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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2011

T.M. Ward, J. Lyle, J.P. Keane, G.A. Begg,
P. Hobsbawn, A.R. Ivey, R. Sakabe and M.A. Steer

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April 2012

Report to the Australian Fisheries Management Authority

Government of South Australia

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EXECUTIVE SUMMARY

1. This report presents fishery statistics and catch at size/age data and synthesises existing stock assessment information for the key target species of the Commonwealth Small Pelagic Fishery (SPF). The report is a requirement of the SPF Harvest Strategy established in 2009.

2. Preliminary Daily Egg Production Method (DEPM) assessments of Blue Mackerel (*Scomber australasicus*) provided a mid-range best estimate of spawning biomass of ~40,000 t in the East region of the SPF (2003 and 2004 survey) and a best estimate of ~56,000 t in the West (2005 survey). Management Strategy Evaluation (MSE) suggested that the spawning biomass was higher than the DEPM estimate in each region. Between 1997/98 and 2010/11, catches in the East ranged from ~300-1,000 t, with ~300 t taken in 2010/11. In the West, catches increased rapidly after 2004 and reached ~2,000 t in 2008/09, with ~400 t taken in 2010/11. Recent annual catches have been below the maximum Recommended Biological Catch (RBC) limit at Tier 2 for each zone. All fish sampled from catches in the West region were above the estimated size at maturity; catches were dominated by 4 and 5 year olds. There is no evidence to suggest that recent catches of Blue Mackerel in either region are not sustainable.

3. Preliminary DEPM assessments of Jack Mackerel (*Trachurus declivis*) in the East region derived from samples collected during October 2002 estimated a spawning biomass of ~114,900–169,000 t (median 141,500 t). Off Tasmania, catches peaked at ~40,000 t in 1986/87, but have not exceeded ~3,000 t since 1999/2000. Negligible landings were made in 2010/11. Jack Mackerel catches in the West have not exceeded 500 t in the period since 1997. The abundance of older age classes in purse-seine catches off Tasmania declined between the mid-1980s and mid-1990s, indicating a possible fishery impact on population structure. Coupled with large declines in historical catches, this gave rise to concern for the status of Jack Mackerel in the East. However, since the mid-1990s fishing effort and catches have remained at relatively low levels, with no evidence to suggest that recent catches of Jack Mackerel in either region are not sustainable.

4. DEPM estimates for Redbait (*Emmelichthys nitidus*) in the East suggest a spawning biomass in excess of 50,000 t, implying that catches during the early 2000s (~7,000 t each year) are sustainable; a view supported by the MSE. There were no catches reported for 2010/11 in either region. While there is no biomass estimate available for the West, fishing has been limited to a small area (off SW Tasmania), suggesting that fishing pressure on this stock has been low. Biological sampling has revealed no obvious impact on size or age composition over the recent history of the fishery. There is no evidence to suggest that recent catches of Redbait in either region are unsustainable.

5. The best estimate of spawning biomass of Australian Sardine (*Sardinops sagax*) 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. 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 2010/11, the catch of Australian Sardine in the East was ~3,000 t. Biological samples from

the south central coast included individuals up to 5 years old, whereas those from northern NSW did not include fish more than 3 years old. The highest annual catch in the East (~5,000 t) is ~17.4% of the best estimate of spawning biomass. There is no evidence to suggest that the current catch level of Australian Sardine in the East is unsustainable. However, the catch is at a level where regular stock assessment using the DEPM may be warranted.

6. There is no evidence to suggest that recent catch levels of any SPF quota species are not sustainable. However, most estimates of spawning biomass are more than five years old. A review of the harvest strategy will occur in 2012. Conducting DEPM surveys off the East coast that will provide information for several species (including Australian Sardine) warrants consideration.

ACKNOWLEDGEMENTS

This report was formally reviewed by Dr Greg Ferguson and Dr Stephen Mayfield (SARDI Aquatic Sciences) and approved for release by Dr Jason Tanner (SARDI Aquatic Sciences).

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1 GENERAL INTRODUCTION

1.1 Background to Small Pelagic Fishery (SPF)

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 and 5 active vessels operating in this fishery targeting several species including Jack Mackerel *Trachurus declivis*, Redbait *Emmelichthys nitidus*, Blue Mackerel *Scomber australasicus* and Australian Sardine *Sardinops sagax* (off New South Wales only). Yellowtail Scad *Trachurus novaezelandiae* is taken as by-product. SPF species are also taken in several State and Commonwealth managed fisheries. Key events in the history of the SPF are listed in Woodhams *et al.* (2011).

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 (ABARE 2009, Woodhams *et al.* 2011). A new Management Plan was implemented in 2009 that established Eastern and Western management sub-areas (zones, hereafter East and West) rather than the previous four (Fig. 1.1, AFMA 2009a) and introduced some new controls such as Individual Transferable Quotas (ITQs).

There is a tiered Harvest Strategy (HS) with prescribed levels of research required for each Tier (ABARE 2009, AFMA 2009b). Recommended Biological Catches (RBCs) are determined by the Small Pelagic Fishery Resource Assessment Group (SPFRAG).

<u>Tier 1:</u> 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.

<u>Tier 2:</u> Maximum RBCs for each Tier 2 species in each zone are specified 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.

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.

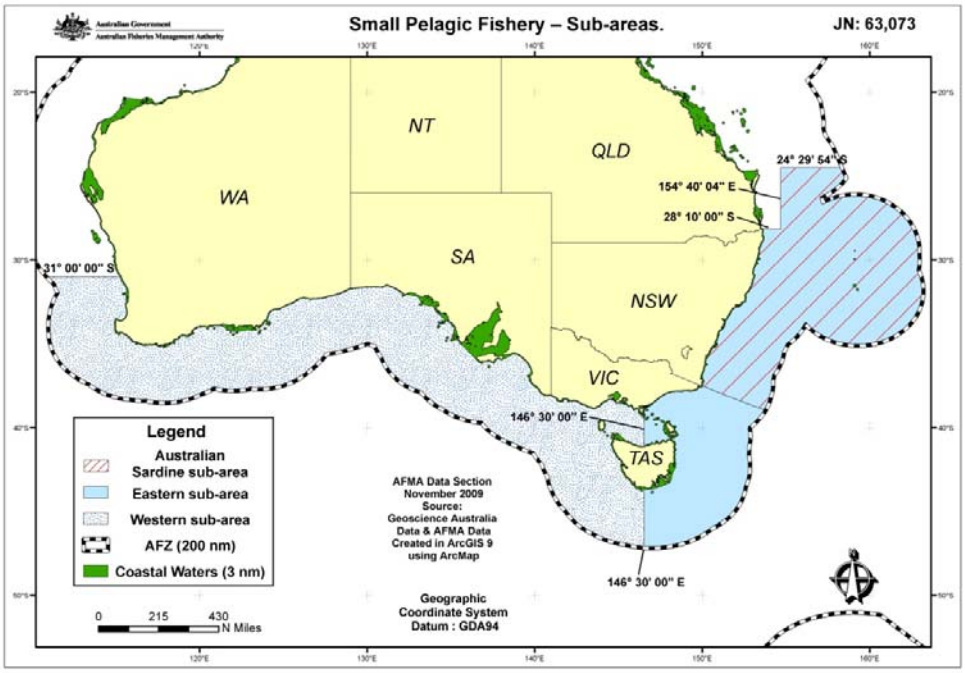

Figure **1.1** Management sub-areas of the Commonwealth Small Pelagic Fishery.

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. 20), Jack Mackerel East (Neira 2011) and yellow tail scad East (Neira 2011). Management Strategy Evaluations (MSEs) have been conducted by ABARES (Giannini *et al.* 2010). This report updates the first annual assessment of the SPF conducted by Ward *et al.* (2010).

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. Biomass estimates and Management Strategy Evaluations (MSE) are also included where available. The report satisfies the requirements of the SPF Harvest Strategy (AFMA 2009b).

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 is also taken in the Great Australian Bight Trawl (GAB), Gillnet Hook and Trap (GHT), Southern and Western Tuna and Billfish (SWTBF and 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 NSW commercial purse-seine fishery has targeted Yellowtail Scad and Blue Mackerel since the early 1980s (Stewart and Ferrell 2001). Blue Mackerel typically comprise ~38% of the catches. The average annual catch of Blue Mackerel in Victorian waters between 1978/79 and 2004/05 was 49 t (±22.9) with catches varying between 0.2 to 370.6 t per annum (Ward and Rogers 2007).

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 season, but limited species-specific information was recorded (Ward and Rogers 2007). Blue Mackerel represented ~2 – 3.7% of catches between 1986 and 1989. Species-specific information was not available during the other years.

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

Most (75%) of the national recreational harvest of Blue Mackerel was taken in NSW, with 14% and 8% taken in Western Australia and South Australia, respectively. Victoria, Tasmania and Queensland made up the remaining 3% of the recreational catch (Henry and Lyle 2003).

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 for 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, 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 NSW 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 NSW (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-Continental 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 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 the egg based stock assessment methods on 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).

2.1.11 Management

In both the East and West region DEPM assessments have been conducted and the fisheries are managed at the Tier 1 level. As such, conservative TACs have been set based on the rules outlined in the tier system. The fishery is not considered to be overfished.

2.2 Methods

2.2.1 Fishery Statistics

Fishery statistics were supplied by the Bureau of Rural Science (BRS). Annual data are reported by financial years.

2.2.2 Biological Information

Samples of Blue Mackerel from the West for seasons between 2008/09 and 2010/11 were supplied by the commercial purse-seine fishery operating from Port Lincoln, South Australia. 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).

2.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Blue Mackerel was obtained for each of the management regions during a study between 2003 and 2005 (Rogers and Ward 2007).

An MSE model was used to test a range of management/harvest scenarios under the Commonwealth Small Pelagic Fishery (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.

The current SPF Harvest Strategy has a three-tiered approach. At the Tier 1 level, the maximum recommended biological catch (RBC) for each stock depends on the time since a daily egg production method (DEPM) survey was conducted, with the maximum RBC decreasing from 20% to 10% of the spawning biomass estimated from the DEPM survey over a five year period (relative tonnage). The maximum RBC for Tier 2 and Tier 3 is set at a specified quantity (absolute tonnage). A maximum RBC for Tier 2 has been defined for each stock with quantities varying from 3,000-6,000 t, while for Tier 3, the maximum RBC has been set at 500 t for each stock.

2.3 Results

2.3.1 Fishery Statistics East / West

2.3.1.1 Location of vessels

The majority of boats landing Blue Mackerel in the East are based in NSW (Fig. 2.1) and South Australia in the West (Fig. 2.2).

2.3.1.2 Annual Patterns – catch, effort & catch-per unit effort

Catches of Blue Mackerel in the East have fluctuated between ~350 and 1,000 t between 1997/98 and 2010/11 (Fig. 2.3). Historically, fishing effort remained between ~3,000 to 4,500 vessel days, however it declined to ~1,400 vessel days in 2010/11 (Fig. 2.3). CPUE remained stable at ~0.2 t per fishing day between 1998/99 and 2006/07 (Fig. 2.4) then dropped to below 0.1 in 2007/08, before increasing back to ~0.2 in 2010/11.

Catches of Blue Mackerel have been more variable in the west than the East with catches below 100 t between 1997/98 and 2003/04 (Fig. 2.5), then rapidly rising to >1,500 t in 2005/06 and 2006/07. The greatest variation in catches has occurred over the last three seasons where landings have increased from ~1,000 t in 2007/08 to ~ 2,000 t in 2008/09 and declining back to ~400 t in 2010/11 (Fig. 2.5). Fishing effort has varied between ~20 to 165 vessel days in the West between 1997/98 and 2010/11 (Fig. 2.5). CPUE remained <1 t per vessel day between 1997/98 and 2003/04 and increased rapidly to ~14 t per vessel day in 2005/06 (Fig. 2.6). Subsequent catch rates have remained high only dropping below 10 t per vessel day in 2007/08 (Fig. 2.6).

2.3.1.3 Intra-annual Patterns - catch and effort

Intra-annual patterns of catch and effort in the East were variable with catches occurring in all months for all seasons from 1997/98 to 2010/11 (Fig. 2.7). Intra-annual data on catch and effort in the West (Fig. 2.8) were highly affected by confidentiality. All of the non-confidential catches were taken between the months of December and April.

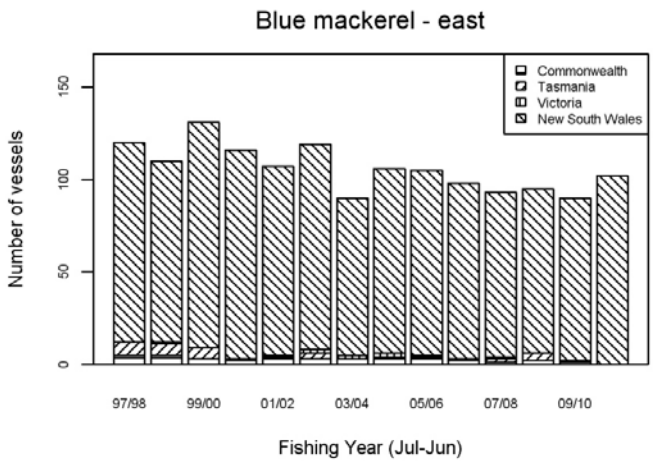

Figure 2.1 Number of vessels which landed Blue Mackerel in the East, from each of the participating management jurisdictions.

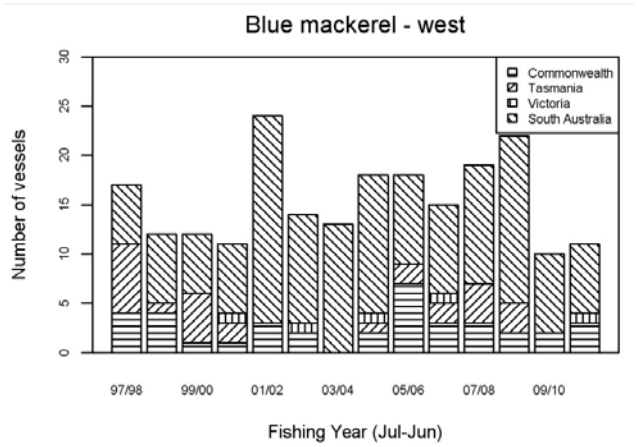

Figure 2.2 Number of vessels which landed Blue Mackerel in the West, from each of the participating management jurisdictions.

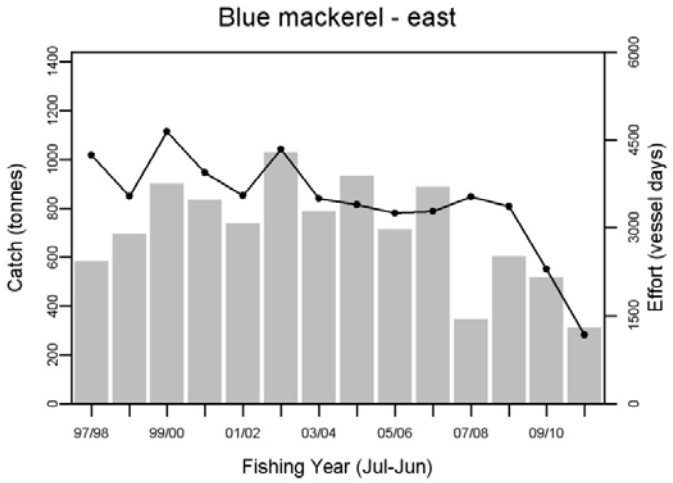

Figure 2.3 Total landed catch (tonnes, bars) and effort (vessel days, line) for Blue Mackerel in the East during financial years over the period 1997/98 – 2010/11.

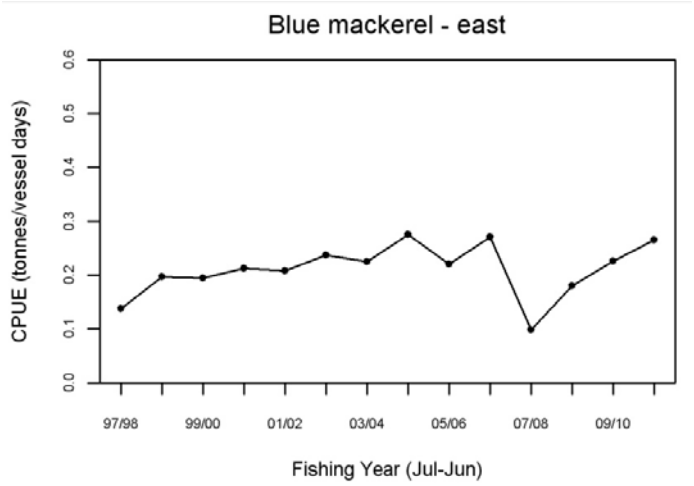

Figure 2.4 CPUE (tonnes per vessel day) for Blue Mackerel in the East during financial years over the period 1997/98 – 2010/11.

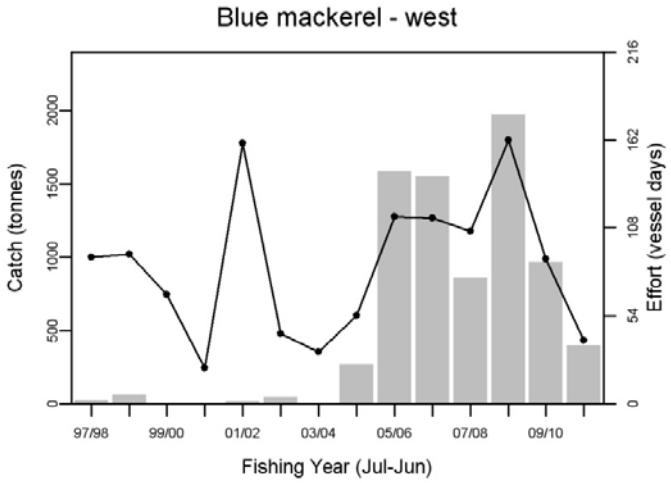

Figure 2.5 Total landed catch (tonnes, bars) and effort (vessel days, line) for Blue Mackerel in the West during financial years over the period 1997/98 – 2010/11.

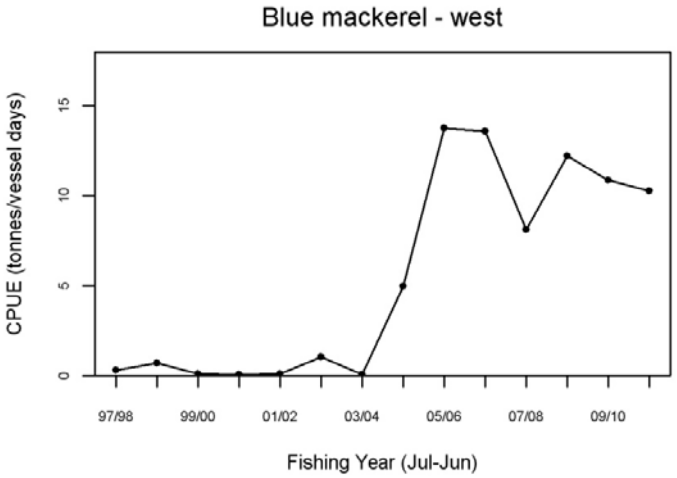

Figure 2.6 CPUE (tonnes per vessel day) for Blue Mackerel in the West during financial years over the period 1997/98 – 2010/11.

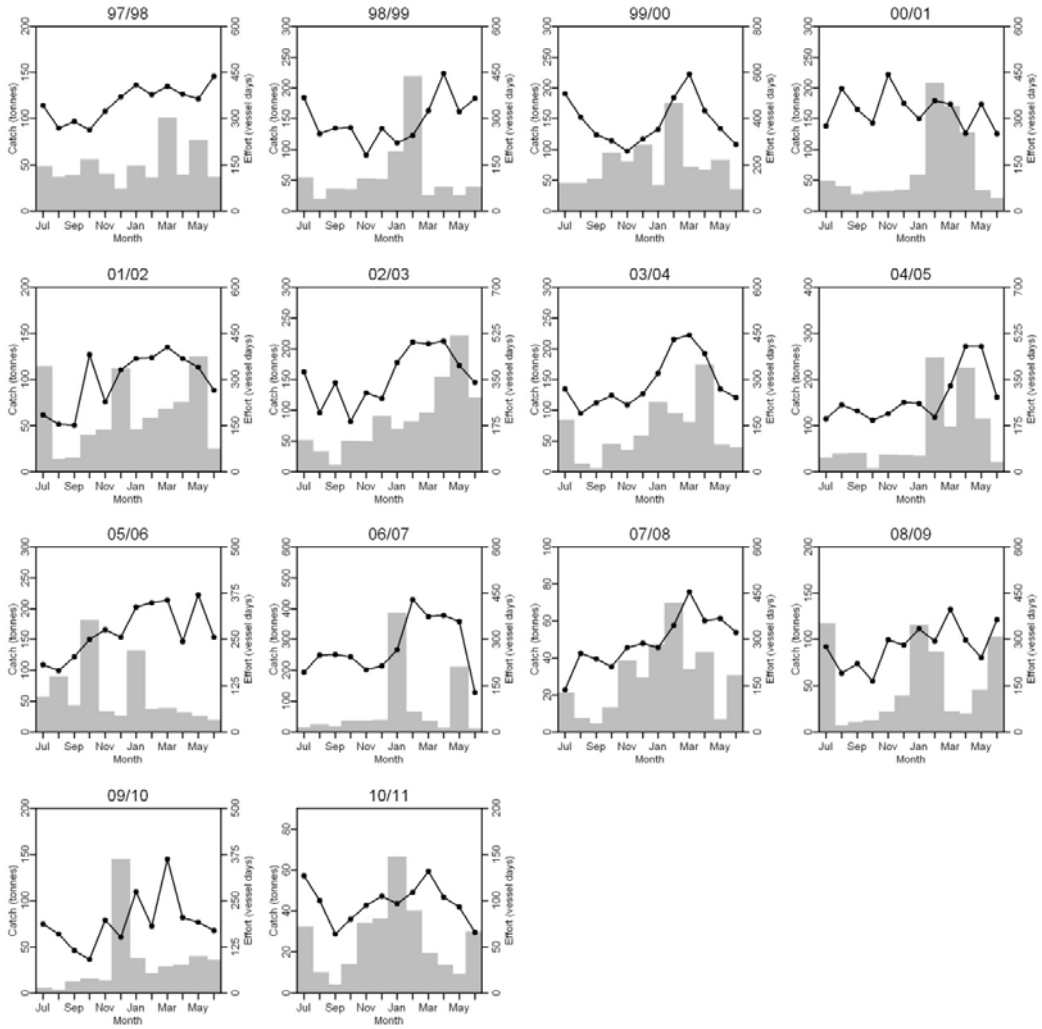

Figure 2.7 Intra-annual patterns of catch (bars) and effort (lines) for Blue Mackerel in the East for the period between 1997/98 and 2010/11.

