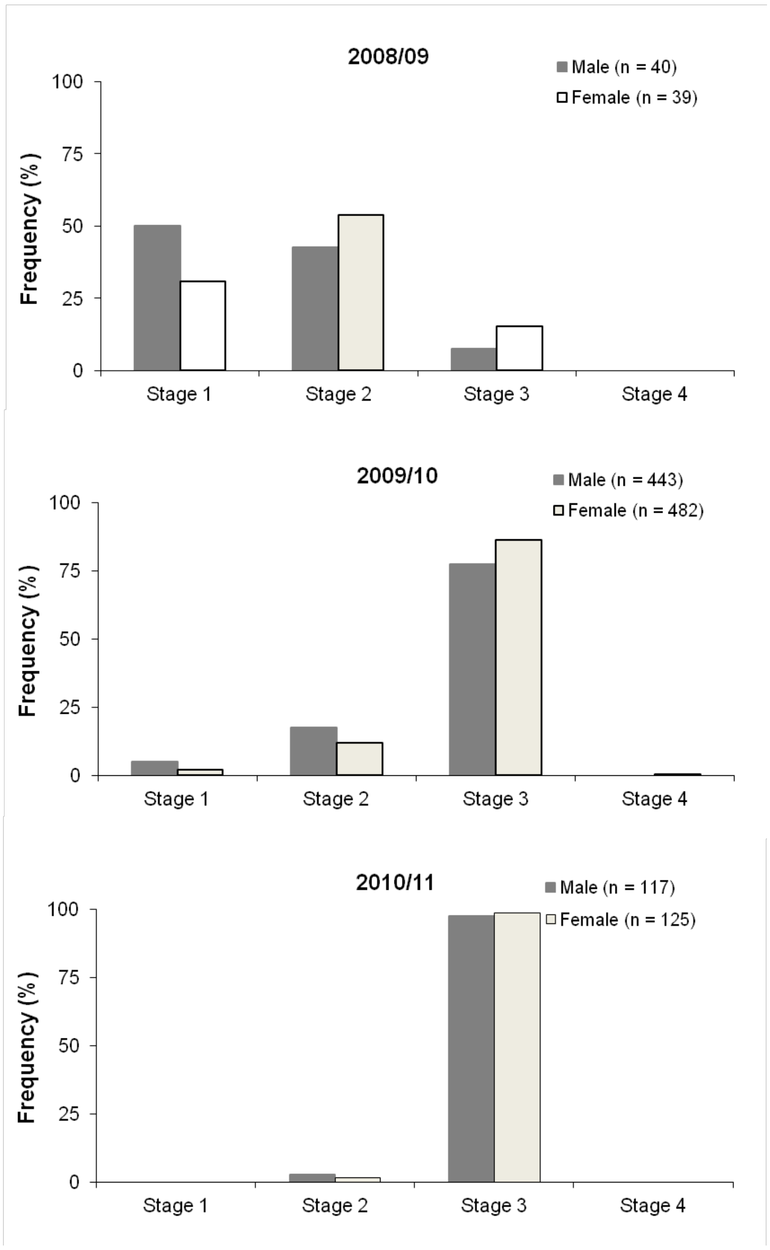

Figure 2.12 Distribution of gonad developmental stages for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11.

2.3.2.5 Size at maturity

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

2.3.2.6 Gonadosomatic index (GSI)

No seasonal GSI data were available for Blue Mackerel. In 2008/09, GSIs for males and females was 0.9% (Figure 2.13). In 2009/10, GSI for both sexes increased to ~5% (Figure 2.13), before increasing again in 2010/11 to 7% and 6% for males and females, respectively (Figure 2.13).

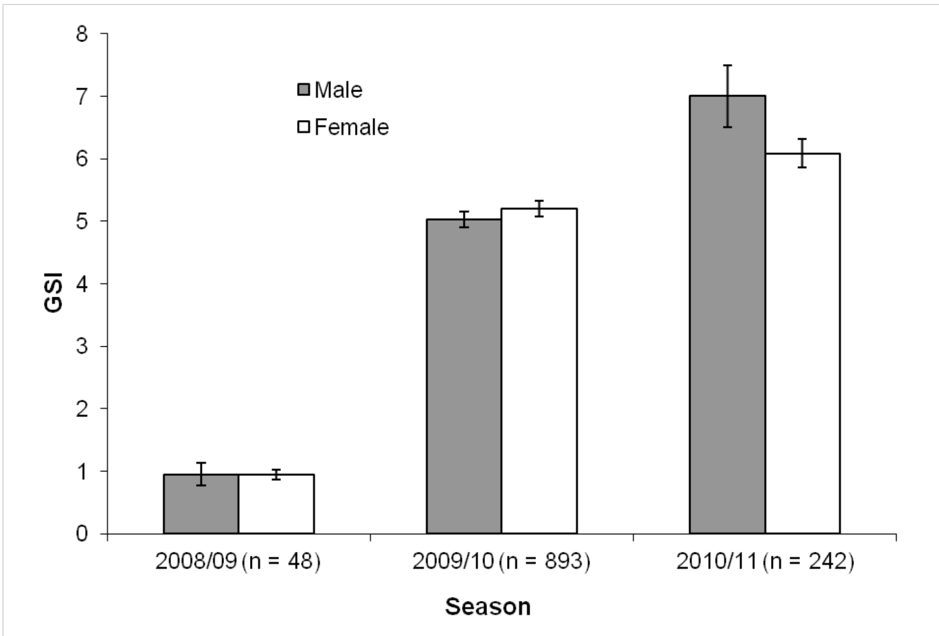

Figure 2.13 Mean gonadosomatic index (%) for mature Blue Mackerel (i.e. excluding Stage 1 fish) landed in Port Lincoln during summer of 2008/09, 2009/10 and 2010/11. Error bars represent standard error.

2.3.2.7 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, respectively. 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), which typically provide 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 GAB). Spawning may also have occurred outside the survey area in the East. The survey conducted off eastern Australia in July 2004 may have also 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. 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 that estimates of spawning biomass were strongly affected by uncertainty in estimates of spawning fraction.

2.3.2.8 MSE

For Blue Mackerel East, the "best" DEPM estimate of spawning biomass was 13% of the model calculated estimate of virgin biomass. 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. 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 Blue Mackerel using the DEPM provided a mid-range best estimate of spawning biomass of 23,009 t for the East and 56,000 t for the West. For each region, 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 March 2008, the SPFRAG agreed to use a mid-range estimate of 40,000 t of spawning biomass for setting the RBC for the East, after a sensitivity analysis was completed (Woodhams *et al.* 2012; AFMA, 2014).

In the East, catches peaked at 1008 t in 2002/03 and declined to 293 t in 2010/11. In 2012/13, the catch was 454 t which was 15% and 2% of the RBC (3,000 t) and DEPM biomass estimate, respectively. The long-term declining trend of catch was similar to the trend of fishing effort, which suggests that recent low catches relate to lower fishing effort rather than reductions in the size of the fishable biomass.

In the West, catches of Blue Mackerel were relatively low from 1997/98 to 2003/04, before increasing to 1977 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. Similar to the East, recent low catches appear to reflect low fishing activity rather than reductions in abundance. Reduced catches in the West can also be attributed to a lack of targeted fishing for blue mackerel. Recent annual catches have been well below the maximum RBCs at Tier 2 for each zone suggesting the impacts of commercial fishing on the spawning biomass of the species are low. Catches in the West comprised mainly fish >4 years of age and well-above the size at maturity for the species (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.

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 industrial 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 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 to reduce dependence on the availability of surface schooling fish. 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 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, with Redbait dominating 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).

A relatively small (300-500 t per annum) fishery for Yellowtail Scad (*Trachurus novaezelandiae*) exists in New South Wales where they are taken predominately in the Ocean Haul Fishery. Small quantities have also been landed in Western Australia (Kailola 1993).

3.1.2 Taxonomy

Jack Mackerel, *Trachurus declivis*, and Yellowtail Scad, *T. novaezelandiae,* belong to the family Carangidae of which there are 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 8 species from four genera inhabit southern temperate waters (Gomon *et al.* 2008). The genus *Trachurus* contains 13 species with three found in Australia, namely *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 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, with a third occurring in New Zealand. Analysis of morphometric measurements and meristic counts showed a significant difference between east Australian fish and those from the Great Australian Bight (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 and 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 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 consume a variety of other prey items in minor quantities including ostrocods, 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: Webb and Grant (1979), Stevens and Hausfeld (1982) and Jordan (1994) using whole otoliths, and Lyle *et al.* (2000) and Browne (2005) using sectioned otoliths. The annual formation of increments in otoliths was validated by Lyle *et al.* (2000) using marginal increment analysis. 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 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 from eastern Tasmania (Neira 2011).

Females have been shown to reach sexual maturity (SAM_{50}) at ~315 mm TL (Marshall *et al.* 1993). Spawning has been known to occur in spring in New South Wales (Maxwell 1979; Keane 2009) and during summer off Tasmania and in the GAB (Stevens *et al.* 1984; Marshall *et al.* 1993; Jordan *et al.* 1995). 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 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 eastern Tasmania and in Bass Strait and the GAB during summer (Stevens *et al.* 1984; Neira 2005; 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 the 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). Young *et al.* (1993) documented a close relationship between oceanographic driven changes the abundance of surface schools of Jack Mackerel off eastern

Tasmania. 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 hydroacoustic surveys of surface and sub-surface schools on the shelf break (Jordan *et al.* 1992).

The DEPM was applied to this species 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. Ecosystem modelling of south east Australian waters indicates that the spawning biomass of Jack Mackerel is likely to be in the vicinity of 130,000 – 170,000 t (Fulton 2013), which is consistent with the estimates provided by Neira (2011).

3.1.11 Management

This fishery has changed dramatically since the commencement of large scale fishing operations in the mid-1980s, from a purse-seine fishery for Jack Mackerel to a mid-water trawl fishery primarily targeting Redbait, with Jack Mackerel an important by-product. Between the late 1980s and prior to the implementation of the Commonwealth Small Pelagic Fishery Management Plan in 2009, the Tasmanian component of the fishery (Zone A: north-eastern Tasmania to central western Tasmania) was managed using a combination of input and output controls, principal among these being a total allowable catch (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 for Zone A 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 2012/13 season, the recommended TAC for Jack Mackerel was 10,100 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 Scads 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 taken in New South Wales, and 26% and 19% taken in Western Australia and Queensland, respectively. 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/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

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, including species composition. This was replaced from 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 South East Trawl Fishery logbook, providing a shot by shot record of catch and effort, including catch composition. More recently, purse-seine operations targeting small pelagic fish have resumed in Tasmanian State waters and shot by shot catch and effort data are recorded in the Tasmanian General Fishery logbook.

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 (near shore and estuarine) fishing operations. After this, all estimates were for oceanic fishing activity only.

3.2.2 Biological Information

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. Some biological information was also collected from samples collected from demersal research trawling conducted by CSIRO and the Tasmanian fisheries agency between 1985 and 1990. Between 1994 and 2001, the level of catch sampling of the purse-seine fishery was limited.

Collection of biological data during the 2001/02 pair-trawl fishing trials was undertaken by AFMA observers on a small proportion of trips, thus data 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 during 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).

Biological data were collected from individual specimens 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). 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 1984/85 and 2009/10 were available for the present review. 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, as part of the present assessment, 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 biological samples were collected for Jack Mackerel from 2010/11-2012/13 due to limited activity in the fishery.

Size frequency information collected for Yellowtail Scad sampled from commercial catches taken in New South Wales in 2011/12 and 2012/13 was the only biological information available for that species. This data was supplied by New South Wales DPI.

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).

3.3 Results

3.3.1 Fishery Statistics East / West

3.3.1.1 Number of vessels

The number of vessels that reported landings of Jack Mackerel in the East has declined since 1998/99 (Figure 3.1) In 2012/13, a total of 3 vessels landed Jack Mackerel in the East, with two from New South Wales 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. In 2012/13, a total of 3 vessels reported catches of Jack Mackerel in the West (Figure 3.2).

For Yellowtail Scad in the East, a total of 23 vessels reported landings in 2012/13, with the majority of these operating in New South Wales waters (Figure 3.3).

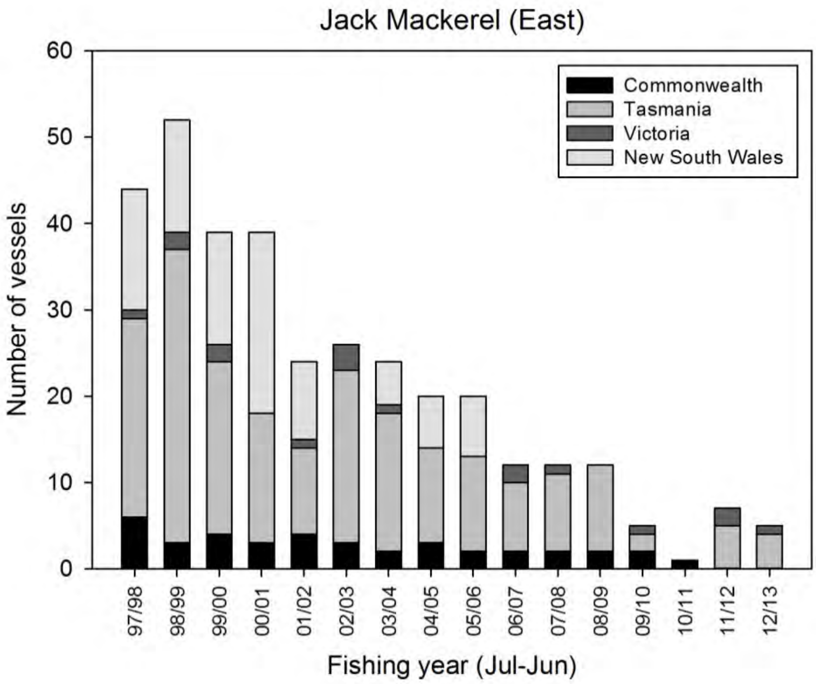

Figure 3.1 Number of vessels which landed Jack Mackerel in the East from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

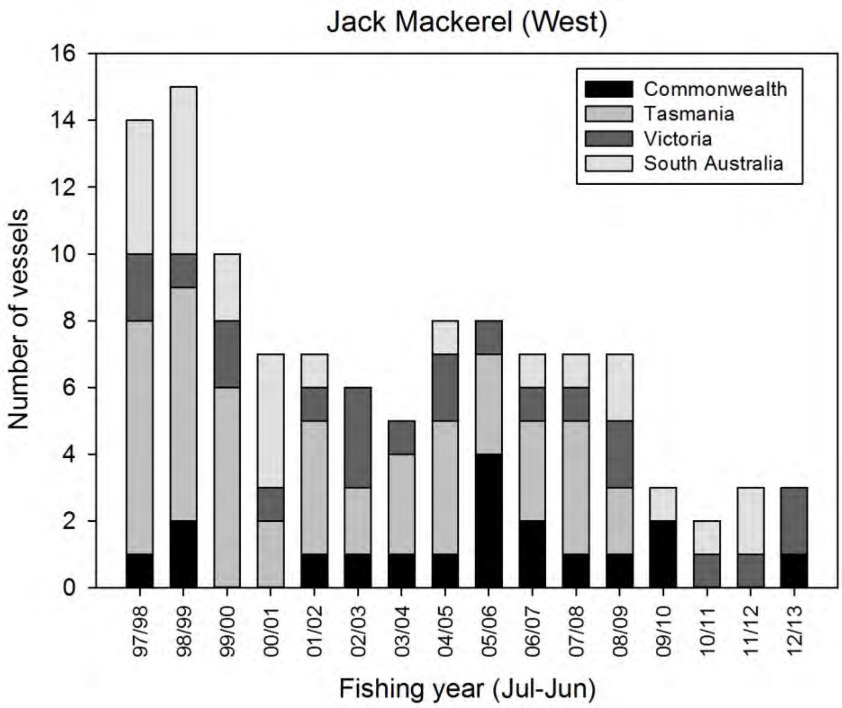

Figure 3.2 Number of vessels which landed Jack Mackerel in the West, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

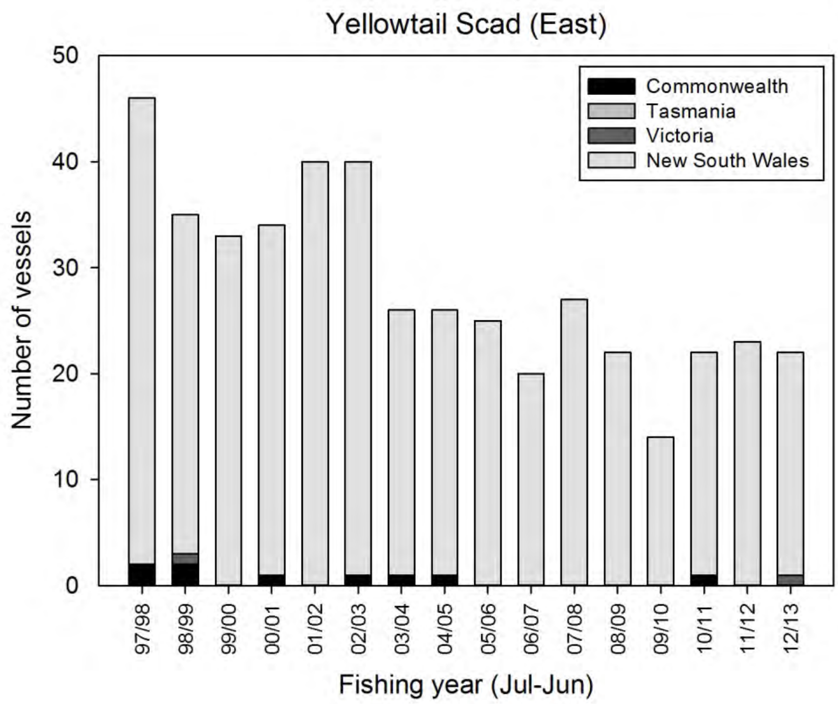

Figure 3.3 Number of vessels which landed Yellowtail Scad in the East, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

3.3.1.2 Annual Patterns – catch, effort and catch-per unit effort

Total catches of Jack Mackerel for the East declined from >9,000 t in 1997/98 to ~100 t in 2000/01 (Figure 3.4). Landings then increased to >3,000 t in 2003/04, before decreasing to 56 t in 2011/12. Catch and effort data for 2012/13 are confidential, due to the low number (<5) of vessels reporting catch. Historically, annual estimates of effort have trended downwards from a peak of 905 vessel days in 1998/99 to 32 days in 2011/12 (Figure 3.4). CPUE fluctuated considerably since 1997/98 (Figure 3.5), possibly due to changes in the type of gear employed and vessels used in this fishery.

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). Peak catches in the mid-2000s coincided with years when effort was relatively high (Figure 3.6). From 1997/98 to 2004/05, catch rates were <2 t per vessel day (Figure 3.7). While CPUE increased to >4 t.vessel day^{-1} from 2005/06 to 2008/09, annual estimates since then are confidential.

