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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2017

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Commonwealth Small Pelagic Fishery: Fishery Assessment Report 2017

Report to the Australian Fisheries Management Authority

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EXECUTIVE SUMMARY

This report presents fishery data and synthesises stock status information for key species in each sub-area (i.e. East and West) of the Commonwealth Small Pelagic Fishery (SPF). This report is required at Tiers 1 and 2 of the SPF Harvest Strategy 2008 (last revised April 2017).

The estimate of spawning biomass for Jack Mackerel East in 2014 was 157,805 t (95% CI = 59,570–358,731). The total catch in 2016/17 was 3,966 t, down from 6,321 t in 2015/16. During 2016/17, the modal size of Jack Mackerel East taken in mid-water trawls (240 mm FL) was below the mean size at 50% maturity (~270 mm FL). Recent fluctuations in catches of Jack Mackerel East reflect changes in fishing effort. Recent catches of Jack Mackerel East are assessed as sustainable, as they were ~3% of the spawning biomass estimate in 2014 and below the Tier 1 exploitation rate for this stock of 12%.

The preliminary estimate of spawning biomass for Jack Mackerel West in the summer of 2016/17 was ~31,000 t. The Atlantis-SPF biomass estimate for this stock was ~62,000 t (typical range: 60,000–110,000 t). The total SPF catch in 2016/17 was 686 t, up from 634 t in 2015/16. During 2016/17, the modal size of Jack Mackerel West taken in mid-water trawls (270 mm FL) was similar to the mean size at 50% maturity (~270 mm FL). The recent increase in catches of Jack Mackerel West reflect the increase in fishing effort. Recent catches of Jack Mackerel West are assessed as sustainable, as they were ~2% of the estimate of spawning biomass and below the Tier 1 exploitation rate of 12%.

The estimate of spawning biomass for Blue Mackerel East in 2014 was ~83,300 t (95% CI = 35,100–165,000 t), which is higher than the preliminary estimate for 2004 of 23,009 t. The total catch in 2016/17 was 1,539 t, down from the historical high of 2,368 t in 2015/16. During 2016/17, the modal size of Blue Mackerel East from mid-water trawl catches (260–270 mm FL) was similar to the mean size of 50% maturity (~260 mm FL). Fluctuations in catches of Blue Mackerel East reflect changes in fishing effort. Recent catches of Blue Mackerel East are assessed as sustainable, as they have been <2% of the estimate of spawning biomass for 2014 and below the Tier 1 exploitation rate for this stock of 15%.

The estimate of spawning biomass for Blue Mackerel West in 2005 was 56,228 t. The total catch in 2016/17 was 766 t, down from 980 t in 2015/16. Catches have mainly contained fish above the mean size at 50% maturity (>260 mm FL). Low annual catches may reflect low fishing effort in areas where Blue Mackerel is known to be abundant (e.g. Great Australian Bight). Recent catches of Blue Mackerel West are assessed as sustainable, as they have been <2% of the estimated spawning biomass for 2005 and below the Tier 3 exploitation rate for this stock of 3.75%.

The spawning biomass of Redbait East was estimated to be ~70,000 t from surveys in 2005 and 2006. The total SPF catch was 101 t in 2016/17, down from 217 t in 2015/16. Catches have mainly contained fish above the mean size at 50% maturity of ~150 mm FL. The modal size of Redbait East taken from mid-water trawl catches was 200 mm FL in 2016/17. Recent catches of Redbait East are assessed as sustainable as they have been <1% of the estimated spawning biomass and below the Tier 2 exploitation rate for this stock of 5%.

The Daily Egg Production Method (DEPM) was applied to Redbait West in 2017, and an empirical estimate of spawning biomass will be available in late 2018. The Atlantis-SPF biomass estimate for this stock is 66,000 t (typical range: 59,000–70,000 t). The total SPF catch was 101 t in 2016/17, down from 217 t in 2015/16. The total SPF catch was 1,140 t in 2016/17, down from 1,157 t in 2015/16. Catches have mainly contained fish below the mean size at 50% maturity of ~250 mm FL. Recent catches of Redbait West are likely to be sustainable, because fishing effort prior to 2015/16 has been low and the 2016/17 catch was 40% of the TAC (2,880 t). Recent catches were 1.7% of the Atlantis-SPF biomass estimate, above the current Tier 3 exploitation rate for this stock of 1.25% (based on Atlantis-SPF biomass estimate).

The spawning biomass of the north-eastern sub-population of Australian Sardine East during the main winter/spring spawning period in 2014 was estimated to be ~49,600 t (95% CI = 24,200–213,300 t). The total catch for the entire East sub-area was 2,887 in 2016/17, up from 1,461 t in 2015/16. In the Sardine sub-area of the East sub-area, total catches were 601 t in 2016/17, up from 526 t in 2015/16. Catches from the Sardine sub-area have mainly contained fish at or above the mean size at 50% maturity of ~150 mm FL. Current catches from the Sardine sub-area of Australian Sardine East are assessed as sustainable, because they are <2% of the 2014 estimate of spawning biomass and below the Tier 1 exploitation rate for this species of 20%.

All SPF species are assessed as sustainable. Age and length structures of SPF species have varied among years and sub-areas. These variations are difficult to interpret due to changes in fishing effort, small sample sizes, and changes in fishing locations over time. Standardised protocols, particularly for ageing, are being established. An empirical estimate of spawning biomass is needed for Redbait West to evaluate the validity of the biomass estimate from Atlantis.

Keywords: Commonwealth SPF, Jack Mackerel, Blue Mackerel, Redbait, Sardine, purse seine, mid-water trawl, AFMA.

1 GENERAL INTRODUCTION

1.1 Overview

This assessment of the Commonwealth Small Pelagic Fishery (SPF) builds on annual reports published since 2010 (Ward et al. 2011, 2012, 2013, 2014c, 2015c, Ward and Grammer 2016, 2017). This report provides a synopsis of information available and current status of SPF quota species, namely Jack Mackerel (*Trachurus declivis*), Blue Mackerel (*Scomber australasicus*), Redbait (*Emmelichthys nitidus*) and Australian Sardine (*Sardinops sagax*) and summarises data available for Yellowtail Scad (*Trachurus novaezelandiae*; a permitted by-product species). The assessment uses commercial catch and effort data up to 30 April 2017 and available biological information (size and age structures, reproduction, maturity). The assessments are underpinned by outputs from several Management Strategy Evaluations (MSEs) and estimates of spawning biomass obtained from fishery-independent surveys. This report satisfies the requirements of the SPF Harvest Strategy (HS) for assessment of stocks at Tiers 1 and 2 (see Section 1.3.1; AFMA 2008, revised in 2017).

1.2 Description of the Commonwealth Small Pelagic Fishery

The SPF is a purse seine and mid-water trawl fishery that operates in Commonwealth waters (3 to 200 nm) from southern Queensland to south-western Western Australia, including Tasmania (Figure 1.1). The fishery is divided into two sub-areas (East and West) by a line through longitude 146°30'E (Figure 1.1, AFMA 2009). There is also a designated Australian Sardine sub-area within the East sub-area that extends from southern Queensland to southern New South Wales (Figure 1.1; referred to here as the 'Sardine East sub-area'). The East and West sub-areas are further divided into seven sub-zones and catch grids (Figure 1.2).

The three main target species of the SPF are Jack Mackerel, Blue Mackerel and Redbait. Australian Sardine is a target species in the Sardine East sub-area. These species are targeted by recreational fishers in some States (Henry and Lyle 2003) and by State-managed commercial fisheries. Small quantities of SPF species are caught in other Commonwealth fisheries, primarily the Southern and Eastern Scalefish and Shark Fishery, Western Tuna and Billfish Fishery and the Eastern Tuna and Billfish Fishery (Moore and Skirtun 2012). Combined catches of SPF quota species in these fisheries have not exceed 40 t per year since their inception in 2002 and are not included in this assessment. Yellowtail Scad is one of several permitted by-product species.

The fishery has changed dramatically since large scale fishing operations targeting Jack Mackerel began in the mid-1980s. Between the late 1980s and prior to the SPF Management Plan being implemented in 2009 (AFMA 2009), the Tasmanian component of the fishery (north-eastern Tasmania to central western Tasmania) was managed using a combination of input and output controls, including a total allowable catch (TAC). A combined species TAC for the Tasmanian component of the fishery was set at 42,000 t in 1988/89 and based on the highest annual catch from the purse seine fishery (Jordan et al. 1992; Pullen 1994). The TAC was decreased to 34,000 t in 2002/03 with the renewed interest in small pelagic species and the commencement of mid-water trawl operations. Despite catches not approaching this level, the TAC was applied in subsequent fishing seasons up until 2008/09 when the SPF was split into East and West sub-areas. Under the SPF Harvest Strategy (SPF HS; AFMA 2008), species and sub-area specific TACs were established. From 2014/15 to 2106/17, effort has increased in the SPF with the introduction of a factory trawler. A detailed history of the SPF is described in Moore and Skirtun (2012).

1.3 Management of the Fishery

The SPF is managed by the Australian Fisheries Management Authority (AFMA) under the SPF Management Plan (AFMA 2009) using a combination of input and output controls that include limited entry, zoning, mesh size restrictions and TAC limits for target species (hereafter referred to as quota species) within each sub-area.

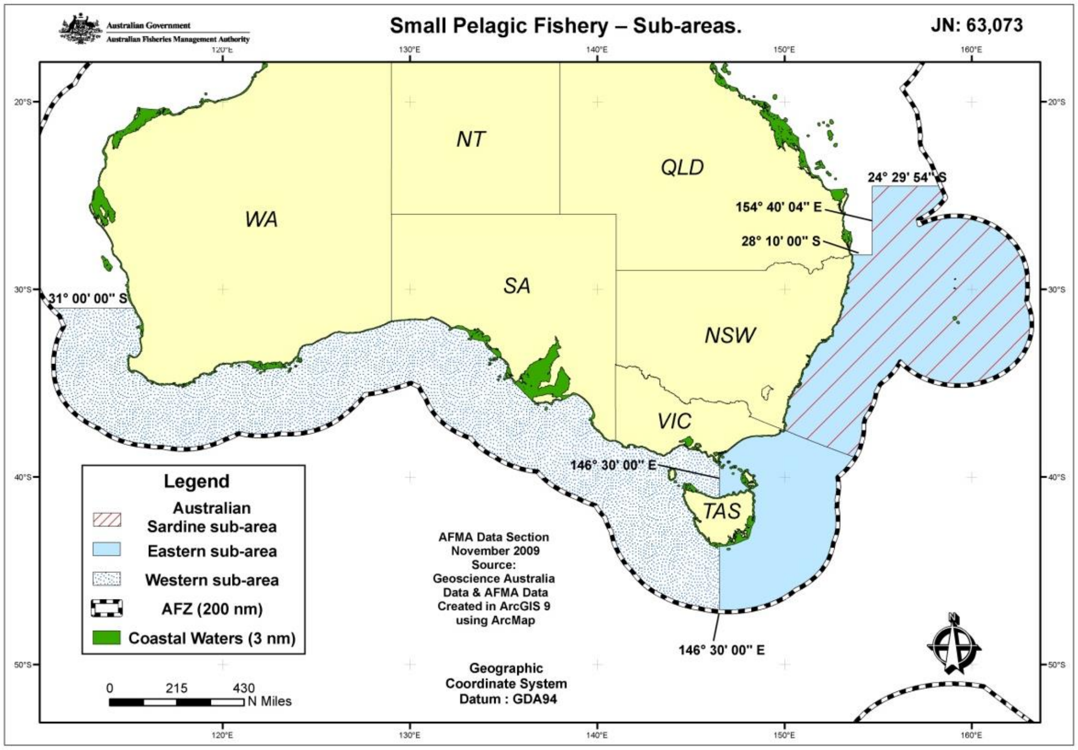


Figure 1.1 Management sub-areas of the Small Pelagic Fishery.

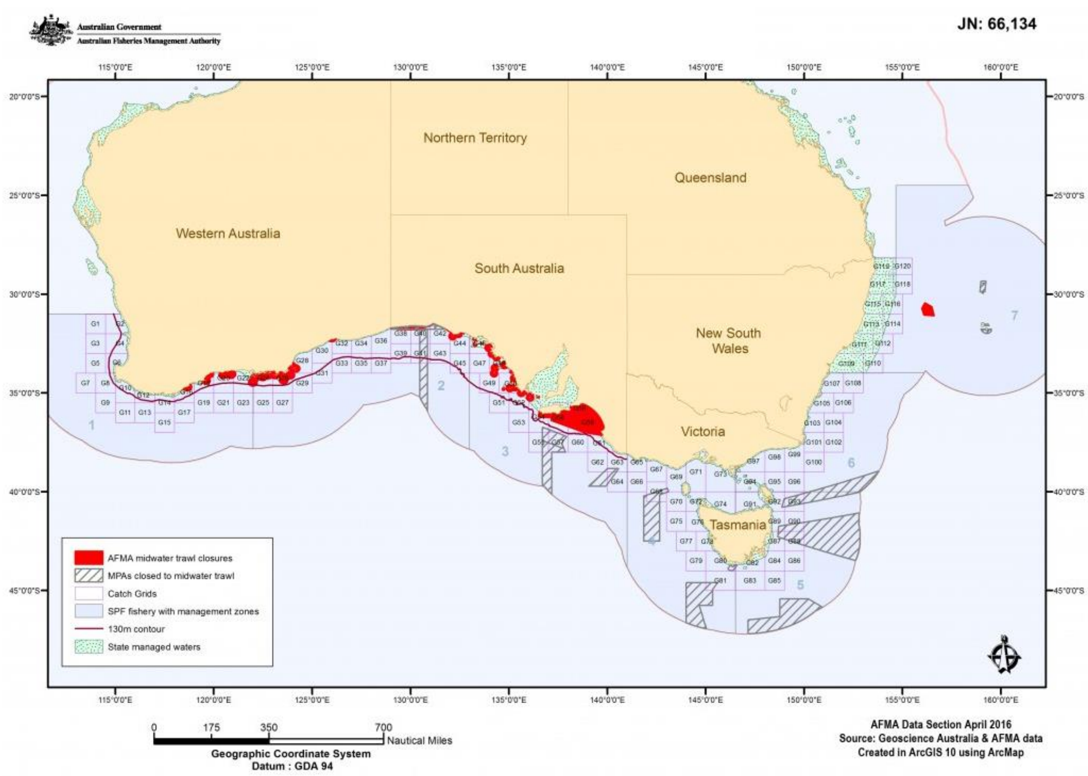


Figure 1.2 Sub-zones, catch grids and areas closed to mid-water trawling within management sub-areas of the Small Pelagic Fishery.

1.3.1 Harvest Strategy

The HS for the SPF established in 2008 was last revised in 2017 (AFMA 2008, revised April 2017). The HS is a three-tiered system used by the SPF Scientific Panel (SPFSP, previously the SPF Resource Assessment Group, SPFRAG) to develop advice on the Recommended Biological Catches (RBCs) for stocks (East and West) for each quota species. Stocks are allocated to a tier based upon the level of knowledge about stock size (spawning biomass), with Tier 1 representing the highest level of available information and Tier 3 the lowest (Moore and Skirtun 2012). Corresponding individual transferable quotas (ITQs) are established; Tier 1 stocks have the largest quota (by weight), and Tier 3 the smallest (Tracey et al. 2013). The tiered system was introduced to ensure that heavy exploitation only occurs in stocks where there is a high level of confidence that such exploitation can be sustained (Moore and Skirtun 2012). TACs for each quota species are determined by subtracting other sources of mortality (i.e. catches taken in other Commonwealth and State fisheries) from the corresponding RBCs.

A brief description of each tier is provided below.

<u>Tier 1:</u> The maximum exploitation rates for Tier 1 species in each sub-area are 10% for Redbait, 12% for Jack Mackerel, 15% for Blue Mackerel and 20% Australian Sardine (East sub-area only). RBCs are set by applying exploitation rates up to these levels based on the median spawning biomass estimated using the Daily Egg Production Method (DEPM). Species remain at Tier 1 for five seasons after a DEPM survey is completed.

<u>Tier 2:</u> The maximum exploitation rates for Tier 2 species are half the level specified at Tier 1. Redbait and Jack Mackerel can remain at Tier 2 for up to 10 seasons. Blue Mackerel and Australian Sardine can remain at Tier 2 for up to 5 seasons.

<u>Tier 3:</u> The maximum exploitation rates for Tier 3 species are half the level specified at Tier 2 when a biomass estimate has been previously based on a DEPM survey, i.e. 2.5% for Redbait, 3% for Jack Mackerel, 3.75% for Blue Mackerel and 5% Australian Sardine (East sub-area only). For stocks with no previous DEPM survey, the exploitation rates may not exceed a quarter of the Atlantis–SPF derived, mean spawning biomass estimate, i.e. West sub-area: 1.25% Redbait and 1.5% Jack Mackerel. A stock can remain at Tier 3 indefinitely. The Atlantis-SPF model is a variant of the Atlantis-SE ecosystem model (see section 1.4.2; Smith et al. 2015).

1.4 Previous Assessments

1.4.1 DEPM

DEPM surveys have been conducted for Blue Mackerel East and West (Ward and Rogers 2007, Ward et al. 2009, 2015b), Australian Sardine East (Ward et al. 2007, 2015a, 2015b), Redbait East (Neira and Lyle 2011), Jack Mackerel East and West (Neira 2011, Ward et al. 2015a, Ward et al. 2016, SARDI unpublished data) and Yellowtail Scad East (Neira 2009).

In December 2016/January 2017, the first dedicated application of the DEPM to Jack Mackerel in the West sub-area was undertaken and quantified the spawning biomass of Jack Mackerel between Kangaroo Island, South Australia and western Tasmania (SARDI unpublished data). This survey also provided new information on the summer spawning area of Australian Sardine in the Bass Strait.

In October 2017, a DEPM survey was undertaken for Rebait in the West sub-area that will quantify the spawning biomass of Rebait between Kangaroo Island, South Australia and western Tasmania. The survey results will be available in late 2018.

1.4.2 Management Strategy Evaluations (MSEs)

Management Strategy Evaluations (MSEs) have been conducted by the Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) (Giannini et al. 2010) and Commonwealth Scientific and Industrial Research Organisation (CSIRO) (Smith et al. 2015). The 2015 MSE included a formal review of the HS for the SPF; these results are discussed in this assessment report.

<u>Giannini et al. (2010)</u>

In 2010, an MSE model was used to test the settings (i.e. exploitation rates) in the SPF HS for each stock (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 (B_{20}). Sensitivities of the model to the various input parameters were also tested. The model was 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.

<u>Smith et al. (2015)</u>

In 2015, an MSE was undertaken using ecosystem and population models to evaluate and provide advice on the reference points (e.g. biomass depletion levels) and settings (e.g. exploitation rates) for the SPF target species (Smith et al. 2015). A new variant of the Atlantis ecosystem model

(Atlantis-SPF) indicated that SPF species are not keystone species within the ecosystem, and population modelling suggested that conventional single species targets and limits (e.g. the defaults under the SPF HS) are appropriate (Smith et al. 2015). Based on results from the ecosystem model and default settings in the Commonwealth Harvest Strategy Policy, Smith et al. (2015) evaluated constant Tier 1 exploitation rates for each species that achieved a median depletion to 50% of unfished levels (B_{50}) while maintaining a <10% chance of falling below 20% of unfished levels (B_{20}). The base case model assumed DEPM surveys every 5 years. Evaluation of the Tier 2 exploitation rate (50% of Tier 1) assumed that it would only be applied after 5 years of exploitation at Tier 1 and no further DEPM surveys would occur. Smith et al. (2015) also produced Atlantis-SPF biomass estimates that have been used in Tier 3 of the SPF HS when DEPM spawning biomass estimates were not available.

Smith et al. (2015) suggested the previous Tier 1 harvest rate of 15% was too high for Jack Mackerel and Redbait and too low for Blue Mackerel and Australian Sardine. Smith et al. (2015) recommended: 1) Tier 1 harvest rates be applied for not more than 5 years after a DEPM survey; 2) Tier 2 harvest rates be 50% of Tier 1 rates; and 3) not be applied for more than 5 years for Blue Mackerel and Australian Sardine or 10 years for Jack Mackerel and Redbait.

1.5 Aims and Objectives

This report collates and presents fishery data for the SPF and available biological information for each of the quota species: Blue Mackerel, Jack Mackerel, Redbait and Australian Sardine, as well as Yellowtail Scad (a by-product species). Biomass estimates and MSEs are included where available. This report satisfies the requirements of the SPF HS (AFMA 2008, revised 2017).

2 JACK MACKEREL (*Trachurus declivis*)

2.1 Introduction

2.1.1 Background to Fishery

A large purse seine fishery for small pelagic fishes was developed off Tasmania in the mid-1980s. The majority of the catch was Jack Mackerel (*Trachurus declivis*), with relatively small quantities of Redbait (*Emmelichthys nitidus*) and Blue Mackerel (*Scomber australasicus*) taken as by-product. The fishery became the largest in Australia by weight, with catches of Jack Mackerel peaking at 39,747 t in 1986/87 (Kailola et al. 1993, Pullen 1994). In 1988/89, the Jack Mackerel catch fell to 8,150 t (Kailola et al. 1993, Pullen 1994). Large-scale purse seine operations for Jack Mackerel continued through the 1990s. However, purse seine operations ceased in 2000 due to large inter-annual fluctuations in catches and an overall downward trend in fishery production.

Mid-water trawling to target sub-surface schools of Jack Mackerel off Tasmania was trialled in 2001/02. Between December 2001 and April 2002, a total catch of over 5,000 t of small pelagic fishes was taken, with 90% being Redbait. A multi-purpose 50 m mid-water trawler was used to target small pelagic fishes from late 2002 onwards. By mid-2003, more than 7,000 t of small pelagic fishes had been taken, with Redbait dominating the catch. Trawl effort declined in the late 2000s, whereas small-scale purse seine operations continued into the early 2010s (Emery et al. 2015).

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

2.1.2 Taxonomy

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

2.1.3 Distribution

Jack Mackerel is widely distributed throughout coastal waters of southern Australia and New Zealand. In Australia, this species occurs along the southern coast from Shark Bay in Western Australia to Wide Bay in Queensland, including the waters around Tasmania (Gomon et al. 2008). Jack Mackerel is found to depths of 500 m, but is most abundant over the continental shelf to 200 m (Pullen 1994).

2.1.4 Stock Structure

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

2.1.5 Movement

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

2.1.6 Food and Feeding

Jack Mackerel feed primarily on aquatic crustaceans (Shuntov 1969, Stevens et al. 1984, Bulman et al. 2008, McLeod et al. 2012), and krill (*Nyctiphanes australis*) are the most common dietary item throughout the fish's distribution. Krill accounts for ~44% of the diet in Jack Mackerel from eastern Tasmania (Webb 1976, Williams and Pullen 1986, McLeod et al. 2012). Jack Mackerel living in deeper waters also feed on mesopelagic fish (Maxwell 1979, Blaber and Bulman 1987). In addition, Jack Mackerel eat minor quantities of other prey items, including ostracods, gastropods, amphipods, isopods, polychaetes and echinoderms (Stevens et al. 1984, Blaber and Bulman 1987, McLeod et al. 2012). Dietary composition varies seasonally (Bulman et al. 2008).

In the GAB, Jack Mackerel generally feed during the day with fish in offshore waters feeding mostly on krill and fish in inshore waters consuming mainly copepods (Shuntov 1969, Stevens et al. 1984). Prey size is dependent on fish size, with larger prey items taken by larger fish (Stevens et al. 1984).

2.1.7 Age, Growth and Size

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

2.1.8 Reproduction

Jack Mackerel are serial spawners (Marshall et al. 1993, Neira 2011), and mean spawning fraction (proportion of mature females spawning per day/night) is estimated at 0.056 (range: 0.0 to 0.134) in Australian waters (Ward et al. 2015a, 2016). Estimates of spawning fraction equate to a mean spawning frequency of 17.9 days (range: 7.5-142.9 days). Mean batch fecundity has been estimated at ~63,000 eggs for fish from eastern Tasmania (Neira 2011) and ~34,000 eggs for fish along the eastern Bass Strait (Ward et al. 2015a, 2016). Both male and female Jack Mackerel off south-eastern Australia are reported to be sexually mature at ~270 mm (Webb 1976), with 50% of females ≥315 mm FL undergoing vitellogenesis during the spawning season (Marshall et al. 1993).