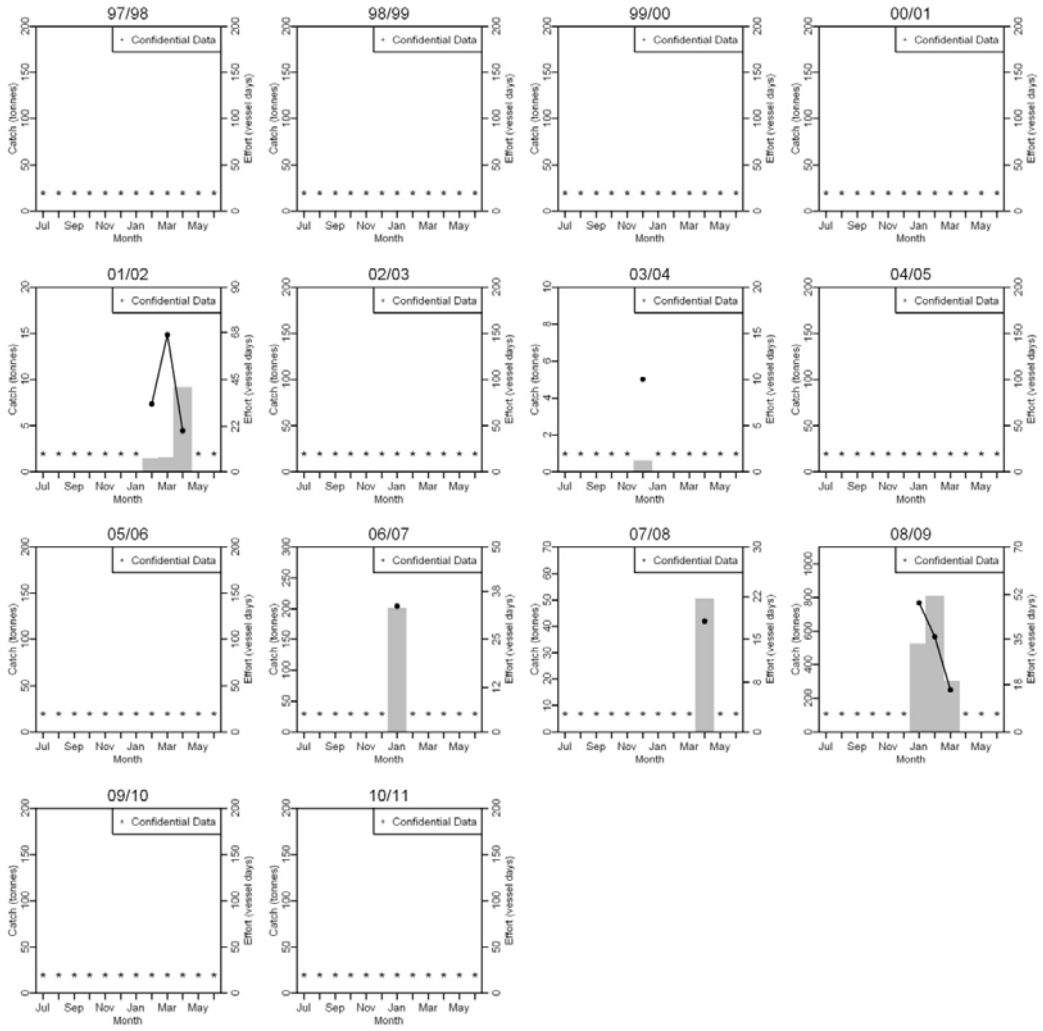

Figure 2.8 Intra-annual patterns of catch (bars) and effort (lines) for Blue Mackerel in the West for the period between 1997/98 and 2010/11. * denotes confidential data (<5 fishers).

2.3.2 Biological Information

2.3.2.1 Sample Summary

A total of 79 Blue Mackerel caught in the 2008/09, 933 in the 2009/10 and 245 in the 2010-11 fishing seasons were supplied for biological analysis. The male to female sex ratios were 1:1, 0.9:1 and 0.9:1, respectively. All samples were supplied by fish processors in Port Lincoln (West).

2.3.2.2 Size Frequency

Fish sampled in the 2008/09 season ranged from 316 – 390 mm FL (Fig. 2.9) and >50 % of fish were between 340 and 370 mm. In the 2009/10 and 2010/11 season fish ranged from 300 – 400 mm. No fish were below the size at maturity reported in Ward and Rogers (2007).

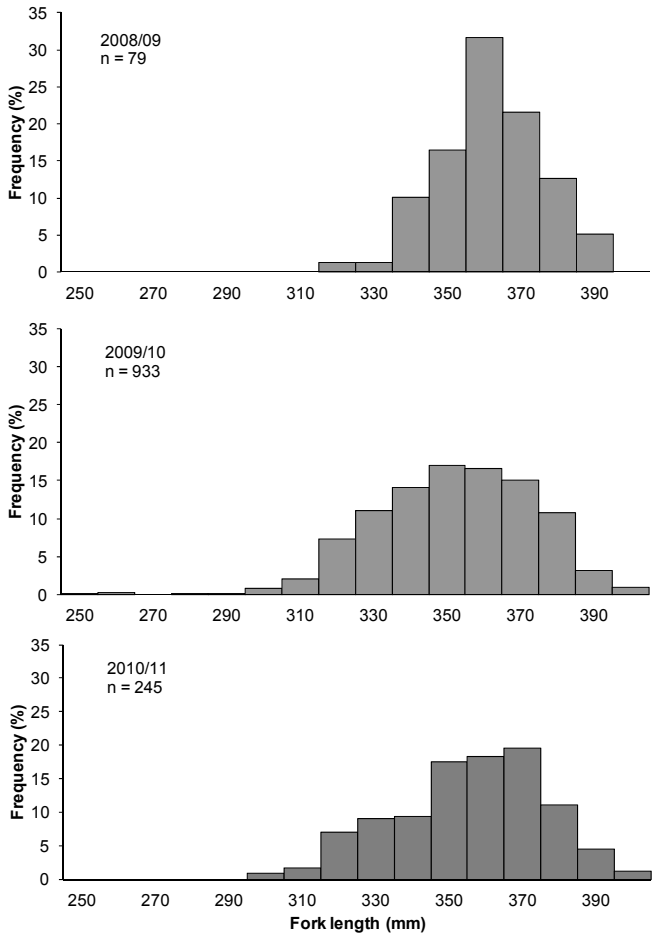

Figure 2.9 Blue Mackerel size frequency for research samples collected from commercial purse-seine shots in South Australia between 2008/09 and 2010/11.

2.3.2.3 Age Structure

The otolith weight-age relationship of Ward and Rogers (2007) was applied to the otolith weights to assign ages. Ages for the 2008/09 samples ranged from 3+ to 6+ year olds (Fig. 2.10) and 82 % of fish were 4+ and 5+ years old. A similar age

structure was identified in 2009/10 and 2010/11, however there was a greater range of ages, in all years the majority of fish were greater than three years old.

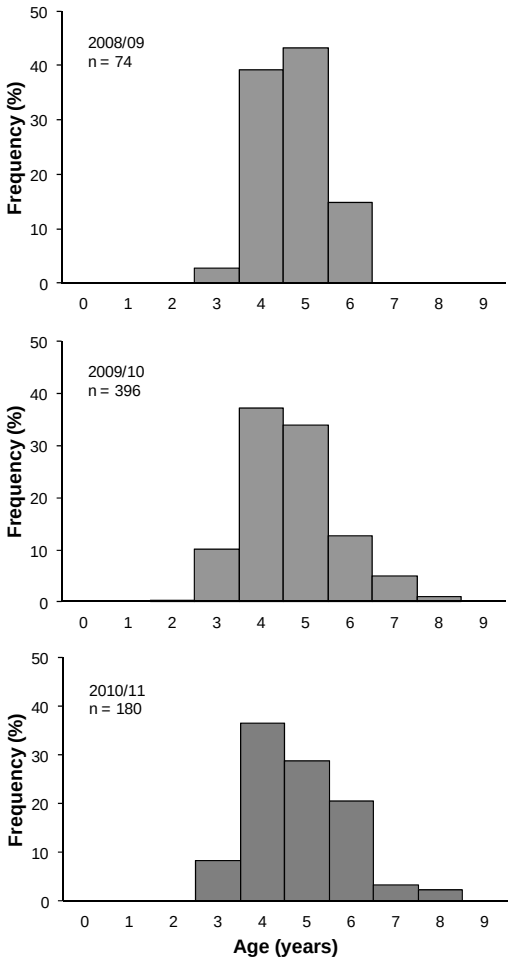

Figure 2.10 Age frequency distribution for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons, based on the otolith weight, age relationship in Ward and Rogers (2007) for South Australia.

2.3.2.4 Gonad stages

Although none of the fish sampled were below the size at maturity reported in Ward and Rogers (2007), 50 and 30.8% of males and females respectively, were immature in the 2008/09 sample (Stage 1, Fig. 2.11). Females were generally at a more advanced stage of gonad development 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 2009/2010 and 2010/11, with both males and females with stage 3 gonads dominating the sample (Fig. 2.11).

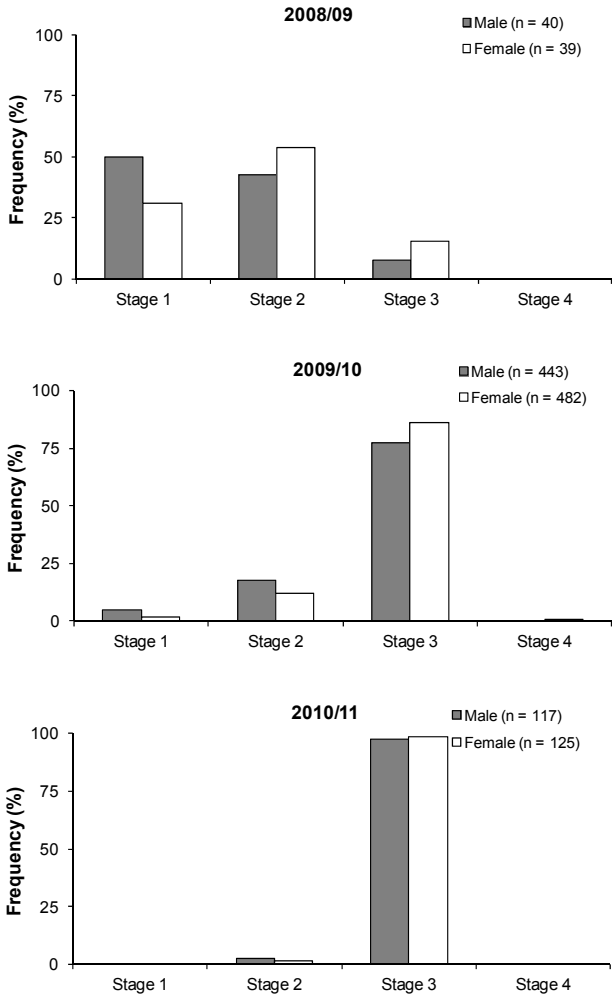

Figure 2.11 Gonad developmental stage distribution for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons.

2.3.2.5 Size at maturity

There was an insufficient number and size range of samples to determine size at maturity (all fish above size at maturity reported in Ward and Rogers (2007)).

2.3.2.6 Gonosomatic index (GSI)

No seasonal GSI data were available for Blue Mackerel. In 2008/09, the average GSI for both sexes was 0.94% of body mass (Fig. 2.12). In 2009/10 the average GSI was ~ 5% (Fig. 2.12). In 2010/11 the average GSI was higher again at 7.0 and 6.1% for males and females respectively (Fig. 2.12).

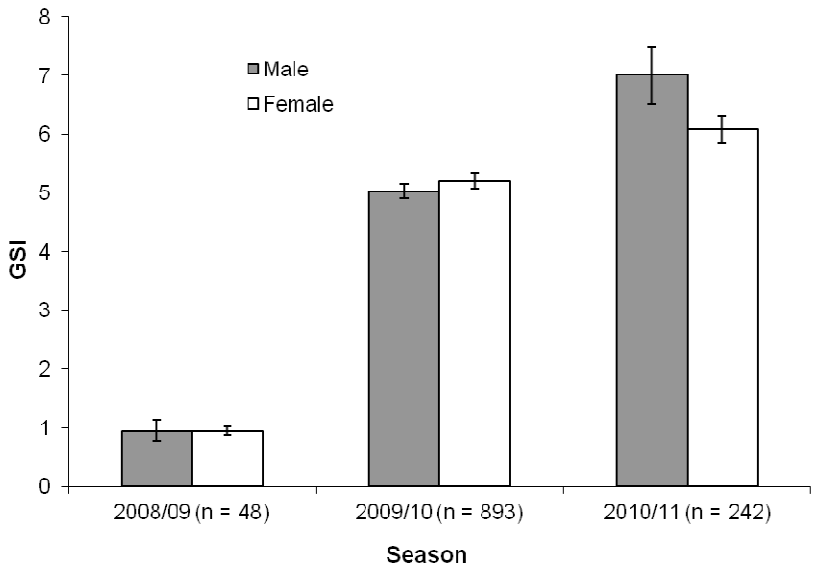

Figure 2.12 Gonosomatic index for Blue Mackerel landed in Port Lincoln during the 2008/09, 2009/10 and 2010/11 seasons, error bars are standard error. Calculated excluding Stage 1 fish.

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 region, 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 provides lower estimates than the 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 off eastern Australia. 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). However, 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 percent 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. The 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 is 31% of the model calculated estimate of spawning biomass.

2.4 Summary and Conclusions

There is no evidence to suggest that recent catches of Blue Mackerel in either region are not sustainable. Preliminary Daily Egg Production Method (DEPM) assessments of Blue Mackerel provided a mid-range best estimate of spawning biomass of ~23,009 t in the East and a best estimate of ~56,000 t in the West. The MSE suggested that the spawning biomass was higher than the DEPM estimate in each region. Between 1997/98 and 2010/11, catches in the East ranged from ~300-1,000 t, with ~300 t taken in 2010/11. In the West, catches increased rapidly after 2004 and reached ~2,000 t in 2008/09 with ~400 t taken in 2010/11. Recent low catches do not appear to reflect reductions in abundance. For example, low catches of Blue Mackerel East in 2010 can be related to a fire in a fish processing facility in Eden in 2010. Recent annual catches have been well below 10% of the DEPM spawning biomass estimate for each zone. No fish sampled from catches in the West were below size at maturity; catches were dominated by 4 and 5 year olds. Both the East and West stocks have been assessed as 'not overfished' (Woodhams *et al.* 2011).

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 developed off Tasmania in the mid-1980s, with catches peaking at over 40,000 tonnes in 1986/87. The majority of the catch consisted of Jack Mackerel (*Trachurus declivis*), with a relatively small component of Redbait (*Emmelichthys nitidus*) and Blue Mackerel (*Scomber australasicus*) also taken as by-product. The fishery became the largest in Australia, by weight, before dramatic 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 production effectively resulted in purse-seine operations ceasing in 2000. The majority of the catch was processed at plants in Triabunna (mid 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 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 tonnes 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 with fishing operations commencing in late 2002. By the end of the 2002/03 fishing year more than 7,000 tonnes of small pelagics was taken, with Redbait dominating the catch. More recent fishing for small pelagics by purse-seine in Tasmanian State waters yielded 203 tonnes of Jack Mackerel in 2007/08, 920 tonnes in 2008/09 and 917 tonnes in 2009/10 (Hartman and Lyle 2011).

A relatively small (300-500 t per annum) fishery for Yellowtail Scad (*Trachurus novaezelandiae*) exists in NSW 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 Australia, 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 are distributed from Shark Bay in Western Australia, south to Wide Bay in Queensland, including the waters around Tasmania (Gomon *et al.* 2008). They are found down to a maximum depth 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 penetrate slightly further to the north on each side of the continent and rarely reaching 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 population 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 NSW 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 focused on 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, Kailola 1993, Stevens *et al.* 1984, 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 account for 44% of relative importance in fish from eastern Tasmania (Webb 1976, Williams and Pullen 1993, McLeod 2005). Fish from deepwater 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, polycheates 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 more frequently on krill while fish in inshore waters feeding more on 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 in length, 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. Lyle *et al.* (2000) validated the aging protocol based on marginal increment analysis. Jack Mackerel grow quickly at a young age, reaching 270 mm with the first 4 years and obtain 335 mm by age 10 years off Tasmania, with no significant difference in growth between males and females (Lyle *et al.* 2000). Yellowtail Scad grow quickly to reach ~200 mm at 2-4 years of age (Stewart and Ferrell 2001), maximum size is 330 mm total length (Kailola 1993) with the oldest recorded individual being 14 years old (Stewart and Ferrell 2001).

3.1.8 Reproduction

Jack Mackerel are serial spawners, although spawning frequency has not been determined in Australian waters (Marshall *et al.* 1993, Neira 2011). Mean batch fecundity was estimated to be ~63,000 eggs for females from eastern Tasmania (Neira 2011). Females have been shown to reach 50% sexual maturity at 315 mm

(Marshall *et al.* 1993). Spawning has been known to occur in spring in NSW (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 female GSI values for eastern Tasmanian fish increase substantially in November and stay high until January, before declining in February (Williams *et al* 1986). Backdated birthdates based on otolith microstructure of larval fish indicated spawning to occur between mid December and mid February (Jordan 1994). Furthermore they indicate spawning to occur in 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 at 200 mm and 220 mm fork length (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 caught off southern NSW during spring and eastern Tasmania and in Bass Strait and in the GAB predominantly 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 (a) evaluate tools for assessment of the Jack Mackerel stocks; (b) describe factors contributing to inter-annual variability in the availability of Jack Mackerel; and (c) 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 the 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). 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). Consequently the DEPM was

applied to this species in 2011 using samples collected off south-eastern Australia in 2002 during a survey targeting Blue Mackerel eggs (Neira 2011). Adult parameters for the DEPM were derived from Tasmanian trawl samples and published data. The spawning biomass of Jack Mackerel was estimated to be ~114,000-169,000 t between Sugarloaf Point and Cape Howe during October 2002.

There has been limited stock assessment work directed at Yellowtail Scad in Australia. Stewart and Ferrell (2001) found that the majority of Yellowtail Scad landed in NSW were 2 and 3 year olds. A recent provisional DEPM spawning biomass estimate (Neira 2009) suggests a biomass of ~2,900 or ~5,900 t depending on the model used to estimate daily egg production. This estimate was based on samples collected during a survey in October 2002 directed at Blue Mackerel. There is significant uncertainty around both egg identification and some adult parameters so this result must be viewed with caution.

3.1.11 Management

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 pelagics 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 eastern and western zones and, under the SPF harvest strategy framework (AFMA 2009b), regional and species specific TACs were allocated. For the 2009/10 season, the recommended TAC for Jack Mackerel was 4,900 tonnes in each of the two zones.

It is significant that the 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.

In the context of the SPF both East and West regions are currently managed at the Tier 2 level. In light of recent DEPM spawning biomass estimates for Jack Mackerel East (Neira 2011) and Yellowtail Scad East (Neira 2009) it may be possible to revise

Tier 2 maximum RBC levels based on a conservative harvest rate (7.5%) that has been recommended for species for which spawning biomass estimates are available but are more than five years old (ref SPF HS). There is some concern for the state of this fishery due to the large decline in historical catches. Yellowtail Scad is classed as a permitted by-catch species in the SPF with a quota of 200 t.

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 pelagics. 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 pelagics have resumed in Tasmanian State waters and shot by shot catch and effort are recorded in the Tasmanian general fishery logbook.

3.2.2 Biological Information

Fishery dependent length frequency and biological data for Jack Mackerel 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 of Jack Mackerel collected from demersal research trawling conducted by CSIRO and the relevant 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, so 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 pelagics 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 2009).

Biological data were collected from individual specimens and included FL (to the nearest millimetre), 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 0.1g). 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 over the period 1984-2011 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 have been analysed to provide current size and age composition estimates of the catch. No biological samples were collected in 2010/11 due to limited activity in the fishery.

3.2.3 Biomass Estimates and MSE

A recent DEPM analysis (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 has not yet been formally incorporated into a MSE.

An MSE model was used to test a range of management/harvest scenarios under the Commonwealth Small Pelagic Fishery (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 stock-recruitment relationship and natural mortality. The model was re-examined in 2011 to address concerns about values used for number of recruits. Spawning biomass estimates produced in 2010/11 have not yet been incorporated into the model.

3.3 Results

3.3.1 Fishery Statistics East / West

3.3.1.1 Number of vessels

In the East, the majority of vessels that reported landing Jack Mackerel were operating in NSW and Tasmanian waters (Fig. 3.1). The total number of vessels landing Jack Mackerel in the East has declined in the last 12 years (Fig. 3.1).

Relatively few vessels reported landings of Jack Mackerel in the West, with less than 10 vessels reporting Jack Mackerel landings since 2000/01 (Fig. 3.2).

Almost all vessels that reported landing Yellowtail Scad were operating in NSW waters (Fig. 3.3).