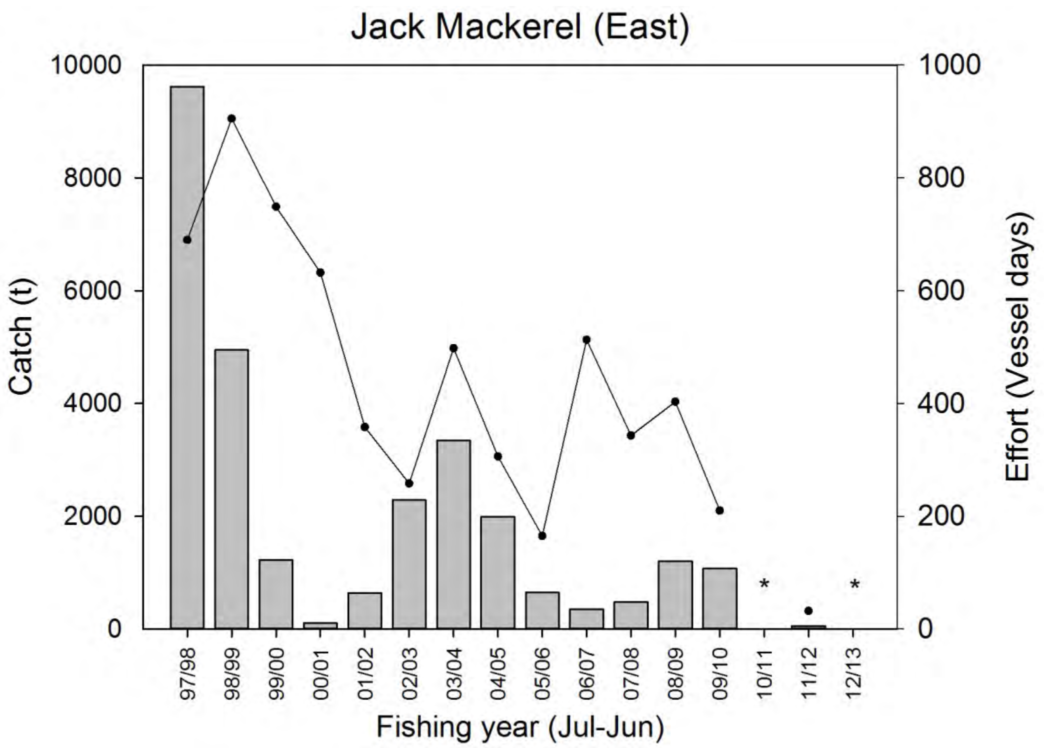

Figure 3.4 Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel in the East for each financial year from 1997/98–2012/13. (*) indicates data confidentiality, where <5 license holders report landings.

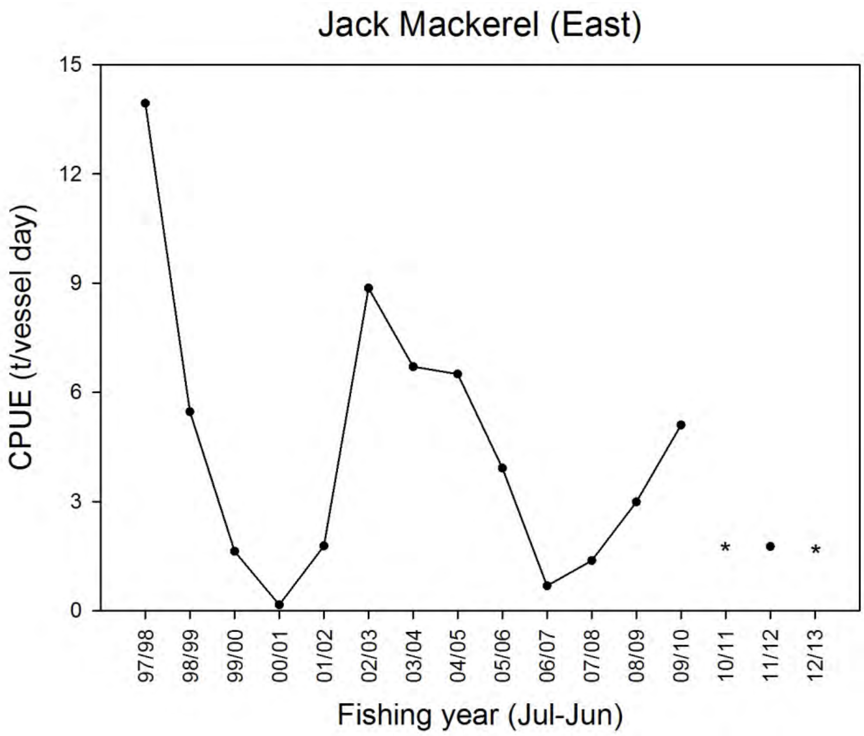

Figure 3.5 CPUE (t per vessel day) for Jack Mackerel in the East for each financial year from 1997/98–2012/13. (*) indicates data confidentiality, where <5 license holders report landings.

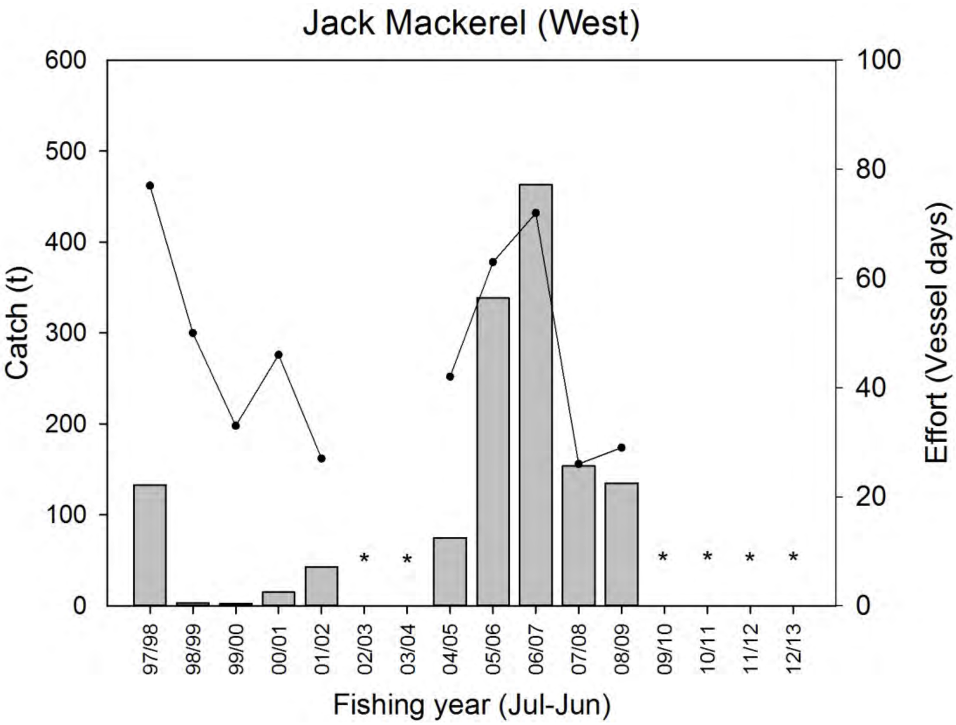

Figure 3.6 Total landed catch (t, bars) and effort (vessel days, line) for Jack Mackerel in the West for each financial year from 1997/98–2012/13. (*) indicates data confidentiality, where <5 license holders report landings.

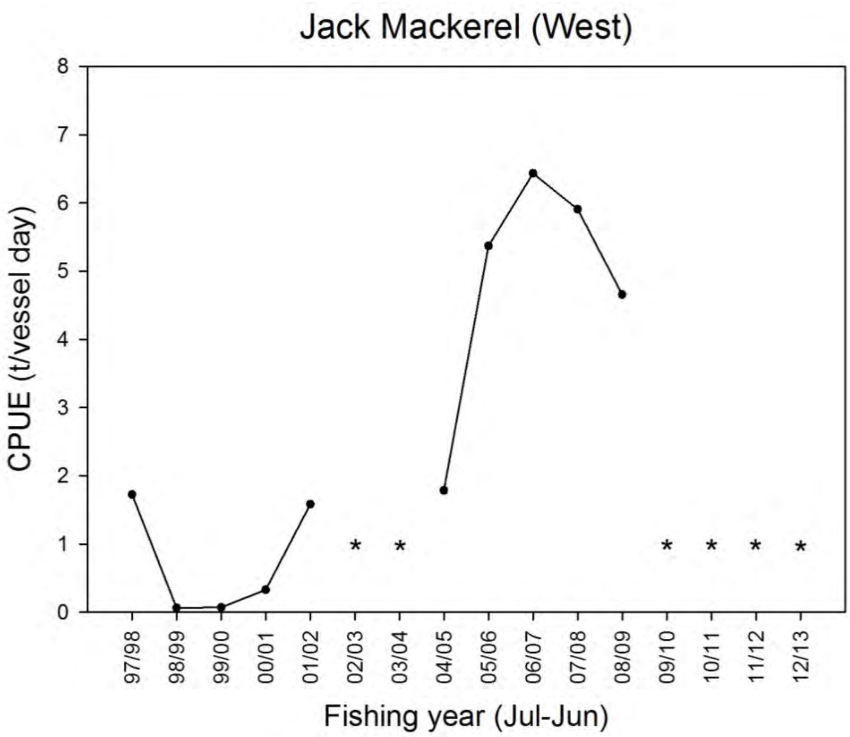

Figure 3.7 CPUE (t per vessel day) for Jack Mackerel in the West for each financial year from 1997/98–2012/13. (*) indicates data confidentiality, where <5 license holders report landings.

Yellowtail Scad catches in the East were ~450 t in 1997/98 and gradually trended down to 177 t in 2009/10, before increasing rapidly to ~727 t in 2010/11 (Figure 3.8) Catch in 2011/12 and 2012/13 declined to 525 t and 477 t, respectively. The interannual trend in fishing effort from 1997/98 - 2008/09 was similar to total catch, i.e. declining. Despite an increase in catch since 2010/11, estimates of effort have been among the lowest on record (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 <0.3 t.vessel day^{-1} between 1997/98 and 2009/10, to >0.84 t.vessel day in 2010/11. Catch rate remained relatively high in 2011/12 and 2012/13 (Figure 3.9).

No Yellowtail Scad catches were reported from the West.

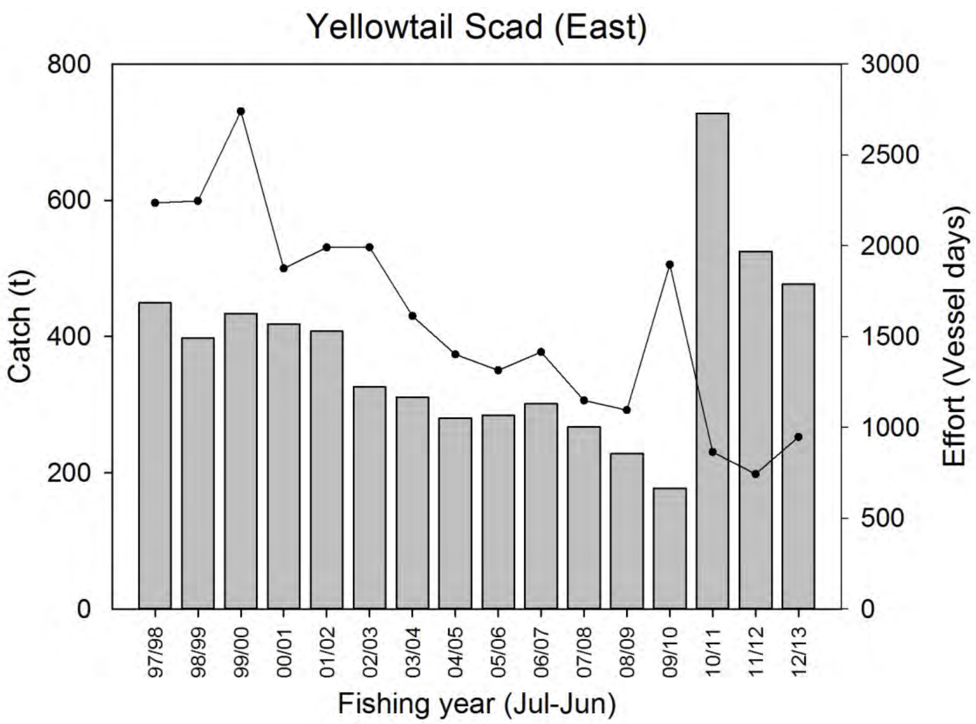

Figure 3.8 Total landed catch (t, bars) and effort (vessel days, line) for Yellowtail Scad in the East for each financial year from 1997/98–2012/13.

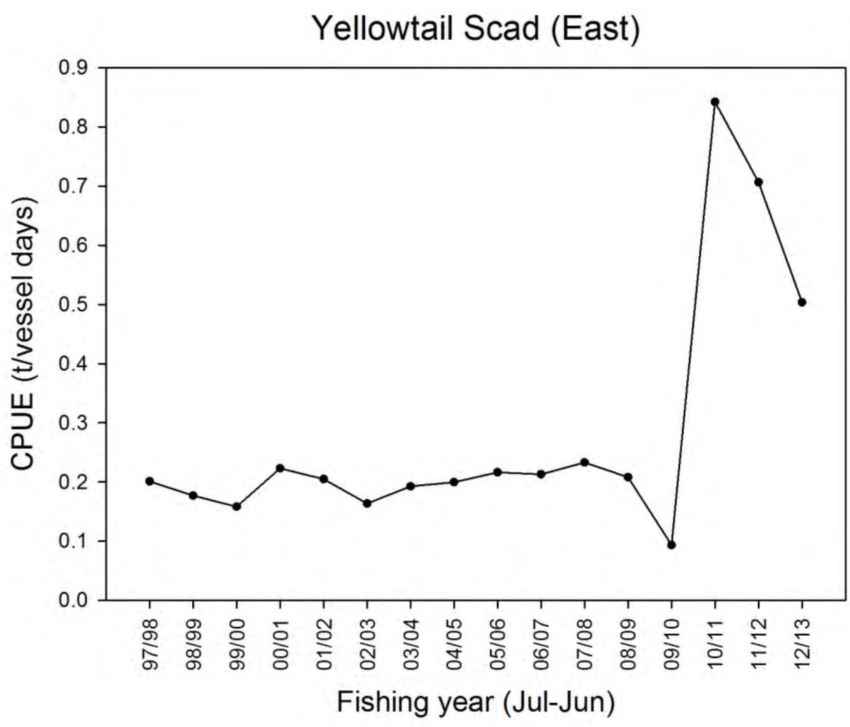

Figure 3.9 CPUE (t per vessel day) for Yellowtail Scad in the East for each financial year from 1997/98–2012/13.

3.3.1.3 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 intra-annual patterns in catch and/or effort were evident in the Yellowtail Scad catches (East). Peak catches in 2010/11 (Figure 3.8), coincided with relatively high catches in each month from January to June 2011 (Figure 3.11).

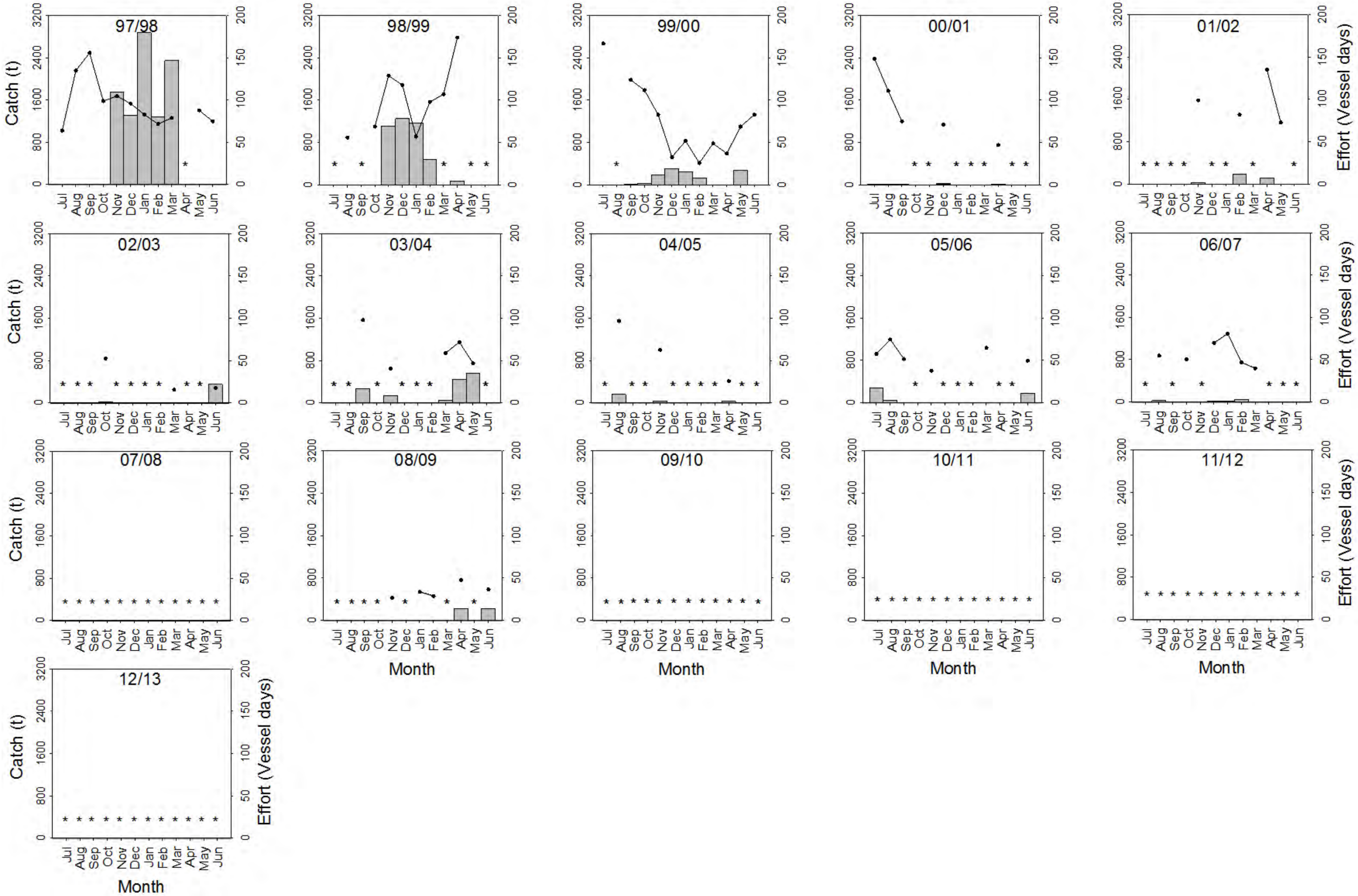

Figure 3.10 Intra-annual patterns of catch (bars) and effort (line) for Jack Mackerel in the East for each financial year from 1997/98–2012/13. Catch and effort data for each year from 2010/11–2012/13 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