Spawning occurs in spring along most of the New South Wales coastline (Maxwell 1979, Keane 2009), and during summer in south-eastern Australia (Eden, New South Wales to St. Helens, Tasmania) and in the GAB (Stevens et al. 1984, Marshall et al. 1993, Jordan et al. 1995, Ward et al. 2015a, SARDI unpublished data). Mean gonadosomatic index (GSI) values for females off eastern Tasmania increase substantially in November and remain high until January, before declining in February (Williams and Pullen 1986; Ward et al. 2011). Back-calculation of birthdates based on otolith microstructure of larval fish otoliths indicates that spawning occurs between mid-December and mid-February and follows a semi-lunar cycle, where peak activity is associated with both full and new moons (Jordan 1994).

2.1.9 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 in Neira et al. (1998). Larvae have been collected off southern New South Wales during spring, and off eastern Tasmania, in Bass Strait and the GAB during summer (Stevens et al. 1984, Keane 2009, Ward et al. 2015a, SARDI unpublished data). Jack Mackerel eggs are morphologically similar to Yellowtail Scad eggs but slightly larger (Yellowtail Scad egg diameter: 0.78–0.88 mm; Neira 2009).

2.1.10 Stock Assessment

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

The first dedicated application of the DEPM to Jack Mackerel off the south-east coast of Australia (i.e. the key spawning area off eastern Australia) occurred in 2014 (Ward et al. 2015a). Prior to this, a preliminary DEPM was done in 2011 using samples collected off south-eastern Australia in 2002–2004 during a survey of Blue Mackerel (Neira 2011). Ecosystem modelling of south-east Australian waters has also been used to estimate the spawning biomass of Jack Mackerel (Fulton 2013). The first dedicated DEPM survey for Jack Mackerel along the southern Australian coast (Kangaroo Island to western Tasmania) occurred during December 2016/January 2017 (SARDI unpublished data).

2.1.11 Recreational fishing

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

2.1.12 Biomass Estimates

<u>East</u>

Preliminary application of the DEPM estimated the spawning biomass of Jack Mackerel East between Sugarloaf Point and Cape Howe, New South Wales during October 2002 to be 114,000–169,000 t (Neira 2011). This estimate was considered imprecise due to a lack of locally collected, species-specific estimates of adult reproductive parameters.

The first dedicated application of the DEPM to Jack Mackerel East was undertaken in January 2014 between Eden, New South Wales and Triabunna, Tasmania and involved concurrent sampling of eggs and adults (Ward et al. 2015a). The estimate of spawning biomass of 157,805 t (95% CI = 59,570–358,731) was considered to be robust, because it was based on reliable estimates of key adult parameters. The 2014 estimate is also within the range of estimates provided by Neira (2011) and within the range of plausible estimates of biomass suggested for the ecosystem (130,000 to 170,000 t) by Fulton (2013).

<u>West</u>

A DEPM survey for Jack Mackerel West occurred during December 2016/January 2017 between Kangaroo Island, South Australia and western Tasmania; this the first dedicated application of the DEPM to Jack Mackerel in the West sub-area (SARDI unpublished data). Two major areas of spawning activity—split by the Bonny Coast—were identified: an area south of Kangaroo Island and an area between King Island and the western Victorian coast. In addition to egg samples collected in the main survey area, opportunistic samples were also taken in Bass Strait where a large amount of spawning activity was detected. The estimate of spawning biomass derived from all samples (main survey + Bass Strait) was approximately 31,000 t, which is considered suitable for setting recommended biological catches as outlined by the SPF HS. This estimate is conservative as Bass Strait was not sampled extensively, and the western Jack Mackerel stock is thought to extend west of Kangaroo Island (e.g. Stevens et al. 1984, Bulman et al. 2015).

2.1.13 Management Strategy Evaluation

2010

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

2015

Smith et al. (2015) concluded the harvest rate of 15% may be too high for Jack Mackerel and suggested a Tier 1 harvest rate of 12% for Jack Mackerel East and West, with the Tier 1 rate being applied for not more than 5 years. Tier 2 harvest rates for Jack Mackerel East and West were recommended to be 50% of Tier 1 rates and should not be applied for more than 10 years. The study results also indicated it is not safe to apply Tier 2 harvest rates unchecked for long periods of time (i.e. >10 years; Smith et al. 2015). The Atlantis-SPF biomass estimate for Jack Mackerel East is 137,000 t (typical range: 91,000–208,000 t) and 62,000 t (typical range: 60,000–110,000 t) for Jack Mackerel West (Smith et al. 2015).

2.1.14 Management

Currently, the Jack Mackerel East and West sub-areas are managed at the Tier 1 level under the SPF HS. A preliminary DEPM assessment of Jack Mackerel East was undertaken in 2011 (data from 2002–2004) and a dedicated DEPM assessment occurred in 2014. A dedicated DEPM assessment for Jack Mackerel West was undertaken in 2016/17.

2.2 Methods

2.2.1 Fishery Statistics

Fishery statistics from 1984/85 to 2015/16 have been supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Unless indicated, annual data are reported in fishing seasons (May 1 to April 30) rather than financial years, as was done in previous assessments (e.g. Ward et al. 2013, 2014c, 2015c).

Estimates of total annual catch for Jack Mackerel East include data from the NSW Ocean Fisheries (Hauling, Trap and Line, Trawl), NSW Estuary General Fishery, Victorian Ocean Purse Seine Fishery, Tasmanian Scalefish Fishery and the Commonwealth SPF. For Jack Mackerel West, total annual catch estimates include data from the Tasmanian Scalefish Fishery, Victorian Ocean Purse Seine Fishery, South Australian Marine Scalefish Fishery and Commonwealth SPF. Due to data confidentiality (<5 license holders reporting catch in 2016/17), fishery data from Victoria were not provided and are not included in total annual catch statistics for 2016/17.

Mean annual catch per unit effort (CPUE) of Jack Mackerel East and West in the Commonwealth SPF is calculated for the gear types of mid-water trawl (tonnes·trawl hour^{-1} ±SE) and purse-seine (tonnes·net-set^{-1} ±SE) from 2000/01 to 2016/17. Zero catch of Jack Mackerel in a trawl was assumed when effort but not catch was reported in the logbook record.

2.2.2 Biological Information

Fishery-dependent length frequency and biological data were collected between 1984 and 1993 as part of a monitoring program of the Jack Mackerel Purse Seine Fishery off Tasmania. Samples collected between 1985 and 1990 during demersal research trawling, conducted by CSIRO and the Tasmanian fisheries agency, supplied some biological information. Between 1994 and 2001, the level of catch sampling of the purse seine fishery was limited.

Biological data were collected by AFMA observers on a small proportion of trips during the 2001/02 pair-trawl fishing trials undertaken off Tasmania. When mid-water trawl operations started in 2002, the Tasmanian Aquaculture and Fisheries Institute (TAFI) began an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length-frequency data collected from 2002 to 2008.

Purse seine operations for small pelagic fish resumed in Tasmanian State waters in 2008/09, mainly targeting Redbait and Jack Mackerel. 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 HS (AFMA 2008). No catch samples were obtained for Jack Mackerel from 2010/11 to 2013/14 due to limited fishing activity. Catch sampling by AFMA observers resumed in the SPF in 2014/15. Samples of Jack Mackerel were collected (n = 50 randomly selected fish per trawl) and supplied to SARDI Aquatic Sciences to estimate the current size and age composition of the catch.

Biological data collected from each fish include: body length (mm FL), total weight (g), sex, gonad developmental stage (following the macroscopic staging criteria described in Marshall et al. 1993) and gonad weight (to the nearest 0.1 g). Gonad stages were designated as: I) immature; II) maturing virgins or recovering spent; III) maturing; IV) ripe; and V) spent. Otoliths were removed from random sub-samples of fish for age estimation. The age structure of Jack Mackerel prior to 2014/15 was estimated using age-length keys based on age data pooled from 1985/86, 1989/90, 1993/94 and 1994/95. Since 2014/15, ages for Jack Mackerel have been based on annual growth increment counts in thin-sectioned otoliths (sub-samples of 5 to 10 fish per sample). Age structure data for catch samples collected in 2016/17 are not yet available and will be presented in the 2017/18 SPF assessment report.

Catch weighting was applied to length- and age-frequency data collected since 2015/16 in each sub-area. Length- and age-frequencies were weighted by the number of fish sampled per trawl to account for uneven sample sizes and then were catch weighted by the total amount of Jack Mackerel taken in the same trawl.

Commercial logbook information, length-frequency and biological data collected between 1984 and 2017 are included in this assessment. In addition to current catch samples, age, growth and reproductive data for Jack Mackerel were available from previous studies (Jordan et al. 1992, Lyle et al. 2000, Browne 2005, Ward et al. 2011). Length-frequency data were also available for Jack Mackerel from research (demersal trawl net) sampling undertaken between St. Helens (Tasmania) and Eden (New South Wales) in January 2014 (Ward et al. 2015a). Summarised biological data prior to 2014/15 are presented in financial years. From 2014/15 to present, all SPF catch sampling data are presented in fishing seasons from 1 May to 30 April.

2.3 Results

2.3.1 Jack Mackerel East

2.3.1.1 Fishery Statistics

Number of vessels

The number of vessels reporting catches of Jack Mackerel East declined from >100 vessels prior to 1998/99 to 12 vessels in 2012/13 and increased to 18 vessels in 2013/14. In 2016/17, 10 vessels landed Jack Mackerel East. One Commonwealth vessel reported catches of Jack Mackerel East in 2016/17.

Annual patterns: Total catch

Total catches of Jack Mackerel East declined from ~40,000 t in 1986/87 to 310 t in 1995/96 (Figure 2.1a). Catches increased to 9,916 t in 1997/98 and decreased through the 2000s with catches of <100 t from 2011/12 to 2013/14. Total catch increased to 6,321 t in 2015/16 and dropped to 3,966 t in 2016/17 (Figure 2.1a). The main fishery for Jack Mackerel East is the SPF (purse seine and mid-water trawl).

Annual patterns: Catch, Effort and CPUE

Within the SPF, purse seining has historically been used to target Jack Mackerel East (Figure 2.1b). Purse seine effort for Jack Mackerel East declined from 15 net-sets in 2004/05 to zero net-sets from 2012/13 to 2016/17 (Figure 2.1b). Annual purse seine catch follows effort with 307 t taken in 2000/01 and no reported catch since 2012/13 (Figure 2.1b). Mean annual CPUE for purse seining in the SPF has declined from 44 t·net-set^{-1} in 2000/01 to 1 t·net-set^{-1} in 2011/12 (Figure 2.1c).

Mid-water trawling replaced purse seining in the SPF for Jack Mackerel East after the early 2000s (Figure 2.1d). Annual trends of mid-water trawl effort and catch are similar since 2000/01: both increased in 2003/04 (1,338 trawl hours; 3,300 t), decreased to zero effort and catch from 2011/12 to 2013/14 and increased to 638 trawl hours in 2015/16, with 6,316 t of catch. Effort and catch declined in 2016/17 to 349 trawl hours and 3,966 t of catch (Figure 2.1d). Mean annual CPUE of mid-water trawls increased from zero in 2011/12 to 10 t·trawl hour^{-1} in 2014/15 and 11 t·trawl hour^{-1} in 2016/17 (Figure 2.1e).

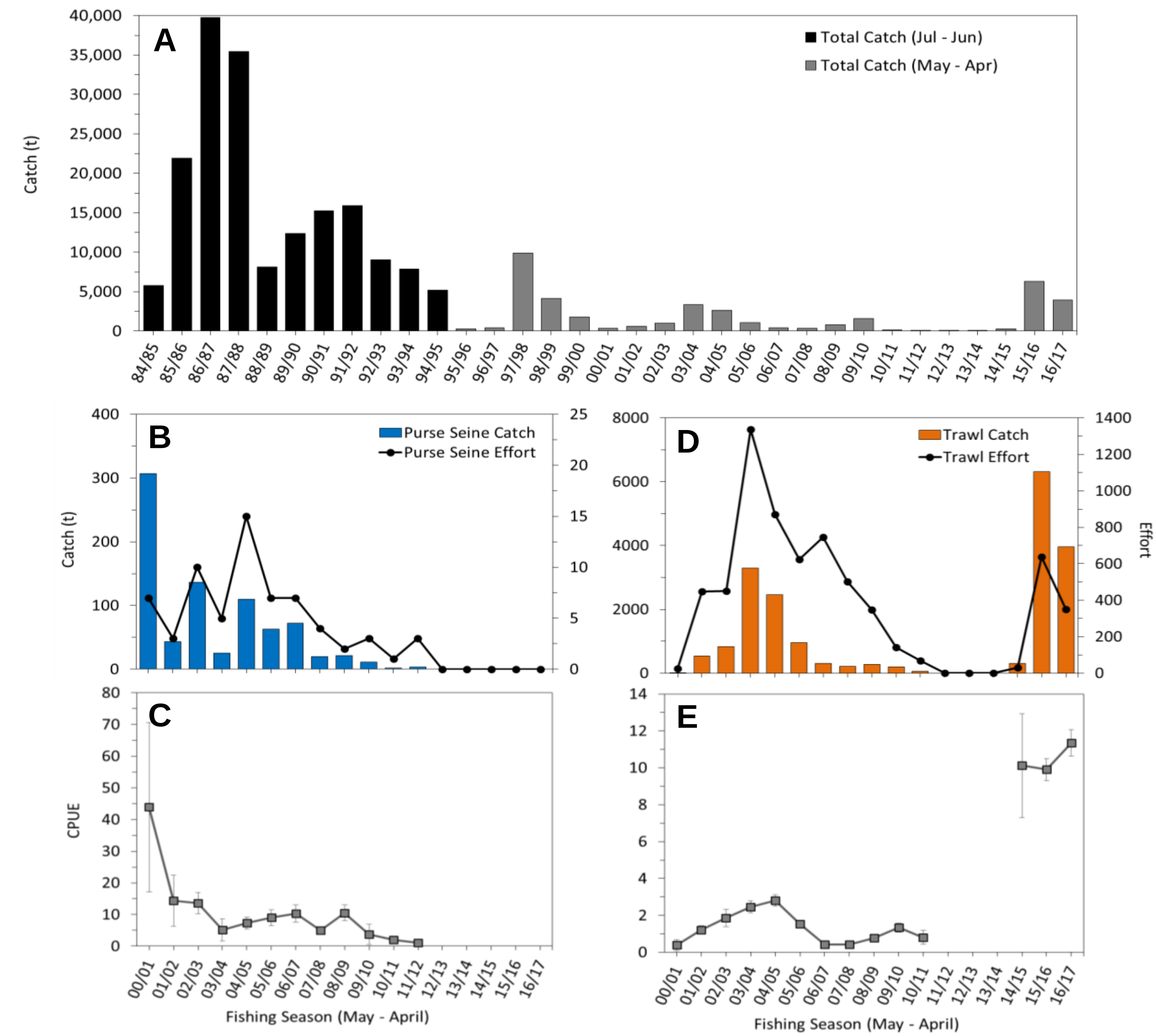


Figure 2.1. Fishery statistics for Jack Mackerel East. (A) Total annual landed catch (tonnes) for all jurisdictions from 1984/85 to 2016/17; black bars: catch per financial year; grey bars: catch per fishing season. Long-term trends in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets) by purse seine; (C) mean annual CPUE ($t \cdot net\text{-}set^{-1}$; ±SE) by purse seine; (D) annual landed catch (tonnes) and effort (trawl hours) by mid-water trawl; (E) mean annual CPUE ($t \cdot trawl\ hour^{-1}$; ±SE) by mid-water trawl.

2.3.1.2 Biological Information

Catch sampling of Jack Mackerel East has varied since 2009/10 due to limited commercial fishing in the SPF. During 2009/10, 1,412 fish were collected from purse seines and 318 fish from mid-water trawls off Tasmania (Table 2.1). Catch samples were not collected from 2010/11 to 2013/14, but in January 2014, 10 samples (n = 1,759) of Jack Mackerel were collected during DEPM research surveys (demersal trawl net) off eastern Victoria and southern New South Wales (Ward et al. 2015a). An additional seven samples (n = 947) were collected from waters off north-eastern Tasmania (no age data taken; Ward et al. 2015a). Catch sampling in the SPF resumed in 2014/15. During 2015/16, length-frequency data were collected from 95 samples (4,558 fish) with age-frequencies collected from 10 samples (118 fish) (Table 2.1). In 2016/17, length-frequency data were collected from 31 samples (n = 1,515). Age frequency data are not yet available for 2016/17.

Table 2.1. Summary of Jack Mackerel East catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency (n)	Age-frequency (n)	Size range (mm FL)	Age range (years)
2009/10	East	purse seine	15	1,412	270	120–320	1–7
2009/10	East	mid-water trawl	5	318	87	150–290	2–7
2014/15	East	mid-water trawl	7	325	102	185–380	2–15
2015/16	East	mid-water trawl	95 (10)	4,558	118	82–325	3–8
2016/17	East	mid-water trawl	31 (–)	1,515	–	144–306	–

<u>Size structure</u>

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

Purse seine catches of Jack Mackerel East off eastern Tasmania between 1984/85 and 1995/96 mainly contained fish between 210 and 350 mm FL, and included individuals up to 440 mm FL (Figure 2.2). The size structure in 1984/85 was bimodal, and fish ranged from 240 to 360 mm FL. From 1985/86 to 1988/89, catches were unimodal with most fish in the 250–350 mm FL size range, shifting towards larger fish. A cohort of small fish (<250 mm FL) was present in 1988/89, and in 1989/90 the size distribution was bimodal with peaks at 240 mm FL and 320–330 mm FL. The size structure was bimodal during the following three years with the position and relative heights of the modes varying among years. From 1993/94–1995/96, size structures were unimodal with a shift to larger fish. In 2009/10, the size structure was unimodal and dominated by smaller fish (190–220 mm FL size range; Figure 2.2).

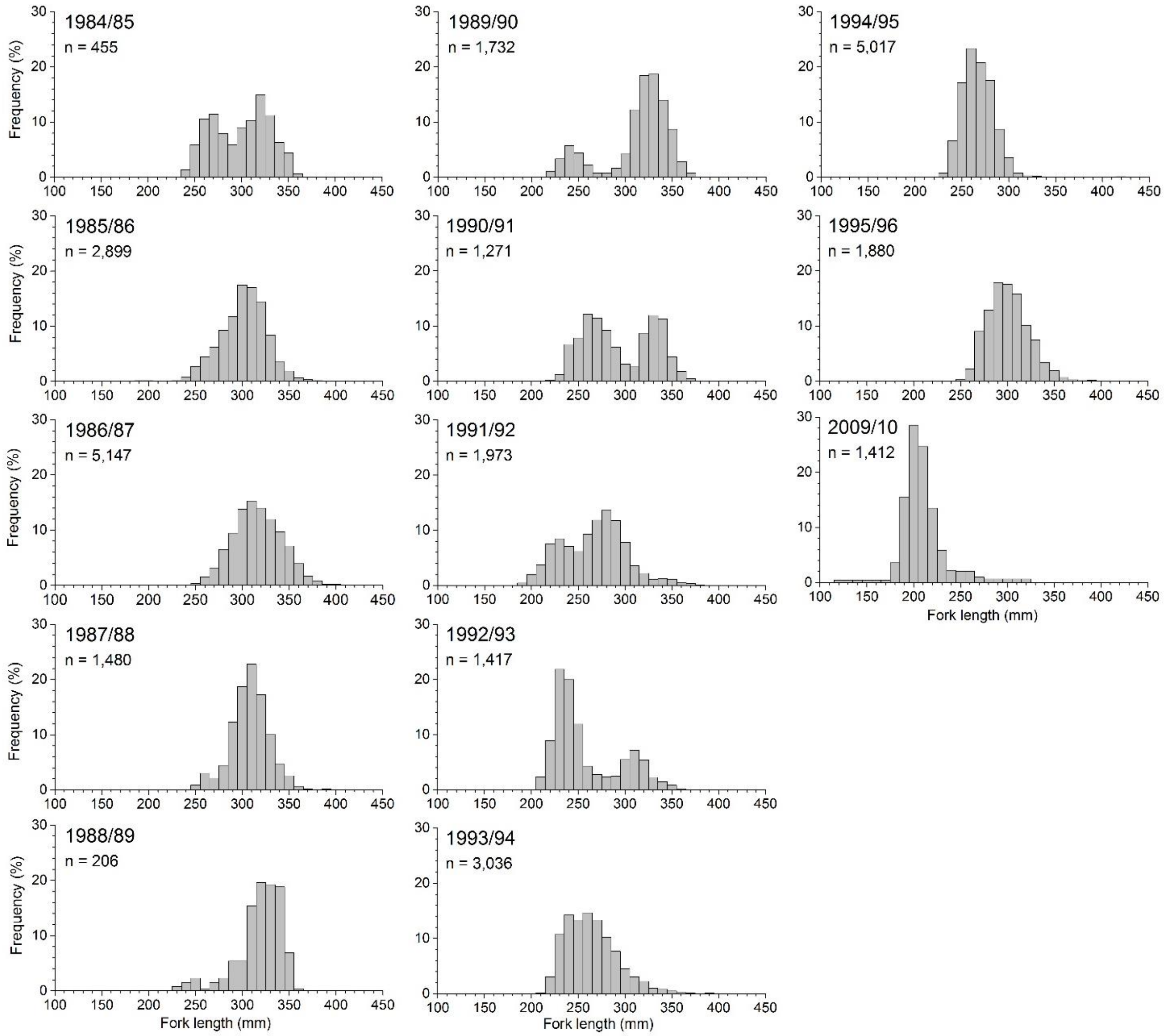


Figure 2.2. Length-frequency distributions of Jack Mackerel East caught in the SPF by purse seine from 1984/85 to 1995/96 and in 2009/10; n = number of fish.

Mid-water trawl fishery: 2002/03–2016/17

Jack Mackerel caught by mid-water trawl off eastern Tasmania from 2002/03 to 2004/05 were mostly between 200 and 300 mm FL (Figure 2.3), and considerably smaller than those caught in earlier purse seine operations. The size composition of mid-water trawl and purse seine catches in the East during 2009/10 were similar, with each dominated by fish between 180 and 240 mm FL (Figures 2.2–2.3).

Modal length of Jack Mackerel increased from 240 to 270 mm FL between 2002/03 and 2004/05 in mid-water trawl catches taken in the East, but only a small proportion of the catch contained fish

>300 mm FL (Figure 2.3). In 2014/15, the size structure of catch samples from mid-water trawling off southern New South Wales increased compared to 2009/10. The modal length increased to 220 mm FL, and more fish were in the 250 to 300 mm FL size classes (Figure 2.3). The modal length of the 2014/15 commercial mid-water trawl catch was smaller (220 mm FL) than the commercial trawl catches of the early 2000s (240–270 mm FL; Figure 2.3). The model length increased to 240 mm FL in 2015/16 and was the same in 2016/17 (Figure 2.3).

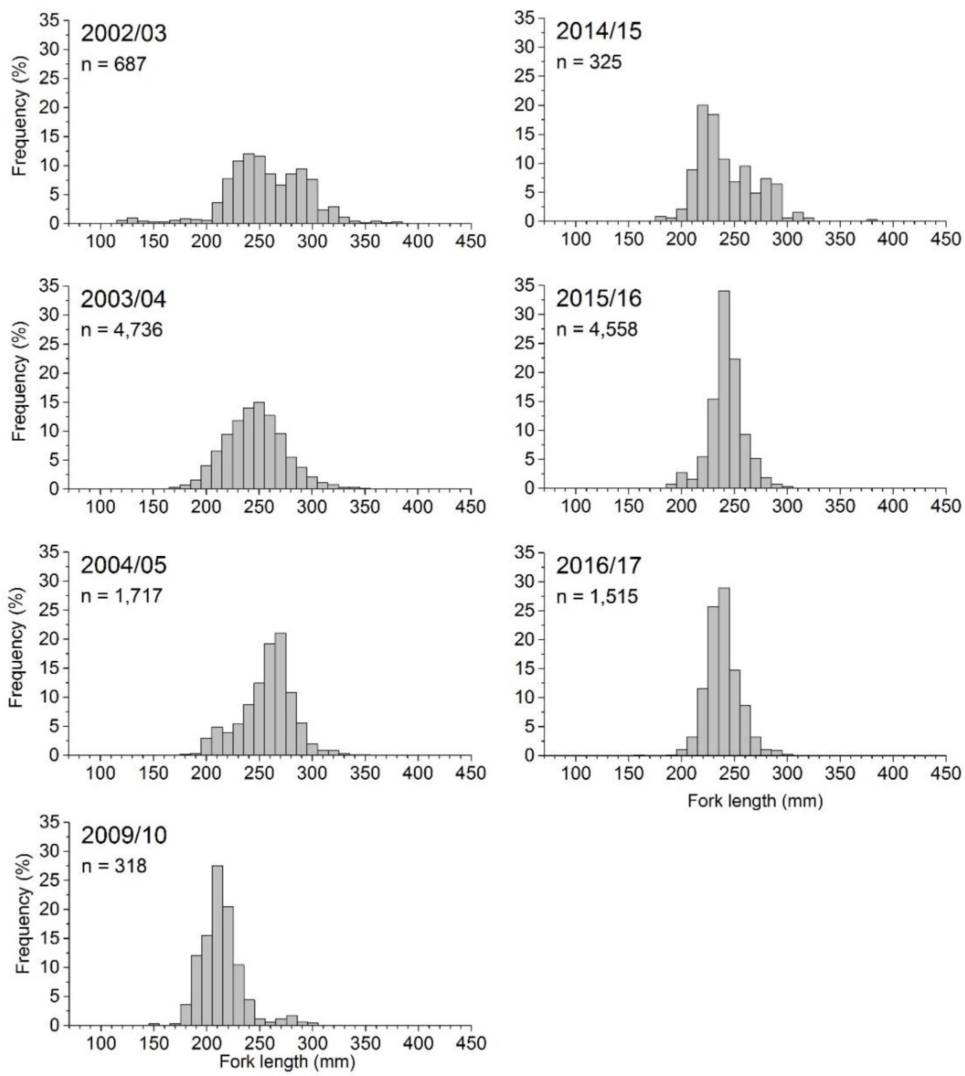


Figure 2.3. Length-frequency distributions of Jack Mackerel East caught by mid-water trawl in the SPF from 2002/03 to 2016/17; n = number of fish.
Research (demersal trawl net) surveys: 2014

The research samples of Jack Mackerel collected off eastern Victoria/southern New South Wales (above 39°S) mainly consisted of fish between 240–310 mm FL, with a mode at 250 mm FL (Figure 2.4). Similarly, the size structure for research samples off north-eastern Tasmania (below 39°S) mainly contained fish between 250–310 mm FL, although with a narrower range and stronger mode (280 mm FL; Figure 2.4). The modal length of the Jack Mackerel in research catches from eastern Victoria/southern New South Wales were larger compared to those from commercial trawl catches taken in the same area in 2014/15 (Figures 2.3–2.4).