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

Combined Jack Mackerel catches for the East declined from >9,000 t in 1997/98 to ~100 t in 2000/01 (Fig. 3.4), landings then increased to >2,000 t between 2002/03 and 2004/05, but have declined again to <2,000 t since 2005/06. Annual estimates of effort have trended downwards from a peak of ~1,100 vessel days in 1998/99 to negligible effort in 2010/11 (Fig. 3.4). CPUE has fluctuated significantly in the East Jack Mackerel fishery (Fig. 3.5). The composition (vessels/gear type) of this fishery has changed over the last 12 years which could possibly explain the fluctuations in CPUE.

Jack Mackerel catches in the West were historically lower than the East (Fig. 3.6). Annual catches have exceeded 330 t on two occasions, 2005/06 and 2006/07, all other non-confidential catches have been <180 t (Fig. 3.6). Fluctuations in catches have not reflected relative changes in annual fishing effort (Fig. 3.6). From 1997/98 – 2004/05, catches rates were <2 t per vessel day, however, over the last five years catch rates have consistently exceeded 4 t per vessel day (Fig. 3.7).

Yellowtail Scad catches in the East were ~500 t in 1997/98 and gradually trended down to 250 t in 2009/10, then increased to ~500 t in 2010/11 (Fig. 3.8). Fishing effort remained between 7,000 and 10,000 vessel days between 1997/98 and 2008/09 then dropped to <3,000 in 2010/11 (Fig.3.8). Catch rates for Yellowtail Scad in the East remained ~0.5 t per vessel day between 1997/98 and 2009/10 then increased to >1.5 t per vessel day in 2010/11 (Fig. 3.9). No Yellowtail Scad were reported from the West.

3.3.1.3 Intra-annual Patterns - catch and effort

Presentation and interpretation of intra-annual data for Jack Mackerel catches from the East were affected by confidentiality issues arising from the small number of vessels participating in the fishery. In the years between 1997/98 and 1999/2000, most of the Jack Mackerel catch in the East was taken during the summer months (Fig. 3.10). No intra-annual data were presentable for Jack Mackerel from the West due to confidentiality issues. No consistent intra-annual patterns were evident in the Yellowtail Scad catches (East), although in some years an increase in catches was evident in summer and early autumn (Fig. 3.11).

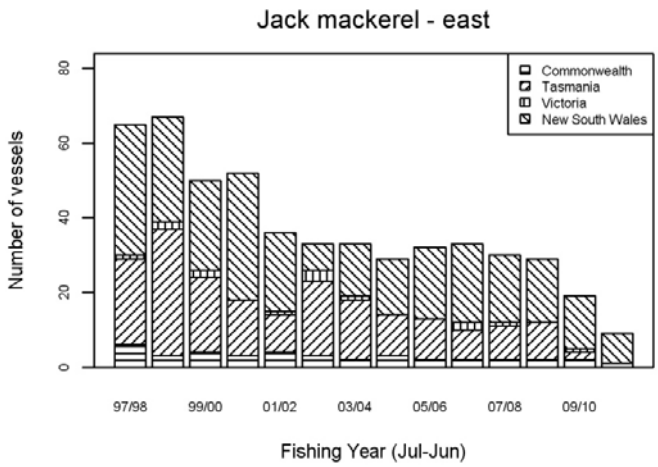

Figure 3.1 Number of vessels which landed Jack Mackerel in the East, from each of the participating management jurisdictions.

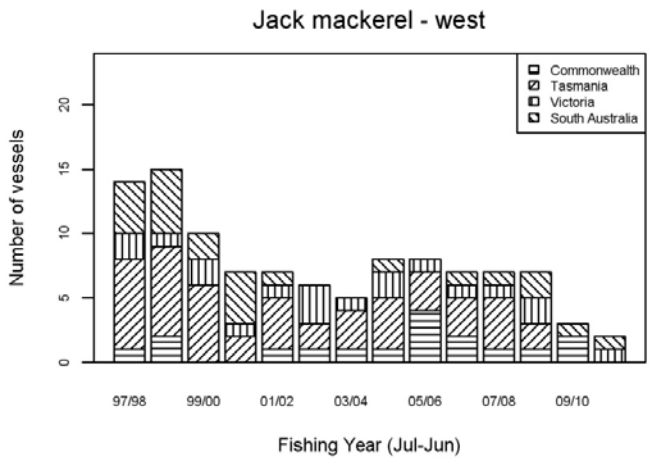

Figure 3.2 Number of vessels which landed Jack Mackerel in the West, from each of the participating management jurisdictions.

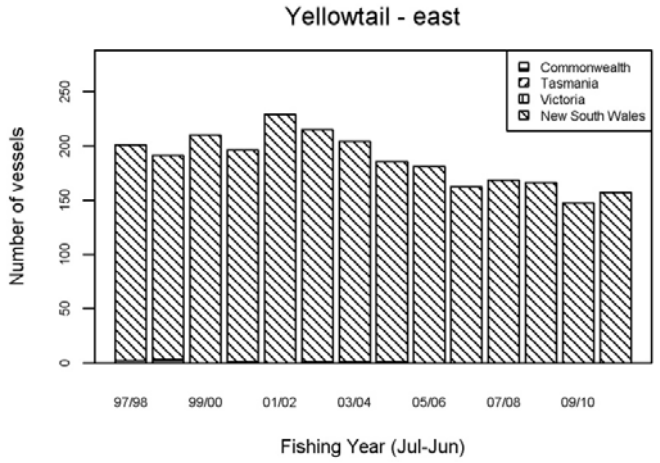

Figure 3.3 Number of vessels which landed Yellowtail Scad in the East, from each of the participating management jurisdictions.

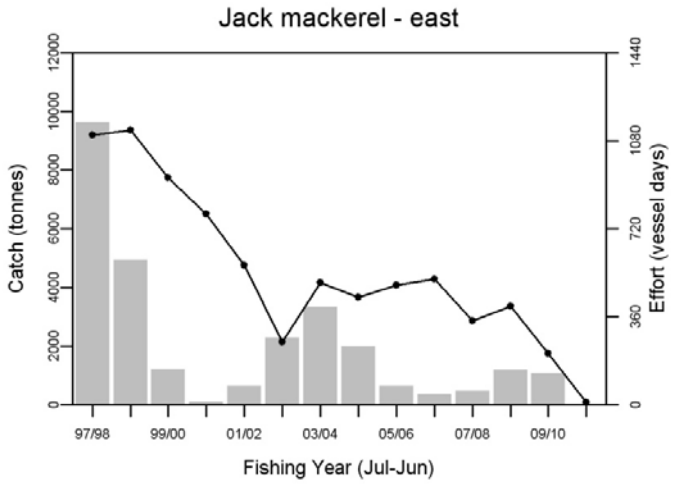

Figure 3.4 Total landed catch (tonnes, bars) and effort (vessel days, line) for Jack Mackerel in the East during financial years over the period 1997/98 – 2010/11.

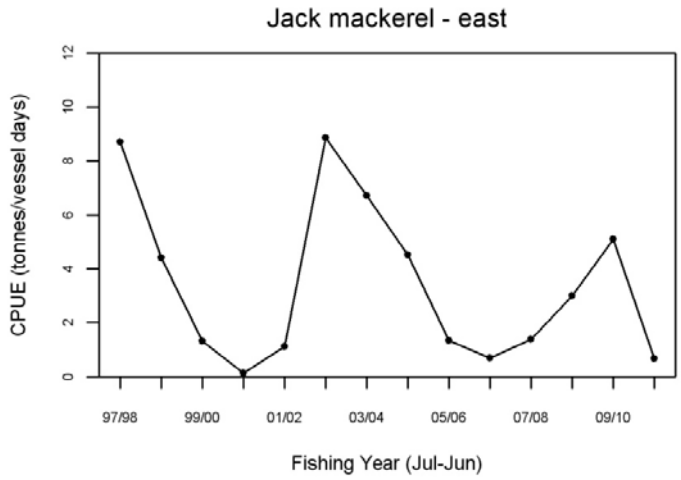

Figure 3.5 CPUE (tonnes per vessel day) for Jack Mackerel in the East during financial years over the period 1997/98 – 2010/11.

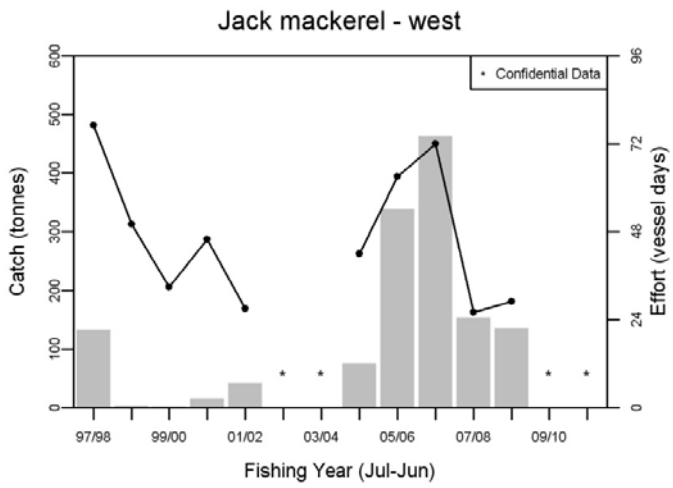

Figure 3.6 Total landed catch (tonnes, bars) and effort (vessel days, line) for Jack Mackerel in the West during financial years over the period 1997/98 – 2010/11.

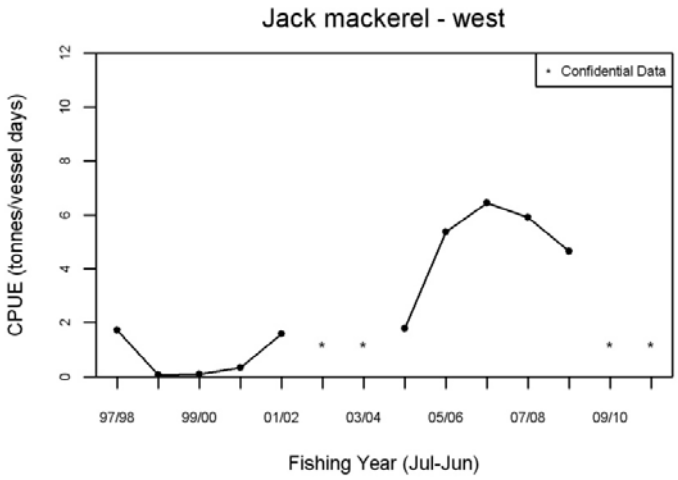

Figure 3.7 CPUE (tonnes per vessel day) for Jack Mackerel in the West during financial years over the period 1997/98 – 2010/11.

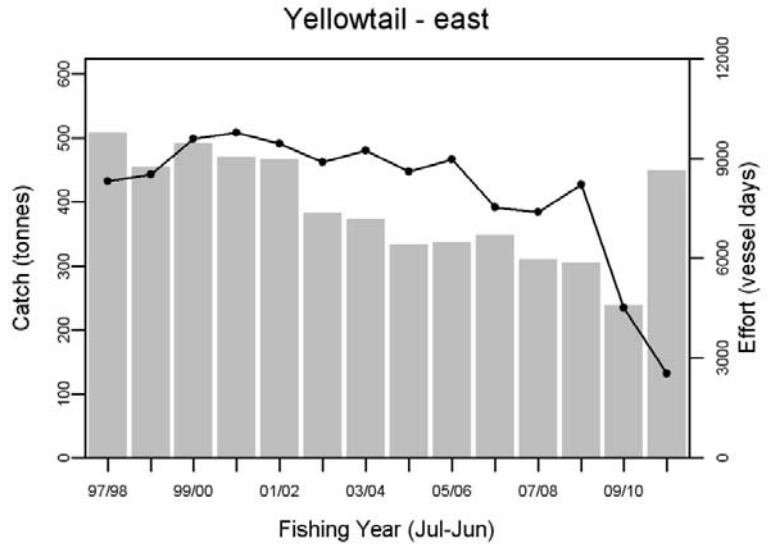

Figure 3.8 Total landed catch (tonnes, bars) and effort (vessel days, line) for Yellowtail Scad in the East during financial years over the period 1997/98 – 2010/11.

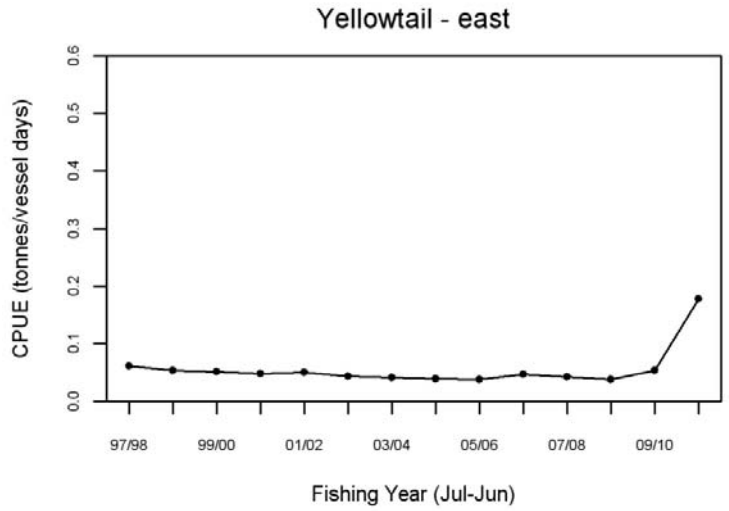

Figure 3.9 CPUE (tonnes per vessel day) for Yellowtail Scad in the East during financial years over the period 1997/98 – 2010/11.

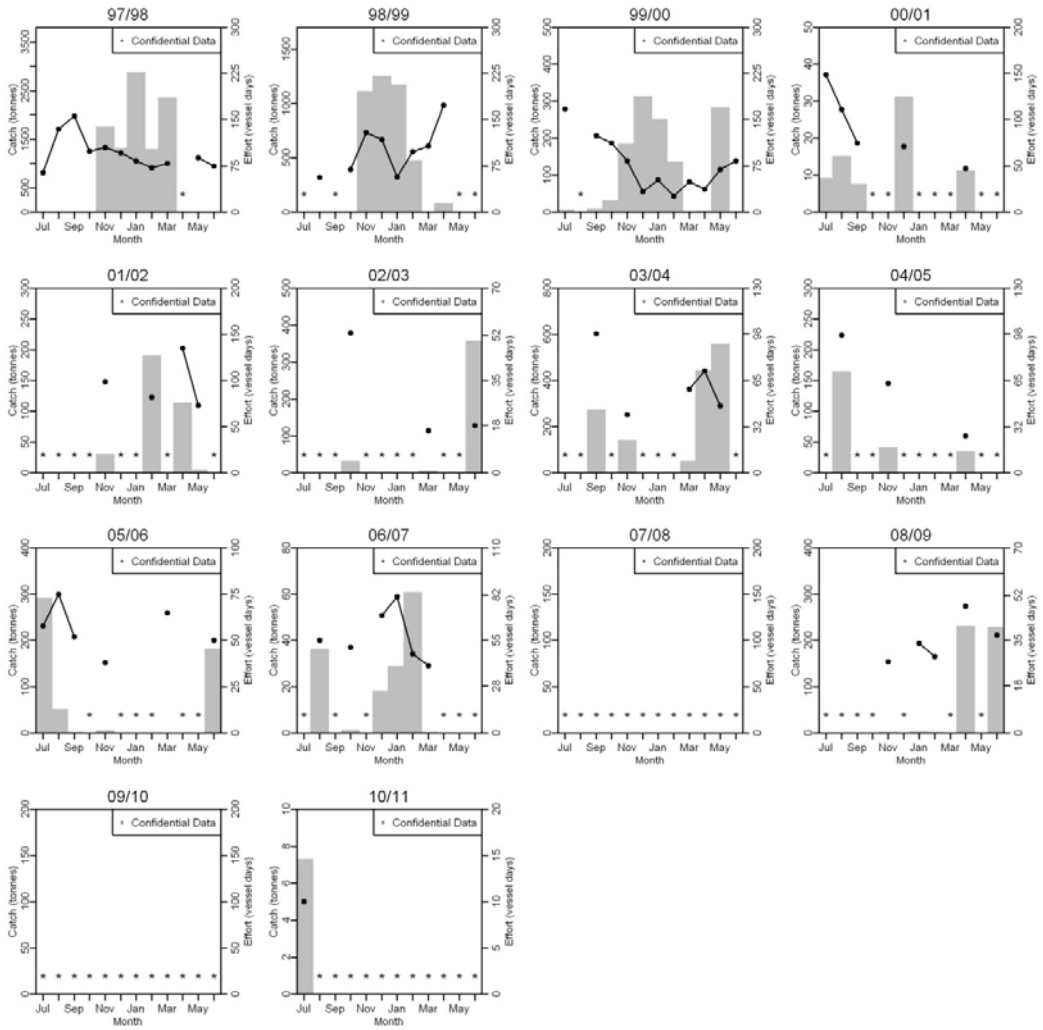

Figure 3.10 Intra-annual patterns of catch (bars) and effort (line) for Jack Mackerel in the East for the period between 1997/98 and 2010/11.

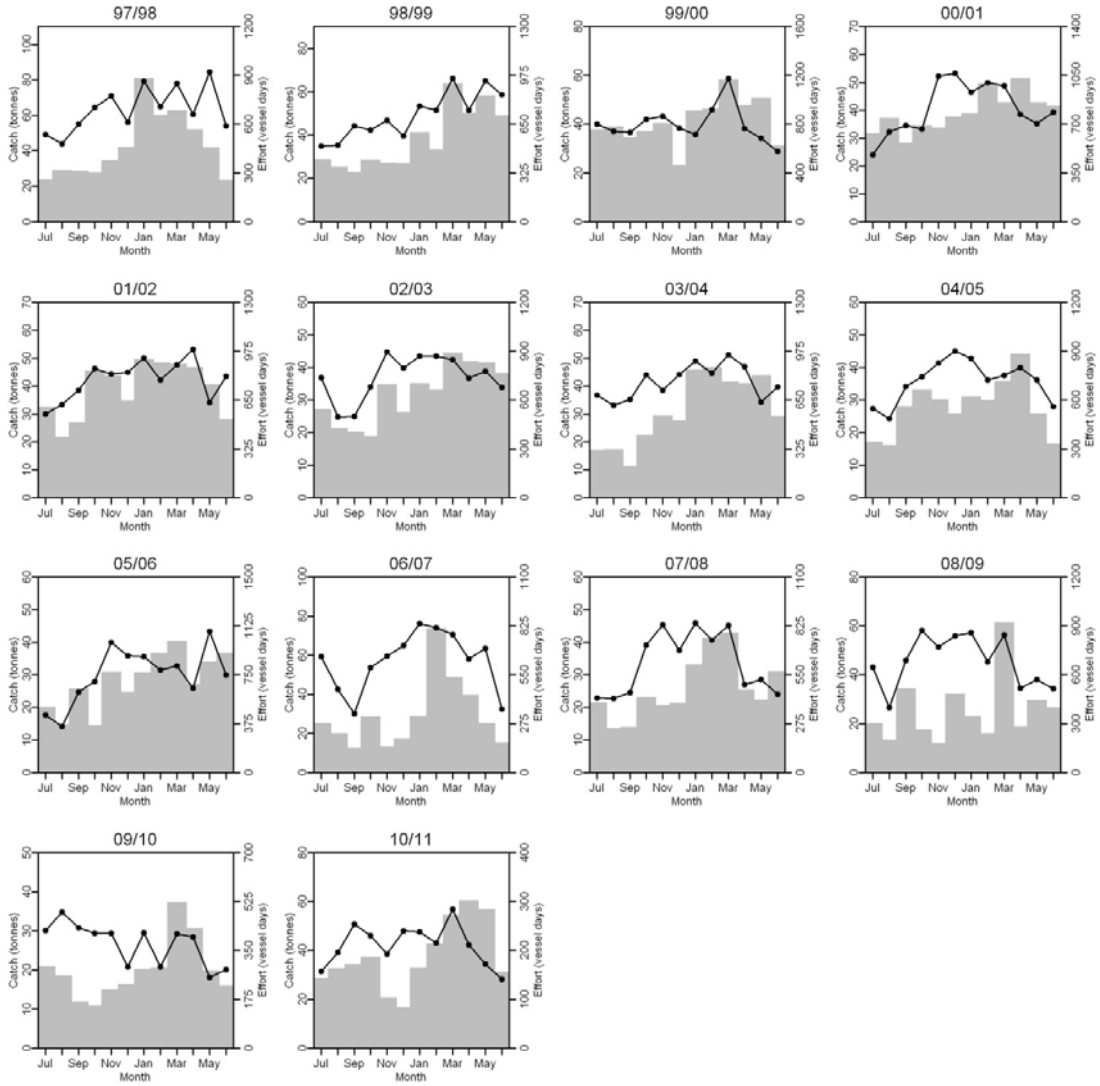

Figure 3.11 Intra-annual patterns of catch (bar) and effort (line) for Yellowtail Scad in the East for the period between 1997/98 and 2010/11.

3.3.2 Biological Information

3.3.2.1 Size Structure

The purse-seine fishery: 1984-2000

Jack Mackerel caught in the purse-seine fishery between 1984 and 1996 off eastern Tasmania were mostly 210-350 mm FL, with individuals up to 440 mm recorded (Fig. 3.12). In the first year of the fishery the catch comprised fish between 240 and 360 mm 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 size range and evidence for a slight shift in size structure to the right. A second cohort of small fish (<250 mm) was first evident in 1988/89 and by 1989/90 the size distribution was bimodal, with peaks at 240 mm and 320-330 mm. Bimodal size structure was evident in the following three years, the position and relative heights of the modes varying between years. The size compositions for 1993/94 through to 1995/96 were unimodal, and showed evidence of a general shift to larger fish.