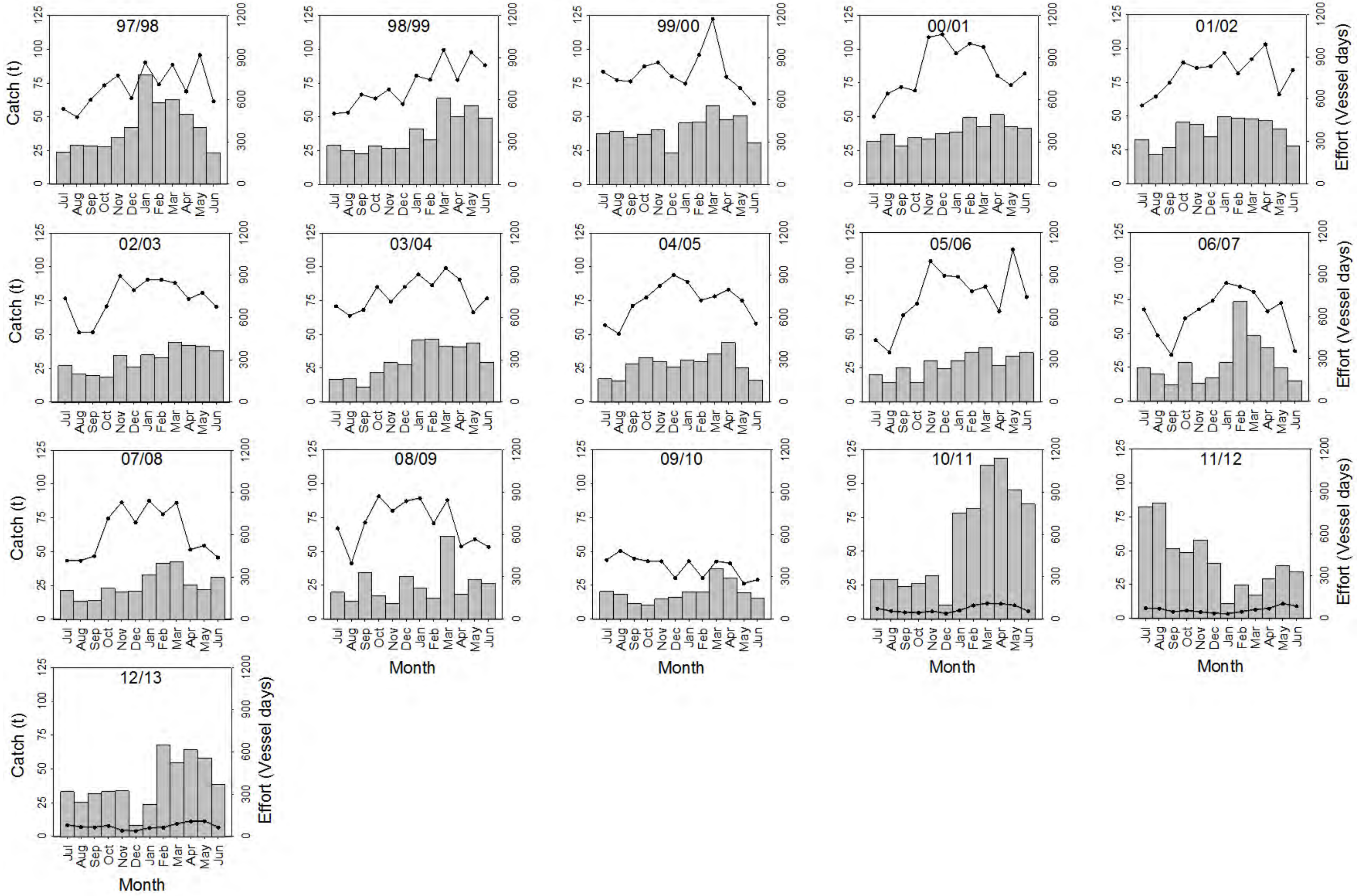

Figure 3.11 Intra-annual patterns of catch (bar) and effort (line) for Yellowtail Scad in the East for each financial year from 1997/98–2012/13. Catch and effort data for each year from 2010/11–2012/13 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

3.3.2 Biological Information

Due to the limited commercial activity targeting Jack Mackerel, biological information has not been collected since 2010/11. For Yellowtail Scad, size frequency information collected from commercial catches taken in New South Wales in 2011/12 and 2012/13 was the only biological information available for that species. This data was supplied by New South Wales DPI.

3.3.2.1 Size Structure

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

Jack Mackerel caught in the purse-seine fishery between 1984/85 and 1996/97 off eastern Tasmania were mostly 210-350 mm FL, with individuals up to 440 mm FL recorded (Figure 3.12). In 1984/85, the catch comprised fish between 240 and 360 mm FL with a bimodal distribution. 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. 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 to 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 from 21 mid-water trawl and purse-seine catches were sampled between July 2009 and June 2010 with all but one sample based on catches taken off eastern Tasmania (Table 3.1).

The size composition of east coast mid-water trawl and purse-seine catches were similar with each dominated by fish between 180-240 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.

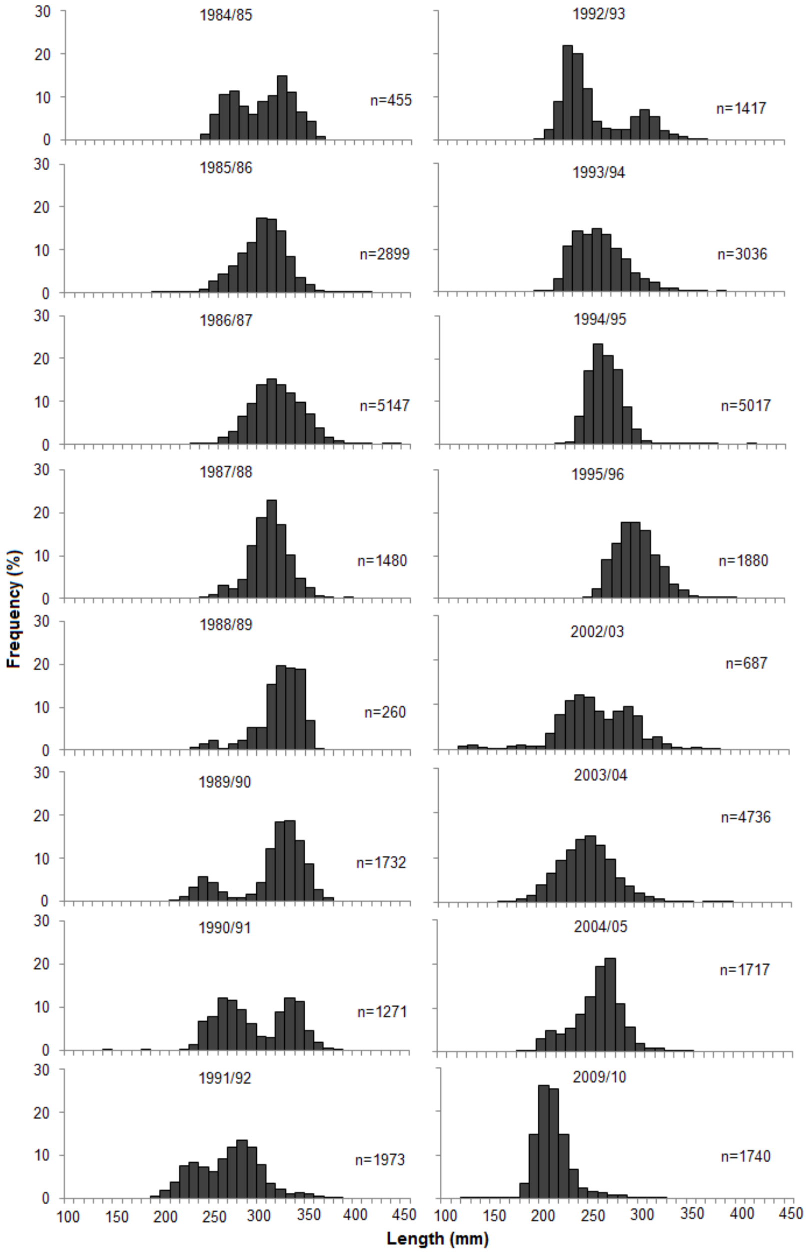

Figure 3.12 Length frequency distributions of Jack Mackerel caught in the SPF by purse-seine (1984/85–1995/96), mid-water trawl (2002/03–2005/06) and both fishing methods combined (2009/10) off eastern Tasmania between 1984/85 and 2010/11. No data were available between 1997/98 and 2001/02. n = sample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

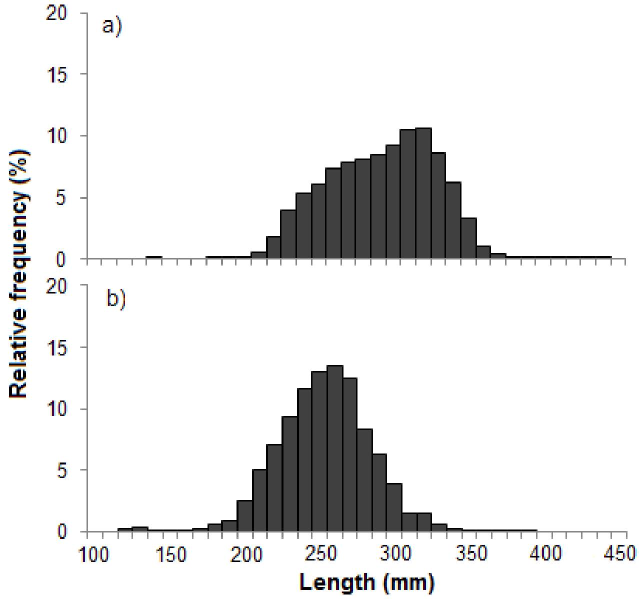

Figure 3.13 Year-weighted length frequency distributions (mm FL) of Jack Mackerel caught in the SPF off eastern Tasmania from (a) purse-seine operations (1984/85–1996/97), and (b) mid-water trawl operations (2002/03–2005/06).

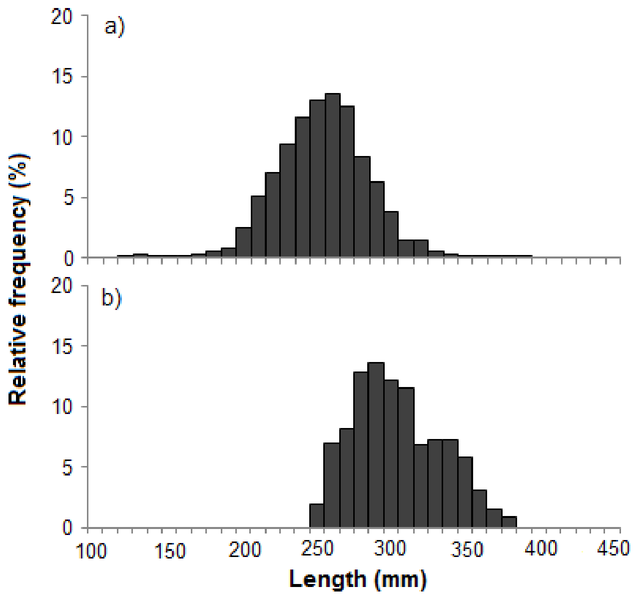

Figure 3.14 Year-weighted length frequency distributions (mm FL) of Jack Mackerel caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2002/03 and 2005/06.

Table 3.1 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 and mode of each length-frequency distribution.

Sampling month	No. of landings	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

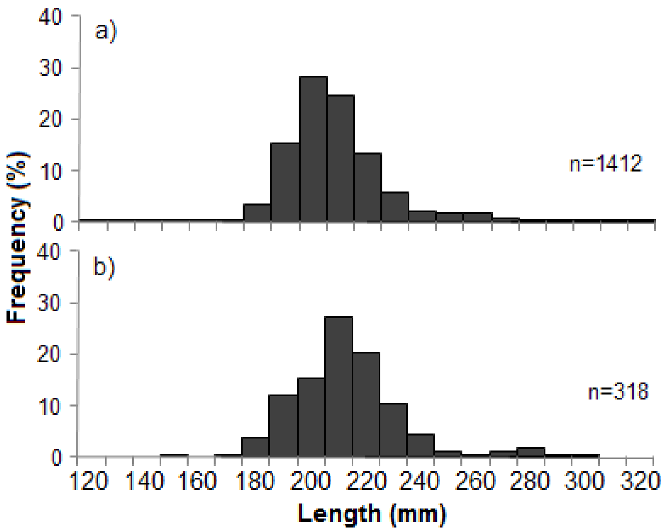

Figure 3.15 Length frequency distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawl operations during 2009/10. n = sample size.

Commercial purse-seine fishing operations: New South Wales only

In 2011/12, Yellowtail Scad sampled from commercial purse-seine net catches ranged from ~130 – 283 mm FL, with a dominant mode at 220 mm FL (Figure 3.16). The range of fish sizes collected in 2012/13 was narrower, i.e. from 183 – 274 mm FL and fish were generally larger with >50% of samples between 225 mm FL and 245 mm FL (Figure 3.16).

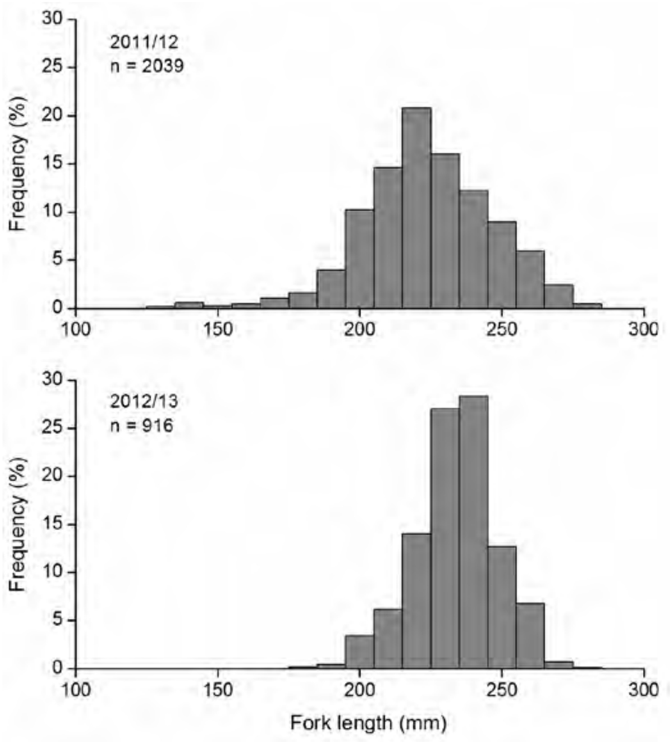

Figure 3.16 Size frequency of Yellowtail Scad collected from commercial purse-seine shots in New South Wales from 2011/12 to 2012/13.

3.3.3 Age and Growth

Growth of male and female Jack Mackerel from eastern Tasmania was described using the von Bertalanffy growth function (VBGF) (Table 3.2, Figure 3.17). 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 3.2 Summary of VBGF parameters of Jack Mackerel off eastern Tasmania. Pooled data includes males, females and unsexed/unknown individuals.

		VBGF parameters		
	n	**L_∞**	**K**	**t_0**
Male	534	364.0	0.27	-0.92
Female	763	360.3	0.29	-0.63
Pooled	2143	362.8	0.29	-0.81

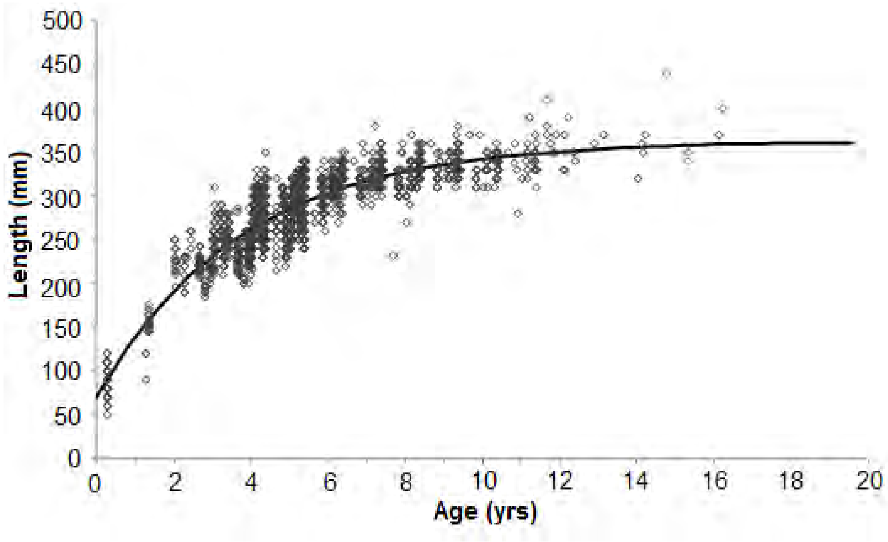

Figure 3.17 Length at age data for Jack Mackerel from eastern Tasmania. The black line represents the VBGF.

3.3.4 Age Structure

3.3.4.1 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 of age also well represented. Between 1991/92 and 1994/95, few fish older than 5 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 that 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 structure appears to have had a smoothing effect on age composition, in particular in terms of representation of the older age groups.

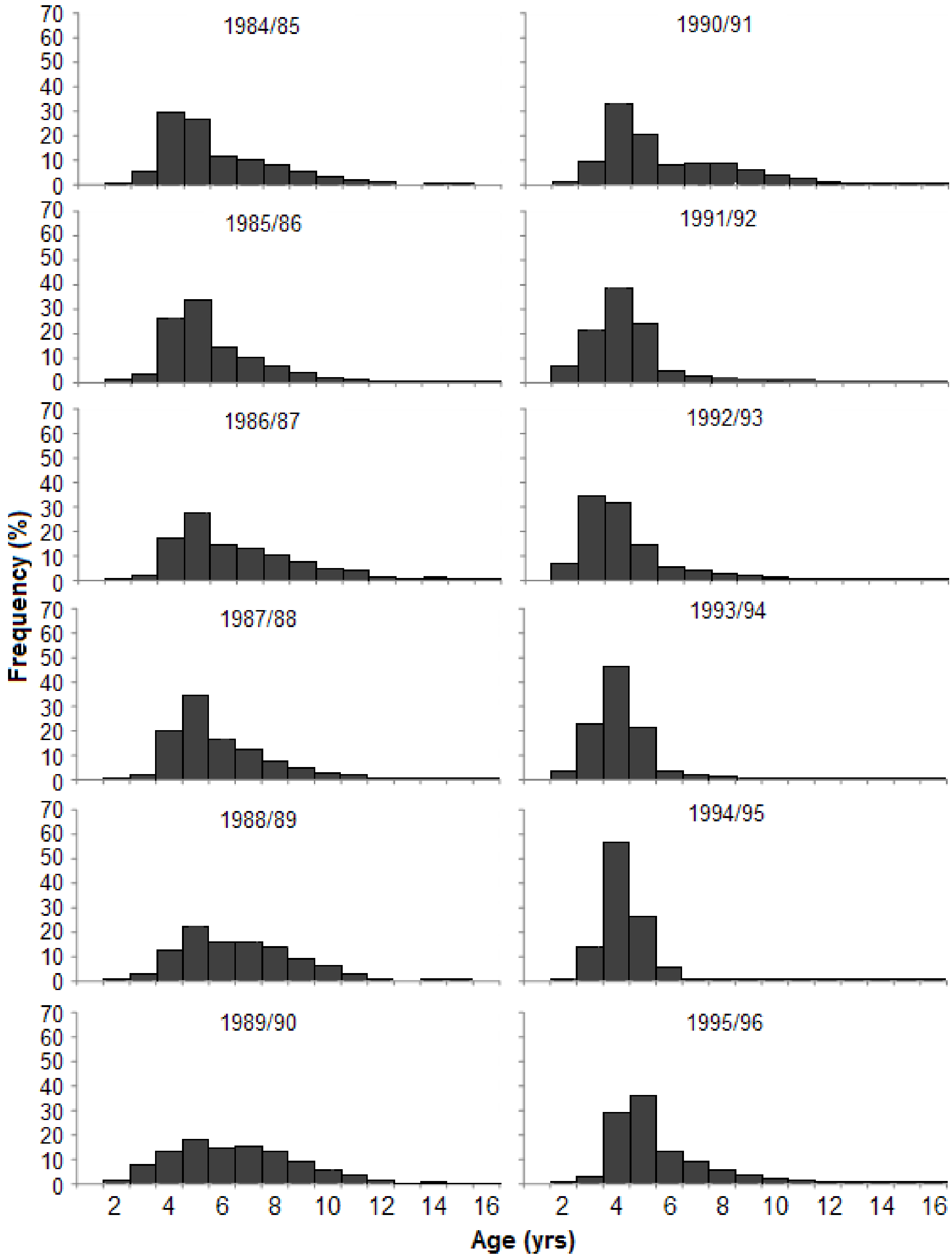

Figure 3.18 Age structure of Jack Mackerel from catch sampling from eastern Tasmania between 1984/85 and 1995/96.