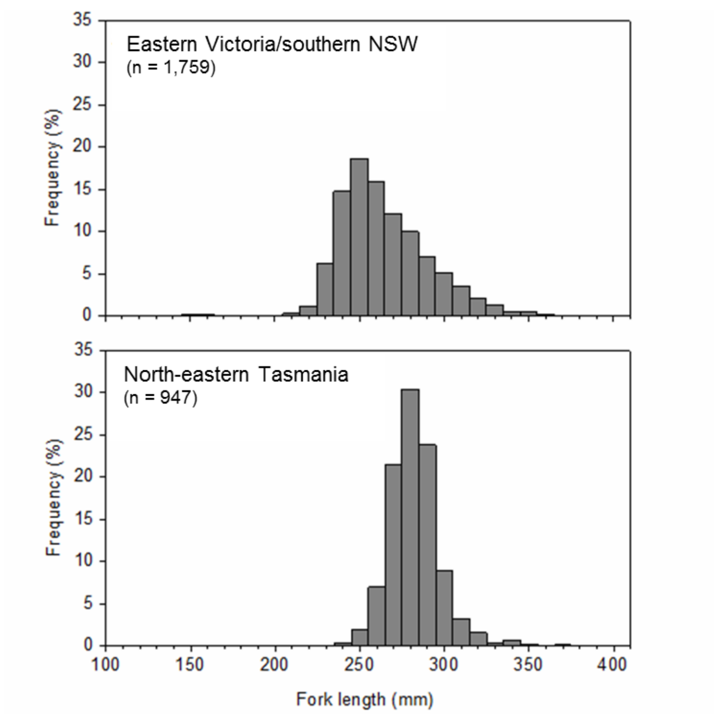


Figure 2.4. Length-frequency distributions for Jack Mackerel from research sampling off south-eastern Australia in January 2014.

<u>Age structure</u>

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

Jack Mackerel East taken by purse seine off eastern Tasmania were generally 3–10 years old (Figure 2.5). Catches between 1984/85 and 1990/91 were dominated by 4–5 year olds with fish up to 9 years also well represented. Between 1991/92 and 1994/95, few fish older than 6 years were taken, with 3 to 5 year olds the dominant age classes. The 1995/96 age structure was similar to that of the mid 1980s suggesting the relative scarcity of older fish in the intervening years may not have been solely due to the impact of fishing on population age structure. However, it should be noted that using a pooled age-length key rather than annual age data may have had a smoothing effect on age composition, in particular when representing the older age groups. In 2009/10, purse seine catches from eastern Tasmania were dominated by fish in the 2–3 year age groups (Figure 2.5).

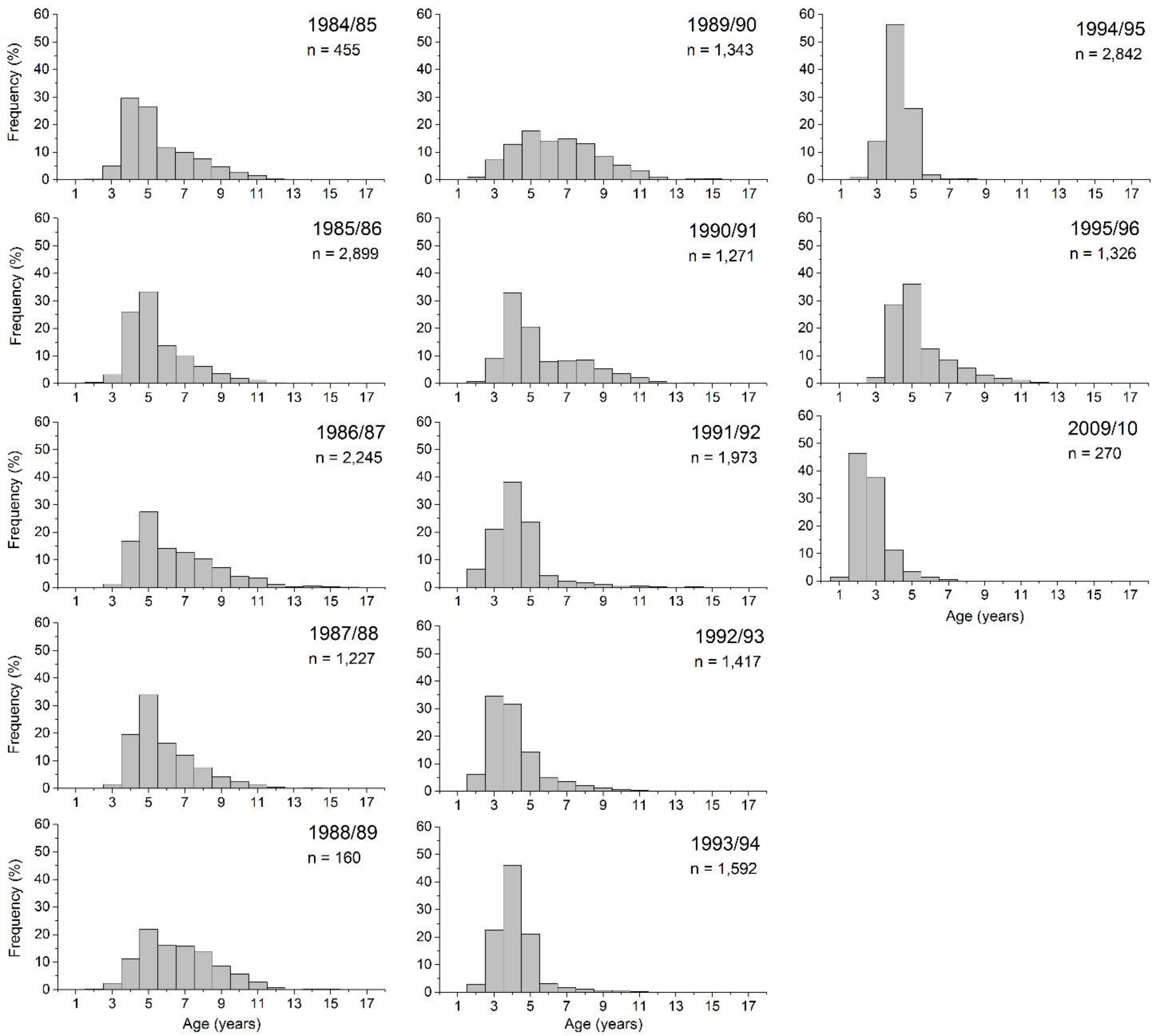


Figure 2.5. Age-frequency distributions of Jack Mackerel East caught in the SPF by purse seine from 1984/85 to 1995/96 and in 2009/10; n = number of fish in distribution.

Mid-water trawl fishery: 2001/02–2015/16

Mid-water trawl catches of Jack Mackerel East off eastern Tasmania between 2001/02 and 2004/05 mainly consisted of fish aged 2–5 years old, with a modal age of 4 years (Figure 2.6). During 2009/10, mid-water trawl catches from eastern Tasmania mostly contained 2–3 year old fish. In mid-water trawl catches off southern New South Wales during 2014/15, 68% of the fish were between 4 and 7 years old (age mode: 7 years) (Figure 2.6). In 2015/16, the modal age was 5 years with 67% of fish between 4 and 5 years. The maximum estimated age of Jack Mackerel East from mid-water trawl catch samples was 16 years (Figure 2.6).

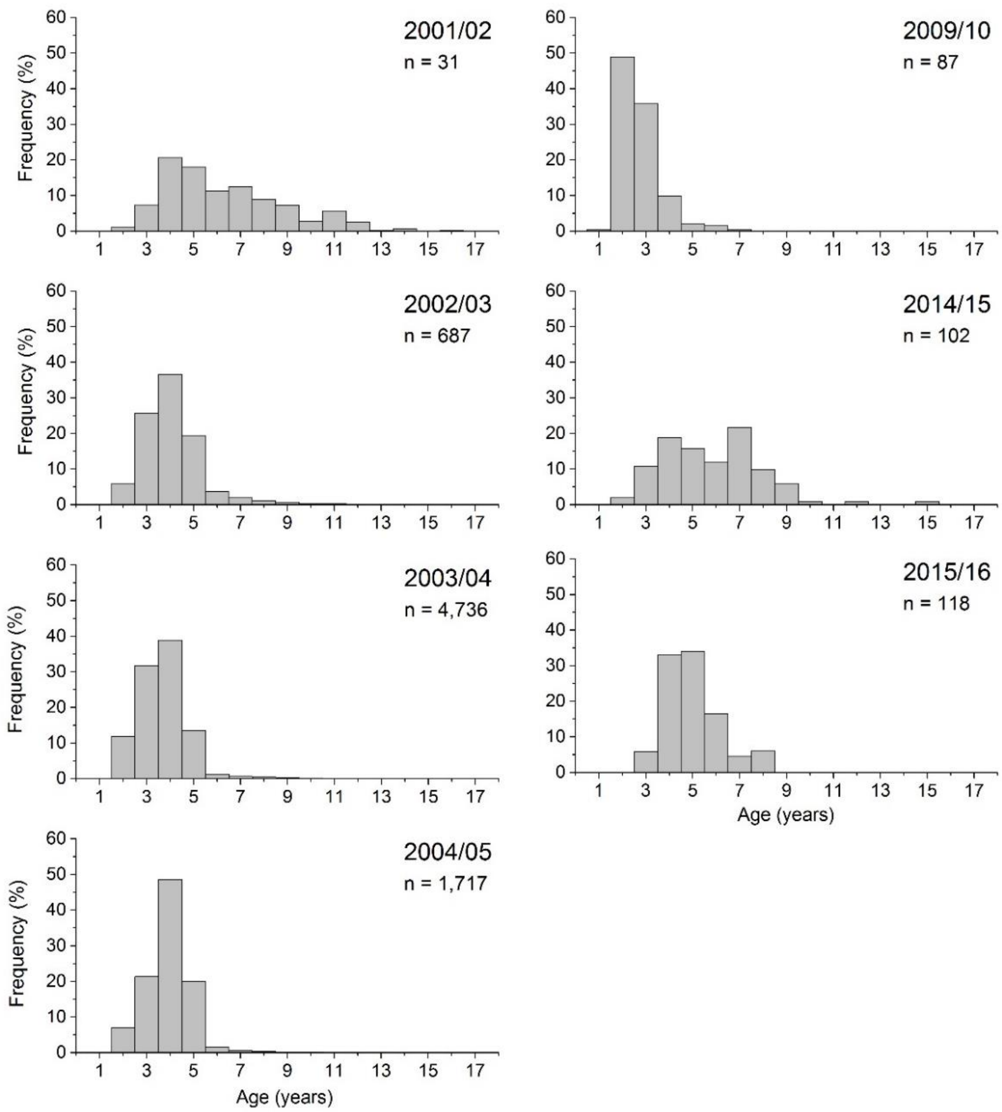


Figure 2.6. Age-frequency distributions of Jack Mackerel East caught by mid-water trawl in the SPF from 2001/02 to 2015/16; n = number of fish in distribution.

<u>Growth</u>

Growth of male and female Jack Mackerel from eastern Tasmania was described using the von Bertalanffy growth function (VBGF) (Table 2.2, Figure 2.7). Growth was rapid within the first few years of life, with individuals reaching a mean length >230 mm FL (~64% of L_∞ in the first three years) and slowing thereafter. Maximum assigned ages were 15 years for females and 16 years for males.

Table 2.2. Summary of von Bertalanffy growth function parameters for Jack Mackerel. Pooled data includes males, females and unsexed/unknown individuals. Based on data collected by Lyle et al. (2000).

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

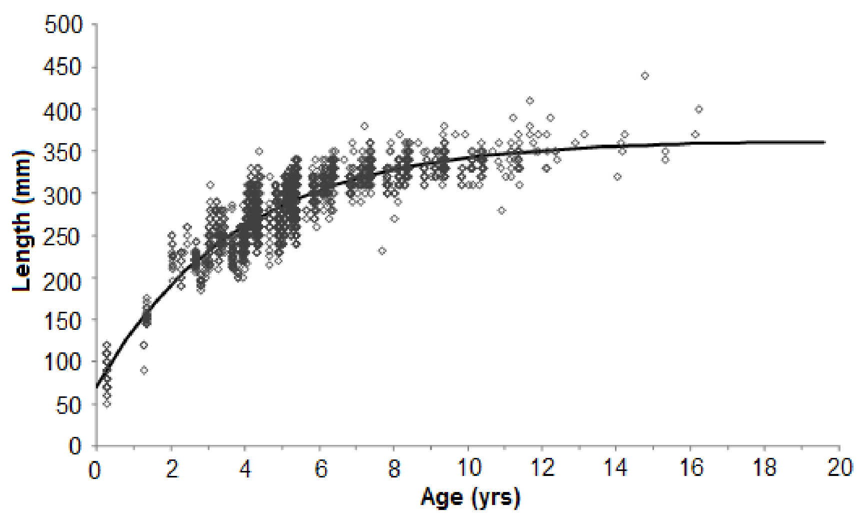


Figure 2.7. Length (mm FL) at age (years) data for Jack Mackerel. The black line represents the von Bertalanffy growth function. Based on data collected by Lyle et al. (2000).

<u>Reproduction</u>

Gonadosomatic Index (GSI)

Trends in male and female GSI indicated that Jack Mackerel from eastern Tasmania have a discrete spawning season that extends over about a three month period from late spring to mid-summer (Figures 2.8–2.9). From October, female GSI rose sharply to 2.6% in January. Male GSI also increased in January. After this, female GSI values declined rapidly and remained low through June (Figure 2.8).

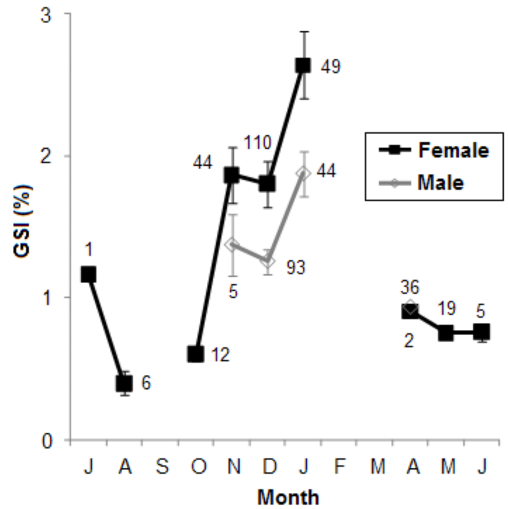


Figure 2.8. Monthly mean GSI values of Jack Mackerel by sex. Numbers associated with data points represent sample size (±SE). Based on data collected by Ward et al. (2011).

Gonad stages

Macroscopic staging of ovaries indicated Jack Mackerel off eastern Tasmania began actively spawning (gonads in Stages IV–V) in November and spawning activity increased during December–January (Figure 2.9).

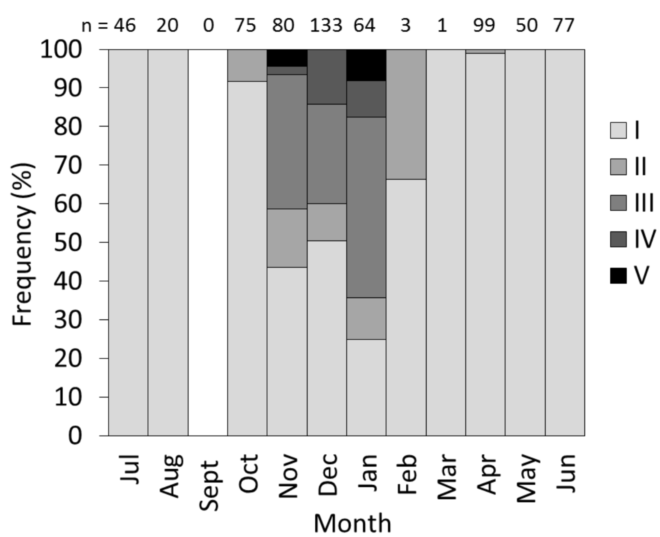


Figure 2.9. Monthly macroscopic ovary stages (Stages I–V) from Jack Mackerel; top numbers represent sample sizes. Based on data collected by Ward et al. (2011).

Size at maturity

Fifty percent maturity was estimated to be 268 mm FL for female Jack Mackerel from eastern Tasmania and 291 mm FL for males (Table 2.3, Figure 2.10). All fish larger than 360 mm FL were mature.

Table 2.3. Size at sexual maturity logistic parameters and 50% maturity (L_{50}) values of Jack Mackerel by sex. Based on data collected by Ward et al. 2011.

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

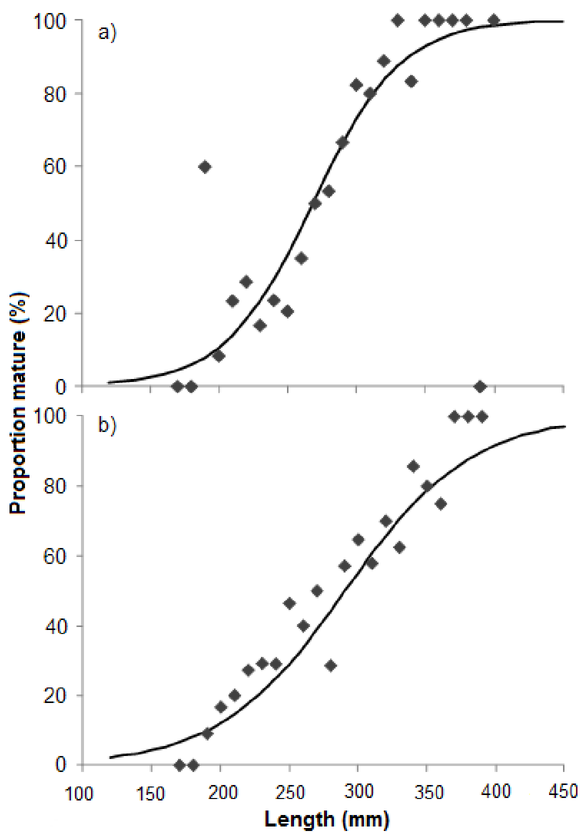


Figure 2.10. Proportion of mature female (a) and male (b) Jack Mackerel by length class (mm FL) fitted with logistic ogives; based on data collected by Ward et al. (2011).

2.3.2 Jack Mackerel West

2.3.2.1 Fishery Statistics

Number of vessels

The total number of vessels reporting catches of Jack Mackerel West declined from 14 in 1997/98 to 1 in 2012/13. Total vessel numbers increased to 5 in 2016/17.

Annual patterns: Total catch

Historically, Jack Mackerel catches in the West sub-area have been lower than those in the East, with the SPF taking 97% of the total annual catch since 1995/96. Due to data confidentiality (<5 license holders reporting catch per year) only SPF catches are discussed in this section (Figure 2.11a). Annual catches of Jack Mackerel West (purse seine and mid-water trawl) did not exceed 360 t prior to 2015/16 (Figure 2.11a). Catches in the SPF peaked at 359 t in 2006/07 and declined from there onwards, with no catches reported from 2010/11 to 2014/15. Catches increased to 634 t in 2015/16. In 2016/17, 686 t of Jack Mackerel West was taken in the SPF (Figure 2.11a).

Annual patterns: Catch, Effort and CPUE

Mid-water trawls have historically been the main gear type used by the SPF for Jack Mackerel West; purse seines have had limited use (Figure 2.11a). Since 2000/01, annual purse seine effort has not exceeded 7 net-sets (2006/07), and the maximum annual catch was 142 t in 2006/07 (Figure 2.11b). There has been no reported purse seine effort and catch of Jack Mackerel West in the SPF since 2010/11 (Figure 2.11b). Mean annual CPUE of purse seining is similar to effort and catch: peaks in 2006/07 (20 $t{\cdot}net\text{-}set^{-1}$) and 2009/10 (19 $t{\cdot}net\text{-}set^{-1}$), with minimal fishing in other years (Figure 2.11c).

Mid-water trawl effort and catch of Jack Mackerel West peaked at 625 trawl hours and 232 t during the mid-2000s and decreased to zero effort and catch from 2010/11 to 2013/14 (Figure 2.11d). Fishing effort resumed in 2014/15 (19 trawl hours; zero catch) and 686 t were taken during 2016/17 in 365 trawl hours (Figure 2.11d). Mean annual CPUE of mid-water trawls in the SPF decreased from 1 $t{\cdot}trawl\ hour^{-1}$ in 2001/02 to <1 $t{\cdot}trawl\ hour^{-1}$ in 2006/07, peaked in 2009/10 (2 $t{\cdot}trawl\ hour^{-1}$) with no further activity until 2015/16 (1 $t{\cdot}trawl\ hour^{-1}$) (Figure 2.11e). CPUE increased to 2 $t{\cdot}trawl\ hour^{-1}$ in 2016/17.