Mid-water trawl fishery: 2001-2005

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

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

Mid-water trawl and purse-seine operations: 2009-2010

Overall 1,862 Jack Mackerel from 21 mid-water trawl and purse-seine catches were sampled between July 2009 and June 2010; all but one 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, dominated by 180-240 mm fish (Fig. 3.15). Overall, these were smaller than those taken by mid-water trawl during the early 2000s and were small in comparison with the purse-seine catches of the 1980s and 1990s. The single mid-water trawl catch sample from south-western Tasmania was comprised of fish of similar size to catches from eastern Tasmania (Table 3.1), being substantially smaller than fish taken by mid-water trawl during the early 2000s.

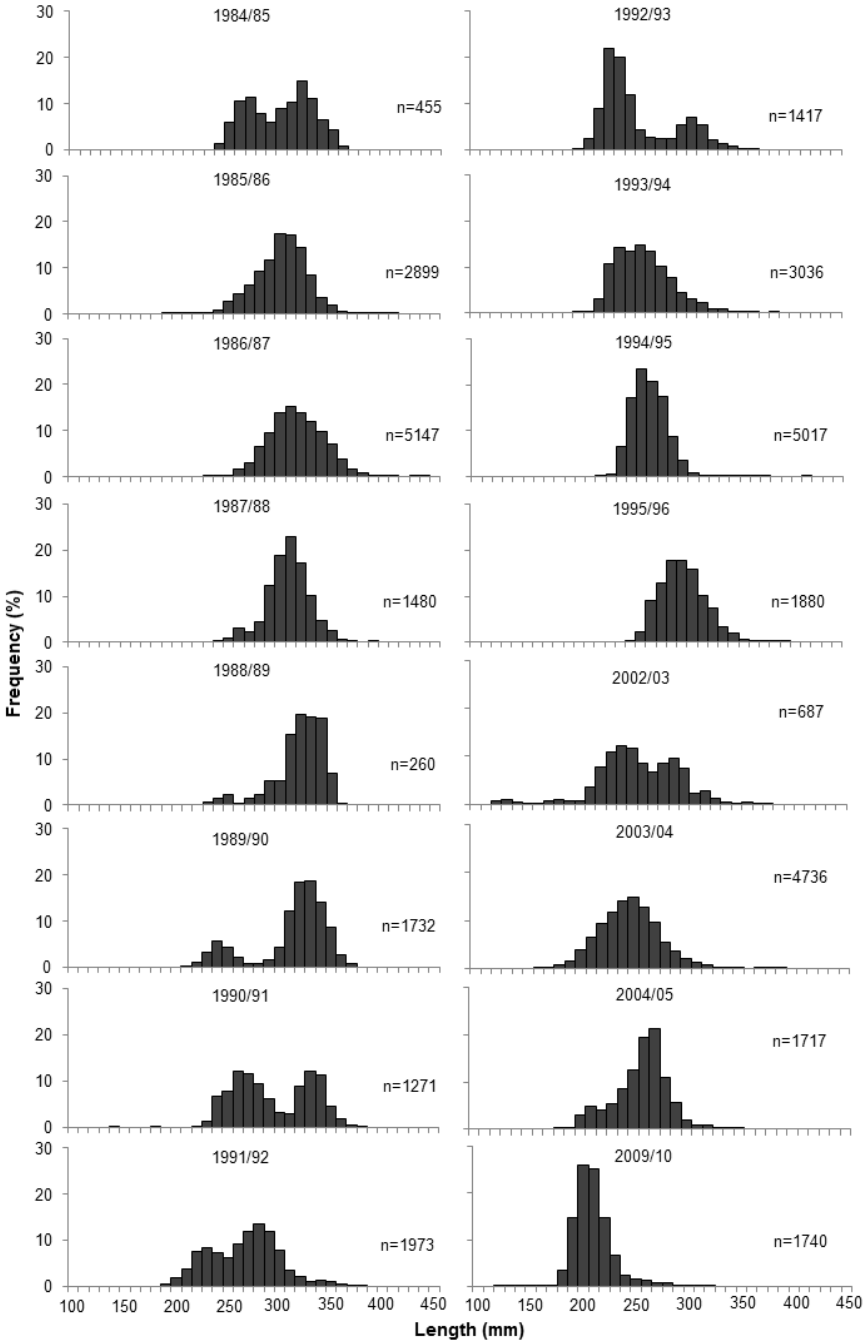

Figure 3.12 Length frequency distributions of Jack Mackerel caught in the SPF by purse-seine (1984 – 1996), mid-water trawl (2002 – 2005) and both fishing methods combined (2009 – 2010) off eastern Tasmania between 1984 and 2010. No data were available between 1997 and 2001. n is sample size.

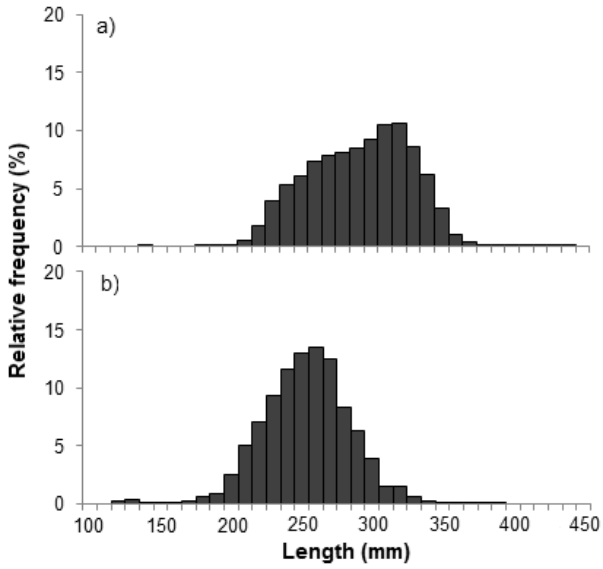

Figure 3.13 Year-weighted length frequency distributions of Jack Mackerel caught in the SPF off eastern Tasmania from (a.) purse-seine operations (1984 – 1996), and (b.) mid-water trawl operations (2002 – 2005).

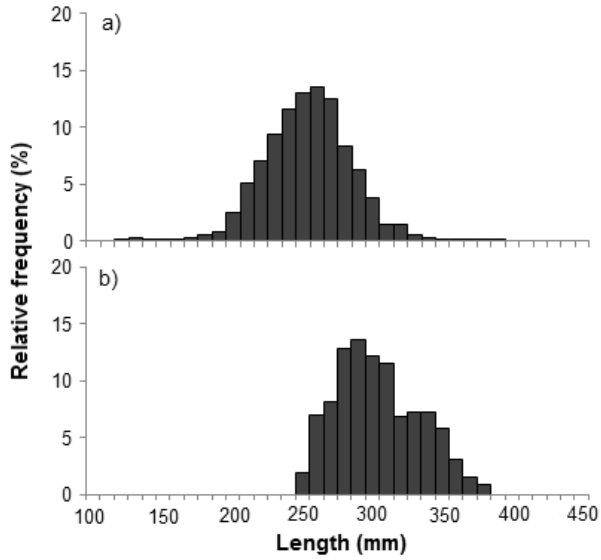

Figure 3.14 Year-weighted length frequency distributions of Jack Mackerel caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2002 and 2005.

Table 3.1 Summary of shots sampled in the SPF off Tasmania for Jack Mackerel length-frequency data during 2009-2010. The number of individuals (n) for which length-frequency data were collected is indicated along with the size range and mode.

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

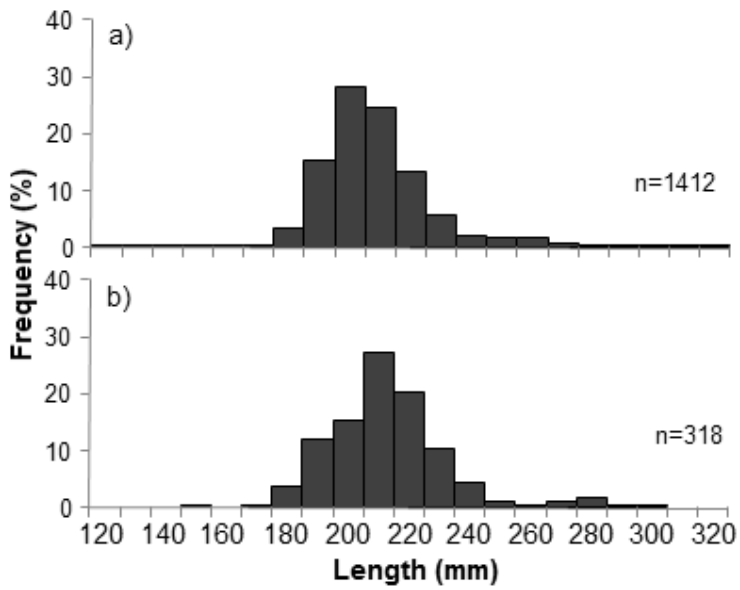

Figure 3.15 Length frequency distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawl operations during 2009/10. n is sample size

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, Fig. 3.16). Growth is rapid within the first few years of life, with individuals reaching a mean length in

excess of 230 mm FL 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.

		VB parameters		
	n	L_∞	K	t_0
♂	534	364.0	0.27	-0.92
♀	763	360.3	0.29	-0.63
Pooled	2143	362.8	0.29	-0.81

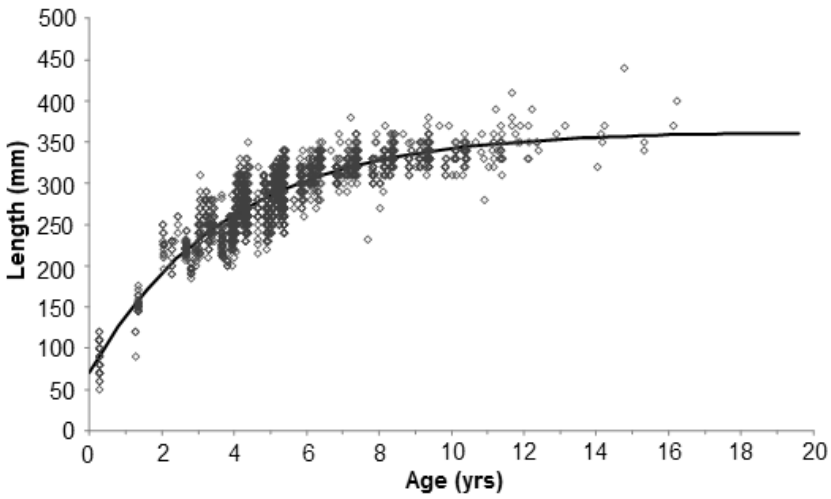

Figure 3.16 Length at age data for Jack Mackerel from eastern Tasmania. The black line represents the VB growth function.

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 the 1985/86, 1989/90, 1993/94 and 1994/95 fishing years. Jack Mackerel taken by the purse-seine fishery were generally 3-10 years old (Fig. 3.17). Catches between 1984/85 and 1990/91 were dominated by 4 and 5 year olds with age classes up to about 9 years 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. It should, however, 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 compositions, in particular in terms of representation of the older age groups.

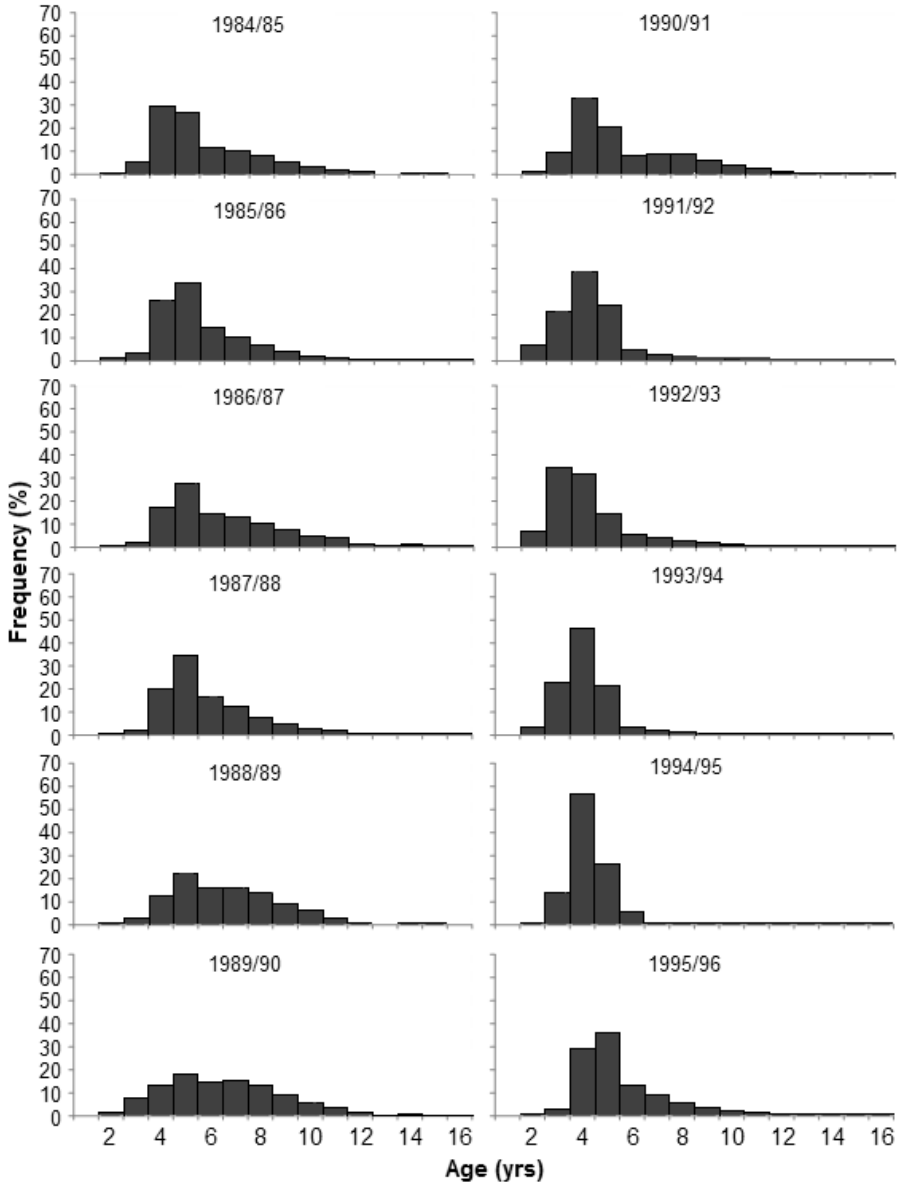

Figure 3.17. Age structure of Jack Mackerel catch samples from eastern Tasmania between 1984 and 1996.

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 were mainly represented by fish aged between 2-5 years old, with a modal age of 3-4 years (Fig. 3.18). 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.

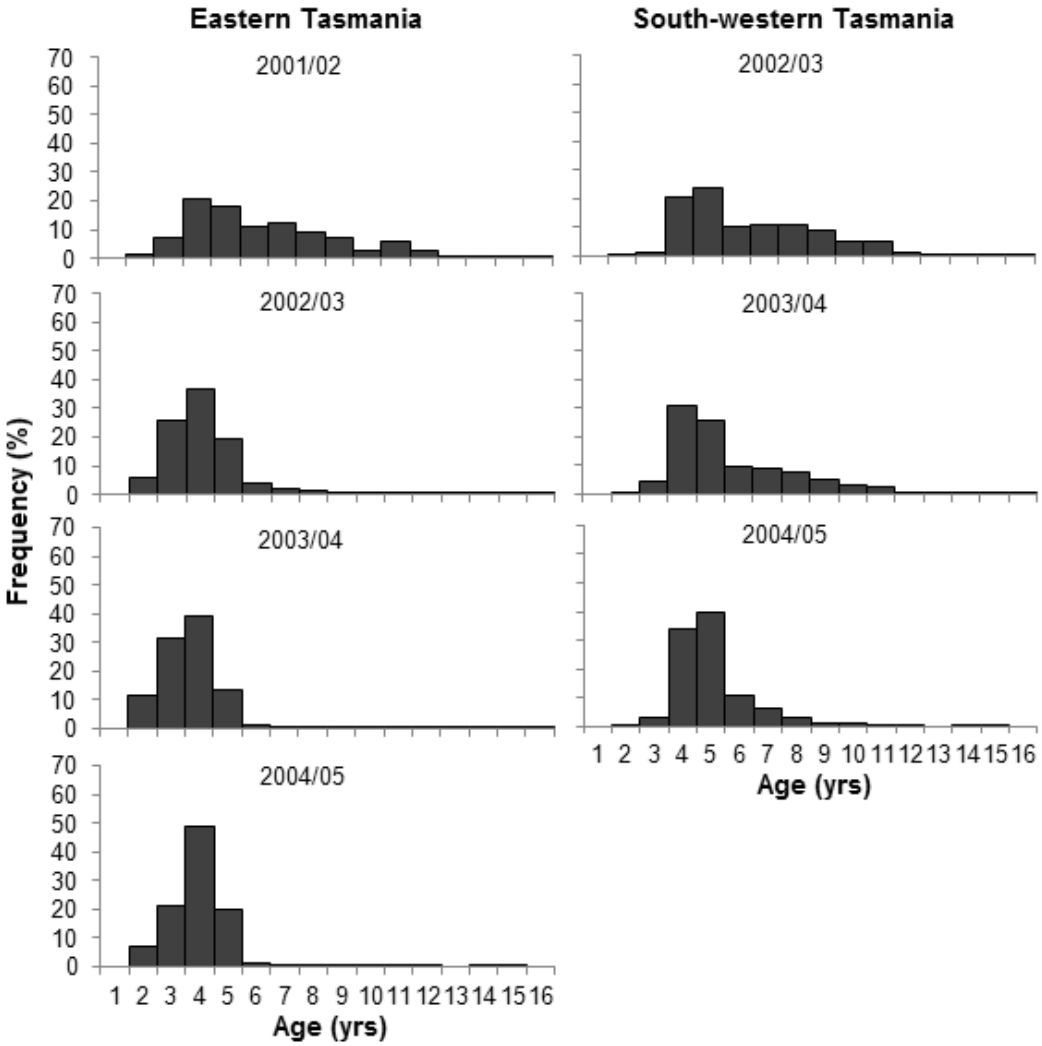

Figure 3.18 Age structure of Jack Mackerel catch samples from eastern and south-western Tasmania between 2001/02 and 2004/05 (few data were available off south-western Tasmania during 2001/02).

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 (Table 3.3) and an age length key developed to determine the catch age structure for 2009/10. Mid-water trawl and purse-seine catches from eastern Tasmania were dominated by 2-3 year old individuals (Fig. 3.19). By 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 numbers.

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

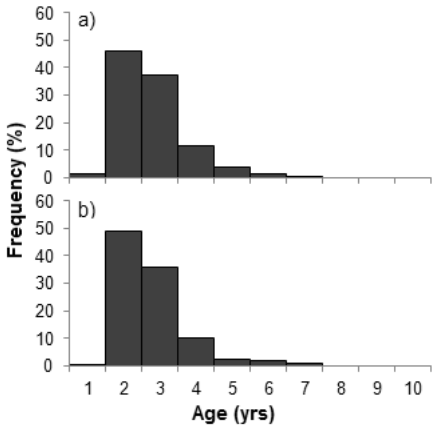

Figure 3.19 Age distribution of Jack Mackerel caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

3.3.5 Reproduction

Due to limited sample size, estimates for age at sexual maturity are not available for the south-western Jack Mackerel population.

3.3.5.1 Gonosomatic index (GSI) and gonad stages

Trends in male and female GSI and female macroscopic staging indicate that Jack Mackerel have a discrete spawning season extending over a 3 month period during late spring and early summer (Figs. 3.20, 3.21). The GSIs rose sharply in November with a maximum of 2.6% recorded in January, followed by a sharp decline thereafter. Fish with hydrated, running ripe and spent gonads (Stages IV-VI) were first evident in November and became more abundant during December-January.

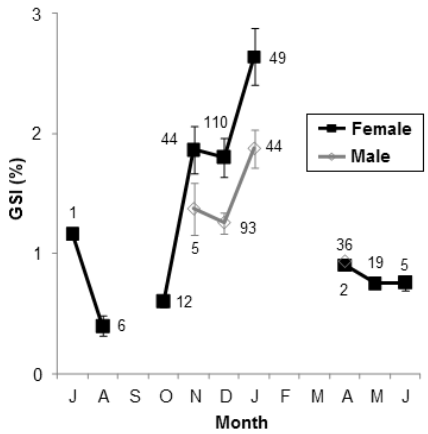

Figure 3.20 Monthly distribution of mean GSI of Jack Mackerel by sex off eastern Tasmania. Numbers represent sample size and error bars are standard error.

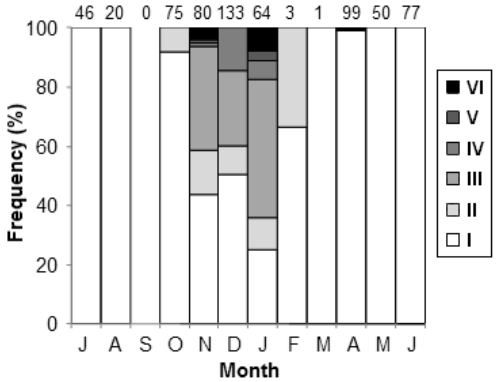

Figure 3.21 Monthly distribution of female Jack Mackerel macroscopic gonad stages off eastern Tasmania. Numbers represent sample sizes.