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

Jack Mackerel mid-water trawl catches off eastern Tasmanian between 2001/02 and 2004/05 comprised 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.

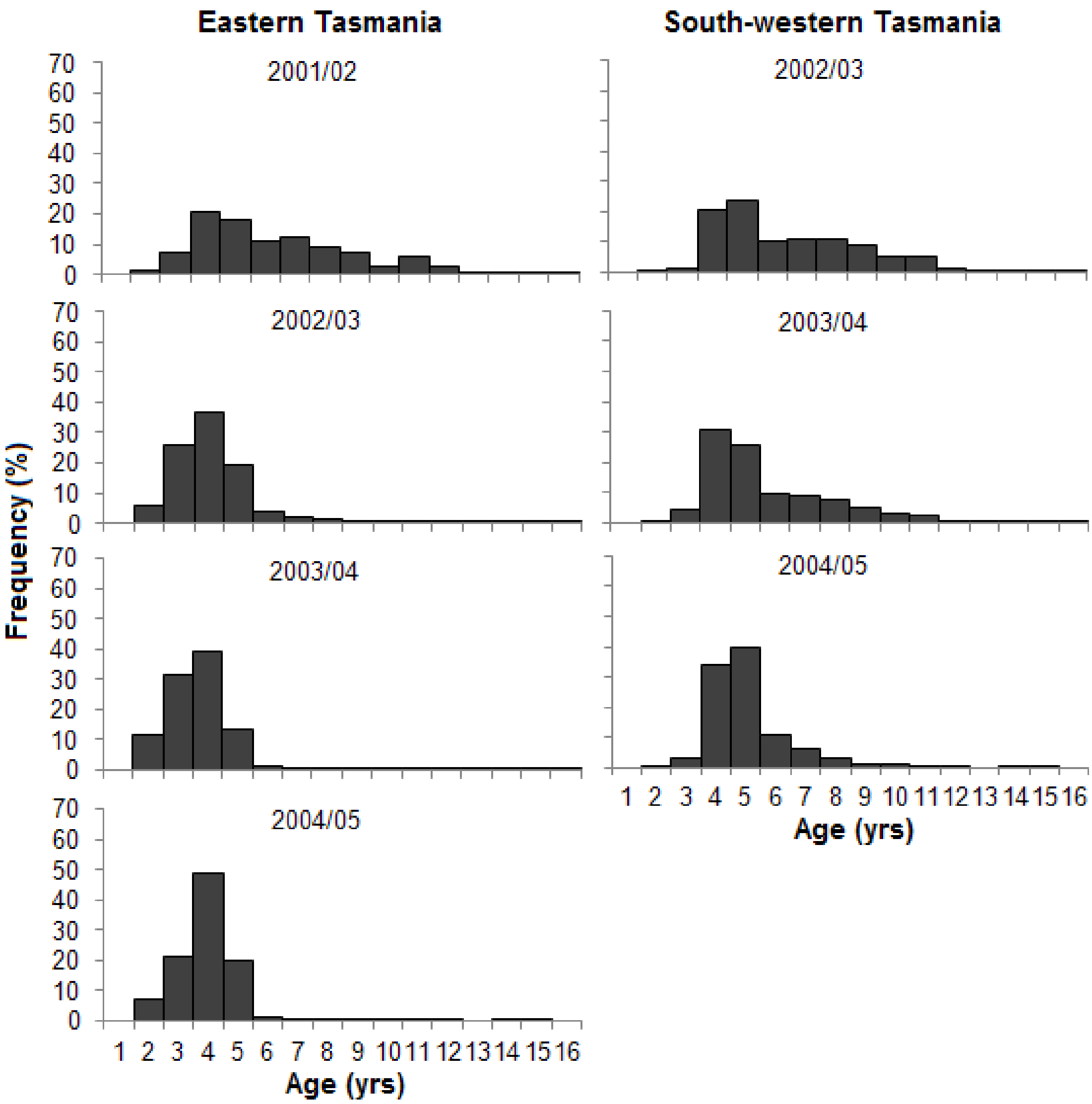

Figure 3.19 Age structure of Jack Mackerel from catch sampling from eastern and south-western Tasmania between 2001/02 and 2004/05 (few data were available from south-western Tasmania during 2001/02).

3.3.4.3 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 (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.

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

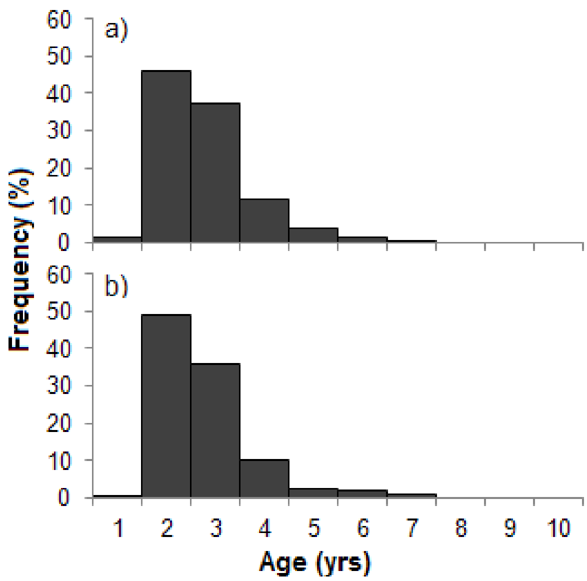

Figure 3.20 Age distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

3.3.5 Reproduction

An estimate for age at sexual maturity for the south-western Jack Mackerel population is not available due to limited sample sizes.

3.3.5.1 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 3-month period from late spring to early summer (Figures 3.21, 3.22). 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. 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.

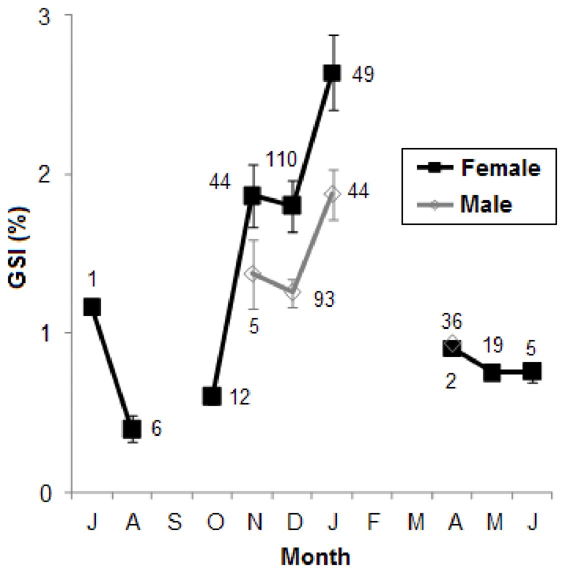

Figure 3.21 Monthly mean GSIs of Jack Mackerel, by sex from eastern Tasmania. Numbers associated with data points represent sample size and error bars are standard error.

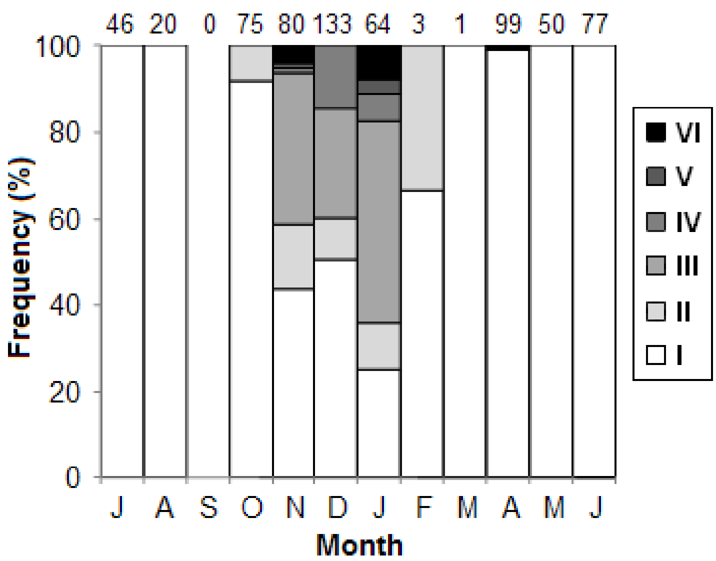

Figure 3.22 Monthly distribution of macroscopic gonad stages from female Jack Mackerel from eastern Tasmania. Numbers represent sample sizes.

3.3.5.2 Size at maturity

Estimates of size at sexual maturity showed small differences between sexes with 50% maturity occurring at 268 mm FL for females and 291 mm FL for males (Table 3.4, Figure 3.23). 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

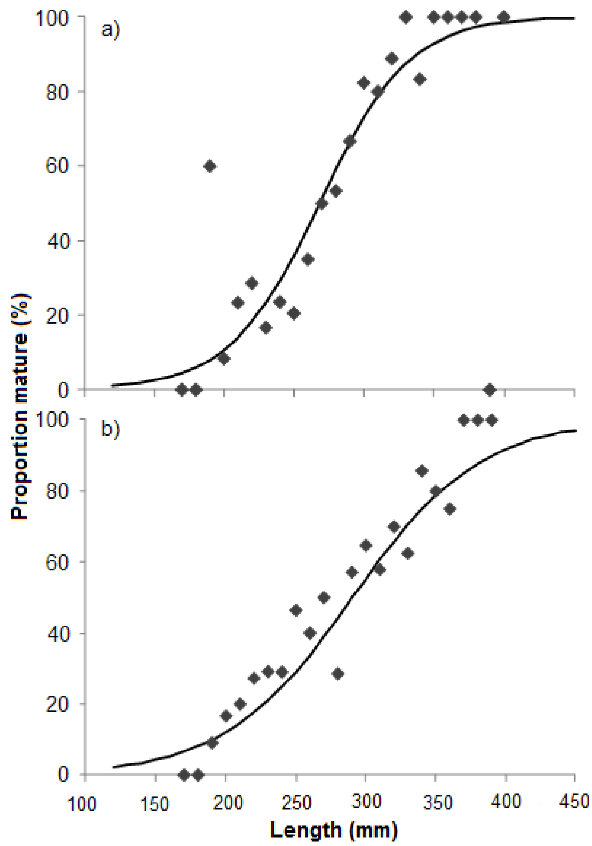

Figure 3.23 Proportion of mature female (a) and male (b) Jack Mackerel by length class with logistic ogives fitted.

3.3.6 Biomass Estimates and MSE

A DEPM analysis by Neira (2011) estimated the spawning biomass of Jack Mackerel to be ~114,000-169,000 t between Sugarloaf Point and Cape Howe (East) during October 2002. This estimate is considered to be imprecise due to the lack of locally collected species-specific reproductive parameters and the lack of a validated temperature-dependant 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 MSE model 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. As a DEPM spawning biomass estimate is now available for Jack Mackerel, incorporation of this information into a MSE warrants consideration.

There have been limited stock assessments of Yellowtail Scad in Australia. Stewart and Ferrell (2001) found that the majority of Yellowtail Scad landed in New South Wales were 2 and 3 year olds. A recent provisional DEPM spawning biomass estimate (Neira 2009) suggests a biomass of ~2,900 - ~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 and are not presented in the context of recent catches by the SPF.

3.4 Summary and Conclusions

The large fluctuations in production levels throughout the history of the fishery for Jack Mackerel are likely the result of a combination of changes in fish availability/abundance and market/economic factors. The potential effects of fishing on abundance and population structure are poorly understood. Several authors have documented the 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. 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 Sardine that must be currently discarded in waters off Tasmania. In 2012/13, reduced mid-water trawl effort coupled with limited purse-seine activity has meant that production levels were low. There is insufficient evidence to determine whether the recent low catches relate to reduced stock abundance.

Between 1984/85 and 1990/91, purse-seine catches were dominated by 4 and 5 year olds, 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 the purse-seine and mid-water trawl catches. While fishery impacts are plausible in the early stages of the fishery due to high catch levels, more recent catches have been relatively small (reflecting limited effort) and may therefore reflect recruitment variability and/or targeting practices.

The fishery-dependent and -independent data presented in this chapter suggest that recent low catches of Jack Mackerel in the East and West are sustainable. In 2012/13, catches of Jack Mackerel in the East were < 1% of both the RBC and most recent DEPM biomass estimates done in 2002. As such, Woodhams *et al.* (2012) assigned Jack Mackerel to the categories of ‘not overfished’ and ‘not subject to overfishing’. The need for DEPM assessments of Jack Mackerel in the both zones warrants consideration.

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 peaking at over 40,000 t in 1986/87. 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 to reduce dependence on the availability of surface schooling fish. 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; Markina and Boldryev 1980; Last *et al.* 1983; Nor *et al.* 1985; May and Maxwell 1986; Smith and Heemstra 1986; Mel'nikov and Ivanin 1995; Parin *et al.* 1997). 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 (Heemstra and Randall 1977; Markina and Boldryev 1980; Meléndez and Céspedes 1986; Oyarzún and Arriaza 1993; Parin *et al.* 1997; Gomon *et al.* 2008). 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.

4.1.5 Movement

No studies have investigated Redbait movement.

4.1.6 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 Blue Mackerel form mixed species schools in Tasmanian waters (Williams and Pullen 1993) it is likely that these species also feed on similar prey items.

4.1.7 Age, Growth and Size

The maximum reported size for female and male Redbait from Tasmania is 317 mm FL 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 scales (Roschin 1985), whole otoliths (Williams *et al.* 1987) or sectioned otoliths (Neira *et al.* 2008) suggest that growth is rapid in the first years of life. On average, Redbait from Tasmanian waters 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 otoilths is 21 and 18 years for females and males, respectively (Neira *et al.* 2008). The much 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. Unvalidated ageing of rubyfish in New Zealand, using otolith sections, has produced age estimates in excess of 80 years for fish over 400 mm (Paul *et al.* 2000), indicating that some emmelichthyids may be long-lived. However, as ageing methods have not been fully validated for any emmelichthyid species, current estimates of growth or maximum age need to be considered with caution.

4.1.8 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, with males and females from south-western Tasmania (261 and 244 mm FL, respectively) maturing at some 100 mm larger and two years older compared to Redbait from eastern Tasmania (157 and 147 mm FL, respectively). Spawning occurs along a narrow 2.5 nautical mile (nm) corridor either side of the shelf break when mid-water temperatures are 12.0-15.2°C (Neira *et al.* 2008).

4.1.9 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 to 3.3 mm TL. Although spawning areas (eggs and larvae) have been described by Neira *et al.* (2008), little is known about the early life history of Redbait post-hatching.

4.1.10 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).

4.1.11 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 2012/13 season, Tier 2 maximum RBC for Redbait in both the East and West was 5,000 t (AFMA 2014).

4.1.12 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, including 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, including 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 4. 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 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 was supplied for 2010/11, 2011/12 and 2012/13.

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

4.3.1.1 Number of vessels

In 2012/13, one fishing vessel reported catches of Redbait in the East (Figure 4.1), while no catches were reported for the West (Figure 4.2).

4.3.1.2 Annual patterns – catch

Prior to 2001/02, Redbait catches in the East were negligible (<200 t). 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 13 t in 2010/11 (Figure 4.3) and were less than 0.1 t in 2011/12 and 2012/13. Redbait catches in the West were typically lower than the East (Figure 4.4). Similar to the East, the trend in catches in the West displayed a clear peak, but it occurred several years later, with catches exceeding 3,000 t in 2005/06. Since then, catches have declined, with no catches recorded from 2010/11 to 2012/13. Since 1997/98, the trend in catch for the East and West has reflected the trend in annual fishing effort.