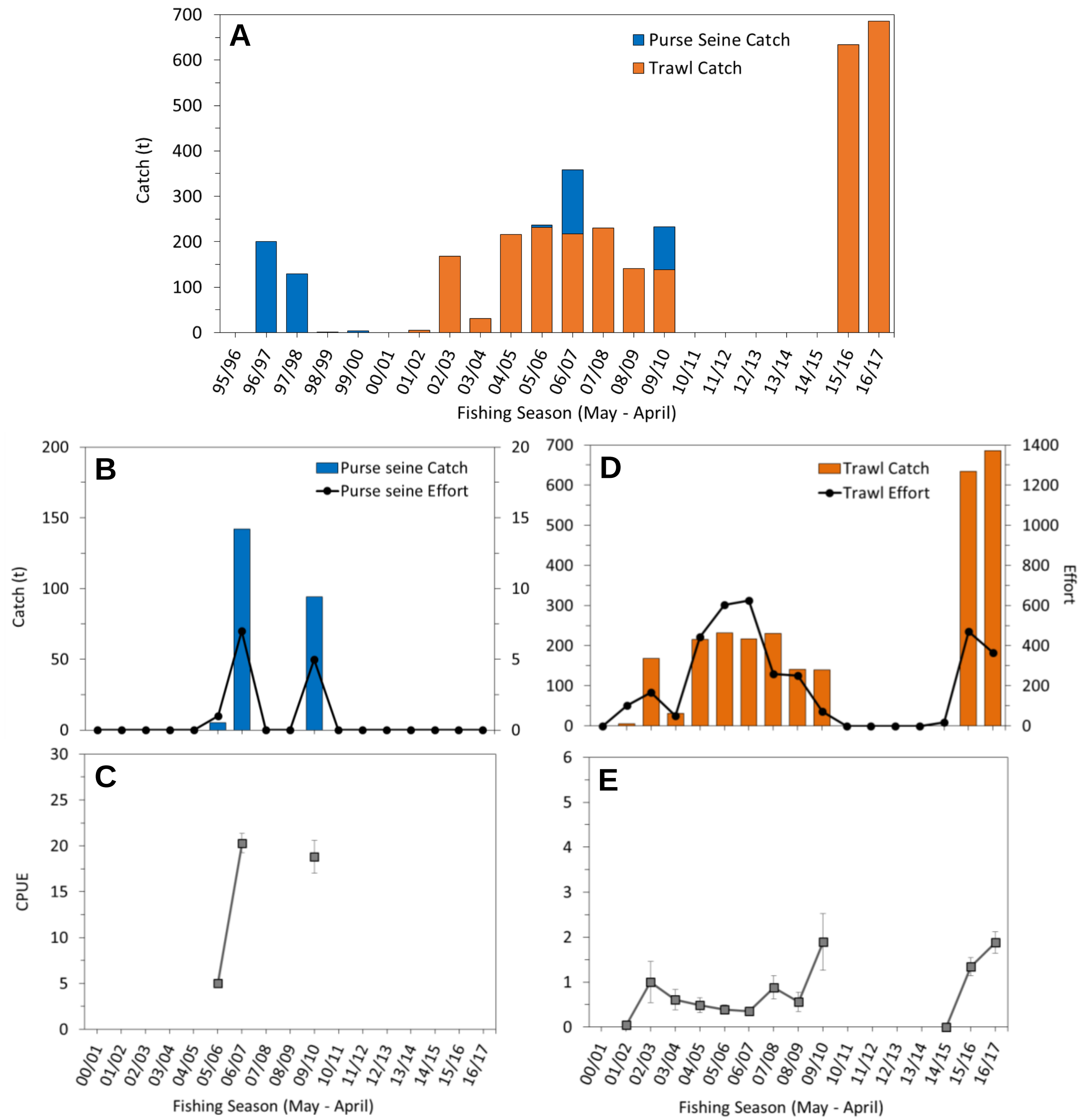


Figure 2.11. Fishery statistics for Jack Mackerel West. (A) Total annual landed catch (tonnes) in the SPF taken by purse seining and mid-water trawling from 1995/96 to 2016/17. Long-term trends in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets) by purse seine; (C) mean annual CPUE (t·net-set^{-1}; ±SE) by purse seine; (D) annual landed catch (tonnes) and effort (trawl hours) by mid-water trawl; (E) mean annual CPUE (t·trawl hour^{-1}; ±SE) by mid-water trawl.

2.3.2.2 Biological Information

Catch sampling of Jack Mackerel West has varied since 2009/10 due to limited commercial fishing in the SPF. During 2009/10, 132 fish were collected from mid-water trawls off south-western Tasmania (Table 2.4). Catch samples were not collected from 2010/11 to 2014/15. Catch sampling in the SPF resumed in 2015/16, and length-frequency data were collected from 14 catch samples (670 fish); age-frequencies were taken from 11 samples (119 fish) (Table 2.4). In 2016/17, length-frequency data were collected from 25 samples (n = 1,246). Age frequency data are not yet available for 2016/17.

Table 2.4. Summary of Jack Mackerel West catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)
2009/10	West	mid-water trawl	1	132	20	160–220	1–3
2015/16	West	mid-water trawl	14 (11)	670	119	211–355	2–8
2016/17	West	mid-water trawl	25 (–)	1,246	–	228–395	–

Size structure

The purse seine fishery

Size structure data are not available for purse seine catches of Jack Mackerel West.

Mid-water trawl fishery: 2002/03–2016/17

Jack Mackerel caught by mid-water trawl operations off south-western Tasmania from 2002/03 to 2004/05 were mainly between 250 and 370 mm FL, with an overall modal length of 290 mm FL (Figure 2.12). Jack Mackerel taken in the West sub-area over this period were larger than those from the East (East overall modal length: 260 mm FL) (Figure 2.12).

In 2009/10, a sample from a single mid-water trawl catch from the West (south-western Tasmania) contained Jack Mackerel of similar sizes (modal length: 190 mm FL) to catches from eastern Tasmania (modal length: 210 mm FL) (Tables 2.1 and 2.4; Figure 2.3). The modal length ranged between 240–250 mm FL in 2015/16 and increased to 270 mm FL in 2016/17. The current mode is slightly smaller than that from the commercial trawl catches of the early 2000s (Figure 2.12).

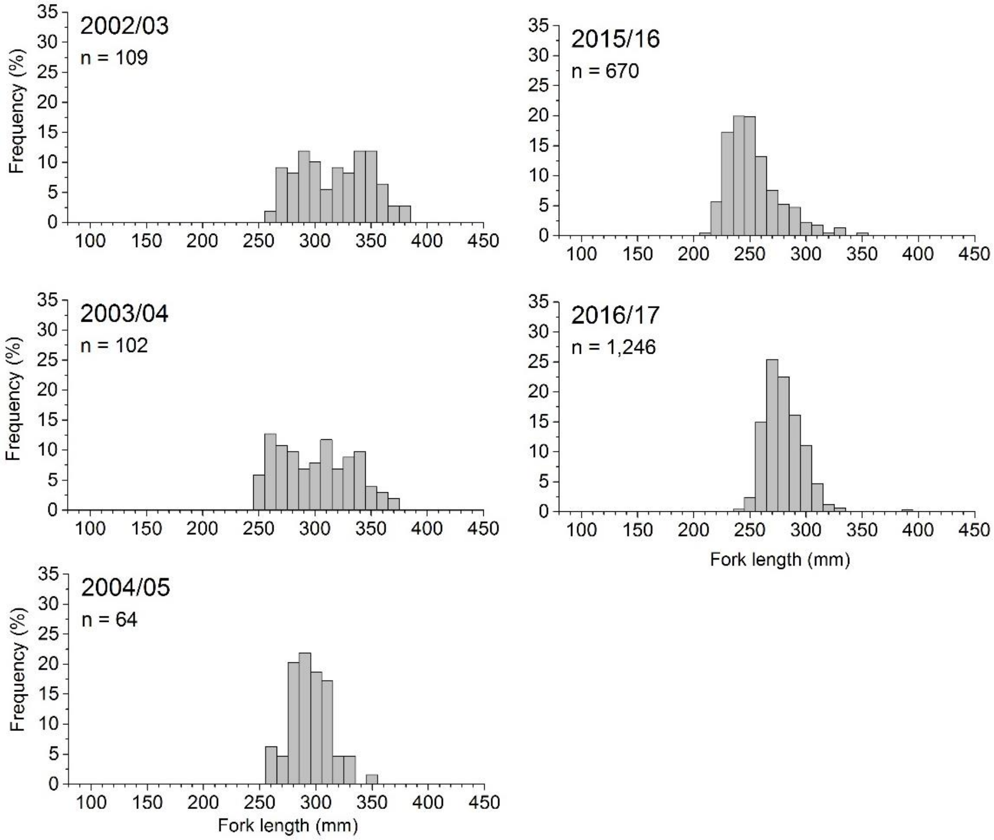


Figure 2.12. Length-frequency distributions of Jack Mackerel West caught by mid-water trawl in the SPF from 2002/03 to 2016/17; n = number of fish in distribution.

Age structure

The purse seine fishery

Age structure data are not available for purse seine catches of Jack Mackerel West.

Mid-water trawl fishery: 2002/03–2015/16

Annual age structures of Jack Mackerel West sampled from catches taken off south-western Tasmania from 2002/03 to 2004/05 had a high proportion of fish >5 years, and a mode of 4–5 years (Figure 2.13). The age structure of the single catch in 2009/10 (Table 2.4) contained a high proportion of 2 year old fish, representing about 70% of the distribution (similar to the 2009/10 age structure in the East; Figure 2.3). In 2015/16, the modal age was 4 years with 75% of fish between 3 and 5 years (Figure 2.13). The maximum estimated age of Jack Mackerel West from mid-water trawl catches was 16 years (Figure 2.13).

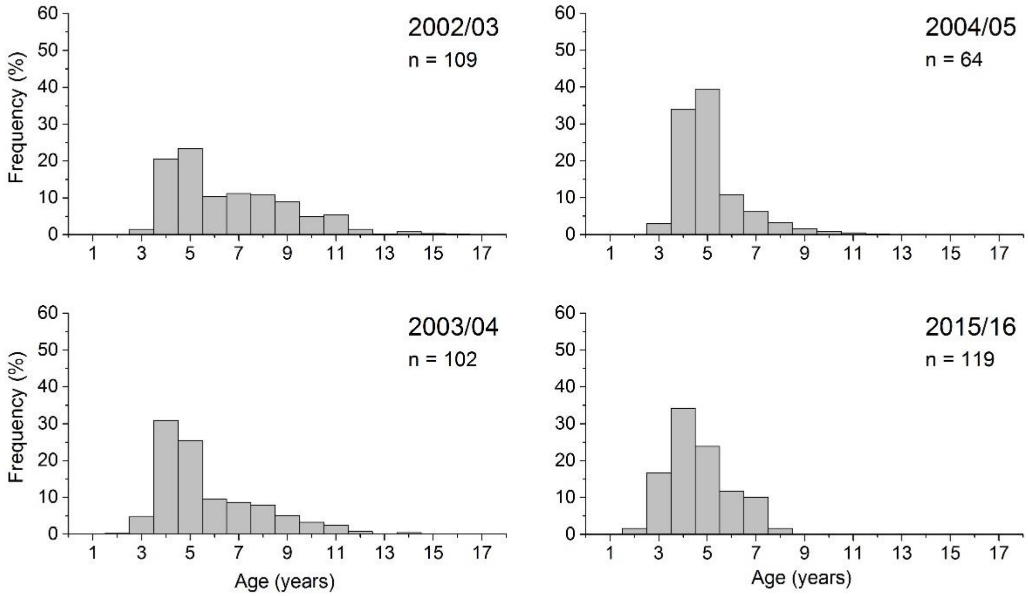


Figure 2.13. Age-frequency distributions of Jack Mackerel West caught by mid-water trawl in the SPF from 2002/03 to 2015/16; n = number of fish in distribution.

2.4 Summary and Conclusions

2.4.1 Jack Mackerel East

The spawning biomass of Jack Mackerel East during 2014 was estimated to be 157,805 t (95% CI = 59,570–358,731) (Ward et al. 2015a), which is within the range of estimates derived from surveys targeting Blue Mackerel in 2002–04 by Neira (2011) of ~114,900–169,000 t and plausible estimates for the ecosystem from simulation studies by Fulton (2013). Ward et al. (2015a) suggested that the estimate of spawning biomass for 2014 was robust because it was based on reliable estimates of critical DEPM parameters (e.g. egg production, spawning area and spawning fraction).

Total annual catches of Jack Mackerel East declined from ~40,000 t in 1986/87 to 310 t in 1995/96, increased to 9,916 t in 1997/98 and remained below 3,000 t until 2015/16. The total catch decreased from 6,321 t in 2015/16 to 3,966 t in 2016/17. Catches were mainly taken by purse seining from 1997/98 to 2000/01 and by mid-water trawling from 2001/02 onwards. Minimal fishing occurred between 2010/11 and 2013/14. Annual CPUE by mid-water trawl increase from 10 t·trawl hour^{-1} in 2015/16 to 11 t·trawl hour^{-1} in 2016/17. Recent fluctuations of total catch reflect changes in fishing effort.

Age and length structures, particularly in mid-water trawls since 2002/03, have varied among years, but are difficult to interpret due to the limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time. The modal size of samples from mid-water trawl catches in 2016/17 (240 mm FL mm) was below the size at 50% maturity (268 mm FL for females; 291 mm FL for males). However, samples used to estimate size at 50% maturity were collected off eastern Tasmania in 2009/10 (e.g. Ward et al. 2011), whereas catch samples for 2016/17 were taken off New South Wales.

Recent catches of Jack Mackerel East are assessed as sustainable, as they were ~3% of the estimated spawning biomass (Ward et al. 2015a), and below the Tier 1 exploitation rate for this stock of 12% (Smith et al. 2015). Stewardson et al. (2016) also found the biological stock of Jack Mackerel East to be sustainable. Patterson et al. (2017) classified Jack Mackerel East as 'not overfished' and 'not subject to overfishing'.

2.4.2 Jack Mackerel West

The spawning biomass of Jack Mackerel West during 2016/17 was estimated to be approximately 31,000 t (SARDI unpublished data). This estimate may be conservative as Bass Strait was not sampled extensively and Jack Mackerel occur west of Kangaroo Island (e.g. Stevens et al. 1984, Bulman et al. 2015). The Atlantis-SPF biomass estimate for this stock is 62,000 t (typical range: 60,000–110,000 t; Smith et al. 2015).

Prior to 2015/16, annual catches of Jack Mackerel West in the SPF did not exceed 400 t; 0 t were taken in the SPF from 2010/11 to 2014/15. The total catch in the SPF during 2016/17 was 686 t. Since 2000/01, mean annual CPUE of mid-water trawls has not been above 2 $t \cdot trawl\ hour^{-1}$. Changes in annual catch reflect changes in fishing effort.

Age and length structures of Jack Mackerel West between 2002/03 and 2004/05 were consistent among years, with dominant age classes of 4–5 years and an overall modal length of 290 mm FL. This was above the mean size at 50% maturity of ~280 mm FL (Ward et al. 2011). The modal length and age of the 2015/16 commercial mid-water trawl catch was 240-250 mm FL and 4 years, respectively. The modal length increased to 270 mm FL in 2016/17. Age and length structures are difficult to interpret due to the limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time. Jack Mackerel taken in the West during 2016/17 were slightly larger than those taken in the East.

Recent catches of Jack Mackerel West are assessed as sustainable, as they were ~2% of the estimated spawning biomass (SARDI unpublished data). The Tier 1 exploitation rate, applied after a dedicated DEPM is completed, is 12% (Smith et al. 2015). Stewardson et al. (2016) also classified the stock status of Jack Mackerel West as sustainable. Patterson et al. (2017) classified Jack Mackerel West as ‘not overfished’ and ‘not subject to overfishing’.

3 BLUE MACKEREL (*Scomber australasicus*)

3.1 Introduction

3.1.1 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. 2001a). The largest fishery for Blue Mackerel in the southern hemisphere is based in New Zealand where annual catches have ranged between ~6,000 t and 15,000 t per annum since the early 1990s (Fu 2013). In Australia, Blue Mackerel is taken in several fisheries with annual catches typically <3,000 t (Ward et al. 2001a, Ward and Grammer 2017).

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

The Tasmanian Purse Seine Fishery has recorded catch and effort data since its inception in 1984. Logbooks contain a record of fishing operations and species taken for each net-set. Landings of Blue Mackerel were first reported in 1985/86 with a catch of 587 t (1984/85: 0 t; Pullen 1994). From 1984/85 to 1989/90, Blue Mackerel represented <4% of the total annual catch of small pelagic fishes in Tasmania (Pullen 1994). Species-specific information was not available for other years.

3.1.2 Taxonomy

The genus *Scomber* (family *Scombridae*) historically included three Mackerel species: Blue Mackerel (*S. australasicus*), Chub Mackerel (*Scomber japonicus*), and Atlantic Mackerel (*Scomber scombrus*). However, *S. australasicu*s and *S. japonicus* have proved to be more closely related to each other than to *S. scombrus*, and morphological and genetic differences in Atlantic and Indo-Pacific populations of *S. japonicus* warranted recognition of two separate species (Scoles et al. 1998). Atlantic Chub Mackerel (*Scomber colias*) was identified through further genetic analyses and replaces *S. japonicus* in the Atlantic Ocean (Infante et al. 2006, Catanese et al. 2010). Thus, two closely related species occur in the Indian and Pacific Oceans: *S. japonicus* and *S. australasicus,* and two closely related species are found in the Atlantic Ocean: *S. scombrus* and *S. colias*.

3.1.3 Distribution

Blue Mackerel occur throughout the Pacific Ocean, including South East Asia, Australia and New Zealand, and in coastal and continental shelf waters of the northern Indian Ocean and Red Sea (depths up to 200m). In Australia, Blue Mackerel are found in subtropical and temperate waters from Queensland to Western Australia and are the only member of the genus present (Ward et al. 2001a, Gomon et al. 2008). Juveniles and small adults usually live in inshore waters, while larger adults form schools in depths of 40–200 m across the continental shelf (Kailola et al. 1993).

3.1.4 Stock Structure

The stock structure of Blue Mackerel in Australasian waters is uncertain. Significant differences in the morphology of monogenean parasites distinguished fish from Australia and New Zealand (Rohde 1987). However, genetic differences have not been found between Blue Mackerel from Australia and New Zealand using mtDNA RFLP analysis and cytochrome *b* sequencing (Scoles et al. 1998). The Australian east coast and west coast Blue Mackerel populations are thought to be genetically separate stocks (Ward and Rogers 2007, Schmarr et al. 2011). An additional stock in southern Australia has tentatively been identified through differentiation with otolith microchemistry and parasite analyses (Ward and Rogers 2007, Schmarr et al. 2011).

3.1.5 Movement

No studies have specifically examined the movement of Blue Mackerel in Australasia.

3.1.6 Food and Feeding

Blue Mackerel are pelagic omnivores, feeding mainly on krill, fish and gelatinous nekton (Bulman et al. 2001, Daly 2007, Bulman et al. 2011). Mackerel (*Scomber* spp.) alter their feeding behaviour and ingestion rates depending on prey size and density (Prokopchuk and Sentyabov 2006, Garrido et al. 2007).

3.1.7 Age, Growth and Size

Age estimation in small pelagic fish can be problematic (Gaughan and Mitchell 2000, Arneri et al. 2011), and Blue Mackerel are no exception (Stewart et al. 1999, Ward and Rogers 2007, Marriott and Manning 2011). Although the otoliths of Blue Mackerel have complex inner microstructures, they have been successfully used to estimate annual ages in both Australia (Stewart and Ferrell 2001, Ward and Rogers 2007) and New Zealand (Marriott and Manning 2011). Juveniles of both sexes grow rapidly and reach ~250 mm fork length (FL) after ~2 years of life (Ward and Rogers 2007). Blue Mackerel reach sizes of up to 440 mm FL in the GAB and are estimated to attain ~8 years (Stevens et al. 1984). Growth rates and trajectories of males and females from waters off

South Australia are similar (Ward and Rogers 2007). Off eastern Australia, an opaque zone forms in the otoliths of one-year old fish during winter and is complete by early summer (Stewart et al. 1999). Commercial catches of Blue Mackerel taken off southern New South Wales contained mostly 1 to 3 year old fish and included individuals up to 7 years old (Stewart and Ferrell 2001).

3.1.8 Reproduction

Blue Mackerel are serial spawners, and spawn multiple times over a prolonged spawning season with 50% sexual maturity occurring around 237 mm FL for males and 287 mm FL for females (Ward and Rogers 2007, Rogers et al. 2009). Spawning in southern Australia takes place from summer to early autumn and late winter to spring in New South Wales (Ward and Rogers 2007, Ward et al. 2015b). 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 (Rogers et al. 2009). Fecundity increases exponentially with fish length and weight. Most of the eggs collected off southern and eastern Australia have been obtained from the mid-shelf. High egg and larval densities are recorded at depths >50 m with sea surface temperatures (SST) of 18-22°C (Ward and Rogers 2007, Ward et al. 2015b). The location of spawning off southern Australia appears to vary substantially among 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).

3.1.9 Early Life History and Recruitment

Blue Mackerel eggs are transparent and spherical, measuring 1.05 to 1.35 mm in diameter. The eggs have a smooth chorion, a prominent unsegmented yolk, and a single oil globule 0.22 to 0.38 mm in diameter (Ward and Rogers 2007, Neira and Keane 2008). Blue Mackerel yolk-sack larvae are <3.2 mm total length (TL) at hatching and metamorphose at lengths of ~23.3 mm TL (Neira et al. 1998).

3.1.10 Stock Assessment

An extensive study that included both the East and West sub-areas of the SPF investigated the application of a range of egg-based stock assessment methods for Blue Mackerel and concluded that the species was suitable for assessment using the DEPM (Ward and Rogers 2007, Ward et al. 2009). A dedicated DEPM survey for Blue Mackerel East was conducted in 2014 (Ward et al. 2015b). Both the annual and daily egg production methods have been used to estimate the spawning biomass of Atlantic Mackerel (*Scomber scombrus*) in the north-eastern Atlantic Ocean (Gonçalves et al. 2009).

3.1.11 Recreational fishing

Recreational fishers harvest Blue Mackerel using rod and line, hand line and troll lines (Ward and Rogers 2007) throughout the waters of southern Australia, including southern Queensland. The Australian National Survey of Recreational and Indigenous Fishing estimated that boat-based recreational fishers harvested 720,814 Blue Mackerel annually, with 21% of these being released back into the water (Henry and Lyle 2003). Of the Blue Mackerel retained, 75% were taken in New South Wales, and 14% and 8% taken in Western Australia and South Australia, respectively (Henry and Lyle 2003). Based on the length/weight key developed by Stewart and Ferrell (2001), the estimated weight of Blue Mackerel harvested annually by the recreational sector in Australia is 228 t (Ward and Rogers 2007).

3.1.12 Biomass Estimates

East

A preliminary estimate of spawning biomass for Blue Mackerel East in 2004, calculated from the 'best' estimate of each parameter, was 23,009 t (Ward and Rogers 2007). 'Minimum' and 'maximum' estimates ranged from 7,565 to 116,395 t. The 'best' estimate of spawning biomass was considered to be conservative due to both the approach used to estimate egg production (i.e. McGarvey and Kinloch 2001) and because the survey most likely occurred outside the peak spawning season in that region (Ward and Rogers 2007).

A DEPM survey, undertaken in August/September 2014 off eastern Australia by Ward et al. (2015b), estimated spawning biomass of Blue Mackerel East to be ~83,300 (95% CI = 35,100–165,000 t). The estimated spawning area for Blue Mackerel off eastern Australia was 17,911 km^2, comprising 27.3% of the total area sampled (65,528 km^2) (Ward et al. 2015b). Live Blue Mackerel eggs (n = 2,330) were collected from 70 of the 262 (26.7%) stations between Sandy Cape, Queensland to just south of Newcastle, NSW. Mean daily egg production (P_0) was 35.1 $eggs \cdot day^{-1} \cdot m^{-2}$. The highest densities of Blue Mackerel eggs were recorded in waters just north of Coffs Harbour and off Port Stephens where SSTs ranged between 18 and 20°C.

The estimate of spawning biomass of 83,300 t was based on estimates of adult parameters from South Australia and should be treated with caution. Sensitivity analyses showed that realistic variations of each parameter produced estimates of spawning biomass for Blue Mackerel that were between about 50,000 t and 100,000 t. The exceptions were the lower estimates of spawning fraction (0.05) and batch fecundity (22,085 $eggs \cdot female^{-1}$) and the higher estimate of daily egg production (69.5 $eggs \cdot day^{-1} \cdot m^{-2}$), which produced estimates of spawning biomass between about 150,000 t to 250,000 t. Sampling intensity for estimates of egg production in the region was higher than in the preliminary surveys conducted in 2003 and 2004. Current estimates of egg production and spawning area are likely to be more robust than those previously reported.

West

The preliminary estimate of spawning biomass for Blue Mackerel West in 2005, calculated from the 'best' estimate of each parameter, was 56,228 t (Ward and Rogers 2007). 'Minimum' and 'maximum' estimates ranged from 10,993 t to 293,456 t. The 'best' estimate of spawning biomass was considered to be conservative due to both the approach used to estimate of egg production (i.e. McGarvey and Kinloch 2001) and because there was evidence to suggest that spawning occurred outside the area surveyed in the West (i.e. in the western Great Australian Bight) (Ward and Rogers 2007).

3.1.13 Management Strategy Evaluation

2010

For Blue Mackerel East, the "best" 2004 DEPM estimate of spawning biomass was 13% of the model calculated estimate of virgin biomass (Giannini et al. 2010). All Tier 1 scenarios reached equilibrium around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels were conservative and sustainable. However, these outputs should be treated with caution as these harvest quantities are "absolute" values and represented a much smaller proportion of the model calculated biomass than the DEPM estimate of biomass.

The outputs for Blue Mackerel West were similar to those for Blue Mackerel East (Giannini et al. 2010). In this case, the 2005 DEPM estimate of spawning biomass was 31% of the model calculated estimate of spawning biomass.

2015

Smith et al. (2015) concluded the harvest rate of 15% may be too low for Blue Mackerel and suggested a Tier 1 harvest rate of 23% for Blue Mackerel East and West, with the Tier 1 rate being applied for not more than 5 years. Tier 2 harvest rates for Blue Mackerel East and West were recommended to be 50% of Tier 1 rates and not to be applied for more than 5 years. The study results also indicated it is not safe to apply Tier 2 harvest rates unchecked for long periods of time, particularly on shorter lived species such as Blue Mackerel (Smith et al. 2015). The Atlantis-SPF biomass estimate for Blue Mackerel East is 52,600 t (typical range: 44,000–60,000 t) and 42,500 t (typical range: 34,000–46,000 t) for Blue Mackerel West (Smith et al. 2015).