3.3.5.2 Size at maturity

Size at sexual maturity showed slight differences between males and females with 50% maturity occurring at smaller size in females (Table 3.4, Fig. 3.22). The size at 50% sexual maturity was 268 mm FL for females and 291 mm FL for males. 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

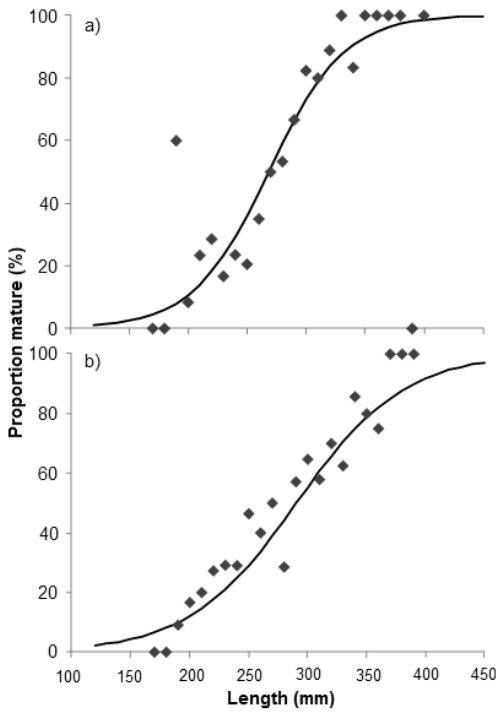

Figure 3.22 Proportion of mature female (a) and male (b) Jack Mackerel by length class with logistic ogives fitted.

3.3.5.3 MSE

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 these harvest quantities are "absolute" quantities and without a DEPM estimate of spawning biomass there is no benchmark to compare against. A DEPM spawning biomass estimate is now available for both Jack Mackerel and Yellowtail Scad, incorporation of this information into a MSE is warranted.

3.4 Summary and Conclusions

Both the East and West stocks of Jack Mackerel have been assessed as 'not overfished' (Woodhams *et al.* 2011). Over the past three decades the fishery for Jack Mackerel has experienced major change; from an initial and rapid expansion of an industrial scale purse-seine fishery to effective economic collapse at the end of the 1990s, to the development of mid-water trawling for small pelagics in the early 2000s and resumption of small scale purse-seine operations in the late 2000s. It has been suggested that unfavourably warm water temperatures have affected the availability of Jack Mackerel in recent years in some areas. Fish processors in Tasmania have reported difficulty in selling Jack Mackerel since 2003/04. Throughout this history a combination of fish availability along with market and economic factors have meant that the fishery has undergone significant variability in production levels. In 2010/11, reduced mid-water trawl effort coupled with limited purse-seine activity has meant that production levels have remained low.

The spawning season of Jack Mackerel off Tasmania occurs between November and February. Females attain maturity at around 260 mm FL and males attain maturity at about 280 mm FL. Mid-water trawl and more recent purse-seine catches are dominated by immature fish, especially those fish taken off eastern Tasmania.

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.

4 REDBAIT (*EMMELICHTHYS NITIDUS*)

4.1 Introduction

4.1.1 Background to Fishery

A major purse-seine fishery for small pelagic fishes, principally Jack Mackerel (*Trachurus declivis*), developed off Tasmania in the mid-1980s, with catches peaking at over 40,000 tonnes in 1986/87. Redbait represented a key by-product species taken by the fishery, though rarely exceeded 5% by weight of the landed catch in any year. Nevertheless, the high volume of production meant that Redbait annual landings in the order of 1,500 tonnes 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 tonnes 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 averaged nearly 7,000 tonnes post 2002/03 and comprised up to 94% of the total catch.

More recent fishing for small pelagics by purse-seine in Tasmanian State waters yielded 300 tonnes of Redbait in 2007/08, 521 tonnes in 2008/09 and 122 tonnes in 2009/10 (Hartman and Lyle 2011). No data were available for Redbait catches in 2010/11. 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 in both hemispheres. They are generally found in schools over continental shelf breaks, seamounts and submarine ridges. They inhabit depths from the surface to >800 m, though they 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 NSW to south-west Western Australia, including Tasmania (Gomon *et al.* 2008).

4.1.4 Stock Structure

There have been no targeted stock structure studies on Redbait in Australia. However, on the weight of evidence, Bulman *et al*. (2008) concluded that Redbait from eastern Australia and eastern Tasmania 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 accounting for the entire diet (Meyer and Smale 1991). Larger individuals (281-493 mm) 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; Bulman *et al.* 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 65.7% and 33.2% of relative importance indices, respectively (McLeod, 2005).

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

4.1.7 Age, Growth and Size

The maximum reported size of Redbait from Tasmania is 317 and 304 mm fork length (FL) for females and males, respectively (Neira *et al.* 2008), somewhat smaller than that recorded elsewhere throughout the distributional range. Redbait have been confirmed to grow to 335 mm FL off eastern Victoria (Furlani *et al.* 2000), 344 mm SL off the coast of Chile (Meléndez and Céspedes 1986) and individuals of 493 mm total length (TL) and possibly larger 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 depth, with larger (>200 mm) Redbait often found deeper and closer to the seafloor than schools of smaller fish (Markina and Boldryev 1980).

Estimates of growth for Redbait, derived from either interpretation of scales (Roschin 1985), whole otoliths (Williams *et al.* 1987) or sectioned otoliths (Neira *et al.* 2008), suggest that it is rapid in the first years of life. Redbait from Tasmanian waters reached a mean FL in excess of 200 mm 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 the maximum age in this species may be higher than indicated from Tasmanian samples, 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 during between September and November, with peak activity during September and October (Ewing and Lyle 2009). There are marked regional differences in size and age at sexual maturity, with males and females from south-western Tasmania (261 and 244 mm, respectively) maturing at some 100 mm larger and two years older compared to Redbait from eastern Tasmania (157 and 147 mm, respectively). Spawning occurs along a narrow 2.5 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, the fishery is managed at the Tier 1 level, as such conservative TACs have been set based on the rules outlined by the SPF harvest strategy. The fishery is considered to not be overfished.

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 pelagics. 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. More recently, purse-seine operations targeting small pelagics have resumed in Tasmanian state waters and shot by shot catch and effort are recorded in the Tasmanian general fishery logbook.

4.2.2 Biological Information

Fishery dependent length frequency and biological data for Redbait 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 of Redbait collected from demersal research trawling conducted by CSIRO and the relevant Tasmanian fisheries agency between 1985 and 1990. Between 1994 and 2001 the level of catch sampling of the purse-seine fishery was limited and targeted mainly at Jack Mackerel.

Collection of biological data during the 2001/02 pair-trawl fishing trials 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 Tasmanian Aquaculture and Fisheries Institute 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 between 2002 through to 2008.

Purse-seine operations for small pelagics 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 2009).

Biological data were collected from individual specimens and included FL (to the nearest millimetre), 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 0.1g). 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 over the period 1984-2010 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 collected for the 2010/11 season.

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 daily egg production method (DEPM) from egg and adult reproductive data collected off eastern Tasmania during October 2005 and 2006 (Neira *et al.* 2008).

An MSE model was used to test a range of management/harvest scenarios under the Commonwealth Small Pelagic Fishery (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 stock-recruitment relationship and natural mortality. The model was re-examined in 2011 to address concerns about values used for number of recruits.

The current SPF Harvest Strategy has a three-tiered approach. At the Tier 1 level, the maximum recommended biological catch (RBC) for each stock depends on the time since a daily egg production method (DEPM) survey was conducted, with the maximum RBC decaying from 20% to 10% of the spawning biomass estimated from the DEPM survey over a five year period (relative tonnage). The maximum RBC for Tier 2 and Tier 3 is set at a specified quantity (absolute tonnage). A maximum RBC for Tier 2 has been defined for each stock with quantities varying from 3,000-6,000 t, while for Tier 3, the maximum RBC has been set at 500 t for each stock.

4.3 Results

4.3.1 Fishery Statistics East / West

4.3.1.1 Number of vessels

Less than 5 vessels reported landing Redbait in both the East and West (Figs. 4.1 and 4.2).

4.3.1.2 Annual Patterns – catch, effort & catch-per unit effort

Prior to 2001/02 Redbait catches in the East were negligible (< 200 t). Catches increased to ~ 3,800 t in 2001/02 and 2002/03 and peaked at ~7,000 t in 2003/04. Catches have sequentially declined over the past six years to ~300 t in 2009/10 (Fig. 4.3). Annual estimates of effort have displayed a similar trend, rapidly increasing from <40 vessel days pre- 2001/02 to >100 vessel days in 2003/04 and subsiding

back to <40 in recent years (Fig. 4.4). Redbait catch rates in the East peaked at ~70 t.vessel day^{-1} in 2001/02, remained above 40 t from 2002/03 to 2005/06 then declined to ~20 t.vessel day^{-1} in 2009/10 (Fig. 4.4). No data were presentable for the 2010/11 season due to confidentiality reasons.

Redbait catches in the West were lower than the East (Fig. 4.5). Like the East the trend in catches in the West also displayed a clear peak, but it occurred a few years later, with catches exceeding 3,000 t in 2005/06. Catches have not exceeded 1,000 t since 2008/09 (Fig. 4.5). The trend in catch has reflected the trend in annual fishing effort (Fig. 4.5). Fishing effort peaked at ~90 vessel days in 2005/06 and over the past two years has been <30 vessel days. Redbait catch rates in the West have sequentially declined from ~100 t.vessel day^{-1} in 2001/02 to ~30 t.vessel day^{-1} in 2009/10 (Fig. 4.6). No data were presentable for the 2010/11 season due to confidentiality reasons.

4.3.1.3 Inter-annual Patterns – catch and effort

In the years 1997/98 to 2002/03 most of the Redbait catch in the East was taken during late summer and autumn (Fig. 4.7). From 2003/04 through to 2008/09, Redbait were also caught during the winter and spring. Annual peaks in Redbait catches during this time generally occurred during late autumn and winter. The seasonality of catches in the West were more discrete and generally confined to autumn and winter (Fig. 4.8). Catches were only prominent during the summer in 2008/09. Trends in catch generally followed trends in effort in both regions.

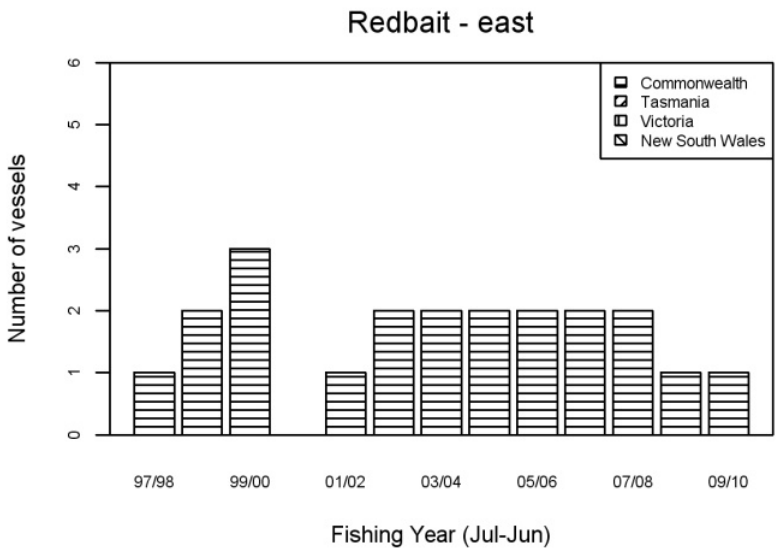

Figure 4.1 Number of vessels which landed Redbait in the East.

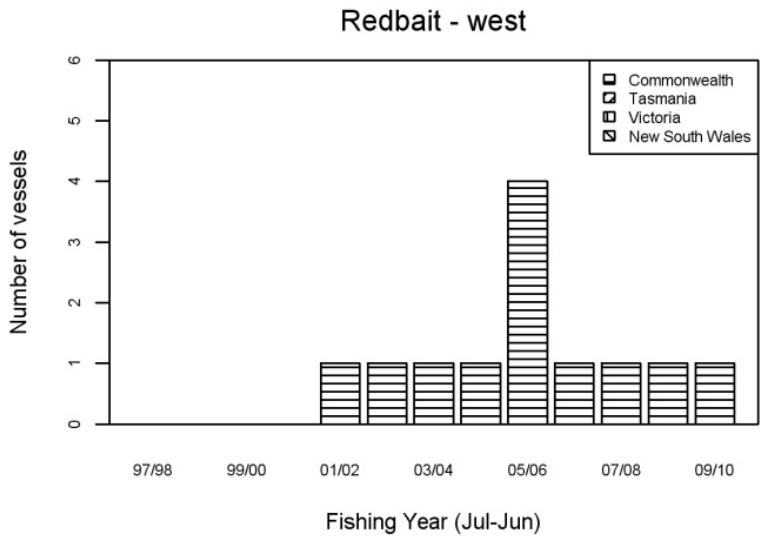

Figure 4.2 Number of vessels which landed Redbait in the West.

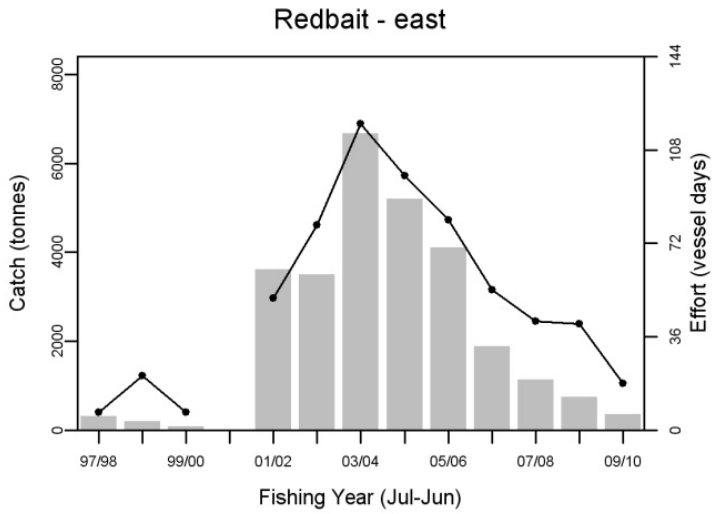

Figure 4.3 Total landed catch (tonnes, bars) and effort (vessel days, line) for Redbait in the East during financial years over the period 1997/98 – 2009/10.

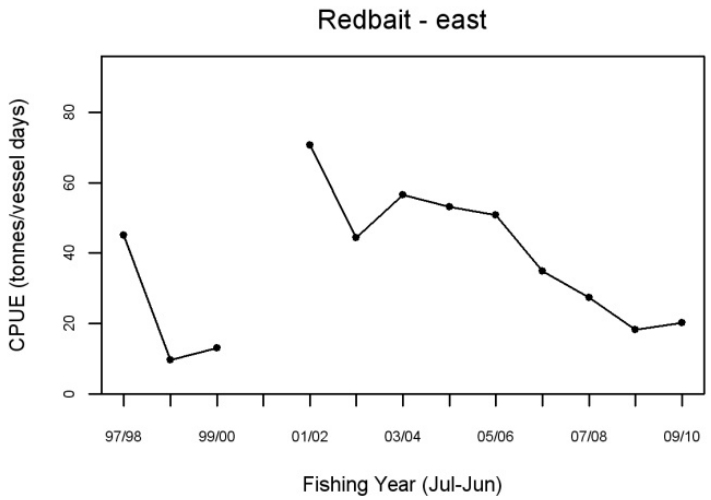

Figure 4.4 CPUE (tonnes per vessel day) for Redbait in the East during financial years over the period 1997/98 – 2009/10.

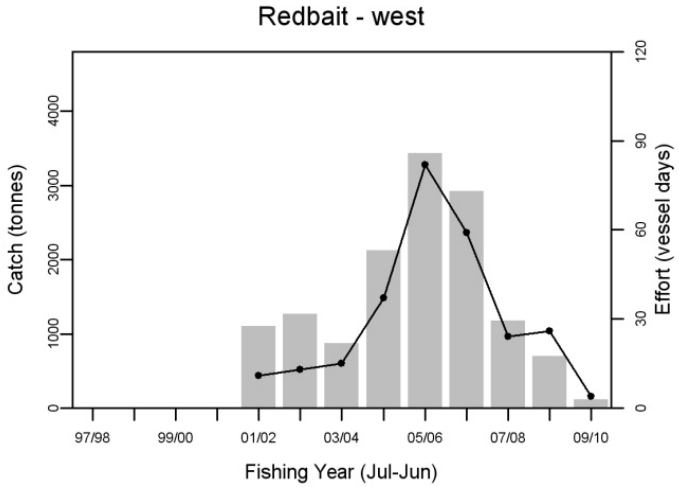

Figure 4.5 Total landed catch (tonnes, bars) and effort (vessel days, line) for Redbait in the West during financial years over the period 1997/98 – 2009/10.

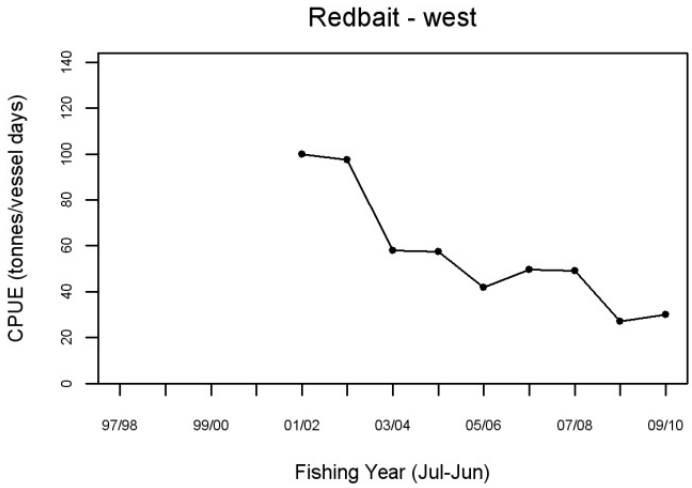

Figure 4.6 CPUE (tonnes per vessel day) for Redbait in the West during financial years over the period 1997/98 – 2009/10.

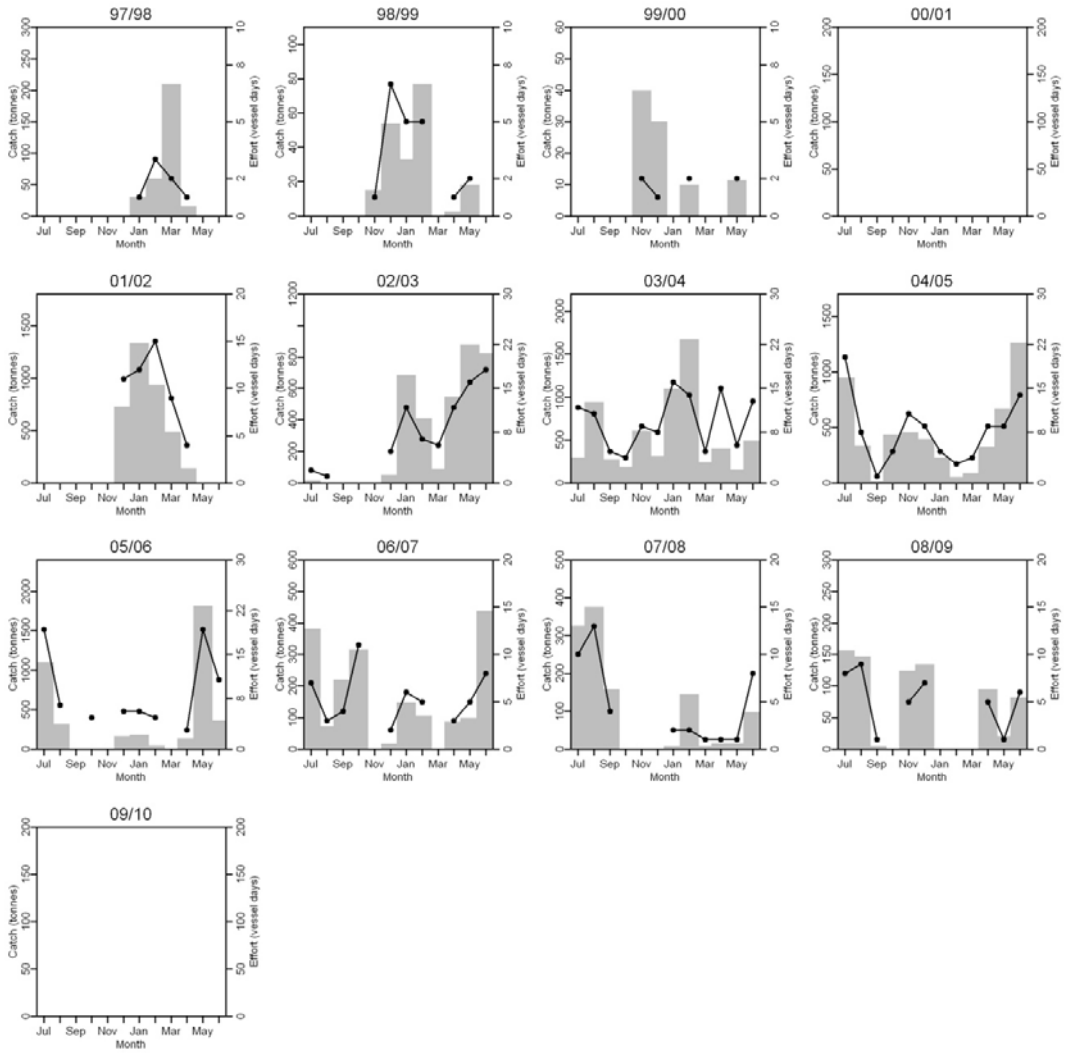

Figure 4.7 Inter-annual patterns of catch (bars) and effort (line) for Redbait in the East for the period between 1997/98 and 2009/10.