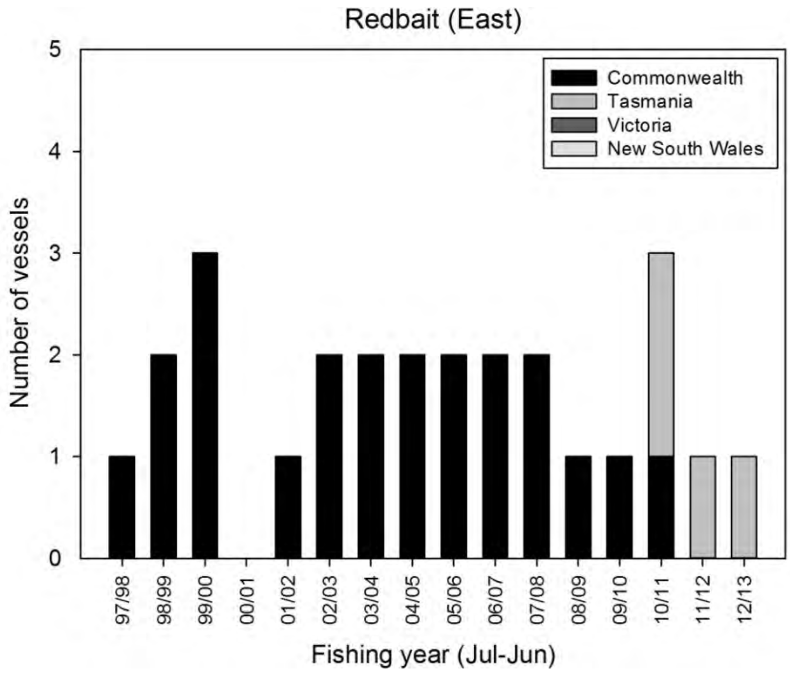

Figure 4.1 Number of vessels which landed Redbait in the East, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

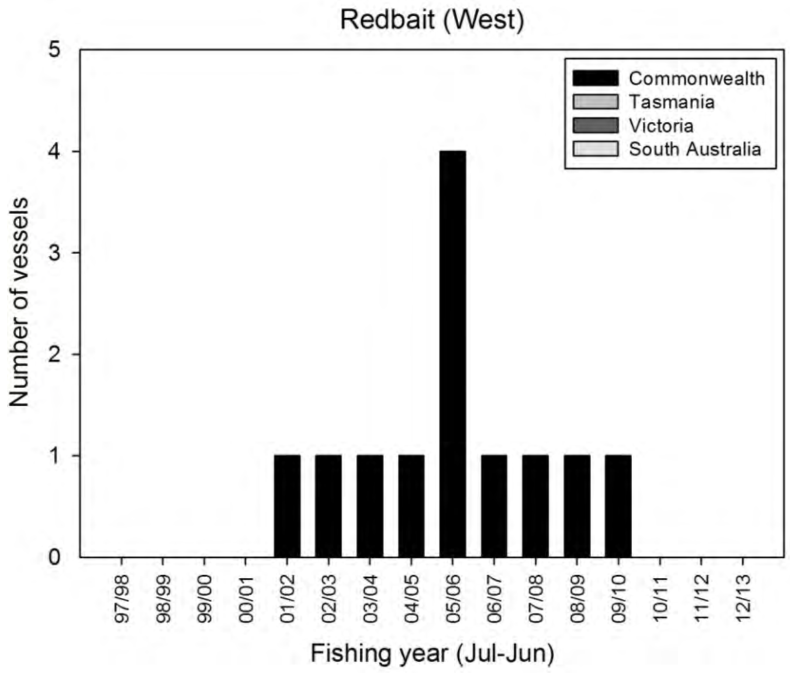

Figure 4.2 Number of vessels which landed Redbait in the West, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

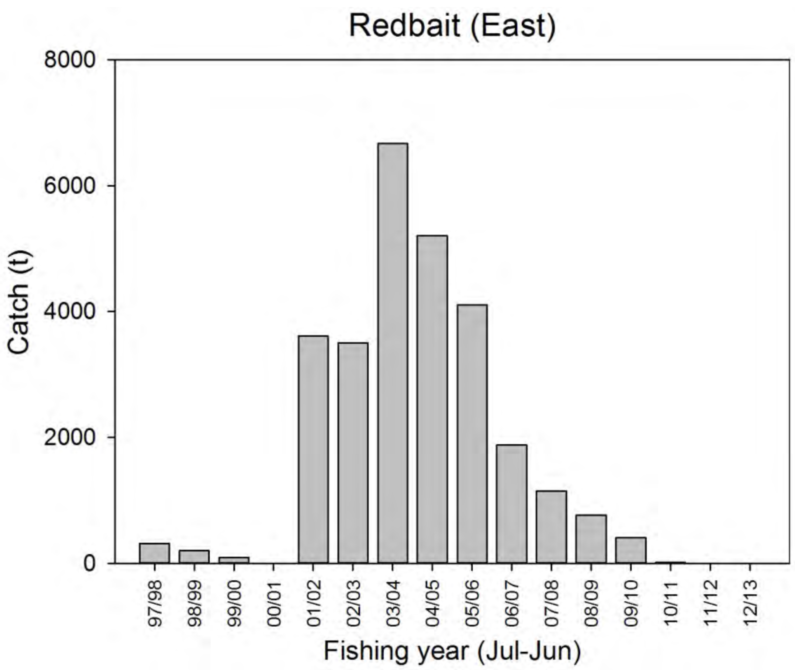

Figure 4.3 Total landed catch (t, bars) for Redbait in the East for each financial year from 1997/98–2012/13.

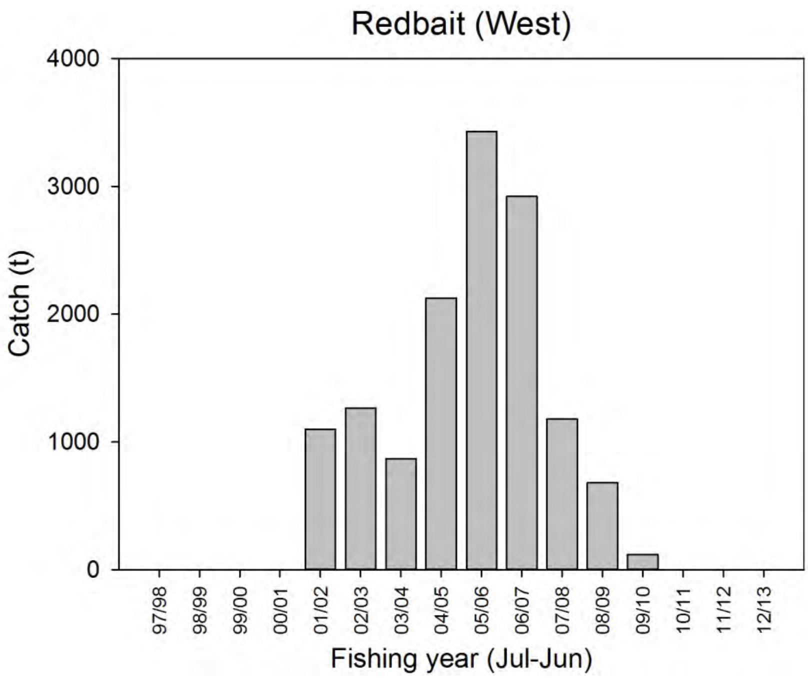

Figure 4.4 Total landed catch (t, bars) for Redbait in the West for each financial year from 1997/98–2012/13.

4.3.2 Biological Information

All biological data for Redbait in the East and West Zones were collected from 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. Data were collected on a small proportion of fishing trips in most years and so are limited and may not be representative of the catch. From 2002–2006, 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.

4.3.2.1 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; 4.6). Catches between 1984/85 and 1987/88 were dominated by fish of 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) was present in the 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 4.6). No data from 2010/11–2012/13 were available.

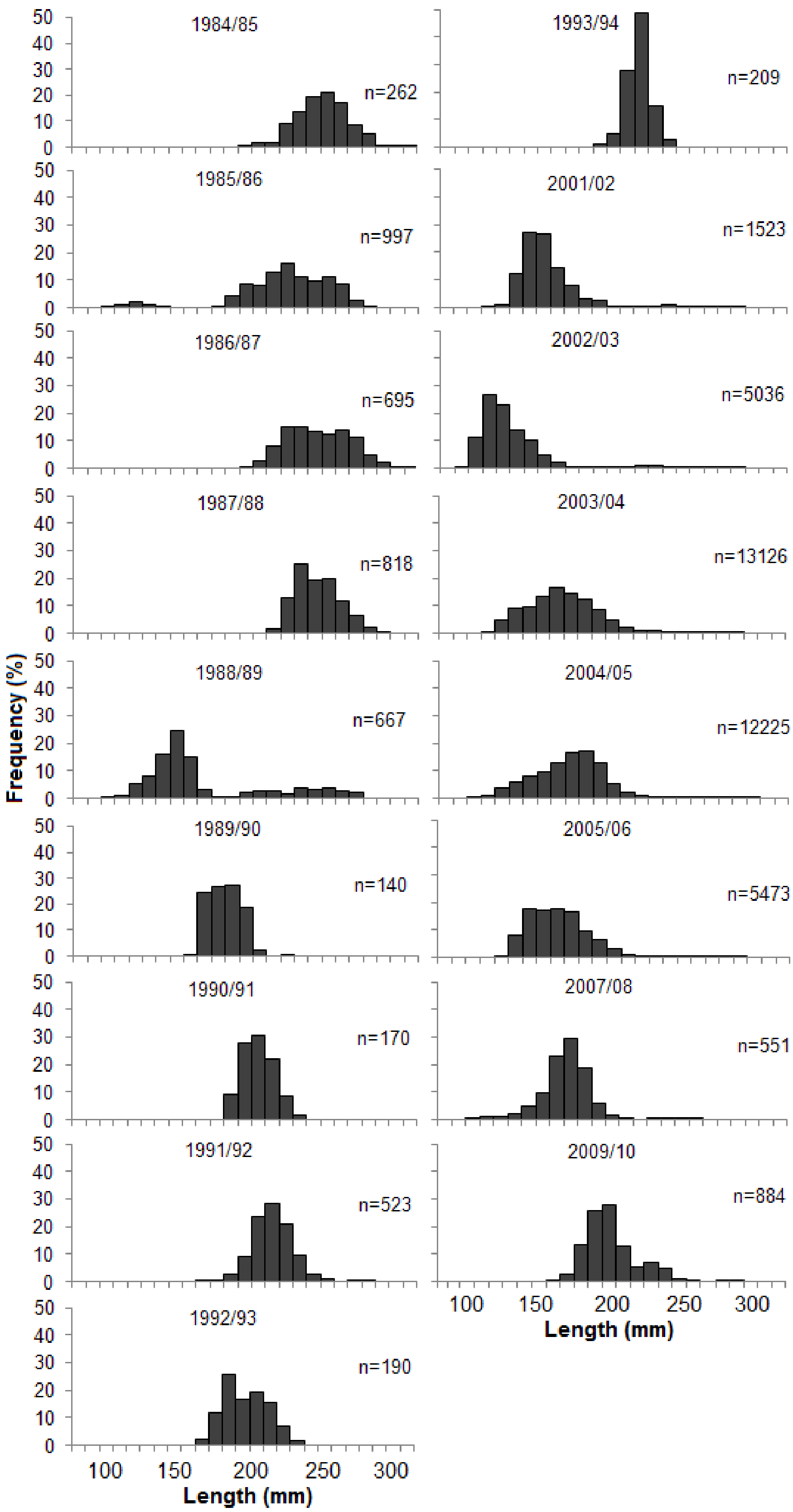

Figure 4.5 Length frequency distributions of Redbait caught in the SPF by purse-seine operations off eastern Tasmania from 1984/85 to 2009/10.

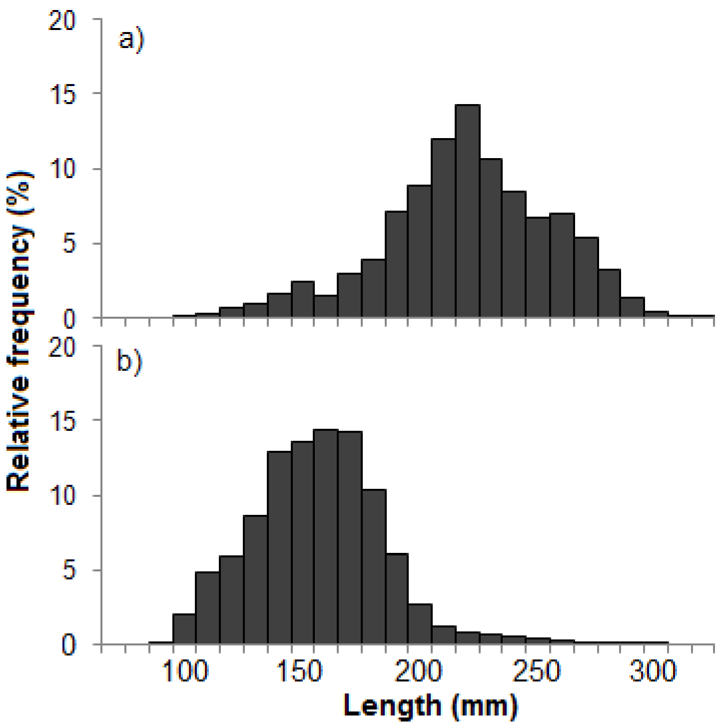

Figure 4.6 Year-weighted length frequency distributions of Redbait caught in the SPF off eastern Tasmania from (a) purse-seine operations (1984/85-1994/95) and (b) mid-water trawl operations (2001/02-2008/09).

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 4.6; 4.7). Annual size distributions show east coast catches were consistently comprised of high numbers of small fish with modes varying between 120 (2002/03) and 180 mm FL (2004/05) (Figure 4.5). 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 130-280 mm FL with a modal length of 200 mm FL (Figures 4.7). While the south-west coast frequency distribution in 2001/02 comprised mainly small fish and mirrored that of the east coast fish in that year, substantially larger individuals dominated south-west coast catches in subsequent years. Overall, the size structure of Redbait catches from south-western Tasmania was bi-modal with peaks at around 140 and 200 mm FL (Figure 4.7).

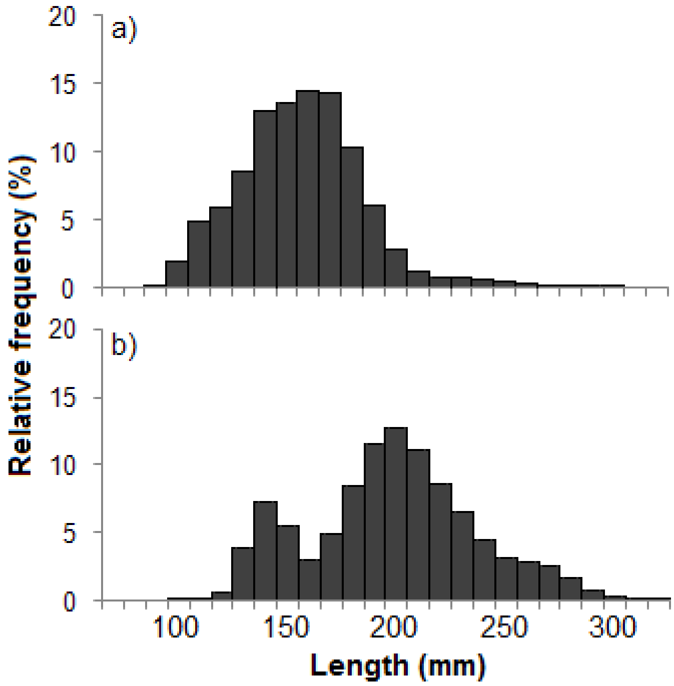

Figure 4.7 Year-weighted length frequency distributions of Redbait caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2001/02 and 2006/07.

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 190-240 mm FL fish (Figure 4.8). By contrast, 180-200 mm FL fish comprised the bulk of the purse-seine catch and individuals larger than 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 of 210-310 mm FL (mode 240 mm). This was consistent with the size range from previous years from that region (Table 4.1).

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)	Mode (mm)
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

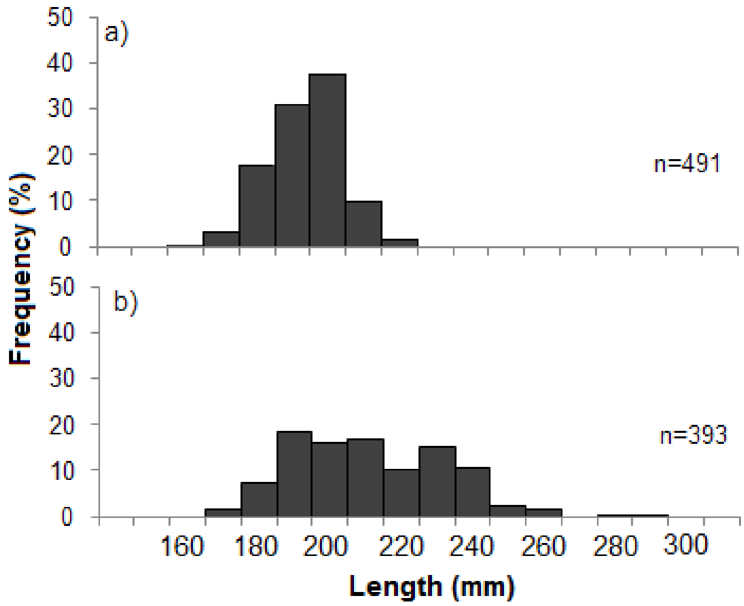

Figure 4.8 Length frequency distribution of Redbait caught in the SPF eastern Tasmania by purse-seine (a) and mid-water trawling (b) operations during 2009/10. n is sample size.

4.3.3 Age and growth

Growth of male and female Redbait was described using the VBGF from eastern and south-western Tasmania (Table 4.2, Figure 4.9). On average, growth was rapid within the first years of life with individuals reaching ~200 mm FL in the first three years, with grow slowing thereafter. Maximum assigned ages for females and males reordered were 21 and 18 years, respectively.

Table 4.2 Summary of VBGF parameters by sex and region. EC and SW refer to eastern and south-western Tasmania and * refers to eastern Tasmanian samples with unsexed juveniles excluded (based on Neira *et al.* 2008).

		VB parameters		
	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

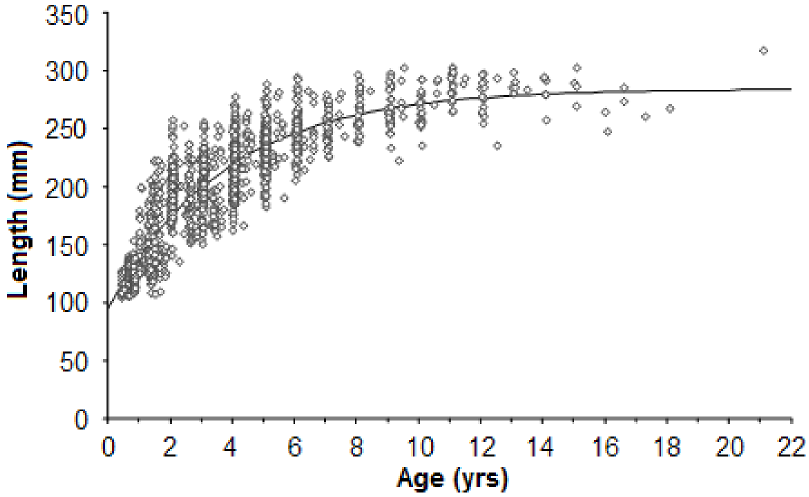

Figure 4.9 Length at age data for Redbait with regions pooled. The grey line represents the VB growth function.

4.3.3.1 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 4.10). 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.

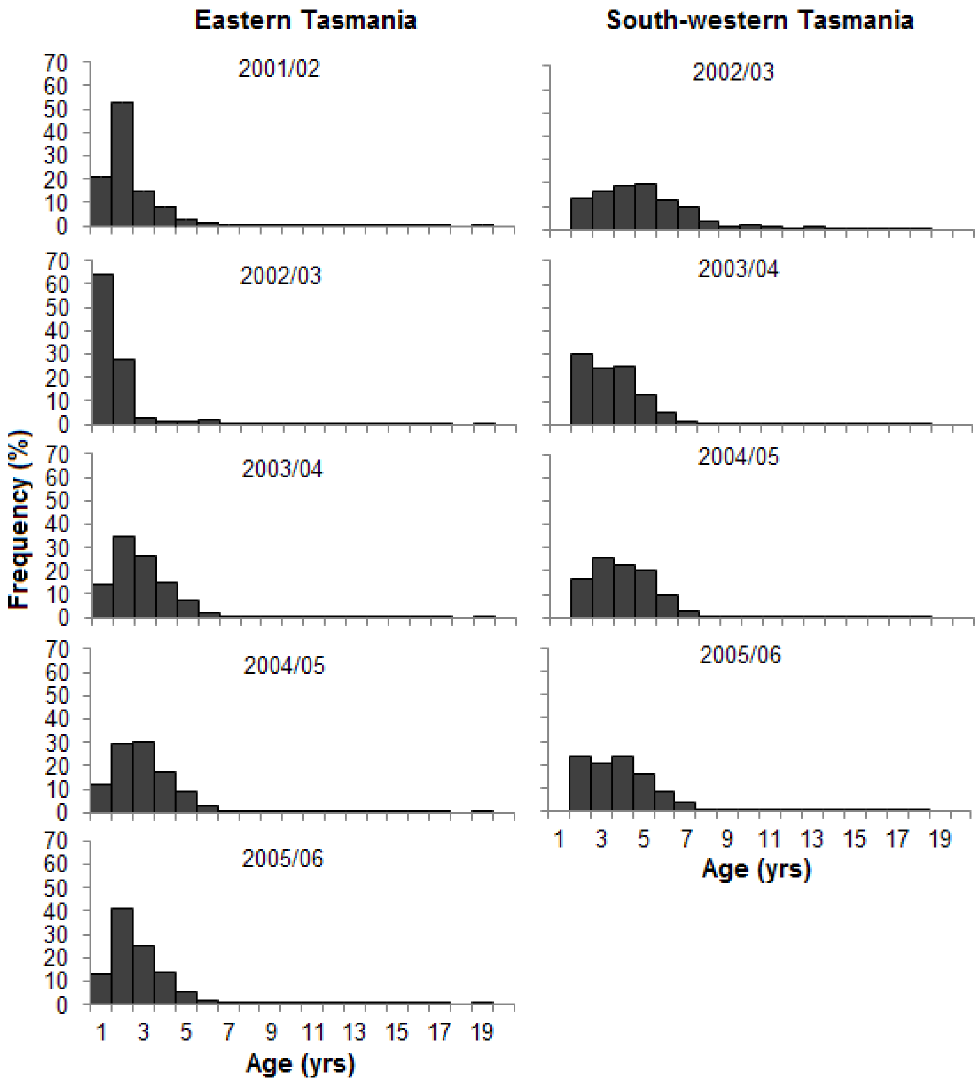

Figure 4.10 Age structure of Redbait catch samples from eastern and south-western Tasmania from 2001/02 to 2005/06 (No data were available off south-western Tasmania during 2001/02).