3.1.14 Management

Currently, Blue Mackerel East is managed at the Tier 1 level, and Blue Mackerel West is managed at the Tier 3 level. DEPM assessments of Blue Mackerel have been conducted for both the East and West sub-areas of the SPF: Blue Mackerel East in 2004 and 2014, and Blue Mackerel West in 2005.

3.2 Methods

3.2.1 Fishery Statistics

Fishery statistics from 1984/85 to 2016/17 have been supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported in fishing seasons (May 1 to April 30) rather than financial years as was done in previous assessments (e.g. Ward et al. 2013, 2014c, 2015c).

Estimates of total annual catch for Blue Mackerel East include data from the NSW Ocean Fisheries (Hauling, Trap and Line, Trawl), NSW Estuary Fisheries (General and Prawn Trawl), Tasmanian Scalefish Fishery, Victorian Ocean Purse Seine Fishery and the Commonwealth SPF. In the West, total annual catch estimates include data from the Tasmanian Scalefish Fishery, Victorian Ocean Purse Seine Fishery, South Australian Marine Scalefish Fishery and Commonwealth SPF. Due to data confidentiality (<5 license holders reporting catch in 2016/17), fishery data from Victoria were not available and are not included in total annual catch statistics for 2016/17.

Mean annual CPUE of Blue Mackerel East and West in the Commonwealth SPF is calculated for the gear types of mid-water trawl (tonnes·trawl hour^{-1} ±SE) and purse-seine (tonnes·net-set^{-1} ±SE) from 2000/01 to 2016/17. Zero catch of Blue Mackerel in a trawl was assumed when effort but not catch was reported in the logbook record.

3.2.2 Biological Information

Length-frequency data for Blue Mackerel East were collected from commercial purse seine catches taken off New South Wales between 2006/07 and 2014/15. These data were supplied by the New South Wales Department of Primary Industries (DPI) and are presented in financial years.

Mid-water trawl operations resumed in the SPF during 2014/15; catch sampling required under the SPF HS (AFMA 2008) also recommenced. Samples of Blue Mackerel from mid-water trawl catches (n = 50 randomly selected fish per trawl), and supplied to SARDI Aquatic Sciences to estimate the size and age composition of the catch.

Samples of Blue Mackerel West prior to 2014/15 were obtained from catches taken in summer/early autumn by the commercial purse seine fishery operating from Port Lincoln, South Australia between 2008/09 and 2010/11.

Biological data collected from each fish included body length (mm FL), total weight (±1 g), sex, gonad developmental stage (following the macroscopic staging criteria described in Ward and Rogers 2007) and gonad weight (±0.1 g). Gonad stages were designated as: I) immature; II) maturing virgins or recovering spent; III) maturing; IV) ripe; and V) spent (full descriptions in Ward and Rogers 2007). Otoliths were removed from random sub-samples of fish for age estimation. Ages for Blue Mackerel East in 2014/15 were based on annual growth increment counts in whole otoliths (sub-sample n = 10 fish per sample). An otolith weight-age algorithm developed by Ward and Rogers (2007) was used to estimate ages of Blue Mackerel West prior to 2015/16. In 2015/16, all Blue Mackerel ages are based on annual growth increment counts in thin-sectioned otoliths (sub-samples of 5 to 6 fish per sample). Age structure data for catch samples collected in 2016/17 are not yet available and will be presented in the 2017/18 SPF assessment report.

Catch weighting was applied to length- and age-frequency data collected since 2015/16 in each sub-area. Length- and age-frequencies were weighted by the number of fish sampled per trawl to account for uneven sample sizes and then were catch weighted by the total amount of Blue Mackerel taken in the same trawl.

Biological data prior to 2014/15 are presented in financial years. From 2014/15 to present, all SPF catch sampling data are presented in fishing seasons from 1 May to 30 April.

3.3 Results

3.3.1 Blue Mackerel East

3.3.1.1 Fishery statistics

Number of vessels

The number of vessels reporting catches of Blue Mackerel East ranged from 236 to 463 between 1984/85 and 2008/09. Since then, vessel numbers decreased and have ranged between 130 and 163 (130 vessel in 2016/17). On average, 97% of the vessels reporting catch in each year are from New South Wales and about 1% are Commonwealth vessels.

Annual patterns: Total catch

Total catches of Blue Mackerel East declined from ~1,400 t in 1986/87 to ~100 t in 1989/90 (Figure 3.1). Catches increased to 1,045 t in 2003/04 and decreased to 309 t in 2011/12. From 2012/13 to 2014/15, catches averaged 486 t. Total catch increased to a historical high of 2,368 t in 2015/16 and decreased to 1539 t in 2016/17 (Figure 3.1a). The main fisheries that take Blue Mackerel East are the NSW Ocean Hauling Fishery (purse seine) and the SPF (purse seine and mid-water trawl). From 1995/96 to 2014/15, NSW Ocean Fisheries and the SPF have taken an average of 69% and 20% of the total annual catch for the East, respectively. The SPF has taken >80% of the total catch since 2015/16.

Annual patterns: Catch, Effort and CPUE

Purse seining has historically been used to take Blue Mackerel East. In the SPF mid-water trawling has replaced purse seining (Figure 3.1b, c, e, f), but in the NSW Ocean Hauling Fishery, purse seining is still the primary method used for Blue Mackerel (Figure 3.1d). There has been a long-term decline in purse seine effort in SPF for Blue Mackerel East from a peak of 20 net-sets in 2004/05 to a mean of 2 net-sets annually from 2010/11 to 2015/16 (Figure 3.1b). Effort increased in 2016/17 to 5 net-sets. Annual purse seine catch is similar to effort with a high of 280 t in 2005/06 and <1 t taken since 2011/12 (Figure 3.1b). Mean annual CPUE of purse seines in the SPF decreased from a long term mean of 14 $t{\cdot}net\text{-}set^{-1}$ between 2000/01 and 2009/10 to ≤2 $t{\cdot}net\text{-}set^{-1}$ from 2010/11 to 2016/17 (Figure 3.1c).

Trends in fishing effort and catch by mid-water trawling in the SPF for Blue Mackerel East are similar (Figure 3.1e). Effort decreased from a peak of 1,338 trawl hours in 2003/04 (catch: 307 t) to 0 trawl hours (2011/12–2013/14) and increased to 638 trawl hours in 2015/16 (catch: 2,022 t). Trawl effort in the SPF decreased to 349 trawl hours in 2016/17 with a catch of 1,247 t (Figure 3.1e). Mean annual CPUE of Blue Mackerel in mid-water trawls in the SPF was <0.4 $t{\cdot}trawl\ hour^{-1}$ prior to 2014/15 (Figure 3.1f). CPUE increased to 7 $t{\cdot}trawl\ hour^{-1}$ in 2014/15 and was 4 $t{\cdot}trawl\ hour^{-1}$ in 2016/17 (Figure 3.1f).

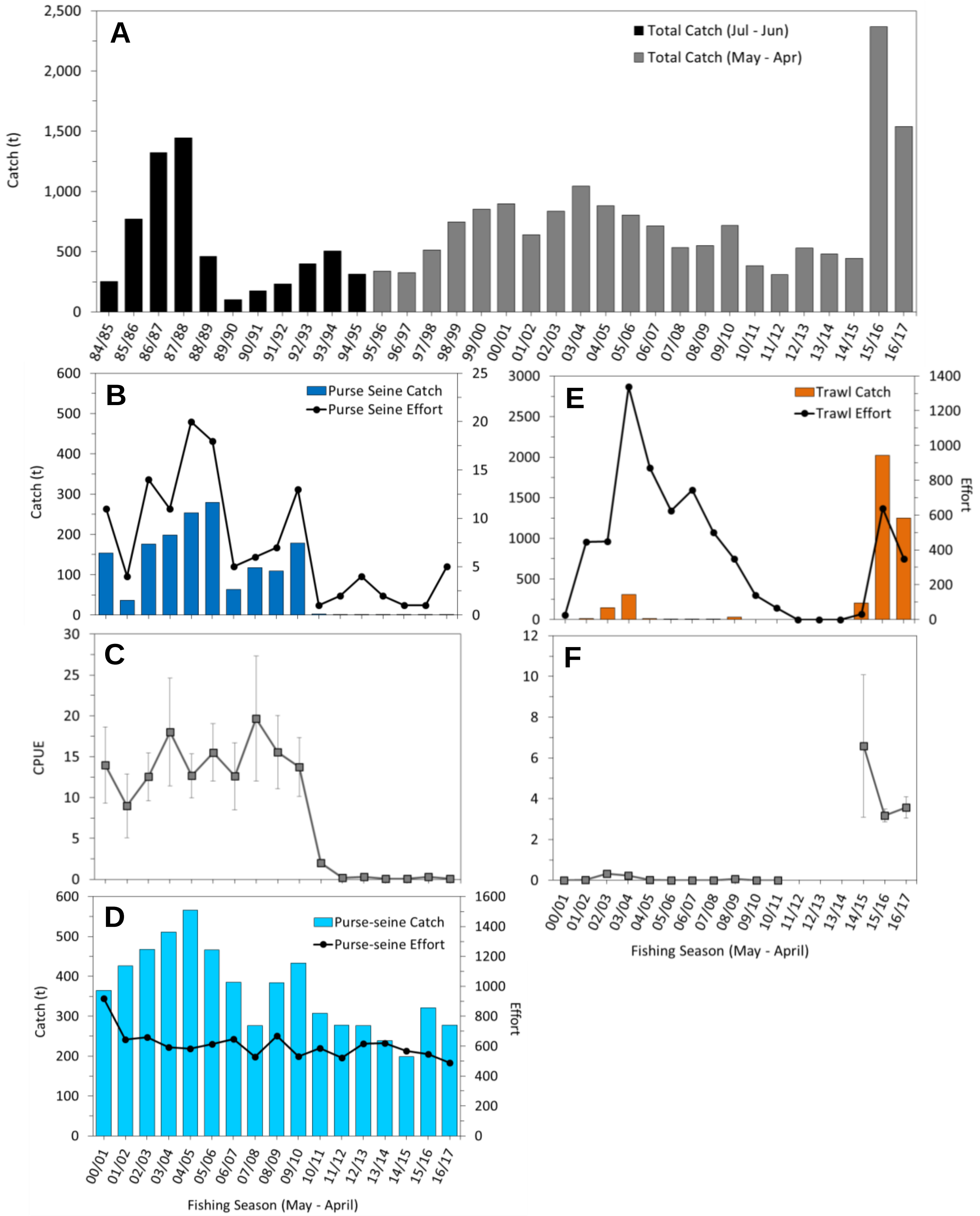


Figure 3.1. Fishery statistics for Blue Mackerel East. (A) Total annual landed catch (tonnes) for all jurisdictions from 1984/85 to 2016/17; black bars: catch per financial year; grey bars: catch per fishing season. Long-term purse seining trends in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets); (C) mean annual CPUE (t·net-set^{-1}; ±SE). Long-term mid-water trawling trends in the SPF: (E) annual landed catch (tonnes) and effort (trawl hours); (F) mean annual CPUE (t·trawl hour^{-1}; ±SE).

3.3.1.2 Biological Information

Length-frequency data were collected from 6,632 Blue Mackerel sampled from commercial purse seine catches off New South Wales between 2006/07 and 2014/15 (Table 3.1). Information on the spatial and temporal coverage of these samples relative to fishery production in New South Wales was not available. In 2014/15, length-frequency data for the SPF were collected from 264 Blue Mackerel sampled from midwater trawl catches in the East sub-area during April 2015. Age-frequency data were obtained from 105 of those fish (Table 3.2). During 2015/16, length-frequency data were collected from 65 catch samples (3,104 fish) with age-frequencies collected from 7 samples and 77 fish (Table 3.2). In 2016/17, length-frequency data were collected from 22 samples (n = 1,090). Age frequency data are not yet available for 2016/17. No biological data were available from Victoria, which has accounted for ~16% of the annual catch in the East over the last 10 years (2005/06–2015/16). Biological samples from New South Wales may not be representative of Blue Mackerel harvested throughout the East sub-area.

Table 3.1. Summary of Blue Mackerel samples collected from commercial New South Wales State catches between 2006/07 and 2014/15 (data supplied by New South Wales DPI).

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Size range (mm FL)
2006/07	East	purse seine	23	1,869	220–400
2007/08	East	purse seine	13	1,286	160–340
2011/12	East	purse seine	13	810	180–390
2012/13	East	purse seine	2	108	280–370
2013/14	East	purse seine	11	1,177	170–360
2014/15	East	purse seine	12	1,382	180–370

Table 3.2. Summary of Blue Mackerel East catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)
2014/15	East	mid-water trawl	7	264	105	242–342	2–8
2015/16	East	mid-water trawl	65 (7)	3,104	77	187–398	2–7
2016/17	East	mid-water trawl	22 (–)	1,090	–	173-351	–

<u>Size structure</u>

Purse seine fishery (NSW): 2006/07–2014/15

There were substantial differences in the size distributions among years of Blue Mackerel East sampled from purse seine catches (Figure 3.2). Fish ranged from 160 to 400 mm FL (Table 3.1). From 2006/07 to 2012/13 (excepting 2007/08), size distributions contained a single mode between 290 and 310 mm FL; the bimodal distribution of 2007/08 had modes at 240 mm FL and 280 mm FL. In 2013/14 and 2014/15, the size distribution included fish from 170 to 370 mm FL, with a single mode at 250 mm FL in each year (Figure 3.2).

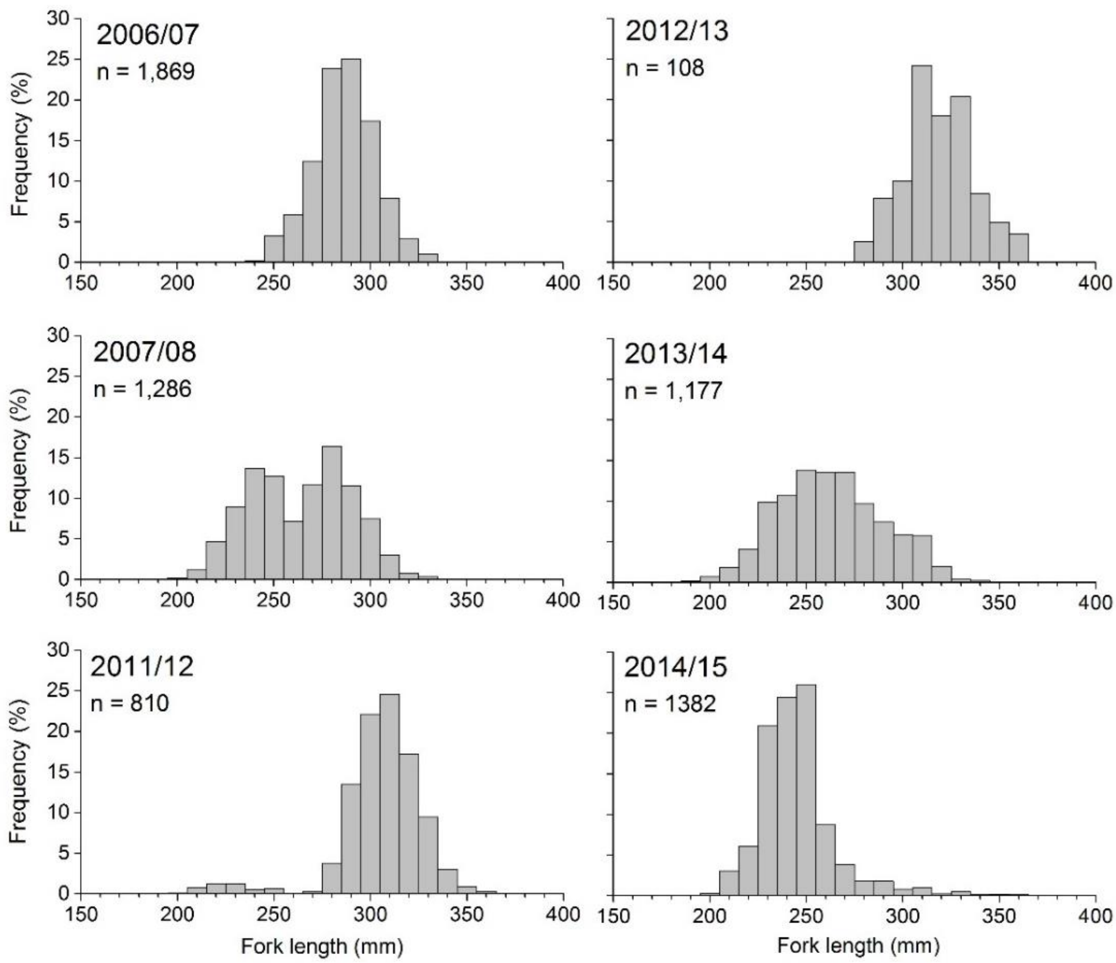


Figure 3.2. Length-frequency distributions of Blue Mackerel East collected from purse seine net-sets in New South Wales between 2006/07 and 2014/15. Data supplied by New South Wales DPI; n = number of fish. See Table 3.1 for sample N.

Mid-water trawl fishery: 2014/15–2016/17

The modal length of Blue Mackerel East from mid-water trawl catch samples during 2014/15 was 280 mm FL, with fish sizes ranging from 242 to 342 mm FL (Figure 3.3; Table 3.2). The modal length decreased to 270 mm FL in 2015/16 (range: 187–398 mm FL) and to 260-270 mm FL (range: in 2016/17 (range: 173-351 mm FL). These length-frequency distributions are similar to those from purse seine catches taken in the East (Figures 3.2–3.3).

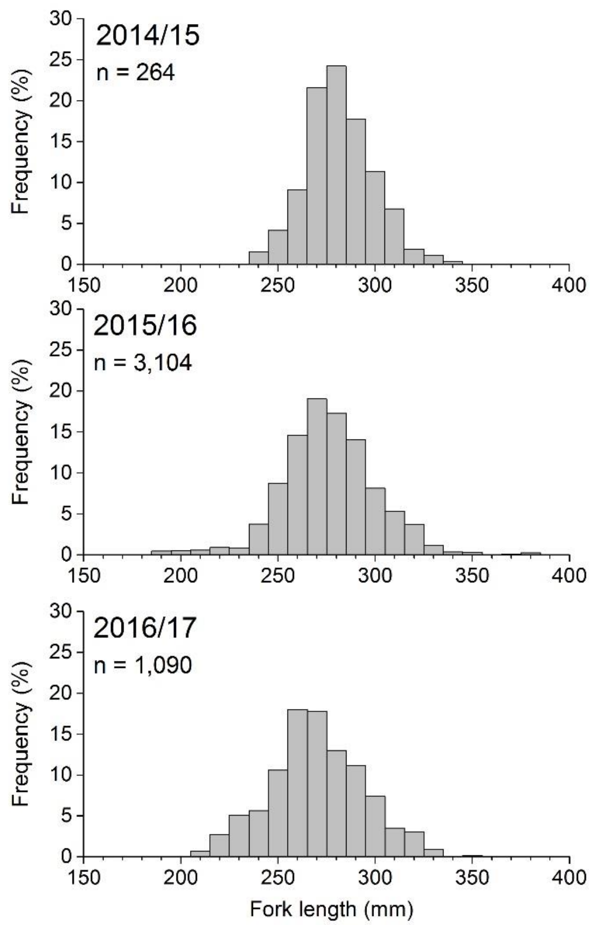


Figure 3.3. Length-frequency distribution of Blue Mackerel East caught by mid-water trawl in the SPF from 2014/15 to 2016/17. n = number of fish. See Table 3.2 for sample N.

<u>Age structure</u>

Mid-water trawl fishery: 2014/15–2015/16

The age structure of Blue Mackerel East caught in mid-water trawls was dominated by 3 to 4 year old fish in 2014/15 (52%) and ages ranged from 1 to 8 years (age mode: 3 years; Figure 3.4). The modal age was also 3 years in 2015/16, but 85% of the fish were 3–4 year olds. In 2015/16, ages ranged from 2 to 7 years.

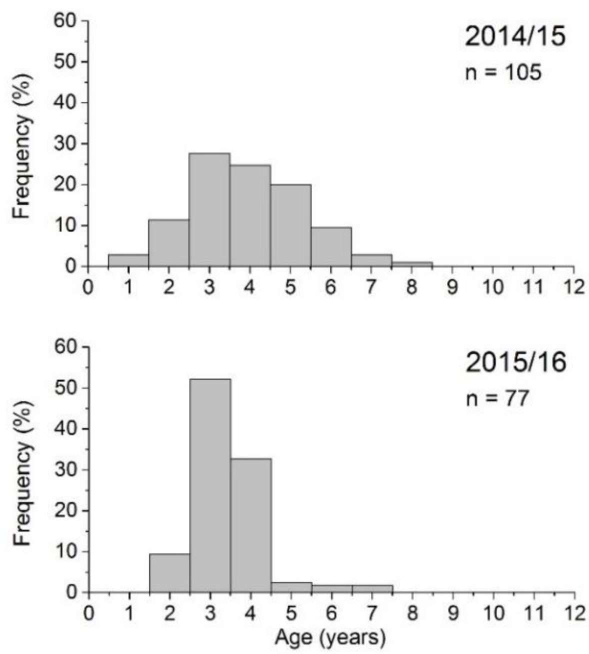


Figure 3.4. Age-frequency distributions of Blue Mackerel East caught by mid-water trawl in the SPF from 2014/15 to 2015/16; n = number of fish. See Table 3.2 for sample N.

3.3.2 Blue Mackerel West

3.3.2.1 Fishery statistics

Number of vessels

The number of vessels reporting catches of Blue Mackerel West declined from a high of 26 vessels in 2008/09 to 5 vessels in 2013/14. During 2016/17, 6 vessels reported catches of Blue Mackerel West; vessel numbers have ranged from 5 to 13 since 2009/10.

Annual patterns: Total catch

Total annual catches of Blue Mackerel West were low in the mid/late 1990s and early 2000s (<65 t) and increased to >2000 t in both 2006/07 and 2008/09 (Figure 3.10). Since then, annual catches decreased to <2 t in 2012/13, remained low through 2014/15 and increased to 980 t in 2015/16 (Figure 3.10). The total annual catch in 2016/17 was 767 t. Historically, the SPF has been the main fishery taking Blue Mackerel West.

Annual patterns: Catch, Effort and CPUE

Purse seines have historically been the main gear type used in the SPF for Blue Mackerel West, and purse seining effort has been variable since 2000/01 (Figure 3.11). Catch and effort peaked in the mid- to late-2000s with effort ranging from 16 to 75 net-sets annually (Figure 3.11). Purse seine effort and catch in the SPF has decreased since 2007/08, with zero effort reported since 2011/12. Mean annual CPUE of purse seines in the SPF decreased from a peak of 41 $t \cdot net\text{-}set^{-1}$ in 2006/07 to 9 $t \cdot net\text{-}set^{-1}$ in 2010/11 (Figure 3.12).

Prior to 2015/16, SPF catches of SPF for Blue Mackerel West (Figure 3.13). Trawl effort increased in the mid-2000s (range: 260–625 trawl hours) when a multi-purpose 50 m mid-water trawler began targeting small pelagic species, particularly Redbait and Jack Mackerel, off Tasmania. In 2015/16, mid-water trawl effort in the SPF increased to 472 trawl hours with a Blue Mackerel catch of 980 t (Figure 3.13). Effort decreased to 365 trawl hours in 2016/17 with 766 t of catch. Mean annual CPUE of mid-water trawls in the SPF was <1 $t \cdot trawl\ hour^{-1}$ prior to 2015/16 and was 2 $t \cdot trawl\ hour^{-1}$ in both 2015/16 and 2016/17 (Figure 3.14).