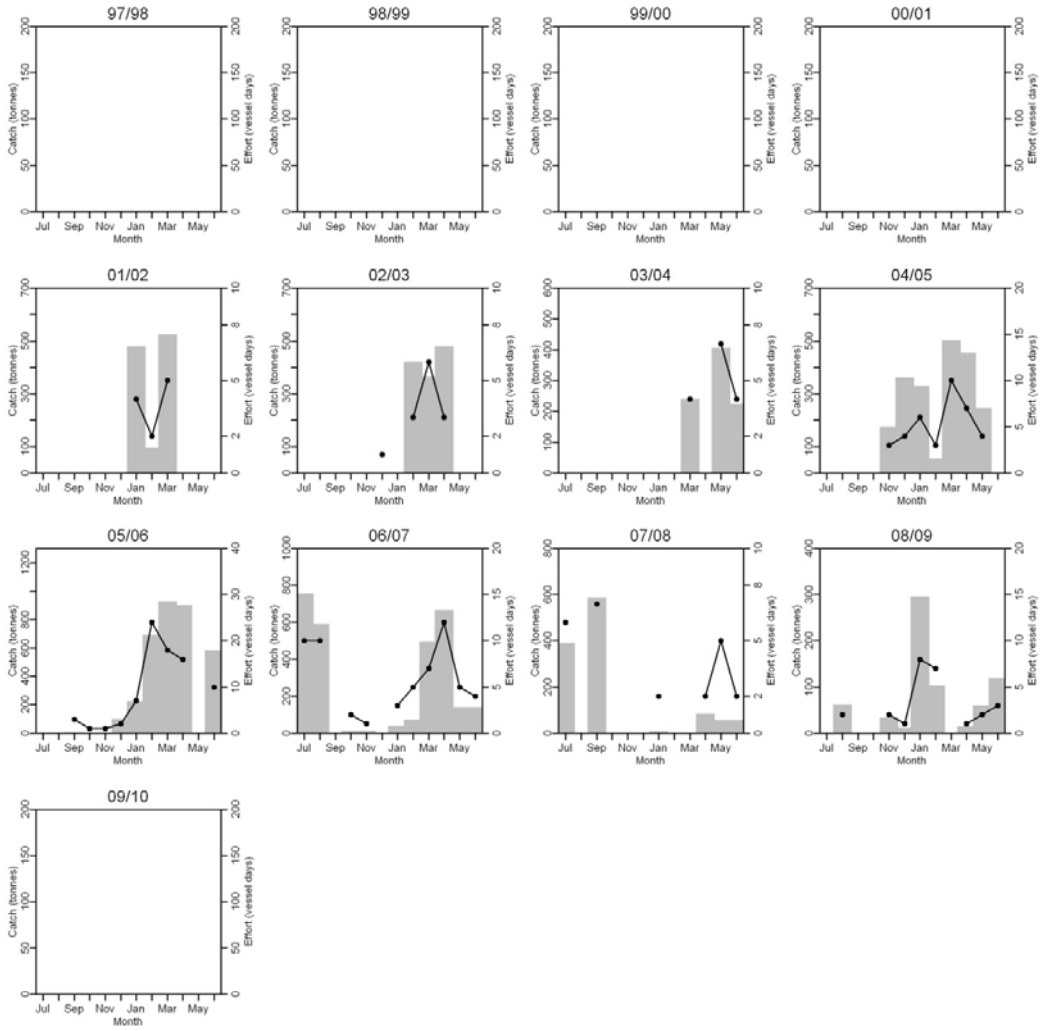

Figure 4.8 Inter-annual patterns of catch (bars) and effort (line) for Redbait in the West for the period between 1997/98 and 2009/10.

4.3.2 Biological Information

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 140-290 mm FL, with individuals up to 320 mm recorded (Figs. 4.9, 4.10). Catches between 1984/85 and 1987/88 were dominated by fish of 200-300 mm, with only a few small fish (100-140 mm) caught in 1985/86. A strong mode (cohort) of smaller fish (120-170 mm) was present in the 1988/89 and this cohort appeared to account for the majority of the catch in the following year. Between the 1989/90 and 2009/10 seasons smaller fish (<200 mm)

tended to dominate the composition of the catch (Fig. 4.9). No data for the 2010/11 season were available.

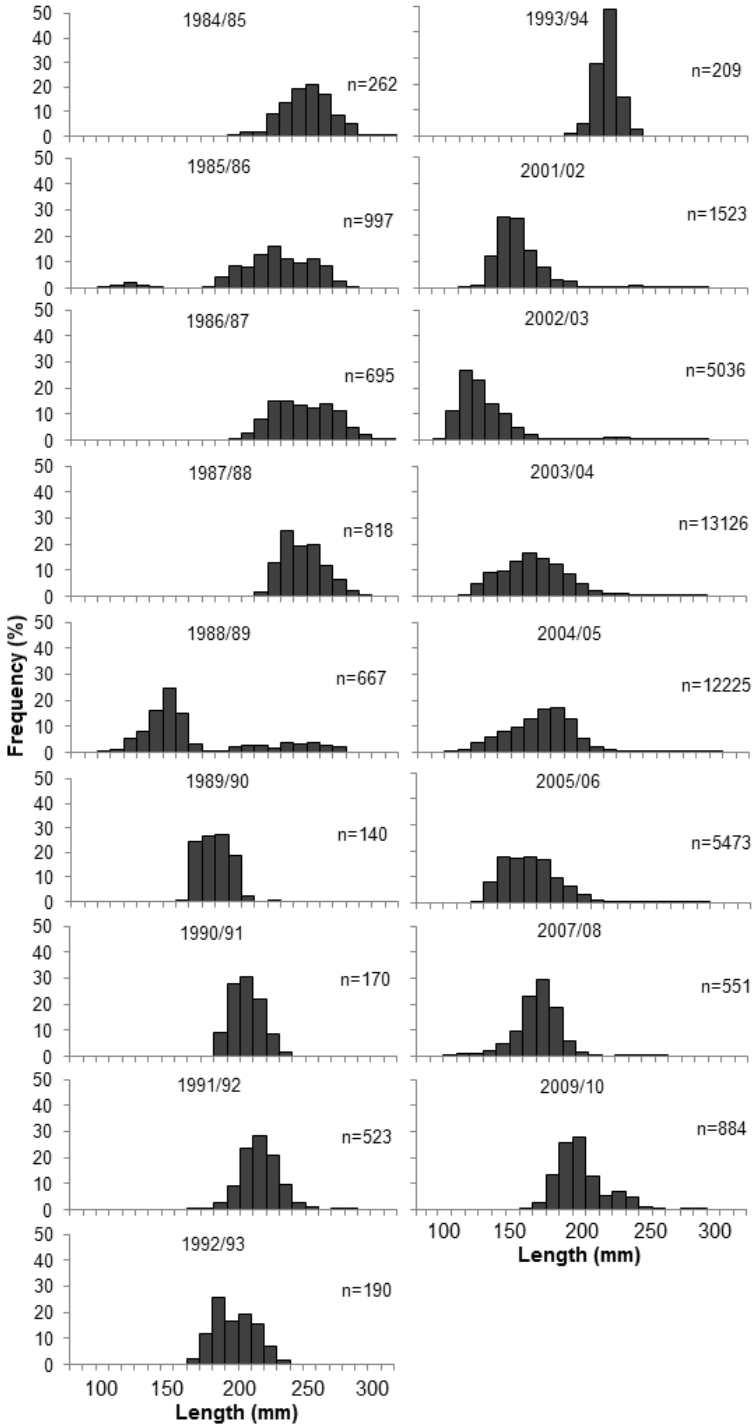

Figure 4.9 Length frequency distributions of Redbait caught in the SPF by purse-seine operations off eastern Tasmania from 1984 to 2010.

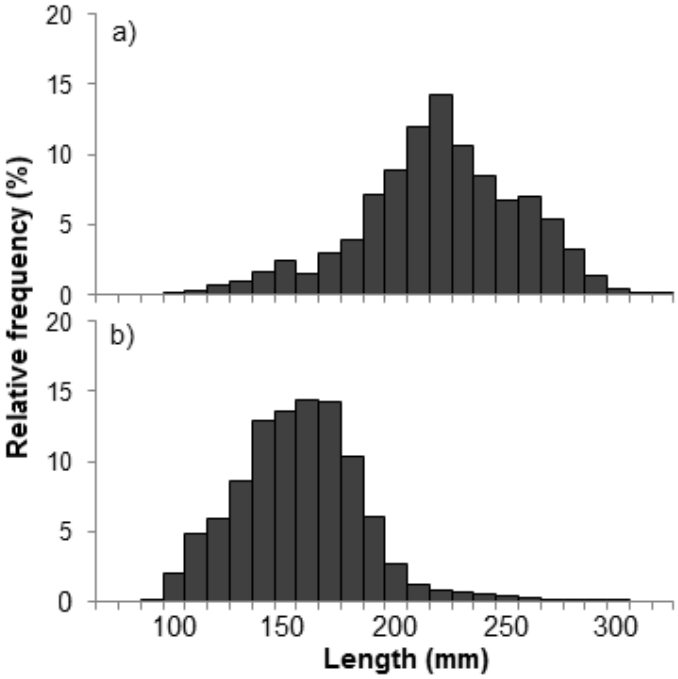

Figure 4.10 Year-weighted length frequency distributions of Redbait caught in the SPF off eastern Tasmania from (a) purse-seine operations (1984-1994) and (b) mid-water trawl operations (2001-2008).

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

Redbait caught by mid-water trawl operations between 2001/02 and 2008/09 off eastern Tasmania where considerably smaller than those caught by the earlier purse-seine operations, with specimens mostly between 100 and 210 mm (Fig. 4.11, 4.12). 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 (2004/05) (Fig. 4.9). Only a small proportion of the catch was made up of fish larger than 200 mm. By contrast Redbait caught by mid-water trawl operations off south-western Tasmania were mostly between 130-280 mm with a modal length of 200 mm (Figs. 4.11, 4.12). While the south-west coast frequency distribution in 2001/02 was comprised mainly of small fish and mirrored that of the east coast catch 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 (Fig. 4.12).

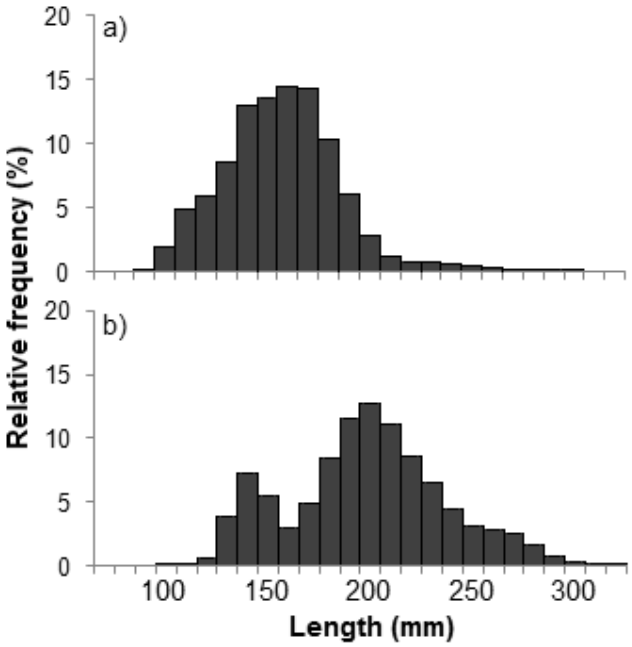

Figure 4.11 Year-weighted length frequency distributions of Redbait caught in the SPF off (a) eastern and (b) south-western Tasmania from mid-water trawl operations between 2001 and 2006.

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

Overall 887 Redbait were sampled from 12 landings based on purse-seine and mid-water trawl operations off eastern Tasmania between August 2009 and June 2010 (Table 4.9).

Mid-water trawl catches from eastern Tasmania were dominated by 190-240 mm fish (Fig. 4.12). By contrast, 180-200 mm FL fish comprised the bulk of the purse-seine catch, few individuals larger than 210 mm were present (Fig. 4.12). In many respects the purse-seine catch size structure 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 was also available and was comprised of 210-310 mm FL fish (mode 240 mm), which was consistent with the size of fish taken in 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

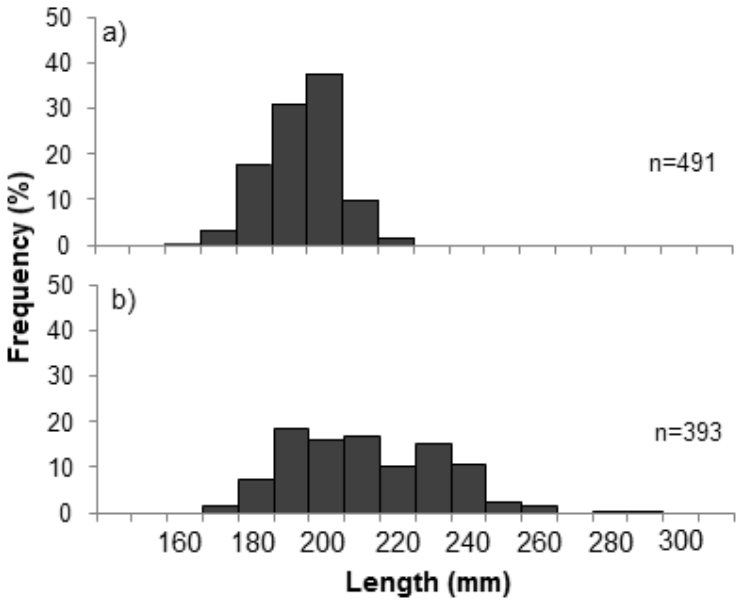

Figure 4.12 Length frequency distribution of Redbait caught in the SPF eastern Tasmania by purse-seine (a) and mid-water trawling (b) operations during 2009/10. n is sample size.

4.3.3 Age and Growth

Growth of male and female Redbait was described using the von Bertalanffy growth function (VBGF) from eastern and south-western Tasmania (Table 4.2, Fig. 4.13). Growth is rapid within the first years of life with individuals reaching a mean of 200 mm FL in the first three years, with growth slowing thereafter. The initial fast growth is also reflected in the negative t_o values in the VBGF. Maximum assigned ages for females and males reordered were 21 and 18 years, respectively.

Table 4.2 Summary of VBGF parameters by sex and by 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

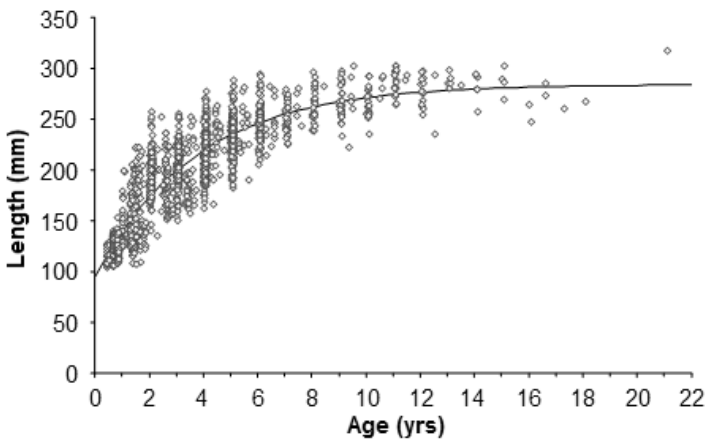

Figure 4.13 Length at age data for Redbait with regions pooled. The grey line represents the VB growth function.

4.3.3.1 Age Structure

4.3.3.1.1 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 (Fig. 4.14). The eastern Tasmanian catches were comprised mostly of fish aged between 1 and 5 years old. 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 percentage of fish aged 2 and under varied between 40% (2004/05) and 94% (2002/03), with few fish (<4%) caught aged above 5 years old. The age structure of the south-west Tasmanian catches showed a higher proportion of older fish, with catches comprised of fish between 2 and 8 years old. A strong cohort of 2 year old fish dominated

catches in the 2003/04 season; this cohort subsequently dominated catches as 3 year olds in 2004/05 and 4 year olds in 2005/06.

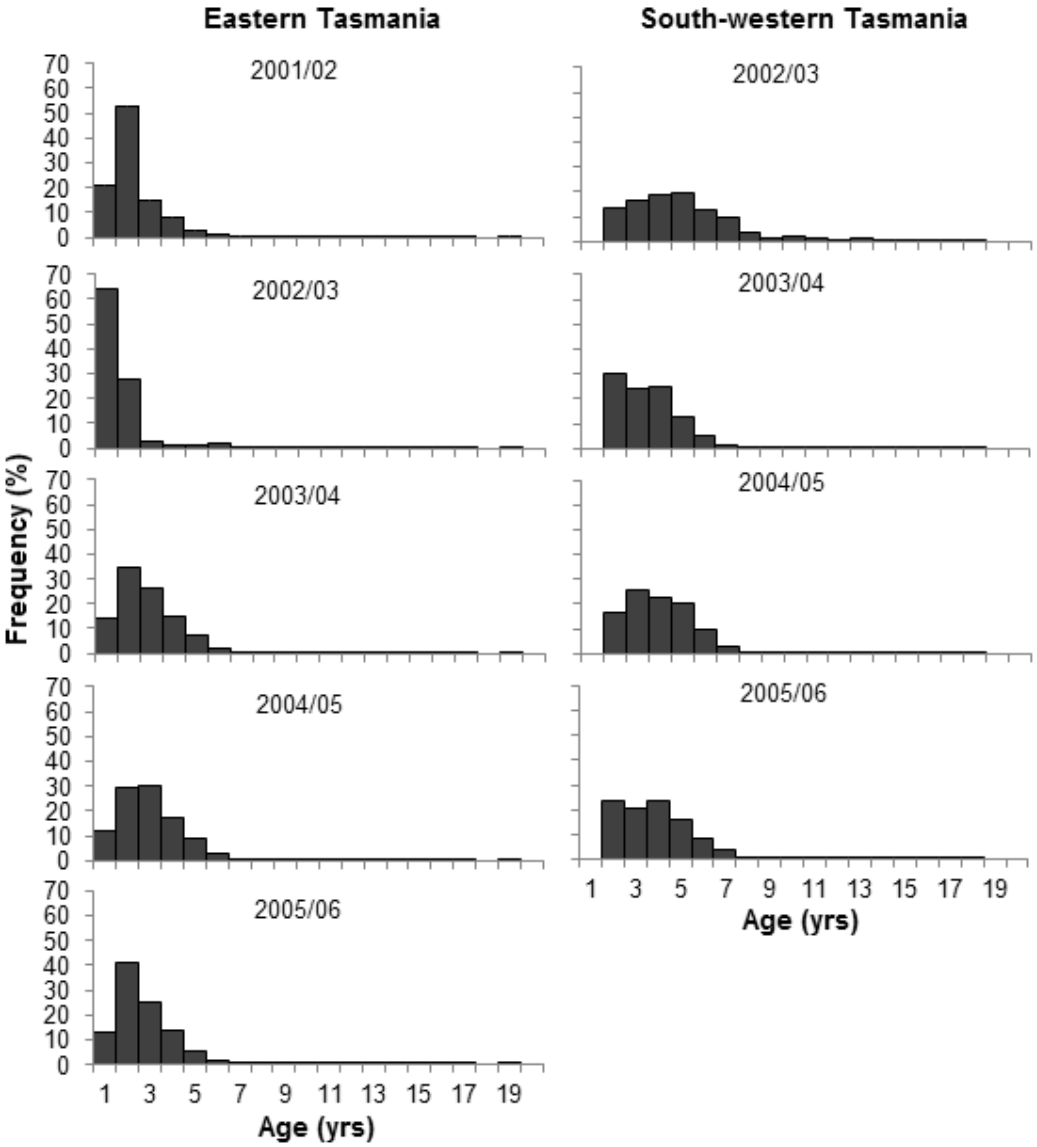

Figure 4.14 Age structure of Redbait catch samples from eastern and south-western Tasmania between 2001 and 2006 (No data were available off south-western Tasmania during 2001/2002).

4.3.3.1.2 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) and an age length key developed to determine the catch age structure for 2009/10. The age composition of the mid-water catch from eastern

Tasmania was similar to that in previous years, with fish mostly between 2-3 years of age (Fig. 4.15). Purse-seine catches were also dominated by 2-3 year old fish, with 2 year olds accounting for over half of the catch.

Specimens aged from the single sample from south-western Tasmania included individuals that were substantially older than those sampled from east coast catches, with 90% of the catch 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 2009-2010. 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)
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

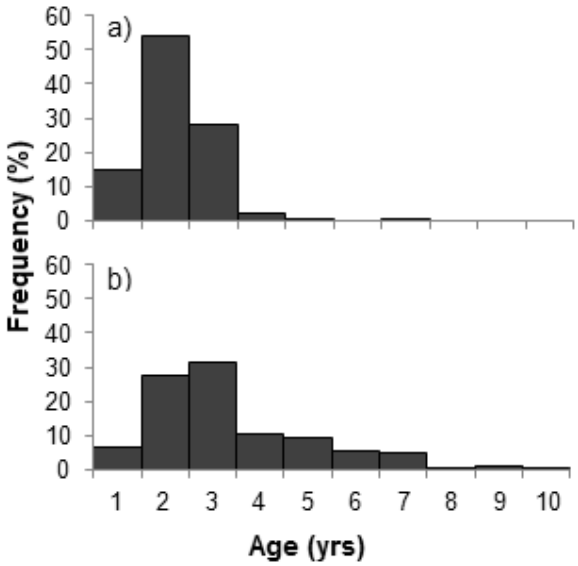

Figure 4.15 Age distribution of Redbait caught in the SPF off eastern Tasmania by (a) purse-seine and (b) mid-water trawling during 2009/10.

4.3.3.2 Gonosomatic index

Trends in male and female GSIs indicate that Redbait have a discrete spawning season extending over a 2-3 month period during spring. The GSIs from east coast Redbait rose sharply in August, peaking in September - October before declining to resting levels by January (Fig. 4.16). A similar pattern was evident for south-western Tasmania, although the GSI peak occurred between October – November, i.e. one month later.