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 2-3 years of age (Figure 4.11). Purse-seine catches were also dominated by 2-3 year old fish, with 2 year olds accounting for over half of the catch (Figure 4.11).

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

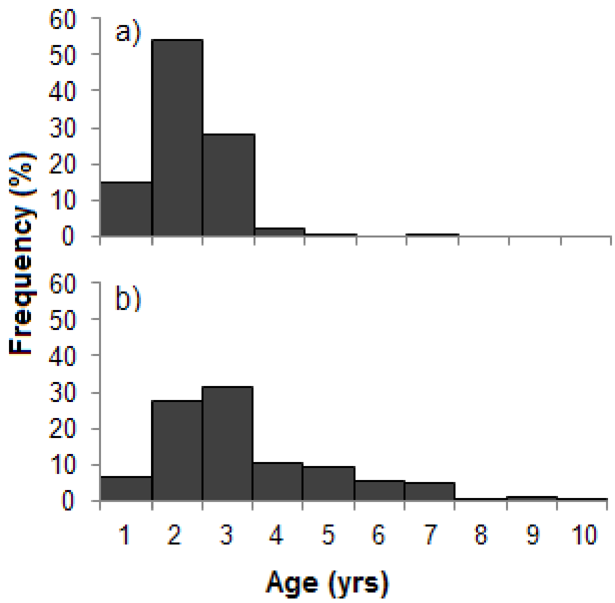

Figure 4.11 Age distribution of Redbait caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

4.3.4 Gonadosomatic index

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 4.12). A similar pattern was evident for south-western Tasmania, although the peak occurred between October and November, i.e. one month later.

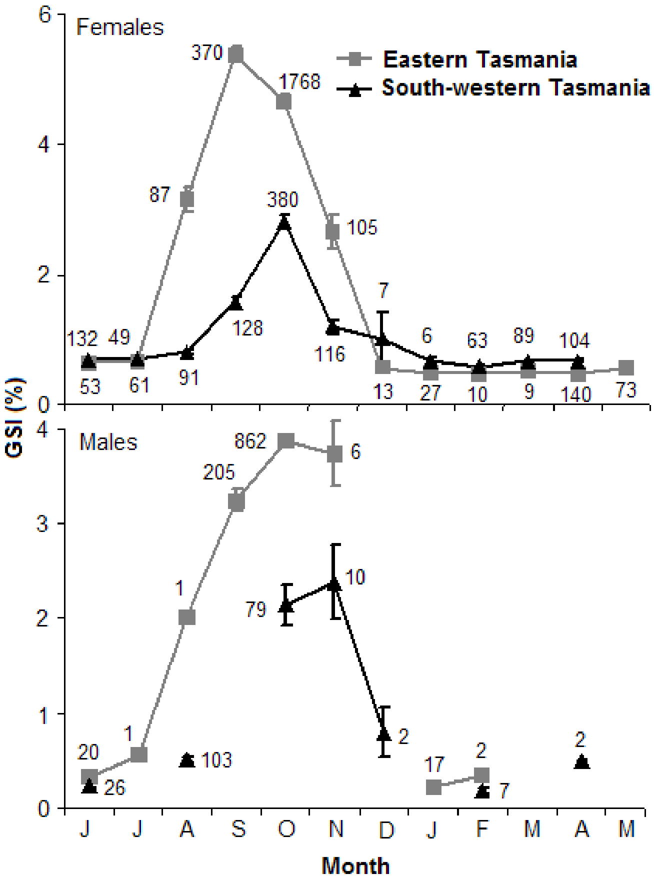

Figure 4.12 Monthly distribution of mean GSI, by sex and region. Numbers represent sample size and error bars are standard error. Based on Neira *et al*. (2008).

4.3.5 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 4.13). 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 4.13).

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.

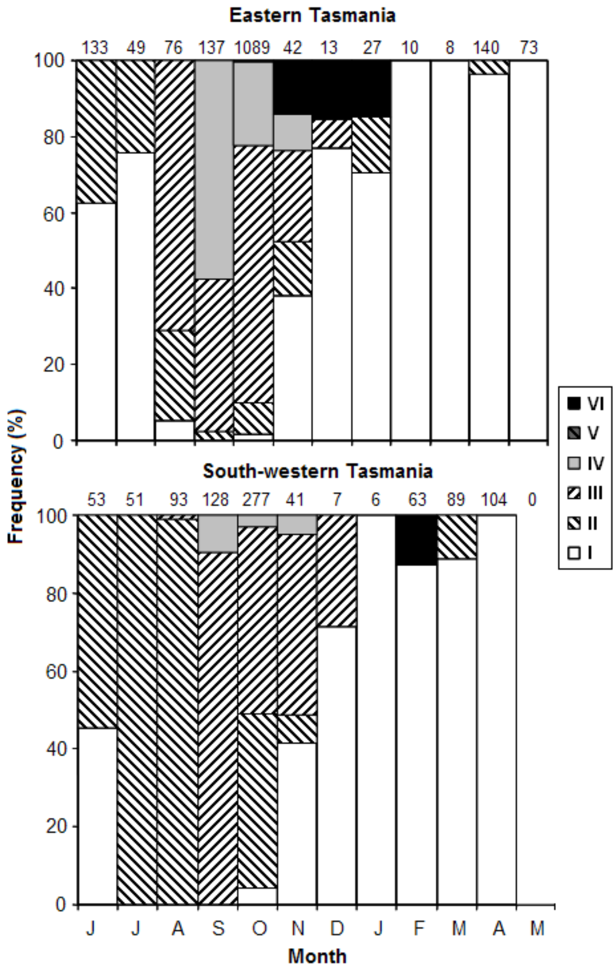

Figure 4.13 Monthly distribution of female macroscopic gonad stages by region. Numbers represent sample sizes. Based on Neira *et al*. (2008).

4.3.6 Size and age at maturity

Logistic growth models indicated that 50% of 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 4.14; 4.15). 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 the eastern Tasmania. The size (age) at 50% sexual maturity was 147 and 244 mm (4.8 and 2.0 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 and age data to determine L_{50} and A_{50} for Australian Sardine 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

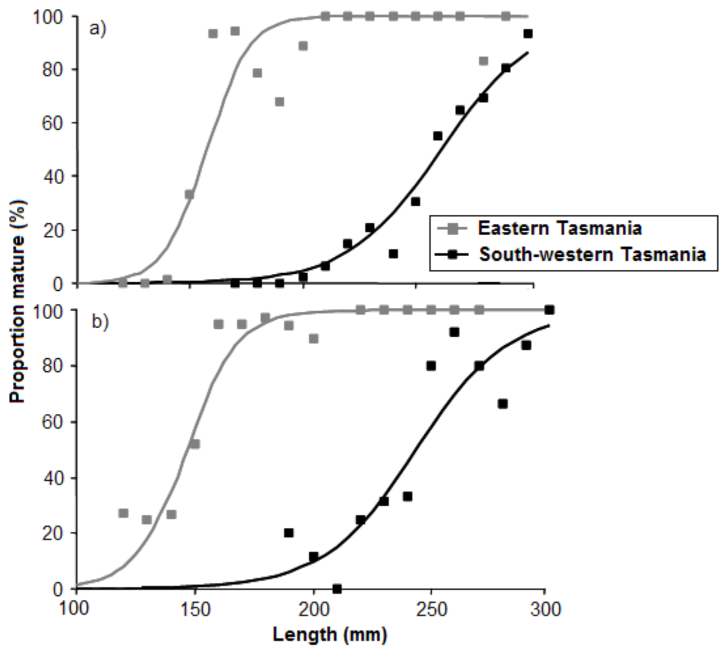

Figure 4.14 Proportion of mature female (a) and male (b) Redbait by length class and region, with logistic ogives fitted. Based on Neira *et al.* (2008).

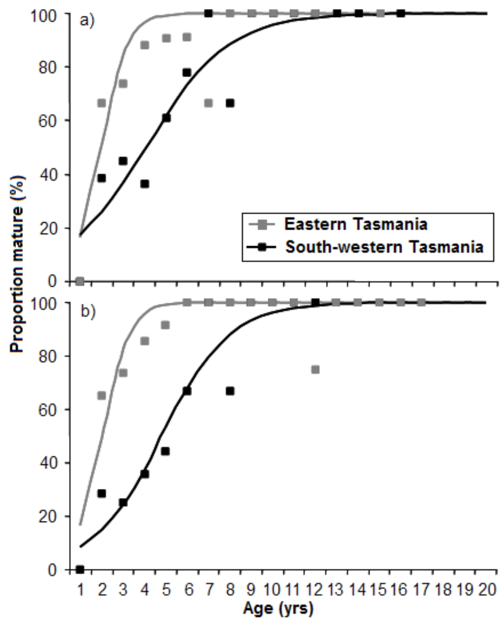

Figure 4.15 Proportion of mature female (a) and male (b) Redbait by age class and region, with logistic ogives fitted. Based on Neira *et al.* 2008.

4.3.7 Biomass estimates

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 between 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.

4.3.8 MSE

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 an 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

Outdated DEPM estimates for Redbait in the East suggest a spawning biomass in excess of 50,000 t, implying that catches since 2001/02 (~7,000 t per annum) have been sustainable. This evaluation is supported by the MSE. However, there is insufficient fishery catch and effort data available for recent years to confidently determine the status of the Redbait stocks in the East and West, due 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). However, as no estimates of spawning biomass are available for the western stock, it remains 'uncertain' whether or not the stock is overfished (Woodhams *et al.* 2012). Biological sampling has revealed no obvious impact on size or age composition over the recent history of the fishery. In 2012/13, the total catch of Redbait in the East was < 1 t which accounted for < 1% of both the RBC and the most recent DEPM biomass estimate from 2006. There were no reported landings of Redbait in the West. The need to conduct DEPM assessments of Redbait in both zones warrants consideration.

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 their fisheries are important (Stratoudakis *et al.* 2006). Australian Sardine (*Sardinops sagax*) occur in temperate waters from southern Queensland to Western Australia (Ward and Staunton-Smith 2002) where they support several commercial fisheries.

Small-scale exploitation of Sardine in Australia has occurred since the 1800s (Kailola 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 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 (Fletcher and Santoro 2008). 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). 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 Sardines (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 more than 4,000 t in the 2007/08 season.

5.1.2 Taxonomy

The Australian Sardine is broadly known as *Sardinops sagax*. Most fisheries scientists throughout the world follow the taxonomy of the genus *Sardinops* proposed by Parrish *et al*. (1989) who suggested the genus is mono-specific with no valid subspecies. Recently, 11 new polymorphic micro-satellites were isolated that have the potential to help resolve some of the minor taxonomic questions that remain for this species (Pereya *et al.* 2004).

5.1.3 Distribution

Australian Sardine (*S. sagax*) is found in waters off Australia, Japan, North and South America, Africa and New Zealand. In Australia, it is found throughout temperate waters between Rockhampton (Queensland) and Shark Bay (Western Australia), including northern Tasmania (Gomon *et al.* 1994).

5.1.4 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). No detailed studies of stock structure have been undertaken across the distribution of Australian Sardine. 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).

5.1.5 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.

5.1.6 Food and Feeding

Sardines switch between particulate-feeding on macro-zooplankton to filter-feeding on micro-zooplankton and phytoplankton, depending on relative prey density (van der Lingen 1994; Louw *et al.* 1998). In a recent study in South Australian waters, Australian Sardine were found to have consumed 12 prey taxa with krill (29.6% biomass) and unidentified crustacean (22.2% biomass) contributing most to the diet (Daly, SARDI Aquatic Sciences unpublished data). 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.

5.1.7 Age, Growth and Size

Growth rates and maximum size of Australian Sardine vary in response to localised variation in food availability and environmental conditions (Ward *et al.* 2003). In southern Australia, Australian Sardine rarely exceed 250 mm FL after 6 to 8 years (Rogers and Ward 2007). Larval and juvenile Sardine 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 are 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.

5.1.8 Reproduction

The reproductive biology of Australian Sardines in some regions of Australia is relatively well known. Approximately 50% of males and females in South Australia reach sexual maturity (L_{50}) at 146 and 150 mm, respectively (Ward and Staunton-Smith 2002). Females spawn batches of 10,000–30,000 pelagic eggs approximately once per week during the extended spawning season. Eggs are most abundant in the southern gulfs of South Australia and in shelf waters (Ward and Staunton-Smith 2002). 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-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).

5.1.9 Early Life History and Recruitment

Sardine eggs hatch approximately two days after fertilization and yolk-sac larvae are ~2.2 to 2.5 mm TL (Neira *et al.* 1998). Larvae metamorphose at 1–2 months of age and at lengths of 35–40 mm TL. 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). Sardine larvae are abundant at temperature and salinity fronts that form near the mouths of South Australia's two gulfs during summer and autumn (Bruce and Short 1990). In South Australia, juveniles occupy nursery areas that include shallow embayments and semi-protected waters. The factors affecting recruitment success of Sardines are poorly understood.

5.1.10 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). DEPM has been used to estimate the spawning biomass of Australian Sardine in South Australia since 1995.

The advantage of this approach is that it provides direct estimates of spawning biomass on which to base management decisions. The disadvantages include high degrees of uncertainty that surround the point estimates of biomass, high running costs of vessels, and extensive laboratory time required to identify eggs from ichthyoplankton samples (Cochrane 1999; Stratoudakis *et al.* 2006).

5.1.11 Management

A DEPM assessment has been conducted for the East Zone and the fishery is managed at the Tier 2 level.

5.1.12 Recreational fishing

Information on the magnitude of recreational catches of Australian 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 (Flood *et al.* 2012).

5.2 Methods

5.2.1 Fishery Statistics

Fishery statistics were supplied by ABARES up to 2010/11, and in 2011/12 and 2012/13 were supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are in financial years. Total effort was not presented for 2012/13, as data from New South Wales were not available.

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.

5.2.2 Biological Information

Catch samples were collected from commercial landings at Eden and Iluka in New South Wales during the 2009 fishing season. Fish were dissected and morphometric data collected by New South Wales DPI, otoliths were interpreted for age by SARDI Aquatic Sciences using the methods of Rogers and Ward (2007). Additional size frequency data were supplied by New South Wales DPI. AFMA observers collected biological samples during trips in September 2012 and August 2013 which were supplied to SARDI Aquatic Sciences.

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 a study of Blue Mackerel, *S. australasicus*. 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

5.3.1.1 Location of vessels

The number of vessels that reported landings of Australian Sardine in the East Zone peaked at 42 in 1997/98 with the majority of these from New South Wales (Figure 5.1). Since then, the number has gradually declined and in 2012/13, only six commercial vessels reported catches of Sardine.

5.3.1.2 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 $t.yr^{-1}$ to 558 $t.yr^{-1}$ (Figure 5.2). From then, catch increased to a peak of 4,768 t in 2008/09, before declining to 2,032 t in 2011/12. In 2012/13, catch declined further to 1,097 t. Fishing effort has been highly variable among years since 1997/98 when it peaked at 1573 vessel days (Figure 5.2). Fishing effort declined to <250 vessel days in 2001/02, increased to >900 vessel days through the mid-to-late 2000s, before decreasing again to 210 vessel days in 2011/12. Whilst effort data were not available for 2012/13, the 40% reduction in the number of vessels landing Australian Sardine from the previous year suggests that fishing effort remained low.

CPUE increased from 0.35 t.vessel day^{-1} in 1997/98 to an historical peak of 11.3 t.vessel day^{-1} in 2010/11 (Figure 5.3). Catch rate decreased to 9.68 t.vessel day in 2011/12. No CPUE estimate was available for 2012/13.

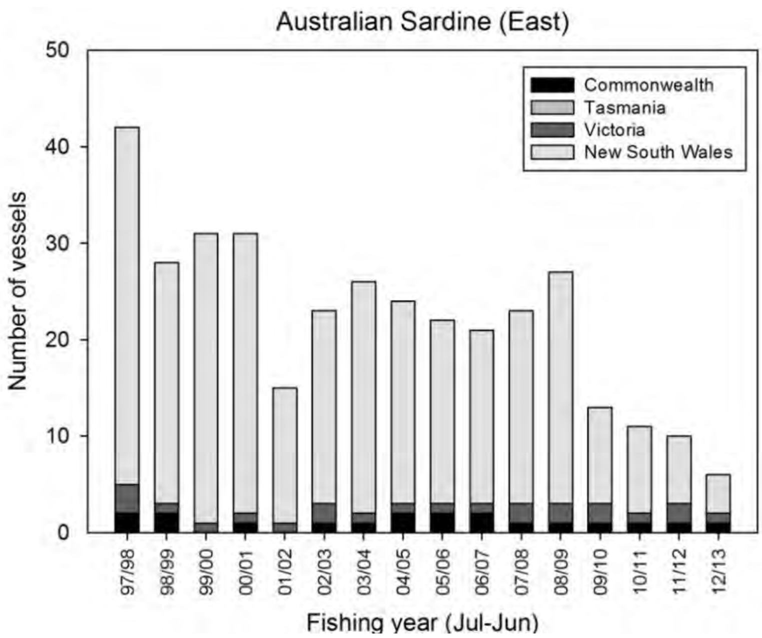

Figure 5.1 Number of vessels that reported landings of Australian Sardine in the East, from each of the participating management jurisdictions for each financial year from 1997/98–2012/13.

5.3.1.3 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 1999/2000, presentation and interpretation of monthly data are limited due to confidentiality issues arising from the small number of vessels participating in the fishery.