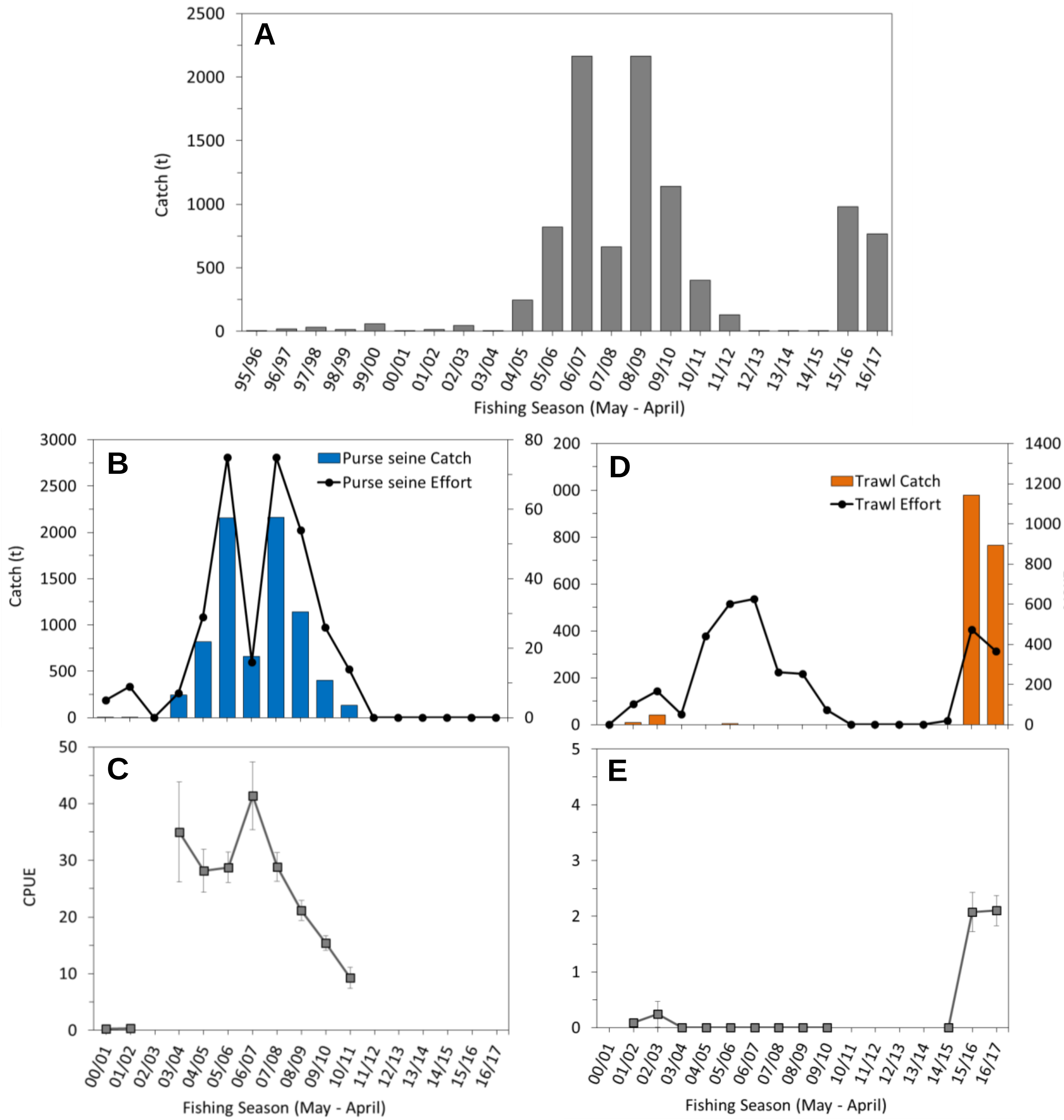


Figure 3.5. Fishery statistics for Blue Mackerel West. (A) Total annual landed catch (tonnes) for all jurisdictions by fishing season from 1984/85 to 2016/17. Long-term trends in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets) by purse seine; (C) mean annual CPUE (t·net-set^{-1}; ±SE) by purse seine; (D) annual landed catch (tonnes) and effort (trawl hours) by mid-water trawl; (E) mean annual CPUE (t·trawl hour^{-1}; ±SE) by mid-water trawl.

3.3.2.2 Biological Information

Sample Summary

Samples of Blue Mackerel West for biological analysis were collected from purse seine catches taken off South Australia (Table 3.3). A total of 1,257 fish were sampled over the three years; sex ratios were close to 1:1 but with slightly more females than males (Table 3.3). Blue Mackerel West catches from 2008/09 to 2010/11 were limited to the summer/early autumn period; biological samples from these catches may not be representative of the population. No samples were collected from 2011/12 to 2014/15, due to low levels of fishing activity. In 2015/16, length-frequency data were collected from 9 catch samples (142 fish), and age-frequencies were collected from 117 of those fish (Table 3.3). In 2016/17, length-frequency data were collected from 22 samples (n = 1,024). Age frequency data are not yet available for 2016/17.

Table 3.3. Summary of Blue Mackerel West catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)	Sex ratio M:F
2008/09	West	purse seine	1	79	74	316–390	3–6	1:1
2009/10	West	purse seine	28	933	396	245–400	2–8	0.9:1
2010/11	West	purse seine	8	245	180	293–395	3–8	0.9:1
2015/16	West	mid-water trawl	9	142	102	239–403	0–11	
2016/17	West	mid-water trawl	22 (–)	1,024	–	229–425	–	

Size structure

Purse seine fishery: 2008/09–2010/11

Blue Mackerel West sampled during 2008/09 off South Australia ranged from 320 to 390 mm FL (Figure 3.15); >50% of fish were between 340 and 370 mm FL. In 2009/10 and 2010/11, most fish ranged between 300 and 400 mm FL. Annual modal lengths of Blue Mackerel from purse seine catches in the West (350–370 mm FL; Figure 3.15) were larger than those of fish caught in the East (250–310 mm FL; Figures 3.7–3.8).

Mid-water trawl fishery: 2015/16–2016/17

The modal length of Blue Mackerel West from mid-water trawl catch samples in 2015/16 was 320 mm FL (range: 239–403 mm FL) and increased to 370 mm FL (range: 229–425 mm FL) in 2016/17 (Figure 3.16; Table 3.3). The length-frequency distributions are similar to purse seine catches in the West, and the modal length is larger than in the East (250–310 mm FL; Figures 3.7–3.8).

Figure 3.6. Length-frequency distributions of Blue Mackerel West caught by purse seine in the SPF from 2008/09 to 2010/11; n = number of fish. See Table 3.3 for sample N.

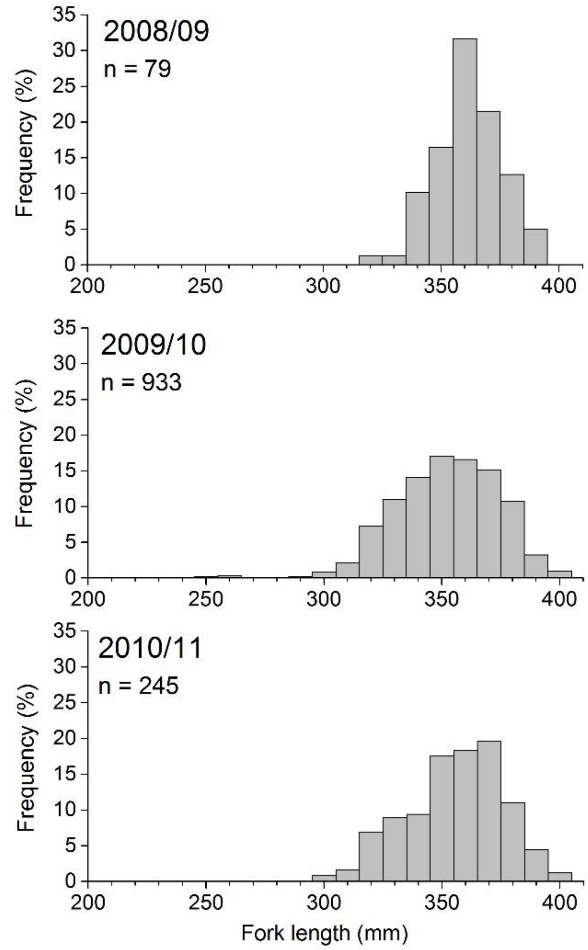
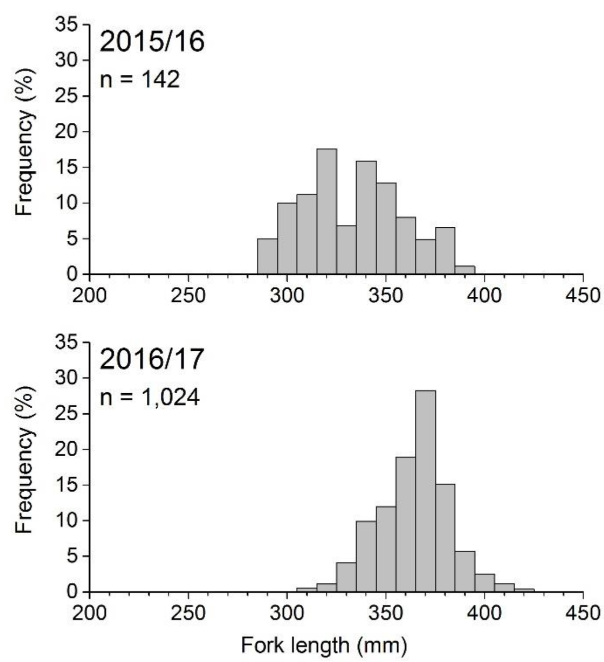


Figure 3.7. Length-frequency distributions of Blue Mackerel West caught by mid-water trawl in the SPF during 2016/17; n = number of fish. See Table 3.3 for sample N.



<u>Age structure</u>

Purse seine fishery: 2008/09–2010/11

In 2008/09, the age of fish in purse seine catches ranged from 3 to 6 years (Figure 3.8); 82% of fish were 4 to 5 years old. A similar age structure was found in 2009/10 and 2010/11, but some fish were up to 8 years old. In all years, most fish were older than 3 years.

Mid-water trawl fishery: 2015/16

The modal age of Blue Mackerel West caught in mid-water trawls in 2015/16 was 5 years (Figure 3.9). Fish ages ranged from 1 to 11 years and 3 to 7 year olds made up 81% of the age structure.

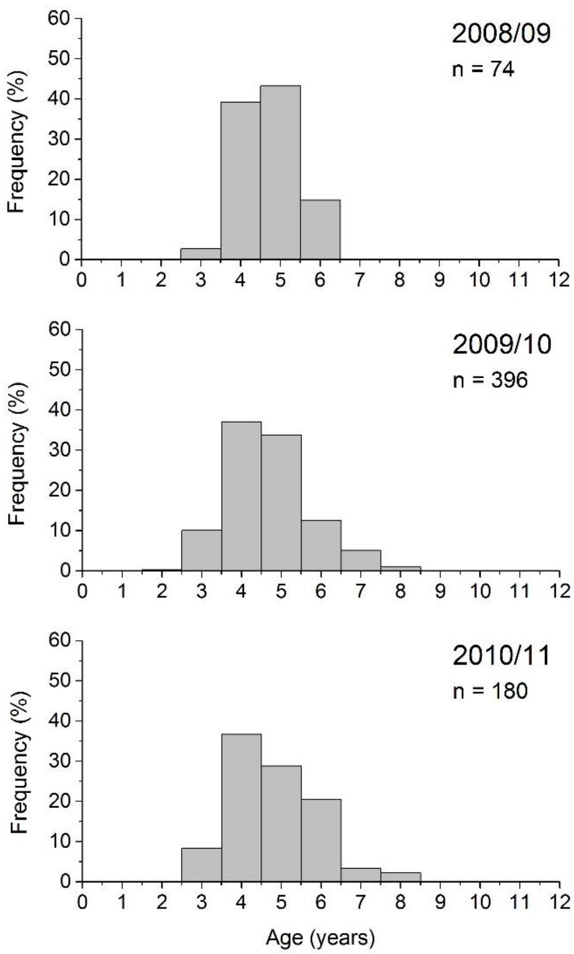


Figure 3.9. Age-frequency distribution for Blue Mackerel West caught by purse seine in the SPF from 2008/09 to 2010/11; n = number of fish. See Table 3.3 for sample N.

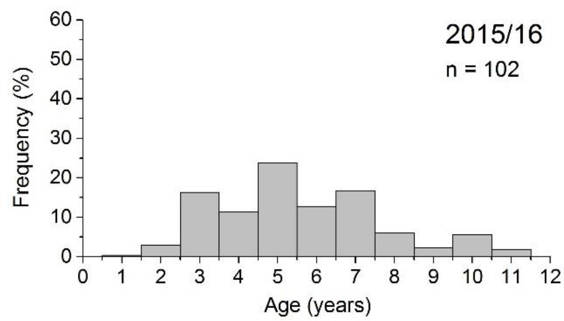


Figure 3.8. Age-frequency distribution for Blue Mackerel West caught by mid-water trawl in the SPF during 2015/16; n = number of fish. See Table 3.3 for sample N.

3.4 Summary and Conclusions

3.4.1 Blue Mackerel East

The spawning biomass of Blue Mackerel East during 2014 was estimated to be ~83,300 t (95% CI = 35,100–165,000 t; Ward et al. 2015b), which is higher than the preliminary estimate obtained for Blue Mackerel East in 2004 of 23,009 t (Ward and Rogers 2007; Ward et al. 2009). Ward et al. (2015b) recommended that the estimate of spawning biomass for 2014 should be used with caution due to uncertainty in the estimates of adult parameters, especially spawning fraction.

Total catches of Blue Mackerel East declined from ~1,400 t in 1986/87 to ~100 t in 1989/90, increased to 1,045 t in 2003/04 and decreased to 309 t in 2011/12. In the SPF, there has been a long-term decline in purse seine effort for Blue Mackerel East with increased mid-water trawl effort since 2014/15. The total catch increased to a peak of 2,368 t in 2015/16 and decreased to 1,539 t in 2016/17. Mean annual CPUE of mid-water trawls in the SPF was 7 t·trawl hour^{-1} in 2014/15 and 4 t·trawl hour^{-1} in 2016/17. Changes in total catch reflect changes in fishing effort.

The size structures from commercial mid-water trawl catch samples since 2014/15 (modal length: 260–280 mm FL) were larger compared to the 2014/15 purse seine structure (modal length: 250 mm FL). Size structures of Blue Mackerel East in purse seine catches since 2006/07 have varied among years, and the modal length has reduced since 2012/13. Modal lengths of Blue Mackerel East from mid-water trawl catches have been at or above the mean size at 50% maturity (~260 mm FL; Ward and Rogers 2007), with age classes of mainly 3–5 years. Age and length structures are difficult to interpret due to limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time.

Recent catches of Blue Mackerel East are assessed as sustainable, as they are <2% of the estimated spawning biomass for 2014 (Ward et al. 2015b), and well below Tier 1 exploitation rate for this stock of 15% (Smith et al. 2015). Stewardson et al. (2016) also found that the biological stock of Blue Mackerel East is sustainable. Patterson et al. (2017) classified Blue Mackerel East as ‘not overfished’ and ‘not subject to overfishing’.

3.4.2 Blue Mackerel West

A preliminary application of the DEPM to Blue Mackerel West off South Australia during 2005 provided a ‘best’ estimate spawning biomass of 56,228 t (Ward and Rogers 2007). This estimate of spawning biomass was considered to be conservative because the survey only covered a limited part of the West sub-area, and there was clear evidence of significant spawning activity outside the survey area in the western Great Australian Bight (Ward and Rogers 2007).

Total annual catches of Blue Mackerel West were low in the late 1990s and early 2000s (<55 t) and increased to >2000 t in 2006/07 and 2008/09. In the SPF, catches have been mainly taken by purse seining prior to 2015/16. Total annual catches decreased to <2 t from 2012/13–2014/15, increased to 980 t in 2015/16 and decreased to 766 t in 2016/17. Mean annual CPUE of purse seines in the SPF peaked at 41 t·net-set^{-1} in 2006/07; CPUE of mid-water trawls rose to 2 t·trawl hour^{-1} in 2015/16 and was the same in 2016/17. Low annual catch in recent years reflects low fishing effort in areas where Blue Mackerel are known to be abundant (e.g. Great Australian Bight).

Blue Mackerel from commercial catch samples from both purse seines and mid-water trawls in the West have been well above the mean size at 50% maturity of ~260 mm FL (Ward and Rogers 2007) and tend to be larger and older than those from the East. In 2015/16, the modal length of Blue Mackerel West from mid-water trawls was 320 mm FL and the modal age class was 5 years (range: 1–11 years). The modal length increased to 370 mm FL (range: 229–425 mm FL) in 2016/17. Age and length structures are difficult to interpret due to the limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time.

Recent catches of Blue Mackerel West are likely sustainable, as they have been <2% of the estimated spawning biomass for 2005 (Ward and Roger 2007) and below the Tier 3 exploitation rate for this stock of 3.75% (Smith et al. 2015). Stewardson et al. (2016) classified the biological stock of Blue Mackerel West as sustainable. The Blue Mackerel stock in the West was classified as ‘not overfished’ and ‘not subject to overfishing’ by Patterson et al. (2017).

4 REDBAIT (*Emmelichthys nitidus*)

4.1 Introduction

4.1.1 Background to Fishery

Redbait was a key by-product species in the Tasmanian Purse Seine Fishery for Jack Mackerel (*Trachurus declivis*) that developed off Tasmania in the mid-1980s. This fishery has recorded catch and effort data since its inception in 1984. Logbooks contain a record of fishing operations and species taken by net-set. Although landings of Redbait rarely exceeded 5% of the total catch in a net-set, annual catches averaged ~700 t from 1984/85 to 1989/90 (Pullen 1994).

Mid-water trawling to target subsurface schools of Jack Mackerel off Tasmania was trialled in 2001/02 (Welsford and Lyle 2003). Between December 2001 and April 2002, a total catch of over 5,000 t of small pelagic fishes was taken; 90% was Redbait. In late 2002, a multi-purpose 50 m mid-water trawler began targeting small pelagic species off Tasmania, particularly Redbait. By mid-2003, more than 7,000 t of small pelagic fishes had been taken, with Redbait dominating the catch. Small-scale purse seine operations were temporarily resumed in response to declining trawl effort in the late 2000s (Emery et al. 2015).

Redbait have primarily been frozen whole for use as feed for farmed Southern Bluefin Tuna (*Thunnus maccoyii*) and have also been used to produce fish meal for the aquaculture industry.

4.1.2 Taxonomy

Redbait (*Emmelichthys nitidus,* Richardson 1845) belong to the family *Emmelichthyidae*, which contains three genera and 15 species (Nelson 2006). 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

Emmelichthyids are found throughout tropical and temperate waters world-wide. Generally, they are found in schools over continental shelf breaks, seamounts and submarine ridges. They inhabit depths from the surface to >800 m, though are mostly recorded from mid-water trawls in 100–400 m water (Heemstra and Randall 1977, Smith and Heemstra 1986, Mel'nikov and Ivanin 1995). Redbait are widely distributed throughout the southern hemisphere, with the species reported from Tristan da Cunha in the southern Atlantic, the south-western coast of South Africa, St Paul and Amsterdam Islands, mid-oceanic ridges and seamounts through the Indian Ocean, Australia, New Zealand, submarine ridges in the south-eastern Pacific, and the southern coast of Chile (Markina and Boldyrev 1980, Meléndez and Céspedes 1986, Parin et al. 1997). Within Australian waters, their range extends from mid New South Wales to south-west Western Australia, including Tasmania (Gomon et al. 2008).

4.1.4 Stock Structure

There have been no studies on the stock structure of Redbait in Australia. However, Redbait from eastern Australia are thought to be a single stock based on spawning dynamics (Bulman et al. 2008). The situation for western Tasmania and the GAB is less clear. Neira et al. (2008) observed that Redbait from eastern and south-western Tasmania exhibit biological differences, which provides some evidence for separation into eastern and western stocks off Tasmania.

4.1.5 Movement

No studies have investigated movement of Redbait.

4.1.6 Food and Feeding

In South African coastal waters, smaller size classes of Redbait (136-280 mm) feed exclusively on small planktonic crustaceans, with euphausiids (*Nyctiphanes* and *Euphausia* spp.), hyperiid amphipods (primarily *Themisto gaudichaudi*), mysids and large copepods comprising the entire diet (Meyer and Smale 1991). Larger Redbait (281–493 mm) also fed primarily on small planktonic crustaceans, but nekton, such as cephalopods, carid shrimp, and small fishes including myctophids, were part of the diet (Meyer and Smale 1991). Redbait captured on the shelf off eastern Victoria (unspecified size) had a varied diet that was dominated by pelagic crustaceans and other invertebrates, including gelatinous zooplankton (Bulman et al. 2000, Bulman et al. 2001). Similarly, Redbait captured off eastern Tasmania consumed mainly pelagic crustaceans, with krill and copepods comprising 66% and 33% of the diet, respectively (McLeod et al. 2012).

The diet of Redbait is similar to that of Jack Mackerel from Tasmania, with krill representing the dominant prey item on the continental shelf (Young et al. 1993, McLeod et al. 2012). Since Redbait and Jack Mackerel form mixed species schools in Tasmanian waters (Williams and Pullen 1993), it is not surprising the two species feed on similar prey.

4.1.7 Age, Growth and Size

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

Growth estimates for Redbait (otolith-based) suggest rapid growth during the first few years (Williams et al. 1987, Neira et al. 2008). On average, Redbait off Tasmania reached >200 mm FL in the first three years, with growth slowing thereafter (Neira et al. 2008). The maximum estimated age for Redbait is 21 years for females and 18 years for males (Neira et al. 2008). The larger Redbait reported from Africa (e.g. Meyer and Smale 1991) suggest that maximum age may be higher than reported for Tasmanian fish or that growth rates vary between regions. Age validation of Rubyfish in New Zealand, using otoliths and the bomb radiocarbon chronometer, has shown fish over 400 mm can be up to 100 years old (Paul et al. 2000, Horn et al. 2012), indicating some emmelichthyids are long-lived.

4.1.8 Reproduction

Redbait is an asynchronous batch spawner with indeterminate fecundity. Annual trends in GSI and macroscopic gonad stages indicated that Redbait from eastern Tasmania spawn between September and November, with a peak in activity during September and October (Ewing and Lyle 2009). A similar pattern was evident for south-western Tasmania, although the peak occurred one month later between October and November (Ewing and Lyle 2009). Spawning occurs along a 2.5 nautical mile (nm) corridor either side of the continental shelf break when mid-water temperatures are 12 to 15.2°C (Neira et al. 2008).

There are regional differences in size and age at sexual maturity for Redbait. Males and females from south-western Tasmania matured ~100 mm larger and two years older than Redbait from eastern Tasmania (Ewing and Lyle 2009). However, Ewing and Lyle (2009) suggested this difference could have resulted from sampling bias due to the different depths fished in each region. The size (age) at 50% sexual maturity for Redbait in eastern Tasmania was 147 mm FL (2 years) for males and 157 mm FL (2 years) for females. In south-western Tasmania, the size (age) at 50% sexual maturity was 244 mm FL (4.8 years) for males and 261 mm FL (4.1 years) for females (Ewing and Lyle 2009).

4.1.9 Early Life History and Recruitment

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

4.1.10 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 DEPM was subsequently applied to estimate the spawning biomass of Redbait East in these years (Neira et al. 2008, Neira and Lyle 2011).

4.1.11 Recreational fishing

There is no known recreational fishery for Redbait in Australia.

4.1.12 Biomass Estimates

East

The DEPM was applied to Redbait East during 2005 and 2006. The survey extended from the north-eastern Bass Strait (38.8°S) to south of the Tasman Peninsula (43.5°S) and involved concurrent sampling of eggs and adults (Neira *et al.* 2008). Estimates of Redbait spawning biomass were 86,994 t (CV: 3.7) in 2005 and 50,782 t (CV: 2.1) in 2006 (Neira and Lyle 2011). These estimates are considered to be negatively biased, as the surveys covered less than half the known spawning area of Redbait in south-eastern Australia (Neira and Lyle 2011).

West

A DEPM survey for Redbait West occurred during October 2017 between Kangaroo Island, South Australia and western Tasmania. This was the first dedicated application of the DEPM to Redbait in the West sub-area; the estimate of spawning biomass will be available in late 2018.

4.1.13 Management Strategy Evaluation

2010

For Redbait East, the DEPM estimate of spawning biomass was 23% of the estimate calculated from the model (Giannini et al. 2010). All Tier 1 scenarios investigated reached equilibrium 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 outputs should be treated with caution as the harvest levels are “absolute” quantities and represent a much smaller proportion of the model biomass than the DEPM estimate of biomass.

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

2015

Smith et al. (2015) concluded the harvest rate of 15% may be too high for Redbait and suggested a Tier 1 harvest rate of 9% for Redbait East and 10% for Redbait West, with the Tier 1 rate being applied for not more than 5 years. Tier 2 harvest rates for Redbait East and West were recommended to be 50% of Tier 1 rates and not to be applied for more than 10 years. The study also indicated that it is not safe to apply Tier 2 harvest rates unchecked for long periods of time (Smith et al. 2015). The Atlantis-SPF biomass estimate for Redbait East is 82,000 t (typical range: 75,000–105,000 t) and 66,000 t (typical range: 59,000–70,000 t) for Redbait West (Smith et al. 2015).

4.1.14 Management

Currently, Redbait east is managed at the Tier 2 level and Redbait West is managed at the Tier 3 level under the SPF HS. A dedicated DEPM assessment of Redbait East occurred in 2005–2006. A dedicated DEPM assessment for Redbait West is currently underway.