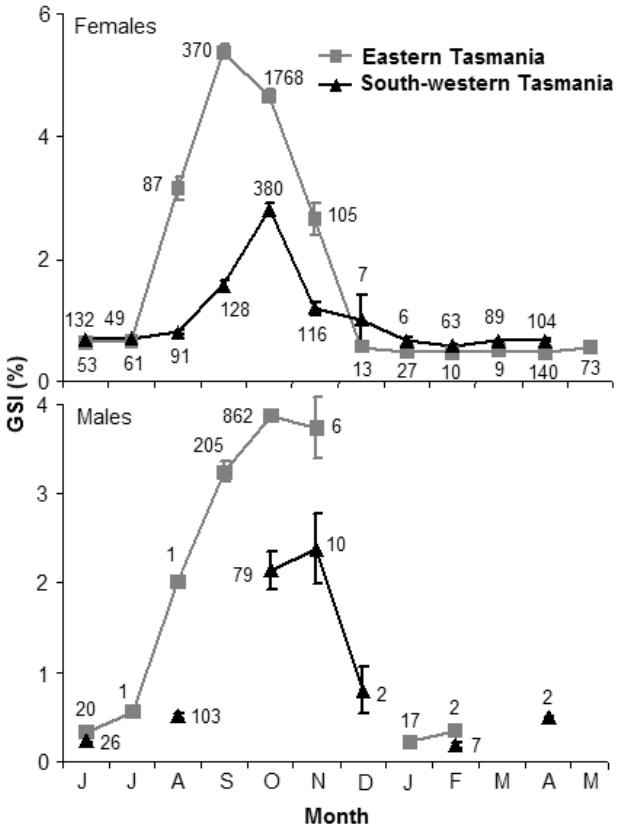

Figure 4.16 Monthly distribution of mean GSI by sex and region. Numbers represent sample size and error bars are standard error. Based on Neira *et al*. (2008).

4.3.3.3 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) (Fig. 4.17). 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 may have extended to December and January. Very few running ripe fish were observed in these samples, possibly an artefact of freezing making such gonads difficult to distinguish from those with hydrated oocytes. Samples collected from 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. Spawning season GSIs for south-western Tasmania were consistently lower than those for fish from eastern Tasmania, presumably in response to the lower proportion of actively spawning fish (≥ stage III) in the samples (Fig. 4.17).

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 the peak in spawning activity was over by mid-November.

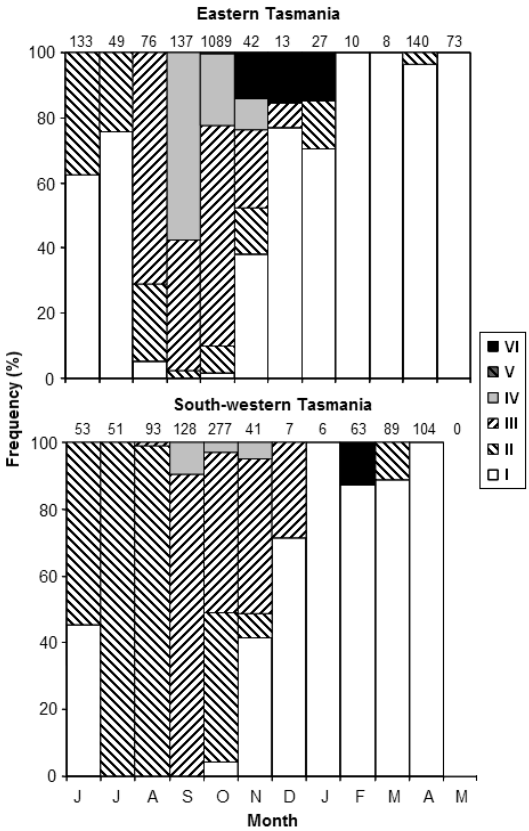

Figure 4.17 Monthly distribution of female macroscopic gonad stages by region. Numbers represent sample sizes. Based on Neira *et al*. (2008).

4.3.3.4 Size and age at maturity

Logistic growth models indicated females attained 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, Figs. 4.18, 4.19). There were, however, marked differences in sizes and ages at maturity between the regions, with both sexes maturing at around 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 Size and age at sexual maturity logistic parameters and 50% maturity (L50) values 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	t_{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

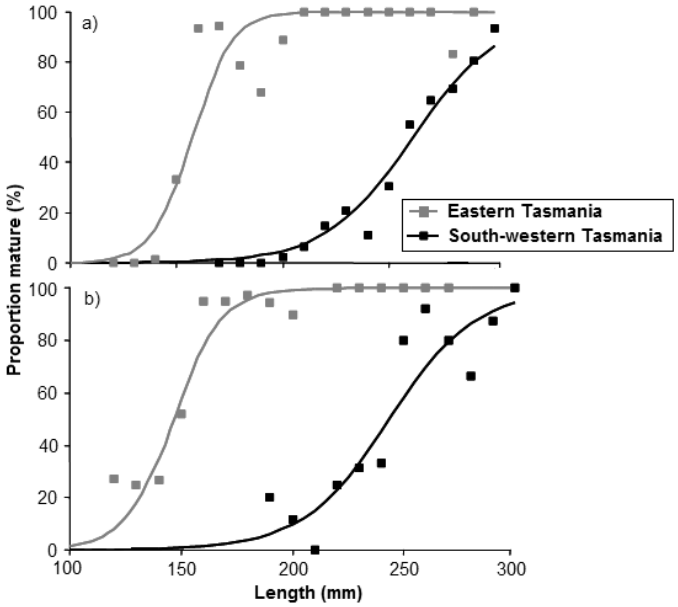

Figure 4.18 Proportion of mature female (a) and male (b) Redbait by length class and region, with logistic ogives fitted. Based on Neira *et al.* (2008).

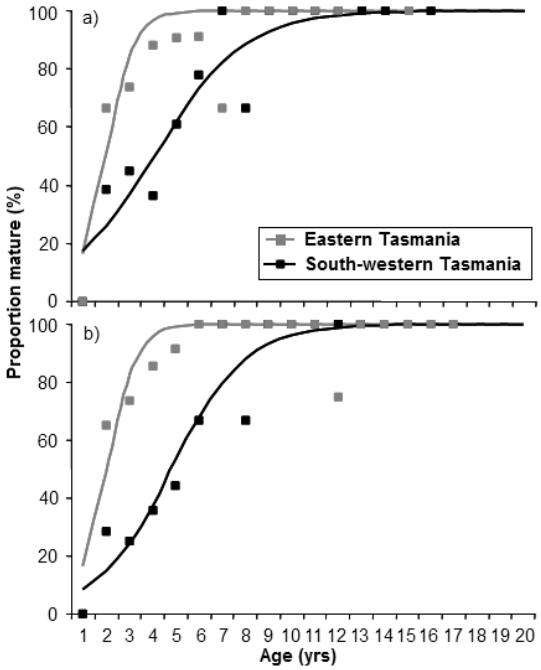

Figure 4.19 Proportion of mature female (a) and male (b) Redbait by age class and region, with logistic ogives fitted. Based on Neira *et al.* 2008.

4.3.3.5 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 2 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 Is. (40.5°S) and the same southern boundary in 2006 (8,695 km^2). Redbait spawning biomass estimates computed using daily egg production 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, GLM models 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 within respective spawning areas were 86,990 t in 2005 and 50,782 t in 2006.

4.3.3.6 MSE

For Redbait East, the DEPM estimate of spawning biomass was 23 percent 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

There is no evidence to suggest that recent catches of Redbait in either region are not sustainable. Although currently dated, 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) are sustainable, a view supported by the MSE. Recent low catches of Redbait East have been attributed to reductions in local abundance associated with increased water temperatures off eastern Tasmania. The eastern stock is therefore assessed as not overfished (Woodhams *et al.* 2011). While there is no biomass estimate available for the West, fishing has been limited to a small area (off SW Tasmania), indicating that much of that stock is subjected to limited fishing pressure at the present time. As no estimates of spawning biomass have been made for the western stock it is 'uncertain' whether overfishing is occurring, or whether the stock is overfished (Woodhams *et al.* 2011). Biological sampling has revealed no obvious impact on size or age composition over the recent history of the fishery.

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 occur in temperate waters from Queensland south to Western Australia (Ward and Staunton-Smith 2002) and several fisheries exploit them within this range.

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 out of ports in south-western Western Australia. The catch in Western Australia increased steadily until 1990 reaching ~8,000 t (Kailola 1993). In 1991, a dedicated 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 3500 and 6500 t. In 1995 and 1998, two mass mortality events affected all Australian Sardine populations, reducing biomass in South Australia by 75% and 70%, respectively (Ward *et al.* 2001a). The Sardine catch in Western Australia has not fully recovered since the mortality events with catches remaining below 2000 t since 1999 (Fletcher and Santoro 2008). The South Australian fishery however appears to have recovered relatively quickly with catch increasing to ~21,000 t in the 2002/03 season and subsequently remaining above 28,000 t (Knight and Tsolos 2009), in line with demand from the tuna mariculture industry and better understanding of the potential of the fishery (Ward *et al.* 2009). Sardine catches from southern Queensland are not well recorded as prior to 1996 only small quantities were taken by beach seine nets to be used as bait (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 fishes, including Sardines (Ward and Staunton-Smith 2002). In 2000, purse-seine fishing was prohibited in Queensland. The annual catch of Sardines in NSW 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 *Sardinops* is mono-specific with no

valid sub-species. 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 their 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 utilizes 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 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 the highest biomass (Daly unpublished data). Krill occurred in greater numbers (65.3%) than crustacean

(27.0 %). Crab zoea, other decapods, copepods, polychaetes, fish eggs and larvae and gelatinous zooplankton were also present.

5.1.7 Age, Growth and Size

Sardine growth rates and maximum size vary in response to localised variation in food availability and environmental conditions (Ward et al. 2003). In southern Australia 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 SA waters than off other parts of the Australian coastline, yet lower than those in more productive boundary current ecosystems. A notable finding of the study was that fish in commercial catches were younger (and smaller) than those obtained in fishery-independent samples. This finding has significant implications for the use of age structured models (based on fishery samples) for stock assessment of the SASF.

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 abundant in the southern gulfs 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 period of January-April (Ward *et al.* 2001b; Ward and Staunton Smith 2002), along the south coast of Western Australia spawning also peaks between January and June (Gaugan *et al.* 2002) and Sardines off Fremantle reached a maximum GSI during June (Murling *et al.* 2008). Along the East Coast of Australia Sardine reach peak GSI in Victoria during spring – early summer (Hoedt and Dimlitch 1995; Neira et al. 1999), in Southern Queensland peak GSI occurs in winter – early Spring (Ward and Staunton-Smith 2002). Off southern NSW 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 in total length, 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 SA's two gulfs during summer and autumn (Bruce and Short 1990). In SA, 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 daily egg production method (DEPM) was developed to assess the status of northern anchovy *E. mordax* stocks off the coast of California (Lasker 1985; Parker 1980) and has been used to estimate the spawning biomass of Australian Sardine in SA since 1995. Estimates of spawning biomass are the key biological indicator in the management plan for the SASF (Shanks 2005). The advantage of this approach is that it provides direct estimates of spawning biomass on which to base management decisions. The disadvantages include the high degrees of uncertainty that surrounds 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). As part of a project to evaluate the use of the DEPM to estimate the spawning biomass of Blue Mackerel *Scomber australasicus* in southern and eastern Australia, ichthyoplankton surveys were conducted along the east coast from 2002 to 2004. Large numbers of Sardine eggs were collected in a survey conducted in southern Queensland and northern NSW in July 2004 (Ward and Rogers 2007), using these samples provides a preliminary estimate of the spawning biomass of Australian Sardine off eastern Australia during July 2004, when the best estimate of spawning biomass was ~28,809 t. Minimum and maximum estimates were 9,161 and 58,673 t, respectively. This report identified options for future assessment and management of Australian Sardine in this region (Ward and Rogers 2007).

Acoustic techniques have been used widely for assessing small pelagic fish stocks (Beckley and van der Lingen 1999; van der Lingen and Huggett 2003) and these studies have contributed to the understanding of Sardine movement (Barange *et al.* 1999); stock structure (Barange and Hampton 1997); relationships with oceanographic features (Lynn 2003; Tameishi *et al.* 1996); predator-prey interactions and inter-annual variability in abundance (Barange *et al.* 1999). Changes in fish behaviour limit the adoption of this technique for routine stock assessment (Freon *et*

al. 1993). Acoustic assessment methods also require rigorous target strength validation for each species (S. McClatchie pers comm.).

5.1.11 Management

A DEPM assessment has been conducted for the East Australian Sardine sub-area, the fishery is managed at the Tier 1 level, as such conservative TACs have been set based on the rules outlined in the tier system. The fishery if considered to not be overfished.

5.2 Methods

5.2.1 Fishery Statistics

Fishery statistics were supplied by the Bureau of Rural science (BRS). Annual data are in financial years.

5.2.2 Biological Information

Catch samples were collected from commercial landings at Eden and Illuka in NSW during the 2009 fishing season. Fish were dissected and morphometric data collected by NSW Fisheries, otoliths were interpreted for age by SARDI Aquatic Sciences using the methods of Rogers and Ward (2007). Additional size frequency data were supplied by NSW Fisheries.

5.2.3 Biomass Estimates and MSE

A preliminary biomass estimate for Australian Sardine in the East was conducted in 2007 using ichthyoplankton samples collected during 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 Daily Egg Production Method (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*. NSW DPI provided some reproductive data for Australian Sardine off southern NSW. 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.

An MSE model was used to test a range of management/harvest scenarios under the Commonwealth Small Pelagic Fishery (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 per cent 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 stock-recruitment relationship and natural mortality.

The current SPF Harvest Strategy has a three-tiered approach. At the Tier 1 level, the maximum recommended biological catch (RBC) for each stock depends on the time since a daily egg production method (DEPM) survey was conducted, with the maximum RBC decaying from 20 percent to 10 percent of the spawning biomass estimated from the DEPM survey over a five year period (relative tonnage). The maximum RBC for Tier 2 and Tier 3 is set at a specified quantity (absolute tonnage). A maximum RBC for Tier 2 has been defined for each stock with quantities varying from 3000-6000 tonnes, while for Tier 3, the maximum RBC has been set at 500 tonnes for each stock.

5.3 Results

5.3.1 Fishery Statistics East

5.3.1.1 Location of vessels

The number of vessels targeting Australian Sardine in the East is almost entirely dominated by vessels from NSW (Fig. 5.1).

5.3.1.2 Annual Patterns – catch, effort & catch-per unit effort

Catches of Australian Sardine in the East remained below 1,000 t during the seasons between 1997/98 and 2001/02 (Fig. 5.2), then increased rapidly to >4,000 t in the 2005/06 season. Catches have subsequently remained above 3,500 t until 2009/10 when they dropped below 3,000 t catch has risen to above 3,000 t in 2010/11. Fishing effort peaked in 1999/2000 at ~5,000 vessel days before stabilising at ~3,000 days from 2000/01 to 2008/09 (Fig. 5.2). Effort dropped significantly to ~500 vessel days in 2009/10 (Fig. 5.2) and remained low in 2010/11.

Catch rates were uncharacteristically high in 2009/10 and 2010/11, exceeding 10 t.vessel day^{-1} in 2010/11. Prior to this catch rates did not exceed 2 t.vessel day^{-1} (Fig. 5.3).

5.3.1.3 Intra-annual Patterns - catch and effort

Intra-annual patterns of catch and effort have been variable across the data period with catches occurring in all months (Fig. 5.4). Annual peaks in catches were also irregular.

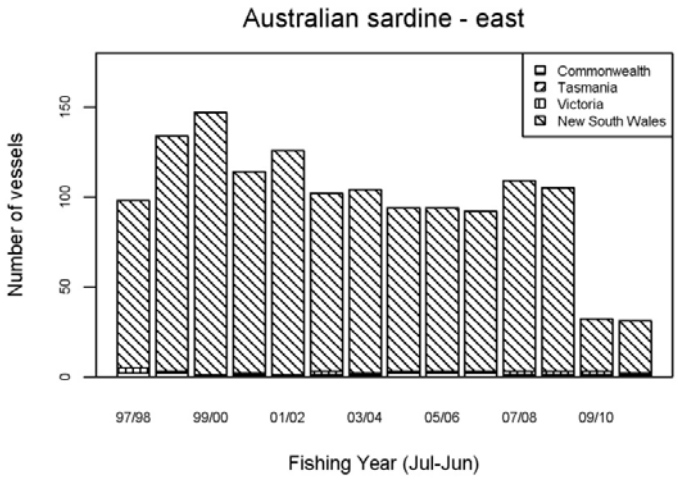

Figure 5.1 Number of vessels that reported landings of Australian Sardine in the East, from each of the participating management jurisdictions, during financial years over the period 1997/98 – 2010/11.

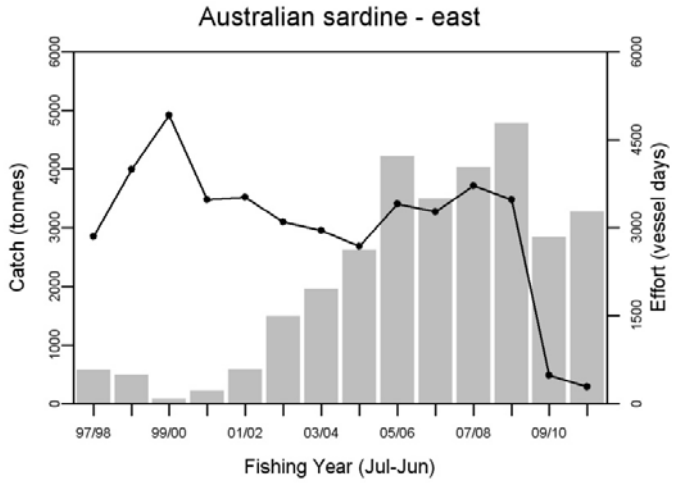

Figure 5.2 Total landed catch (tonnes, bars) and effort (vessel days, line) for the East during financial years over the period 1997/98 – 2010/11.

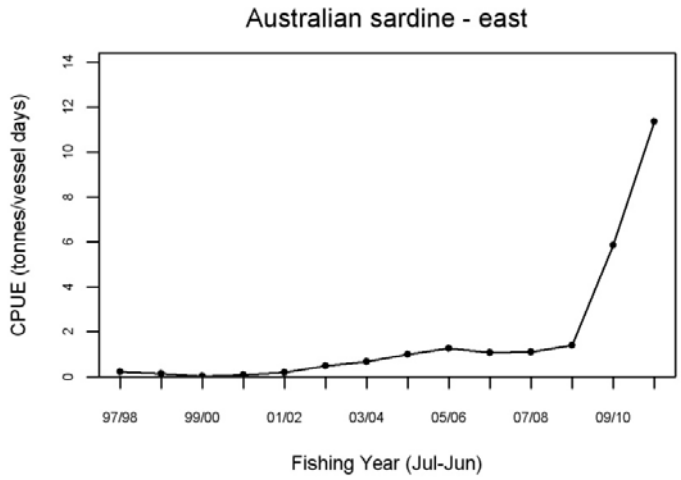

Figure 5.3 CPUE (tonnes per vessel day) for the East during financial years over the period 1997/98 – 2010/11.

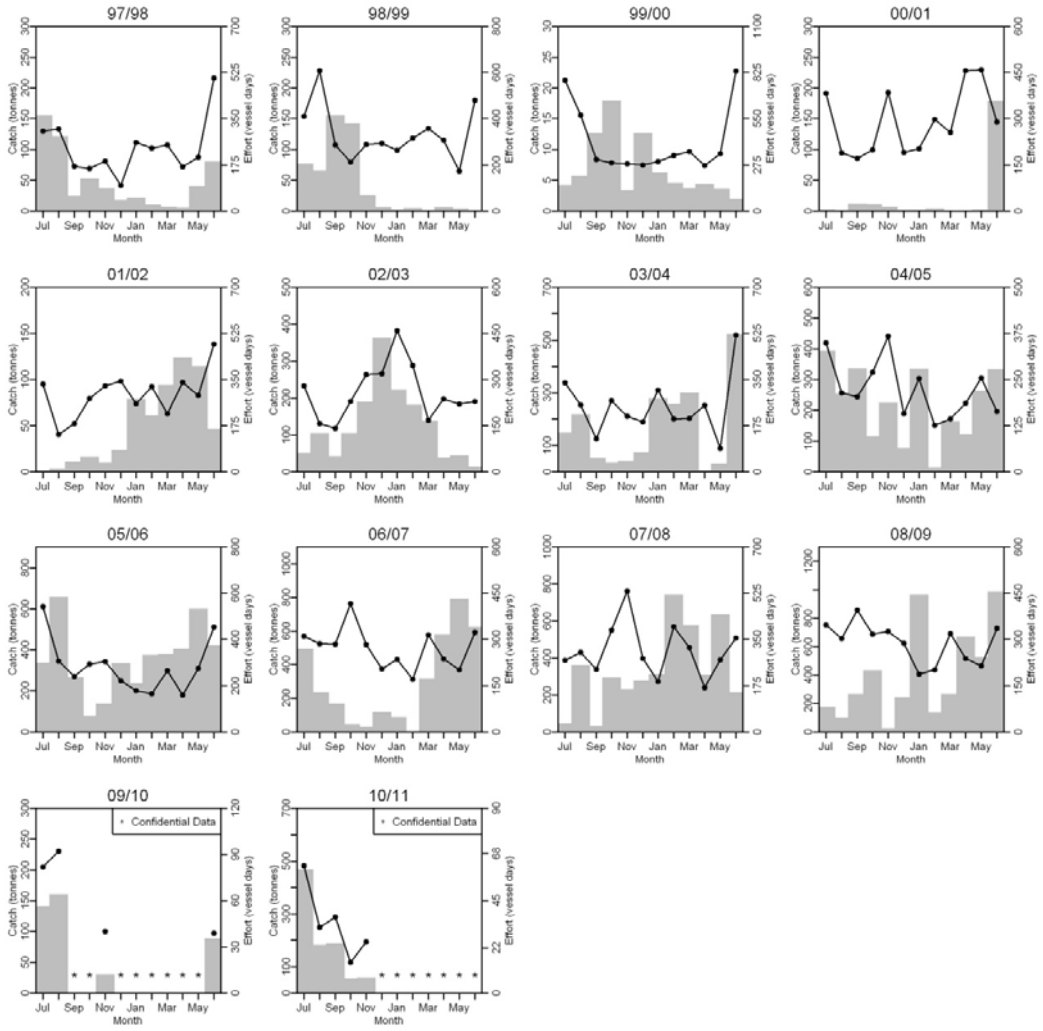

Figure 5.4 Intra-annual patterns of catch (bars) and effort (line) for Sardine for the East for the period between 1997/98 and 2010/11.