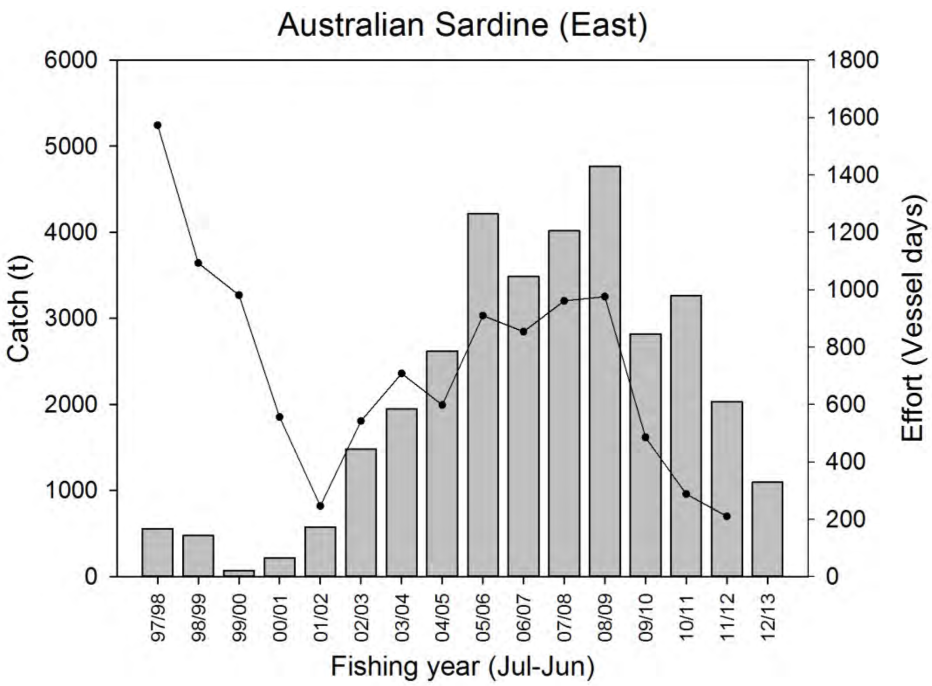

Figure 5.2 Total landed catch (t, bars) and effort (vessel days, line) for the East for each financial year from 1997/98–2012/13. Effort data was not available for 2012/13.

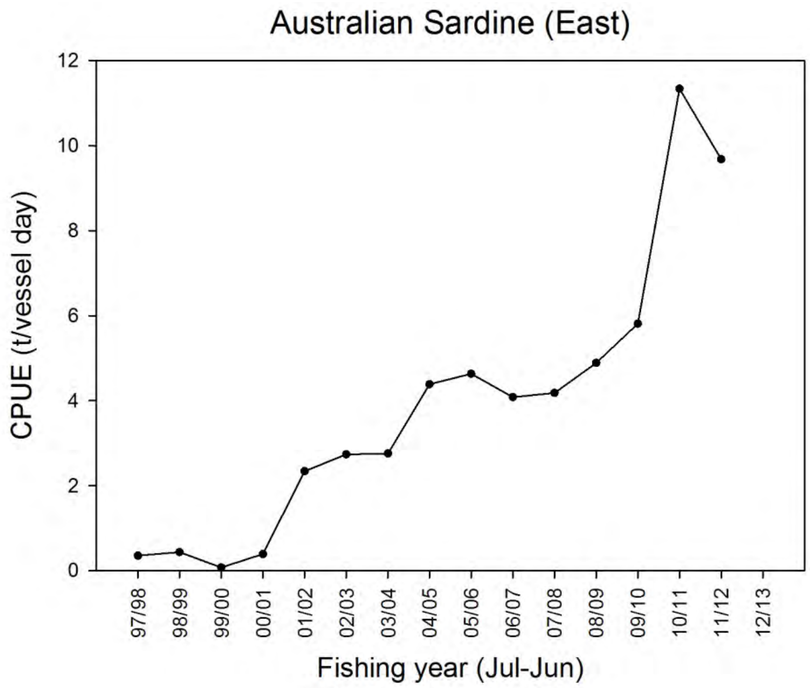

Figure 5.3 CPUE (t per vessel day) for the East for each financial year from 1997/98–2012/13. CPUE data was not available for 2012/13.

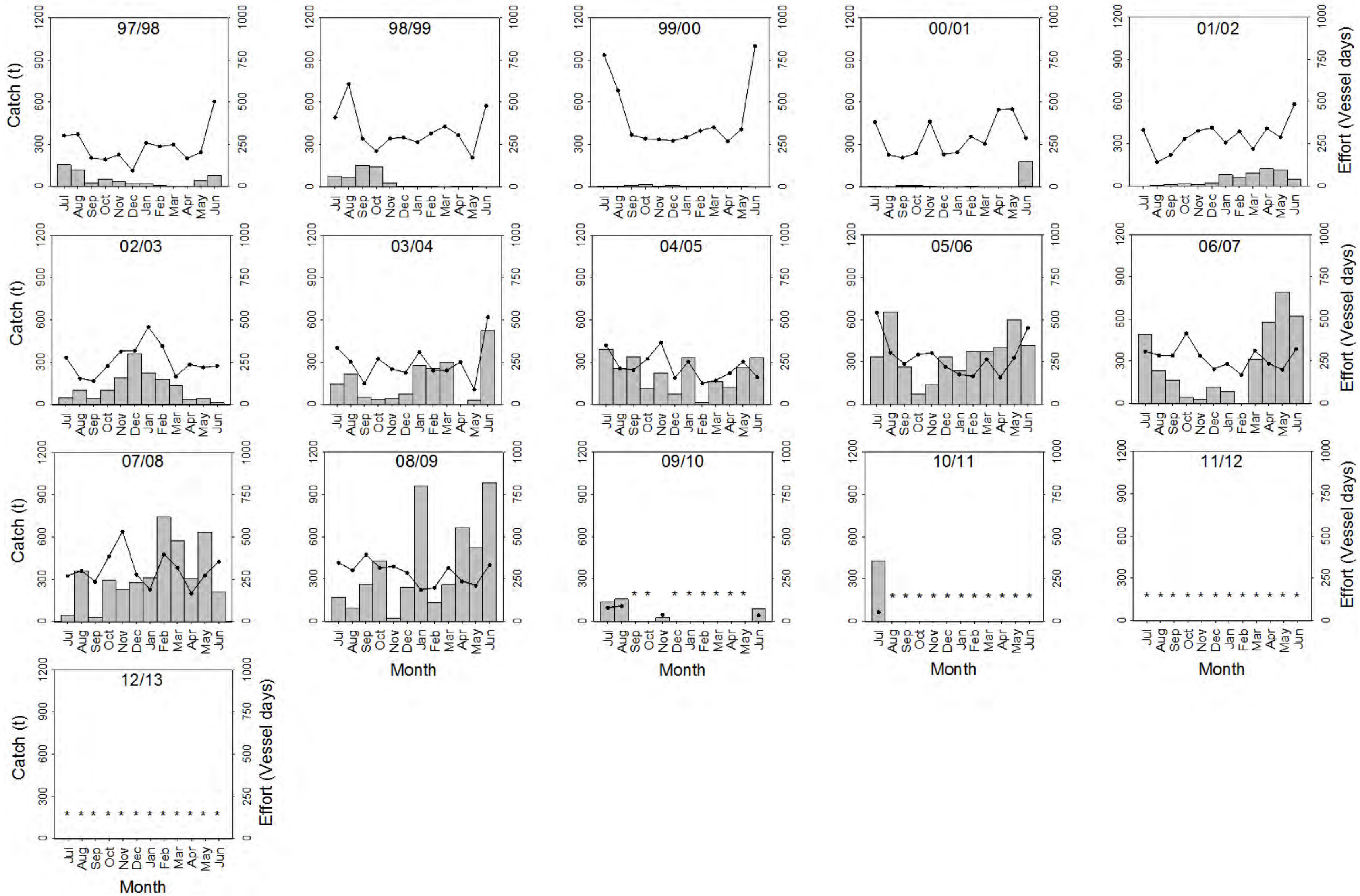

Figure 5.4 Intra-annual patterns of catch (bars) and effort (line) for Australian Sardine for the East for each financial year from 1997/98–2012/13. Catch and effort data for each year from 2010/11 - 2012/13 excludes non-oceanic fishing activity. (*) indicates data confidentiality, where <5 license holders report landings from individual month.

5.3.2 Biological Information

5.3.2.1 Sample Summary

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 5.1). Length frequency data for an additional 13,289 fish landed in New South Wales between 2004/05 and 2012/13 were supplied by New South Wales DPI. Length data for an additional 1,188 Australian Sardine, measured by AFMA observers in September 2012 (n=208) and August 2013 (n=980), were provided to SARDI. From these samples, a total of 32 and 246 fish in 2012 and 2013, respectively, were retained for ageing.

Table 5.1 Spatial and temporal summary of number of Australian Sardines supplied to SARDI for biological analysis from New South Wales in 2009 and 2010.

Month	North Coast	South Central Coast
March 2009		8
June 2009		70
July 2009	120	160
August 2009	80	100
September 2009	40	151
October 2009		120
November 2009		79
January 2010		100

In the context of the magnitude of catches of Australian Sardine in the East by the SPF 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.

5.3.2.2 Size Structure

Most Australian Sardines taken in New South Wales in 2009/10 were between 120 and 200 mm FL (Figures 5.5, 5.6). Samples from both north and south central regions tended to have smaller fish at the beginning of the season. The length distribution of annual (financial year) Australian Sardine catches were bimodal from 2004/05 to 2006/07 (Figure 5.7), with the smaller mode around the size at maturity. Length distributions for 2009/10 and 2010/11 were unimodal with the mean size above the size at maturity. In 2011/12, the length frequency was bimodal with >50% of fish sampled below the size at maturity. The age structure for 2012/13 comprised a single, narrow mode at ~145 mm FL (i.e. the approximate size at sexual maturity for Australian Sardine).

The size frequency of fish sampled from commercial vessels by AFMA observers on the north coast of New South Wales in 2012 and 2013 had a single mode at 150 mm FL (Figure 5.8).

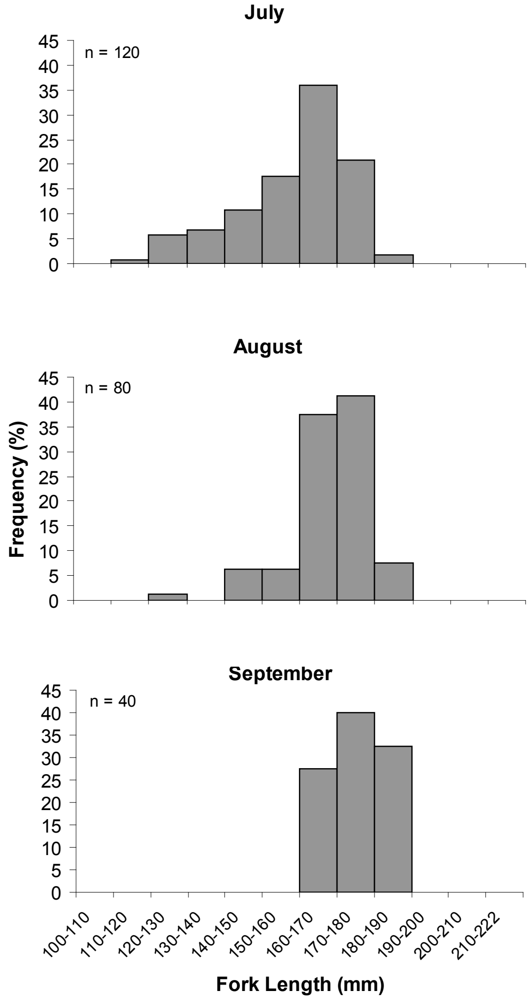

Figure 5.5 Size frequency histograms for Australian Sardine samples from commercial catches from the north coast of New South Wales in 2009.

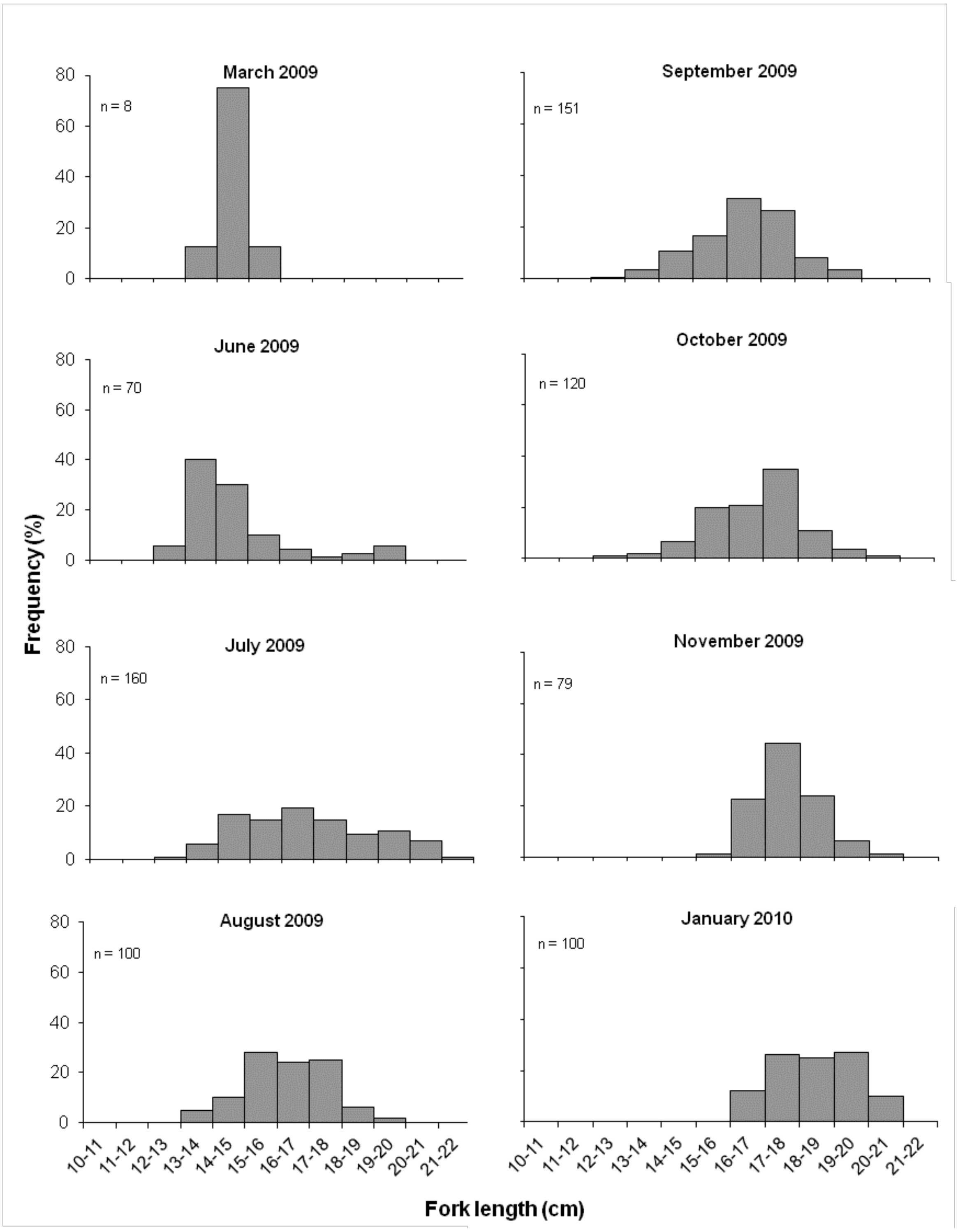

Figure 5.6 Size frequency histograms for Australian Sardine samples from commercial catches from the south central coast of New South Wales in 2009 and 2010.

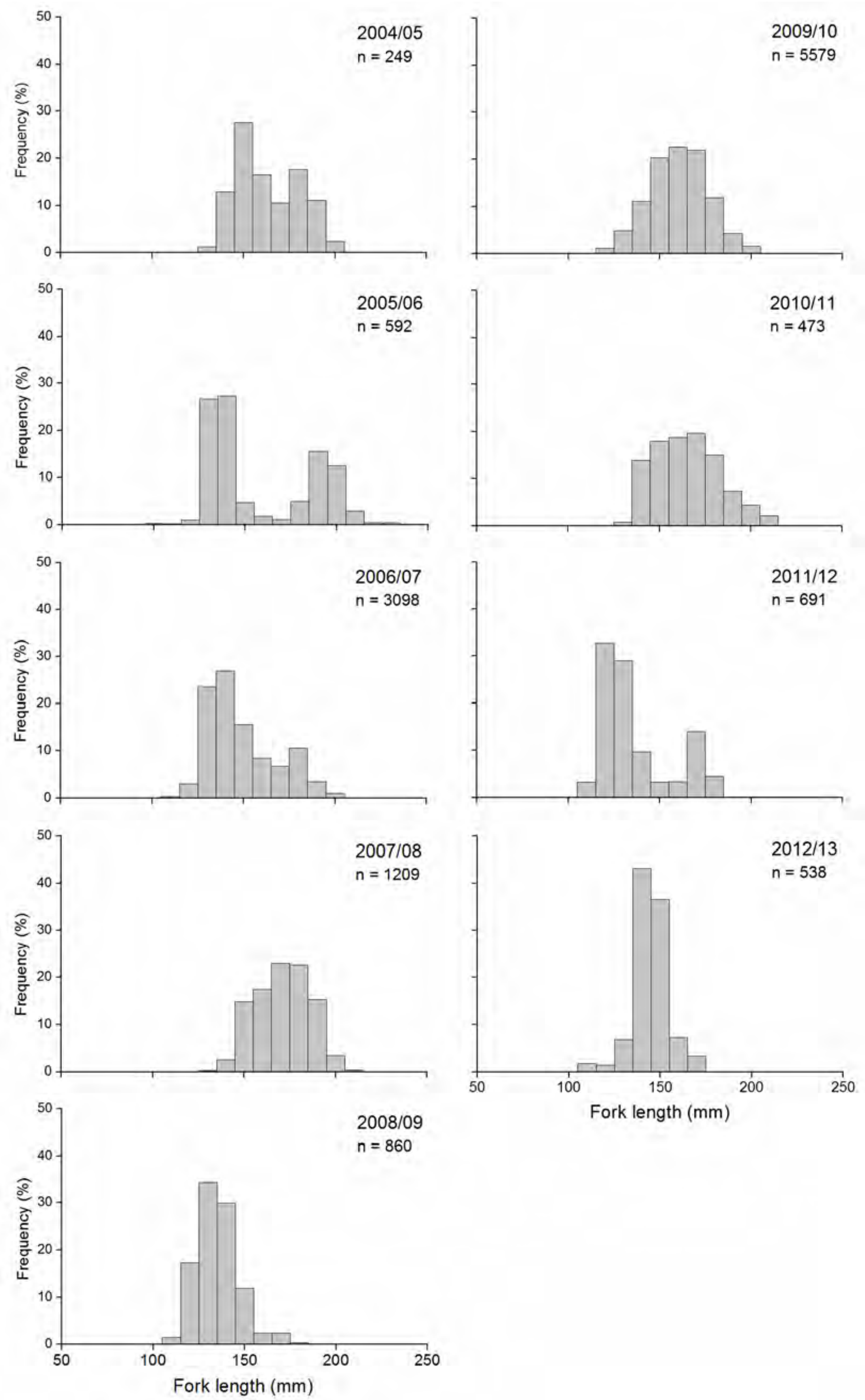

Figure 5.7 Length frequencies of commercial catches of Australian Sardine for the northern (since 2008/09) and southern regions of New South Wales combined. Weighted against the size of landings (data supplied by New South Wales Department of Primary Industries).