4.2 Methods

4.2.1 Fishery Statistics

Fishery statistics from 1995/96 to 2016/17 were provided by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported in fishing seasons (May 1 to April 30) rather than financial years as was done in previous assessments (e.g. Ward et al. 2013, 2014c, 2015c).

Estimates of total annual catch supplied for Redbait East include data from the NSW Ocean Fisheries (Hauling, Trap and Line, Trawl), Victorian Ocean Purse Seine Fishery, Tasmanian Scalefish Fishery and the Commonwealth SPF. In the West, total annual catch estimates include data from the Tasmanian Scalefish Fishery and Commonwealth SPF. Due to data confidentiality (<5 license holders reporting catch in 2016/17), fishery data from Victoria were not available and are not included in total annual catch statistics for 2016/17.

Mean annual CPUE of Redbait in the Commonwealth SPF by sub-area is calculated for the gear types of mid-water trawl (tonnes·trawl hour^{-1} ±SE) and purse-seine (tonnes·net-set^{-1} ±SE) from 2000/01 to 2016/17. Zero catch of Redbait in a trawl was assumed when effort but not catch was reported in the logbook record.

4.2.2 Biological Information

Fishery-dependent length frequency and biological data were collected for Redbait between 1984 and 1993 as part of a monitoring program of the Jack Mackerel Purse seine Fishery off Tasmania. Some biological information was obtained from samples collected between 1985 and 1990 from demersal research trawls conducted by CSIRO and the Tasmanian fisheries agency. Between 1994 and 2001, there was limited catch sampling of the purse seine fishery.

Biological data were collected by AFMA observers from a small proportion of trips during the 2001/02 pair-trawl fishing trials undertaken off Tasmania. When mid-water trawl operations started in 2002, TAFI began an intensive biological monitoring program that continued to 2006. AFMA also provided observer coverage of mid-water trawl operations, with additional length-frequency data collected from 2002 to 2008.

Purse seine operations for small pelagic fish resumed in Tasmanian State waters in 2008/09, mainly targeting Redbait and Jack Mackerel. Catch sampling of mid-water trawl and purse seine operations adjacent to Tasmania began in 2009/10 as part of the SPF monitoring program under the SPF HS (AFMA 2008). Catch samples were not collected for Redbait from 2010/11 to 2013/14 due to limited fishing activity. Catch sampling by AFMA observers resumed in the SPF during 2014/15. Samples of Redbait were collected (n = 50 randomly selected fish per trawl) and supplied to SARDI Aquatic Sciences to estimate the size and age composition of the catch.

Biological data collected from each fish include: body length (mm FL), total weight (±1 g), sex, gonad developmental stage (following the macroscopic staging criteria described in Neira et al. 2008) and gonad weight (±0.1 g). Gonad stages were designated as: I) immature; II) maturing virgins or recovering spent; III) maturing; IV) ripe; and V) spent. Otoliths were removed from random sub-samples of the fish for age determination. The age structure of Redbait prior to 2014/15 was estimated using age-length keys based on age data pooled between 2001/02 to 2005/06. From 2014/15 to present, ages for Redbait have been based on annual growth increment counts in thin-sectioned otoliths (sub-samples of 5 to 10 fish per sample). Age structure data for catch samples collected in 2016/17 are not yet available and will be presented in the 2017/18 SPF assessment report.

Catch weighting was applied to length- and age-frequency data collected since 2015/16 in each sub-area. Length- and age-frequencies were weighted by the number of fish sampled per trawl to account for uneven sample sizes and then were catch weighted by the total amount of Redbait taken in the same trawl.

Commercial logbook information, length-frequency and biological data collected between 1984 and 2017 are included in this assessment. In addition to current catch samples, age, growth and reproductive data for Redbait were available from previous studies (i.e. Welsford and Lyle 2003 and Neira et al. 2008). Summarised biological data prior to 2014/15 are presented in financial years. From 2014/15 to present, all SPF catch sampling data are presented in fishing seasons from 1 May to 30 April.

4.3 Results

4.3.1 Redbait East

4.3.1.1 Fishery Statistics

Number of vessels

Since 1995/96, a limited number of vessels have reported catches of Redbait East; annual vessels numbers have ranged from zero to seven. On average, over the last 21 years, four boats per year have reported catches of Redbait East. On average, ~50% of the vessels reporting catch in each year are Commonwealth vessels. Since 2013/14, only 1 vessel annually has landed Redbait East.

Annual patterns: Total catch

Due data confidentiality (<5 license holders reporting catch per year), only SPF catches are reported. From 1995/96 to 2000/01, Redbait East catches did not exceed 315 t, and purse seining was the prevailing method (Figure 4.1a). Mid-water trawling began to replace purse seining in the early 2000s (Figure 4.1a). With the change to mid-water trawling, catches increased to 3,610 t in 2001/02 and peaked at 7,728 t in 2003/04. From then onwards, annual catches declined to 75 t in 2010/11. No catches of Redbait East were reported from 2011/12 to 2013/14; 217 t were taken in 2015/16 and 101 t in 2016/17.

Annual patterns: Catch, Effort and CPUE

There has been limited use of purse seines in the SPF for Redbait East; mid-water trawls have historically been the main gear type (Figures 4.1a). Since 2000/01, purse seine effort has not exceeded 7 net-sets with a maximum catch of 54 t in 2004/05 (Figure 4.1b). There has been no reported purse seine effort and catch of Redbait East in the SPF since 2008/09 (Figure 4.1b). Mean annual CPUE of purse seining in the East peaked in 2004/05 (8 $t \cdot net\text{-}set^{-1}$) and decreased to ≤3 $t \cdot net\text{-}set^{-1}$ in 2005/06–2006/07, with minimal to no fishing in other years (Figure 4.1c).

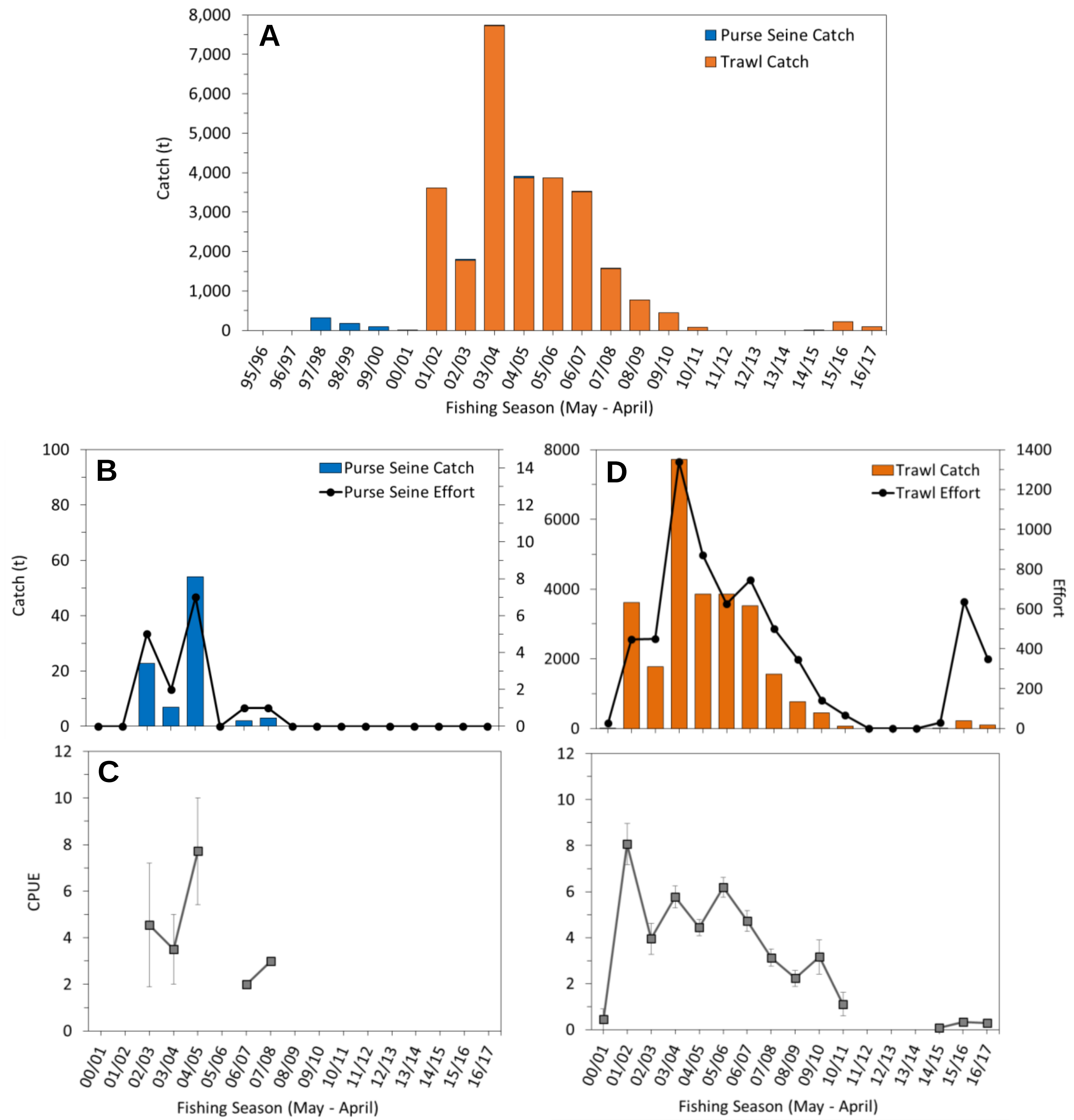


Figure 4.1. Fishery statistics for Redbait East. (A) Total annual landed catch (tonnes) in the SPF taken by purse seining and mid-water trawling from 1995/96 to 2016/17. Long-term trends in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets) by purse seine; (C) mean annual CPUE (t·net-set^{-1}; ±SE) by purse seine; (D) annual landed catch (tonnes) and effort (trawl hours) by mid-water trawl; (E) mean annual CPUE (t·trawl hour^{-1}; ±SE) by mid-water trawl.

Mid-water trawl effort in the SPF for Redbait East peaked at 1,338 trawl hours (catch: 7,721 t) in 2003/04, decreased to 0 trawl hours (2011/12 to 2013/14) and increased to 638 trawl hours (catch: 217 t) in 2015/16 (Figure 4.1d). In 2016/17, trawl effort decreased to 349 trawl hours (catch: 101 t). Mean annual CPUE of Redbait in mid-water trawls in the SPF declined from 8 t·trawl hour^{-1} in 2001/02 to 1 t·trawl hour^{-1} in 2010/11, with no further activity until 2014/15 (Figure 4.1e). Mean annual CPUE was <1 t·trawl hour^{-1} in 2016/17 (Figure 4.1e).

4.3.1.2 Biological Information

Catch sampling of Redbait East has varied since 2009/10 due to limited commercial fishing in the SPF. During 2009/10, 494 fish were collected from purse seines and 393 fish from mid-water trawls (Table 4.1). Catch samples were not collected from 2010/11 to 2013/14. Catch sampling in the SPF resumed in 2014/15, and length-frequency data were collected from 62 Redbait (age-frequency n: 42) sampled from mid-water trawl catches off southern New South Wales (Table 4.1). During 2015/16, length-frequency data were collected from 39 catch samples (2,091 fish) with age-frequencies collected from 6 samples (77 fish) (Table 4.1). In 2016/17, length-frequency data were collected from 5 samples (n = 242). Age frequency data are not yet available for 2016/17.

Table 4.1. Summary of Redbait East catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)
2009/10	East	purse seine	6	494	140	170–230	1–5
2009/10	East	mid-water trawl	6	393	120	170–300	1–9
2014/15	East	mid-water trawl	3	62	42	200–275	2–14
2015/16	East	mid-water trawl	39 (6)	2,091	77	94–277	0–13
2016/17	East	mid-water trawl	5 (–)	242	–	119–278	–

<u>Size structure</u>

The purse seine fishery: 1984/85 to 1993/94 and 2009/10

Purse seine catches of Redbait between 1984/85 and 1994/95 off eastern Tasmania mainly contained fish between 140 and 290 mm FL (max length: 320 mm FL; Figure 4.2). Catches between 1984/85 and 1987/88 were dominated by fish from 200–300 mm FL, with only a few small fish (100–140 mm FL) caught in 1985/86. A strong cohort of smaller fish (120–170 mm FL) was present in the size structure for 1988/89 and accounted for most of the catch in the following year. Between 1989/90 and 2009/10, smaller fish (<200 mm FL) were prevalent in the catch (Figure 4.2). No catch samples have been collected from purse seines since 2009/10.

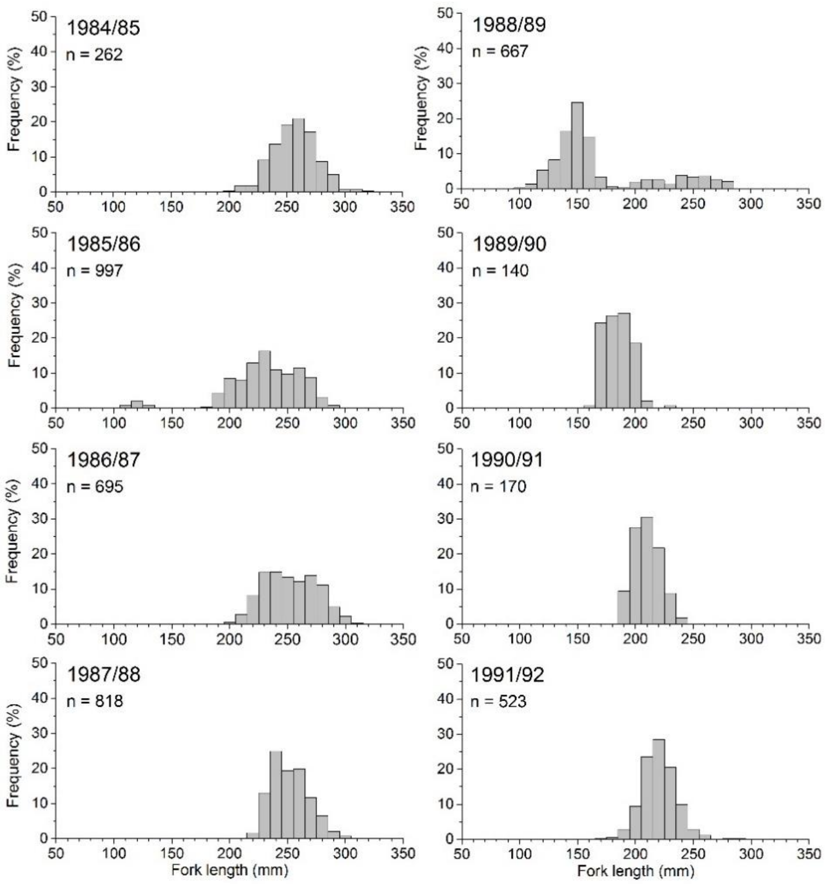


Figure 4.2. Length-frequency distributions (mm FL) of Redbait caught in the SPF by purse seine from 1984/85 to 1993/94 and in 2009/10. n = number of fish.

Mid-water trawl fishery: 2001/02–2016/17

Redbait East caught by mid-water trawl operations between 2001/02 and 2007/08 off eastern Tasmania were considerably smaller than those caught by the earlier purse seine operations, with individuals mainly between 100 and 200 mm FL (Figures 4.2–4.3). Redbait East catches contained a high proportion of small fish with modes varying between 110 and 180 mm FL (Figure 4.3). Only a small proportion of the catch was made up of fish larger than 200 mm FL.

The size structure of Redbait East in mid-water trawl catches increased during 2009/10; fish were primarily 190–240 mm FL (modal length: 190 mm FL; Figure 4.3). The size structure continued to increase through 2015/16 (modal length: 230 mm FL; Figure 4.3). In 2016/17, the modal length decreased to 200 mm FL. The size structures of recent mid-water trawl catches have been larger than those of purse seine catches in 2009/10 (Figures 4.2–4.3; Table 4.1).

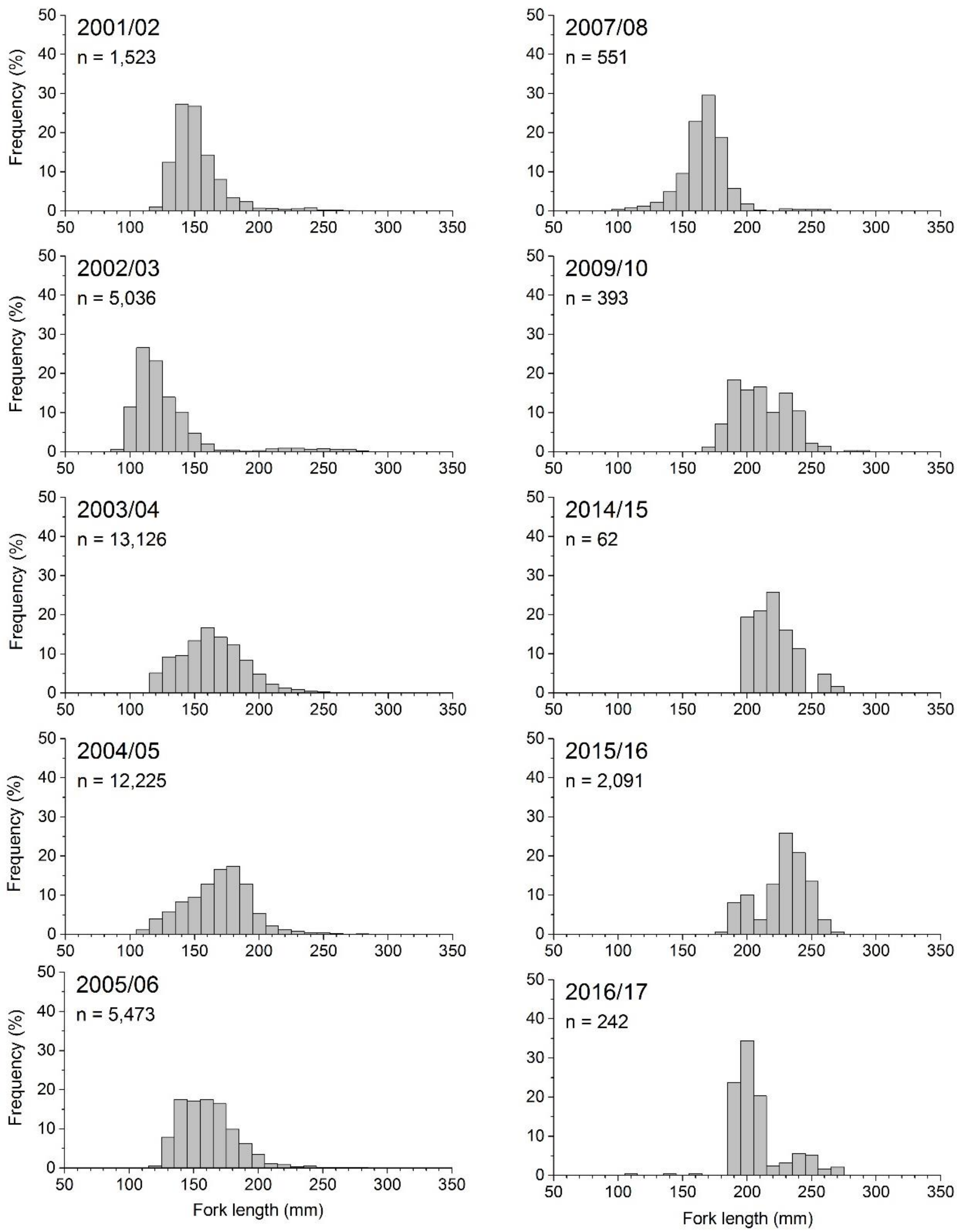


Figure 4.3. Length-frequency distributions of Redbait East caught by mid-water trawl in the SPF from 2001/02 to 2016/17. n = number of fish. See Table 4.1 for sample N since 2009/10.

Age structure

The purse seine fishery: 2009/10

Purse seine catches off eastern Tasmania mainly contained 2–3 year old fish in 2009/10, with 2 year olds making up >50% of the catch (Figure 4.4). Age data for Redbait East caught by purse seine in the SPF were not available for other years.

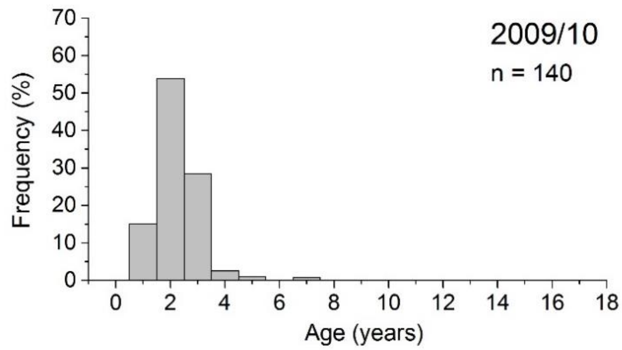


Figure 4.4. Age-frequency distribution of Redbait East caught by purse seine in the SPF during 2009/10; n = number of fish. See Table 4.1 for sample N.

Mid-water trawl fishery: 2001/02–2015/16

Mid-water trawl catches of Redbait East mainly comprised fish between 1 and 5 years with maximum ages of 14 years (Figure 4.5). Catches off eastern Tasmania were dominated by 1 and 2 year olds from 2001/02 to 2002/03; during 2003/04 to 2009/10, the age structure shifted to 2 and 3 year olds (Figure 4.5). Mid-water trawl catches of 2009/10 had slightly older age structures than purse seine catches in the same year (Table 4.1; Figures 4.4–4.5). In 2014/15, the age structure comprised an increasing proportion of older fish: 51% of the fish were 3 to 4 years old (Figure 4.5). The presence of greater ages in the age structure is again seen in 2015/16 where the modal age is 8 years, and there is a greater proportion of fish between 8 and 13 years (Figure 4.5).

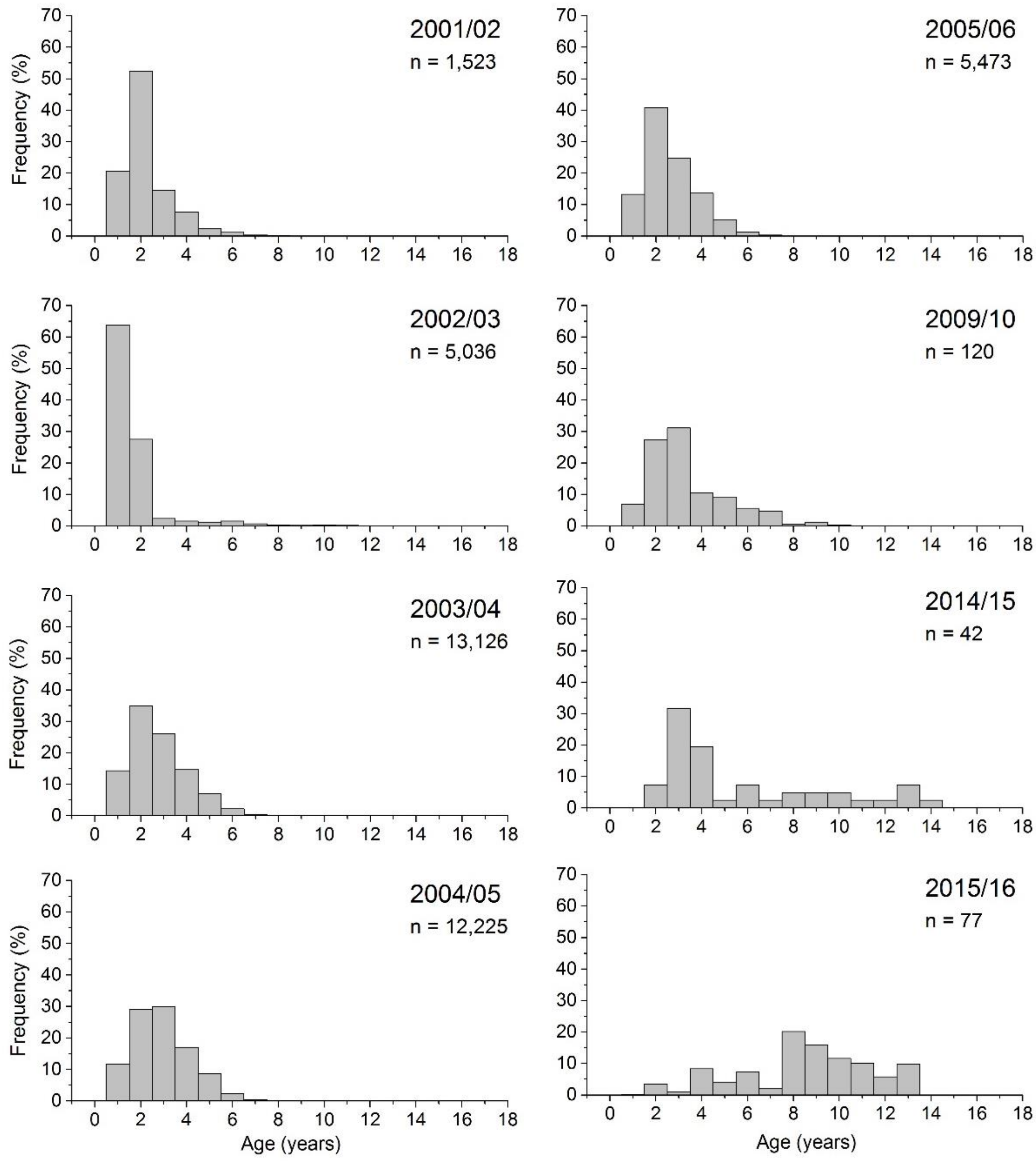


Figure 4.5. Age-frequency distributions of Redbait East caught by mid-water trawl in the SPF from 2001/02 to 2015/16; n = number of fish. See Table 4.1 for sample N since 2009/10.