5.3.2 Biological Information

5.3.2.1 Sample Summary

A total of 1,028 *S. sagax* were collected from commercial fishers in NSW for biological analysis during 2009 and 2010 comprising 240 from the north coast (Illuka) and 788 from the south central coast (Eden). These samples represented three months from the north coast and eight months from the south central coast (Table 5.1). Length frequency data for an additional 12,060 *S. sagax* landed in NSW between 2004/05 and 2010/11 were supplied by NSW Department of Primary Industries.

Table 5.1 Spatial and temporal summary of data supplied to SARDI for biological analysis.

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

5.3.2.2 Size Structure

Most Australian Sardines taken in NSW in 2009/10 were between 120 and 200 mm (Figs. 5.5, 5.6). Samples from both the 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 (Fig. 5.7), with the smaller mode around the size at maturity. Length distributions for the last two seasons (2009/10 and 2010/11) have been unimodal with the mean size above the size at maturity (Fig. 5.7).

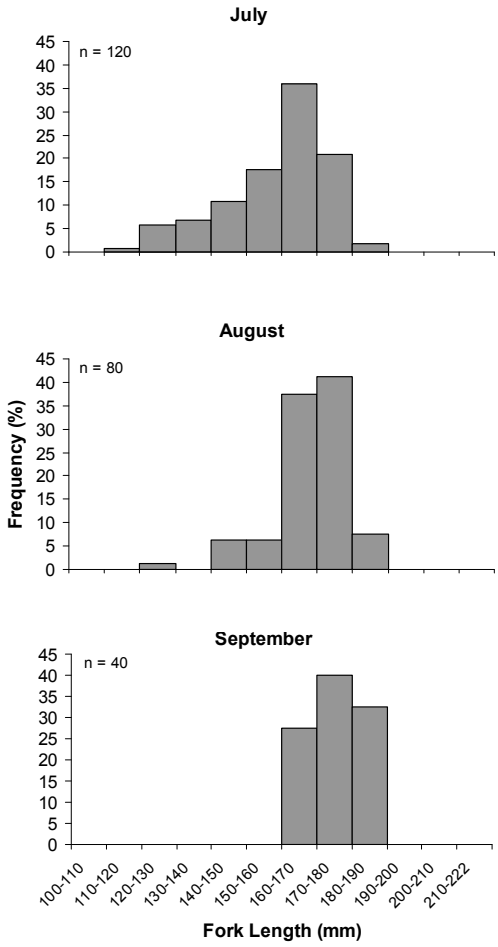

Figure 5.5 Size frequency histograms for Australian Sardine samples from commercial catches from the north coast of NSW in 2009.

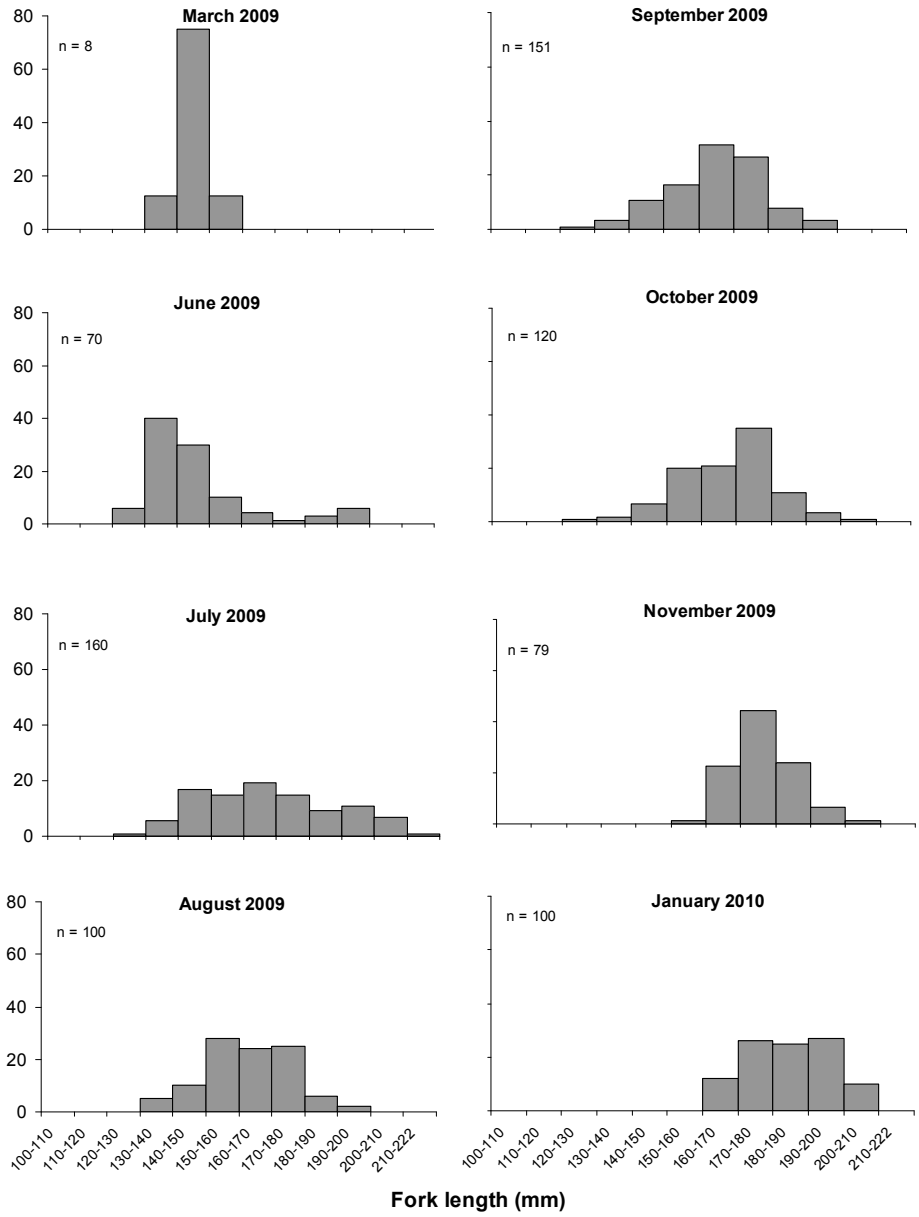

Figure 5.6 Size frequency histograms for Australian Sardine samples from commercial catches from the south central coast of NSW in 2009 and 2010.

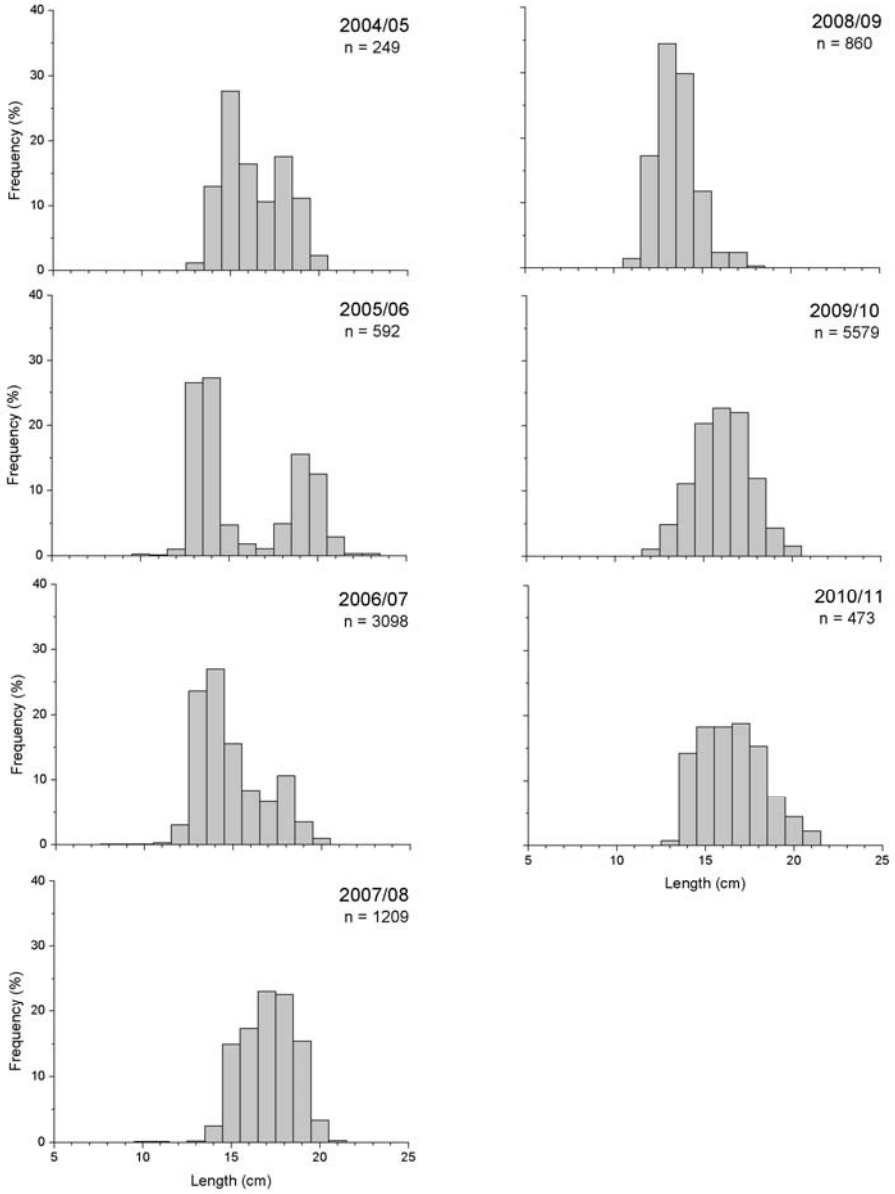

Figure 5.7 Length frequencies of commercial catches of Australian Sardine for the northern (since 2008/09) and southern regions of NSW combined. Weighted against the size of landings (data supplied by NSW Department of Primary Industries).

5.3.2.3 Age structure

Commercial samples from the south central coast ranged from 0 to 5 year olds whereas catches from the northern region of NSW consisted of 0 to 3 year olds (Fig. 5.8).

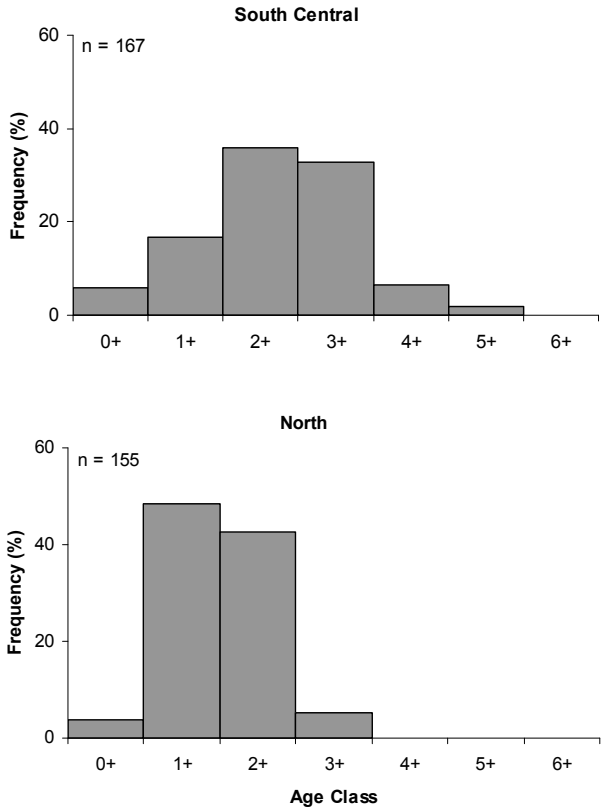

Figure 5.8 Age frequency histograms for Australian Sardine samples from commercial catches from the south central and north coast of NSW in 2009. Data derived from ring count analysis, otoliths of poor readability (readability index 4 and 5) were omitted.

5.3.2.4 Growth atterns

The Growth patterns for Australian Sardines collected from both the North and South Central coasts of NSW were similar (Fig. 5.9). Both exhibited considerable variation in size for each of the age classes.

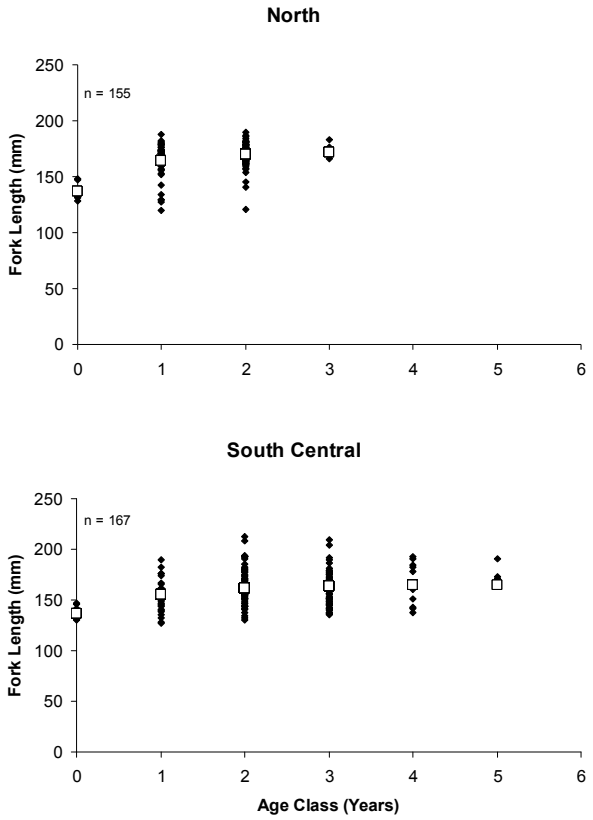

Figure 5.9 Growth patterns for Australian Sardines collected from commercial catches from the north and south central coast of NSW in 2009. Ages derived from ring count analysis, otoliths of poor readability (readability index 4 and 5) were omitted. Open squares generated from von Bertalanffy growth function.

5.3.2.5 Gonad stages

Samples from both the north and south central coast were comprised predominately of mature fish (> stage 1) across the sampling period (Fig. 5.10). Insufficient numbers of immature fish were collected to allow size at maturity to be determined. 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.

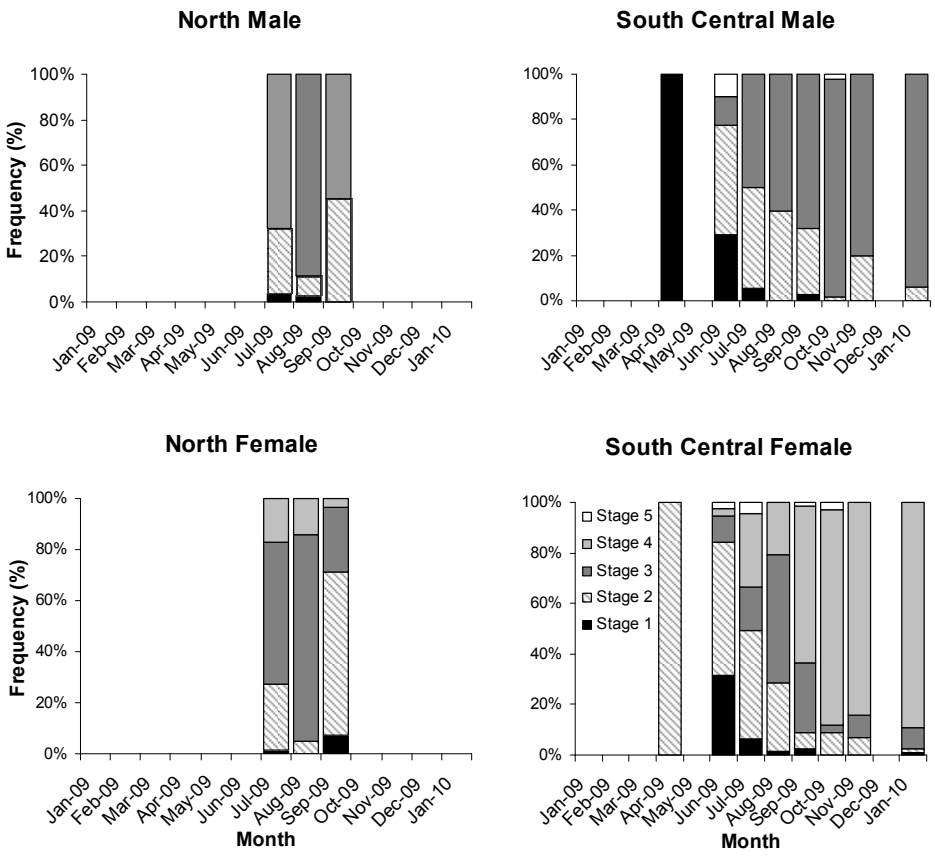

Figure 5.10 Frequency of occurrence of each stage of gonad development for each month of sampling for Australian Sardine from both the north and south central coast of NSW. Number for each month are shown in Table 5.2.

5.3.2.6 Sex ratio

The sex ratio for all months and regions was biased towards females (Table 5.2).

Table 5.2. Sex ratio (R) of Australian Sardine samples taken in the 2009-10 fishing season.

	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 Gonosomatic index

GSI were generally higher for both males and females from the north coast (Fig. 5.11), 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 (Fig. 5.11).

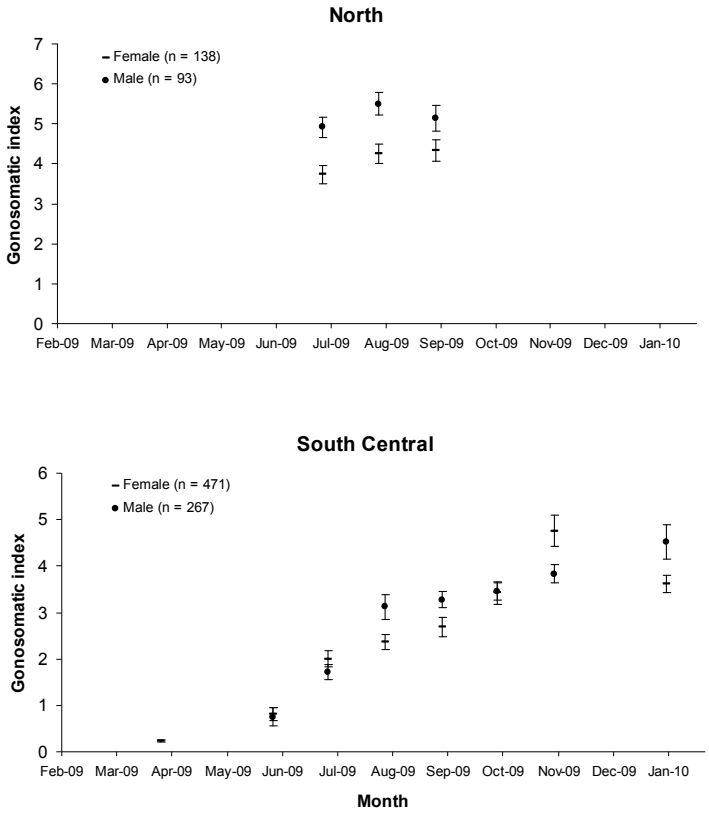

Figure 5.7 Monthly gonosomatic index for Australian Sardine from the north and south central coast of NSW. Error bars are standard error. Immature fish (stage 1) have been omitted from data.

5.3.2.8 DEPM

The total area sampled during the July 2004 ichthyoplankton survey was ~41,585 km^2. A total of 2,441 Australian Sardine eggs was 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.

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 East, the 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

There is no evidence to suggest that the current catch level of Australian Sardine in the East is not sustainable. As such it falls within the categories as being 'not overfished' and 'not subjected to overfishing' (Woodhams *et al.* 2011). The best estimate of spawning biomass of Australian Sardine (*Sardinops sagax*) 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. The MSE estimate of spawning biomass was similar to the DEPM estimate. Catches of Australian Sardine in the East region remained below 1000 t up to 2001/02, but have exceeded 2,000 t since 2004/05 and reached almost 5,000 t in 2008/09. Catches have been ~3,000 t for the last two seasons. These catches come from fisheries managed separately by three jurisdictions (NSW, Victoria and the

Commonwealth). Recent low catches of Australian Sardine off NSW can be related to a fire in a fish processing facility in Eden in 2010. The recent reduction in effort in Australian Sardine East appears to reflect a change in the way effort is categorised in the NSW Ocean Haul Fishery, rather than a reduction in fishing activity. Commercial samples from the south central coast of NSW ranged from 0+ to 5 year olds, whereas catches from the northern part of NSW consisted of 0+ to 3 year olds. The highest annual catch in the East region of ~5,000 t is ~17.4% of the best estimate of spawning biomass. Catches are now above the level where a previous study (Ward and Rogers 2007) recommended that regular assessment using the DEPM would be warranted.

6 GENERAL SUMMARY AND CONCLUSIONS

Catches of Blue Mackerel, Jack Mackerel and Redbait during 2010-11 were low (i.e. well below the Tier 2 maximum RBCs) in both the West and East zones of the SPF. There is no evidence to suggest that this reduction in catch reflects a decline in the abundance or overfishing of any of these stocks. The reductions in catch appear to be driven by market constraints. These three species have been classified as 'not over-fished', except Redbait West which has been classified as 'uncertain' (Woodhams *et al.* 2011). Similarly, there is no evidence to suggest that the current catch level of Australian Sardine in the East region is not sustainable and has been classified as 'not overfished'. This reduction in catch does not appear to reflect a reduction in abundance, but is in part related to the destruction of a processing factory in Eden by fire. Despite this the reduction in catch, the catch taken from the East in 2010/11 slightly exceeds the RBC for this species (3 000 t). Conducting DEPM surveys of the East coast that provide information on all SPF species, especially Australian Sardine, warrants consideration.

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