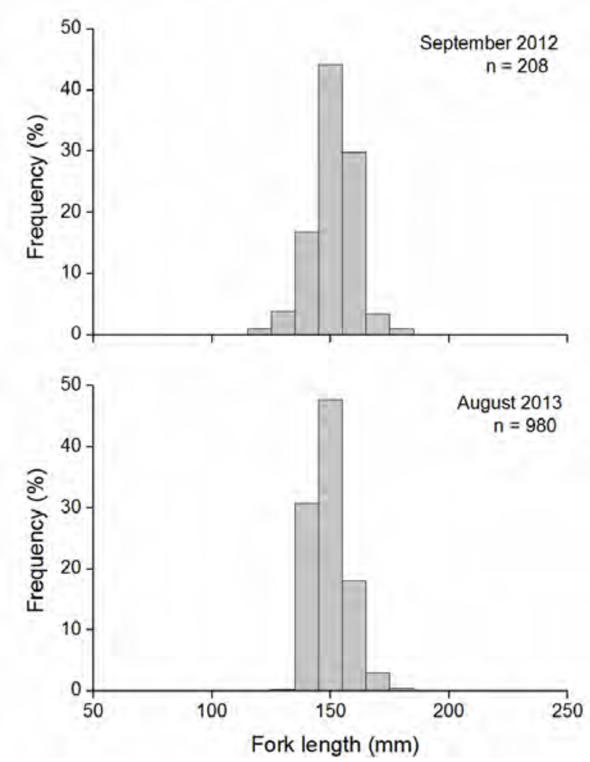

Figure 5.8 Size frequency histograms for Australian Sardine samples collected by AFMA observers aboard commercial fishing vessels in September 2012 and August 2013 on the north coast of New South Wales.

5.3.2.3 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).

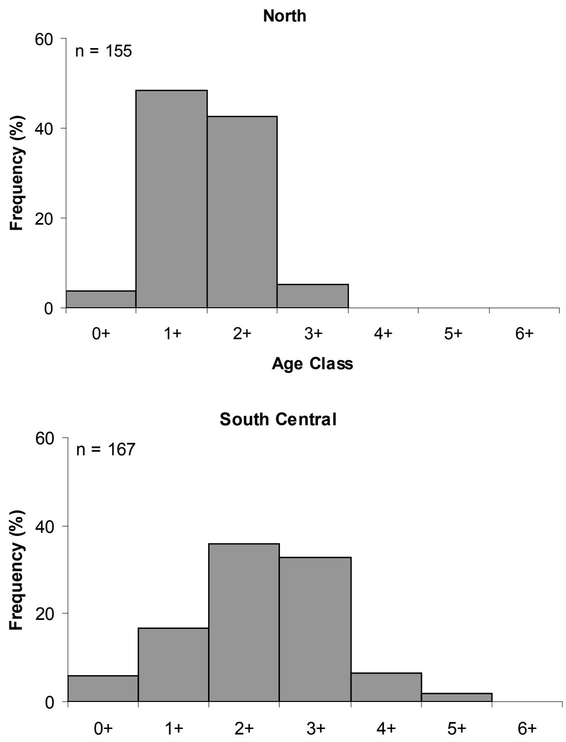

Figure 5.9 Age frequency histograms for Australian Sardine samples from commercial catches from the south central and north coast of New South Wales in 2009. Data derived from otolith ring counts. Otoliths with poor readability (index 4 and 5) were omitted.

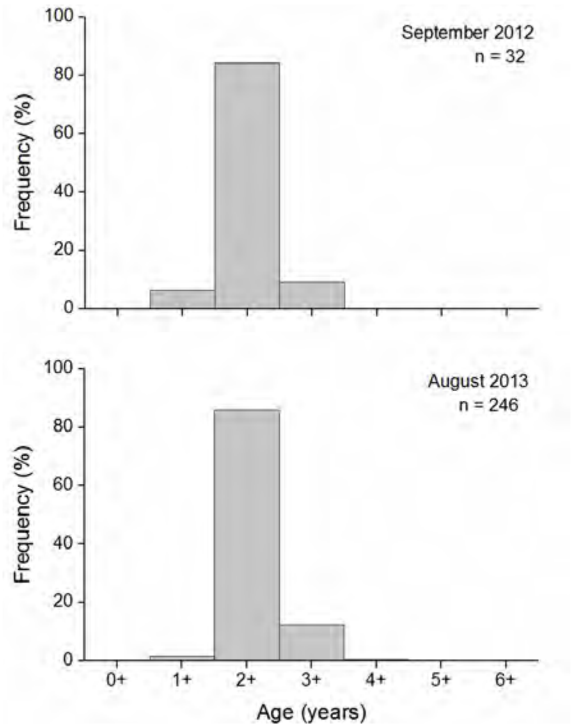

Figure 5.10 Age frequency histogram for Australian Sardine collected from commercial vessels on the north coast of New South Wales in September 2012 and August 2013. Ages are derived from the otolith weights using the South Australian commercial catch relationship (Rogers and Ward 2007).

5.3.2.4 Growth

The growth patterns for Australian Sardines collected from the North and South Central coasts of New South Wales were similar (Figure 5.11). Samples from both regions exhibited considerable variation in size for each of the age classes.

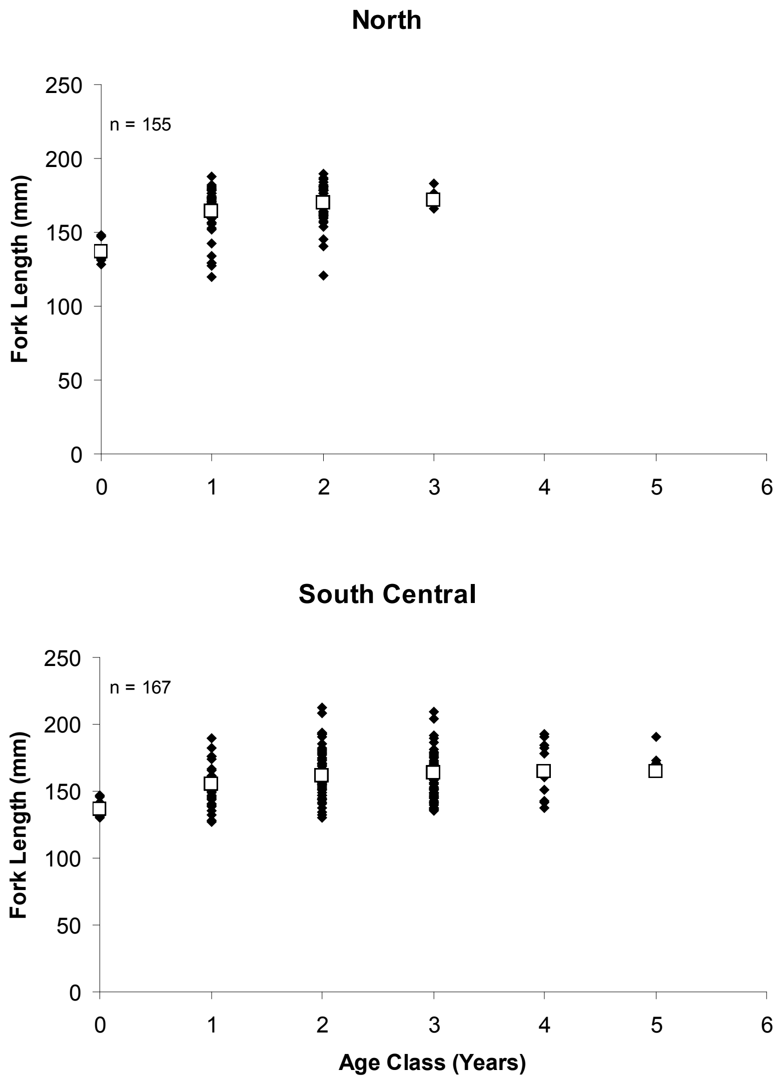

Figure 5.11 Growth patterns for Australian Sardines collected from commercial catches from the north and south central coast of New South Wales in 2009. Ages derived from ring count analysis, otoliths with poor readability (readability index 4 and 5) were omitted. Open squares generated from the VGBF.

5.3.2.5 Gonad stages

Samples from the north and south central New South Wales coast were comprised mainly of mature fish (≥ Stage 2) across the sampling period (Figure 5.12). 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.

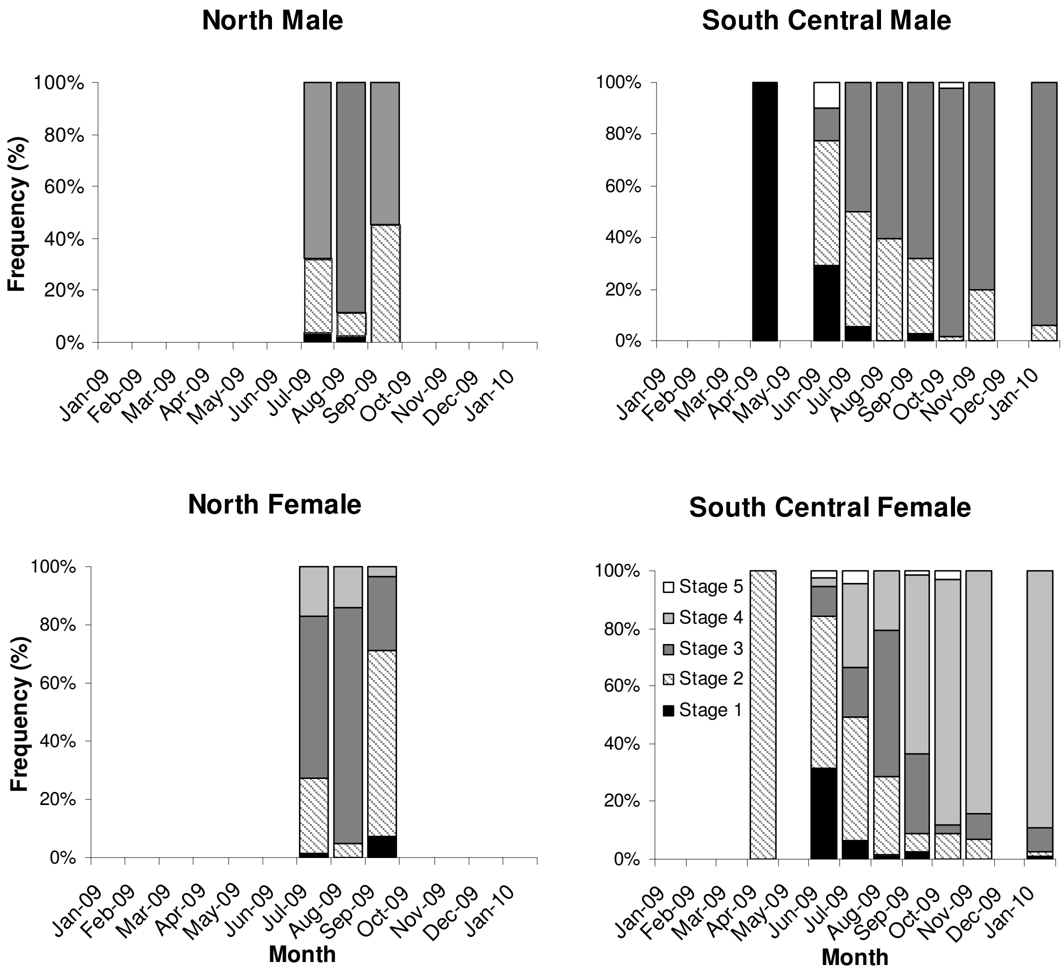

Figure 5.12 Frequency of occurrence of each stage of gonad development for monthly sampling of Australian Sardine from both the north and south central coast of New South Wales. Number for each month are shown in Table 5.2.

5.3.2.6 Sex ratio

Sex ratios of samples of Australian Sardine collected in all months and regions were biased towards females (Table 5.2).

Table 5.2 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

5.3.2.7 Gonadosomatic index

GSI was relatively high for both males and females from the north coast of New South Wales (Figure 5.13), with the highest GSI for males recorded in August for both regions. GSI for females was highest in September on the north coast and July on the south central coast (Figure 5.13).

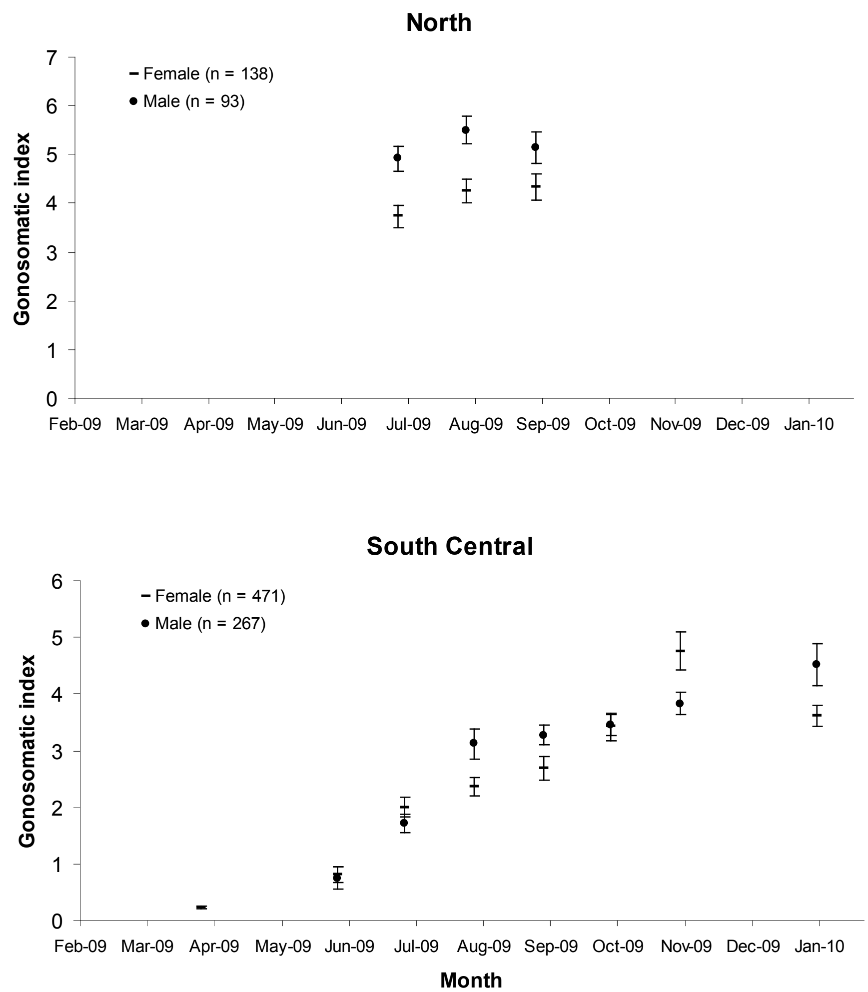

Figure 5.13 Monthly gonadosomatic index for Australian Sardine from the north and south central coast of New South Wales. Error bars are standard error. Immature fish (stage 1) have been omitted from data.

5.3.2.8 DEPM

The total area sampled during the July 2004 ichthyoplankton survey was ~41,585 km^2. 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 area obtained using the Voronoi near neighbour method (Ward *et. al.* 2007) to estimate grid size was 9,363 km^2. Spawning may have occurred south of the area surveyed. The best estimate of mean daily egg production (P_0) obtained using the linear version of the exponential mortality model was 69.96 $eggs.day^{-1}.m^{-2}$. Best estimates of reproductive parameters were: female weight, W = 51.35 g; sex ratio, R = 0.56; spawning fraction, S = 0.14; and batch fecundity, F = 15,108 hydrated oocytes.

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. As such the RBC for 2012/13 was increased accordingly.

Estimates of spawning biomass provide a context for assessing the suitability of recent catch levels. The highest annual catch of ~5,000 t is ~17.4% of the best estimate of spawning biomass, suggesting that fishing is being conducted within sustainable limits.

5.3.2.9 MSE

For Australian Sardine in the East Zone, DEPM estimate of spawning biomass 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 during July 2004 was ~29,000 t. 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. Catches of Australian

Sardine in the East Zone were less than 1000 t up to 2001/02, but exceeded 2,000 t in 2004/05 and reached almost 5,000 t in 2008/09. Catches were ~3,000 t in 2009/10 and 2010/11 and declined to 2,022 t in 2011/12. In 2012/13, the total catch of Australian Sardine by the SPF was 1,097 t, which was 4% of the most recent DEPM biomass estimate and 37% of the maximum RBC for the species (AFMA 2014). 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 Zone since 2008/09 reflects a significant reduction in the size of the fishing fleet with only six commercial vessels reporting catch in 2012/13. Other factors that may have also contributed to this reduction include a fire in a major fish processing factory in Eden and movement of Sardine from inshore waters, where they could be purse seined, to offshore waters where they are being caught in trawl nets (AFMA 2014). Other than the apparent decline in Sardine availability off southern New South Wales in recent years, which may relate to changes in oceanographic conditions, there is no evidence to suggest that the recent low catches of Australian Sardine by the Commonwealth SPF in the East Zone are not sustainable. As such, Woodhams *et al.* (2012) assigned Australian Sardine to the categories of ‘not overfished’ and ‘not subject to overfishing’. While Flood *et al.* (2012) classified the stock status of Australian Sardine as ‘sustainable’ in all regions. As identified in previous reports, the need for further DEPM assessments of Australian Sardine in the East Zone warrants consideration.

6 GENERAL SUMMARY AND CONCLUSIONS

Catches of Blue Mackerel in 2012/13 were relatively low (i.e. below the Tier 2 maximum RBCs) in both the West and East Zones of the SPF. Whilst catches of Jack Mackerel and Redbait for 2012/13 were confidential, the historically low number of vessels reporting catch in each zone suggests that catches were likely to have been relatively low. There is no evidence to suggest that the recent reduction in catch for these species reflects a decline in abundance or overfishing. The reductions in fishing effort and catch appear to be driven by market constraints. These three species 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).

In 2012/13, a total of six commercial fishing vessels reported catches of Australian Sardine in the East totalling 1,097 t, which was well below the RBC for this species (3000 t). In 2012, the Australian Sardine stock in the East was classified as ‘not overfished’ (Flood *et al.* 2012; Woodhams *et al.* 2012). The evidence presented in this report suggests that the current catch level of Australian Sardine in the East is sustainable.

The paucity of biological samples collected for most species in the SPF over recent years is due mainly to the low levels of fishing effort. It should be a priority to implement comprehensive catch sampling regimes in the event of increases in fishing effort across the SPF.

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. Consideration should be given to conducting additional dedicated multi-species DEPM in both zones. A survey of Jack Mackerel in the East zone was undertaken in January 2014. The large size of the West zone makes stock assessment in that area difficult and increases the potential for localized depletion. Consideration should be given to sub-dividing the West Zone for the purposes of stock assessment and management.

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