4.3.2 Redbait West

4.3.2.1 Fishery Statistics

Number of vessels

In the West sub-area of the SPF, the number of vessels reporting catches of Redbait since 1995/96 were lower than those in the East: the annual average has been 1 boat per year. The SPF is the principal fishery reporting catches of Redbait West. From 2011/12 to 2014/15, no vessels reported catches of Redbait West; 1 vessel landed Redbait West in 2015/16 and 2016/17.

Annual patterns: Total catch

Due data confidentiality (<5 license holders reporting catch per year), only SPF catches are reported. Historically, Redbait catches in the West sub-area have been lower than those in the East, but follow a similar temporal trend (Figure 4.6a). Mid-water trawling has been the primary method used to target Redbait West. From 1995/96 to 2000/01, there were no reported catches of Redbait West; annual catches began increasing in 2001/02, peaked at 3,228 t in 2006/07 and declined to 298 t in 2009/10 (Figure 4.6a). Redbait was not caught again in the West sub-area until 2015/16 (1,157 t). In 2016/17, 1,140 t of Redbait West were taken (Figure 4.6a).

Annual patterns: Catch, Effort and CPUE

In the SPF during the mid-2000s, mid-water trawling effort for Redbait West (442–625 trawl hours) peaked in the years the catch was highest (2,511–3,228 t; Figure 4.6b). No fishing effort was reported for Redbait West from 2010/11 to 2013/14 (Figure 4.6b). Effort began increasing in 2014/15, peaked at 472 trawl hours (catch: 1,157 t) in 2015/16, and decreased to 365 trawl hours (catch: 1,140 t) in 2016/17 (Figure 4.6b). Mean annual CPUE of mid-water trawls for Redbait West decreased from 11 $t \cdot trawl\ hour^{-1}$ in 2001/02 to 4 $t \cdot trawl\ hour^{-1}$ in 2009/10, with no effort reported until 2014/15 (Figure 4.6c). Mean annual CPUE increased to 3 $t \cdot trawl\ hour^{-1}$ in 2016/17 (Figure 4.6c).

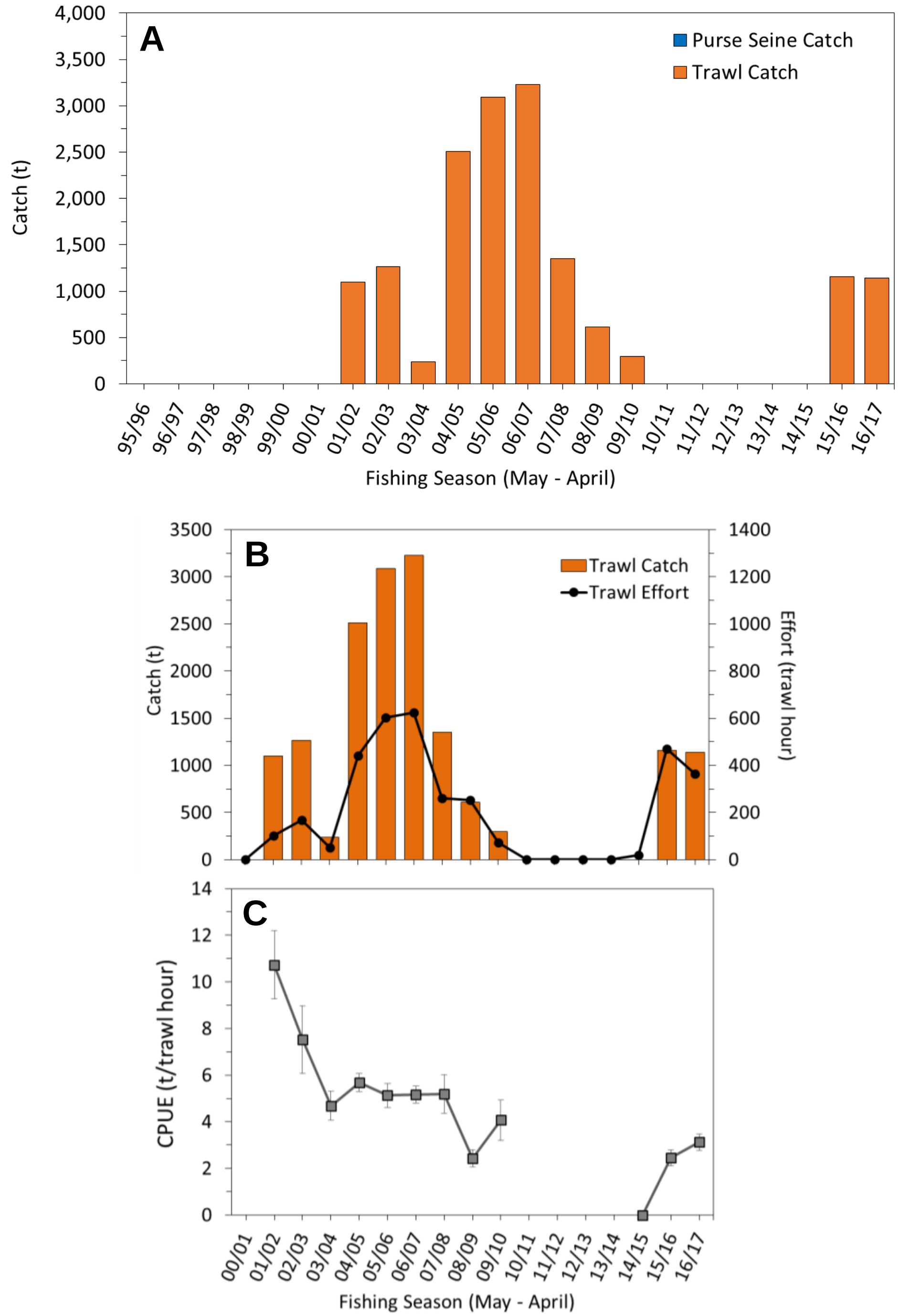


Figure 4.6. Fishery statistics for Redbait West. (A) Total annual landed catch (tonnes) in the SPF taken by purse seining and mid-water trawling from 1995/96 to 2016/17. Long-term trends of mid-water trawling in the SPF by fishing season from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (trawl hours); (C) mean annual CPUE (t·trawl hour^{-1}; ±SE).

4.3.2.2 Biological Information

Catch sampling of Redbait West has varied since 2009/10 due to limited commercial fishing in the SPF. During 2009/10, 77 fish were collected from mid-water trawls (Table 4.2). Catch samples were not collected from 2010/11 to 2014/15. Catch sampling in the SPF for Redbait West resumed in 2015/16; length-frequency data were collected from 19 catch samples (1,529 fish) and age-frequencies from 6 samples (120 fish). In 2016/17, length-frequency data were collected from 26 catch samples (1,241 fish; Table 4.2). Age frequency data are not yet available for 2016/17.

Table 4.2. Summary of Redbait West catch samples collected from commercial SPF landings. Note: number of samples in brackets is number for age frequency if different from length frequency.

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)
2009/10	West	mid-water trawl	1	77	20	210–310	2–13
2015/16	West	mid-water trawl	19 (6)	1,529	120	94–291	0–7
2016/17	West	mid-water trawl	26 (–)	1,241	–	148–304	–

<u>Size structure</u>

Mid-water trawl fishery: 2001/02–2016/17

Redbait West from mid-water trawl catches off south-western Tasmania during 2001/02 to 2007/08 ranged mainly from 130–280 mm FL (overall modal length: 200 mm FL; Figure 4.7). Redbait West taken over this time period were larger than those from the East (overall modal length: 160 mm FL; Figure 4.3). A single catch of Redbait West in 2009/10 (from south-western Tasmania) contained fish between 210–310 mm FL (mode 240 mm) (Table 4.2). The size structure was bimodal in 2015/16 with modes at 130 and 220 mm FL. In 2016/17, the modal length increased to 240 mm FL. The size structure of Redbait West in 2016/17 is similar to those of the purse seine catches in the mid-1980s off eastern Tasmania (Figures 4.2 and 4.7).

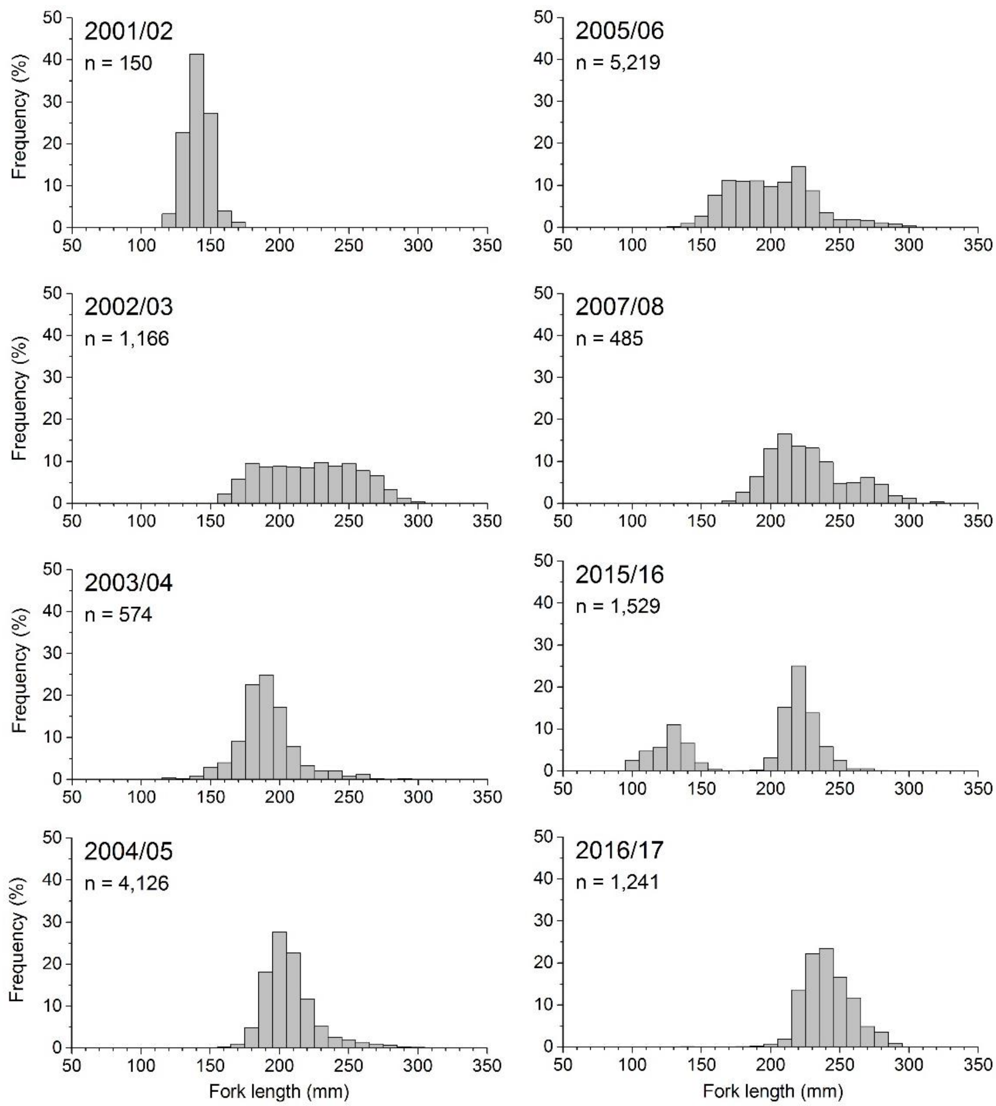


Figure 4.7. Length-frequency distributions of Redbait West caught by mid-water trawl in the SPF from 2001/02 to 2016/17. n = number of fish. See Table 4.2 for sample N.

Age structure

Mid-water trawl fishery: 2002/03–2015/16

From 2002/03 to 2007/08, catches of Redbait West off south-west Tasmania had a higher proportion of older fish than in the East; Redbait West ages ranged from 2–18 years (Figure 4.8). There was a strong cohort of 2 year old fish in 2003/04 catches that was prevalent in 2004/05 catches as 3 year olds and as 4 year olds in 2005/06 (Figure 4.8). One sample of Redbait West from south-western Tasmania in 2009/10 had fish that were older than those from 2009/10 catches in the East (up to 13 years; Table 4.2), with 90% of fish estimated to be over 4 years of age (East: 97% <4 years). In 2015/16, the age structure ranged from 0–7 years, with 88% 2–5 year olds and a modal age of 4 years (Figure 4.14). During 2015/16, the age structure in the West was younger than in the East.

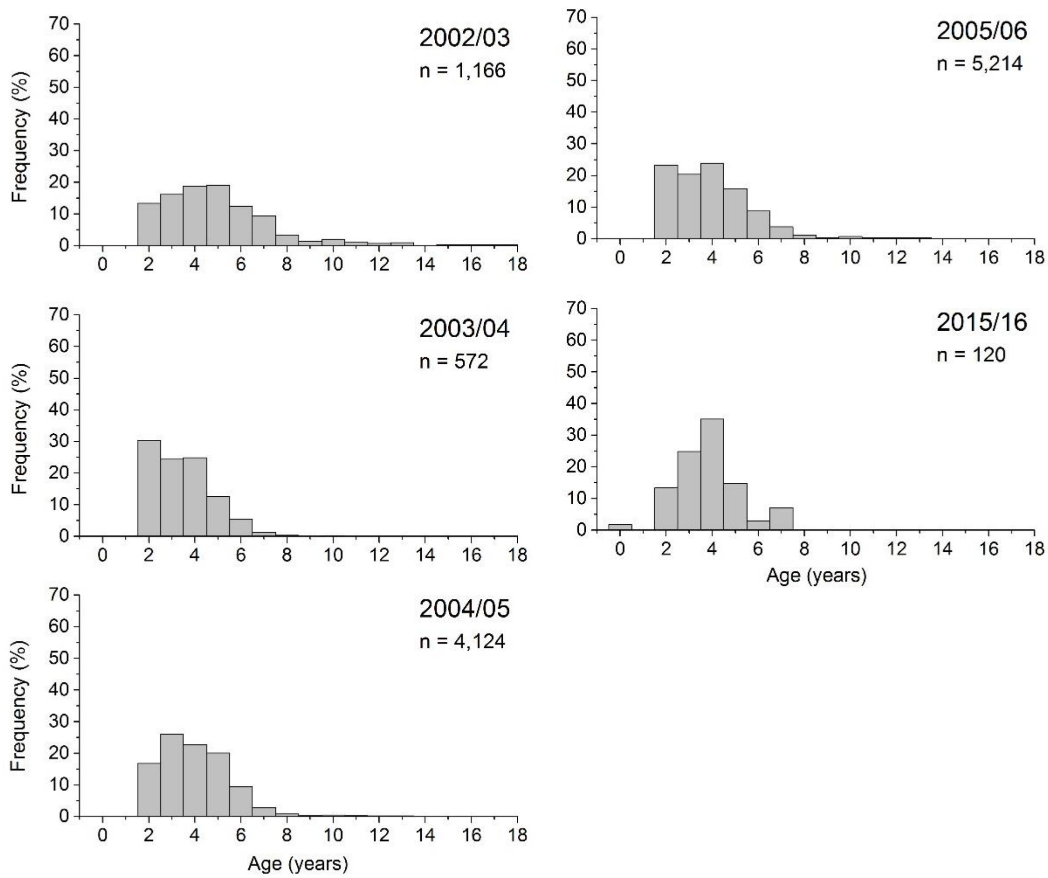


Figure 4.8. Age-frequency distributions of Redbait West caught by mid-water trawl in the SPF from 2002/03 to 2015/16; n = number of fish. See Table 4.2 for sample N.

4.4 Summary and Conclusions

4.4.1 Redbait East

The application of the DEPM for Redbait East in 2005 and 2006 estimated a spawning biomass of ~70,000 t (surveys combined; Neira et al. 2008). Neira and Lyle (2011) suggested these estimates may be negatively biased, since the survey area covered less than half of the known spawning area of Redbait in south-eastern Australia.

Catches of Redbait East in the SPF were mainly taken by purse seining from 1995/96 to 2000/01 and by mid-water trawling from 2001/02 onwards. Annual catches peaked at 7,728 t in 2003/04 and declined to 75 t in 2010/11. Catches have been minimal since 2010/11 but increased to 217 t in 2015/16 and 101 t in 2016/17. Mean annual CPUE of mid-water trawls in the SPF declined from 8 t·trawl hour^{-1} in 2001/02 to ≤1 t·trawl hour^{-1} since 2010/11. Recent low catches of Redbait East reflect low fishing effort in areas where survey data show that Redbait are abundant.

Age and length structures of Redbait East since 2001/02 have varied among years and are difficult to interpret due to the limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time. The modal sizes (ages) of samples obtained from mid-water trawl catches since 2014/15 of ≥200 mm FL (≥3 years) have been above the size (age) at 50% maturity of ~150 mm FL (2 years).

Recent catches of Redbait East are assessed as sustainable, as they are <1% of the estimated spawning biomass for 2005 and 2006 (Neira et al. 2008), and below the Tier 2 exploitation rate for this stock of 5% (Smith et al. 2015). Using the classification system of Stewardson et al. (2016), the stock of Redbait East is also classified as sustainable. Patterson et al. (2017) classified the Redbait East stock as 'not overfished' and 'not subject to overfishing'.

4.4.2 Redbait West

The DEPM has not been applied to Redbait West, but an empirical estimate of spawning biomass will be available for this stock in late 2018. The Atlantis-SPF biomass estimate for this stock is 66,000 t (typical range: 59,000–70,000 t; Smith et al. 2015). Catches of Redbait West are mainly taken in the SPF by mid-water trawling. Annual catches peaked at 3,228 t in 2006/07, declined to 298 t in 2009/10. No Redbait were taken in the West sub-area until 2015/16 (annual catch: 1,157 t). In 2016/17, 1,140 t were taken. Mean annual CPUE of mid-water trawls in the SPF has decreased from 11 t·trawl hour^{-1} in 2001/02 to 4 t·trawl hour^{-1} in 2009/10, with no effort reported until 2014/15. CPUE increased to 3 t·trawl hour^{-1} in 2016/17.

Age and length structures of Redbait West from 2001/02–2016/17 have varied among years, but are difficult to interpret due to the limited fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time. The modal size (age) of catch samples from mid-water trawling has ranged from 130–240 mm FL (2–5 years), and has mostly been below the size and age at 50% maturity of ~250 mm FL and 4 years. However, reported size and age at 50% maturity should be reviewed for Redbait West as differences between East and West population may have resulted from depth-based sampling bias (Ewing and Lyle 2009).

Recent catches of Redbait West are likely to be sustainable, because fishing effort prior to 2015/16 has been low and the 2016/17 catch was 23% of the recommended biological catch (5,000 t) and 40% of the TAC (2,880 t). Recent catches were 1.7% of the Atlantis-SPF biomass estimate (Smith et al. 2015) and above the Tier 3 exploitation rate for this stock of 1.25% (Atlantis-SPF based rate). The stock of Redbait West is also classified as sustainable using the classification system of Stewardson et al. (2016). Patterson et al. (2017) classified the Redbait West stock as ‘not overfished’ and ‘not subject to overfishing’. The empirical estimate of spawning biomass obtained in 2018 will provide an opportunity to evaluate the Atlantis-SPF biomass estimate and confirm the status of Redbait West.

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 (e.g. Stratoudakis et al. 2006). In Australia, Sardine (*Sardinops sagax*) support several commercial fisheries in waters from southern Queensland to Western Australia (Ward and Staunton-Smith 2002).

Exploitation of Sardine in Australia has occurred since the 1800s (Kailola et al. 1993), but combined national catches did not exceed 1,000 t until the 1970s. Several purse seine fisheries developed in south-western Western Australia, and the annual catch in the west reached ~8,000 t in 1990 (Kailola et al. 1993). In 1991, a Sardine fishery was established in South Australia to provide fodder for the tuna mariculture industry (Ward and Staunton-Smith 2002).

In 1995 and 1998, two mass mortality events caused by Pilchard herpesvirus (Whittington et al. 2008) reduced the adult biomass of Australian Sardine populations by ~70% (Ward et al. 2001b). Catches in Western Australia have remained low since the mortality events (<3,000 t since 1999). In 2014, ~1,500 t of Australian Sardine were taken off Western Australia (Fletcher and Santoro 2015). The South Australian fishery grew quickly after the mortality events; in 2016, the total catch by the South Australian fishery was 37,940 t (Ward et al. 2017).

Off eastern Australia, the annual catch of Sardine increased rapidly from historical averages of 30–40 t to almost 5,000 t in 2008/09, but declined since then as a result of a reduction in fishing effort (Ward et al. 2014a, Izzo et al. 2017).

5.1.2 Taxonomy

Australian Sardine (*Sardinops sagax*, Jenyns 1842) belong to the order Clupeiformes, which contains about 400 species in seven families, including *Clupeidae* (sardines, shads, menhadens, herrings) and *Engraulidae* (anchovies) (Eschmeyer and Fricke 2016).

The genus *Sardinops* has historically included five species: *S. ocellatus* off southern Africa; *S. neopilchardus* off southern Australia and New Zealand; *S. sagax* off the west coast of South America; *S. caeruleus* off the west coast of North America; and *S. melanostictus* off the Japanese coast (Whitehead 1985). Parrish et al. (1989) proposed the genus *Sardinops* is mono-specific with no valid sub-species, and that the name *Sardinops sagax* (Jenyns 1842) has taxonomic priority. This finding was confirmed by Grant and Leslie (1996). Grant et al. (1998) suggested that cluster and parsimony analyses of haplotypic divergences supported the hypothesis that there were three lineages within the genus: southern Africa (*ocellatus*) and Australia (*neopilchardus*); Chile (*sagax*) and California (*caeruleus*); and Japan (*melanostictus*). Currently, the accepted taxonomic classification for Sardine in the Indo-Pacific region is as one species, *Sardinops sagax*, with three confirmed linages within the genus.

The common name for Sardine off Australia has also varied through the years. It has been referred to as either the Australian Sardine or Pilchard. Since May 2006, Australian Sardine and *Sardinops sagax* (Jenyns 1842) have been listed in the Standard Fish Names List for Australia. *Sardinops sagax* is also the name used in the Australian Faunal Directory, Eschmeyer's Catalogue of Fishes Fishes of Australia, and FishBase. In this report, we use Sardine to refer to *S. sagax* in Australia and elsewhere.

5.1.3 Distribution

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

5.1.4 Stock Structure

The Australian Sardine population has a complex stock structure. It is a meta-population with extensive mixing among adjacent sub-groups, illustrated by the rapid spread of Pilchard herpesvirus through the population in the late 1990s (Ward et al. 2001b, Whittington et al. 2008, Izzo et al. 2017). An integrated analysis that of genetic, morphological, otolith, growth, reproductive and fishery data by Izzo et al. (2017) suggested the existence of least four stocks: 1) south-western Australia (Western Australia); 2) Great Australian Bight and Spencer Gulf (South Australia); 3) Victoria, Tasmania and southern NSW); and 4) eastern Australia (southern Queensland and northern New South Wales). The stock off south-western Australia appears to comprise two sub-stocks: west and south.

5.1.5 Movement

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

5.1.6 Food and Feeding

Sardines have two feeding modes: filter-feeding on micro-zooplankton and phytoplankton, and particulate-feeding on macro-zooplankton. Sardines switch between the two modes depending on relative prey density (van der Lingen 1994, Louw et al. 1998). In South Australian waters, Sardines consume at least 12 different prey taxa; krill (29.6% biomass) and other unidentified crustaceans (22.2% biomass) are the major prey items (Daly 2007). Krill were found in greater numbers (65.3%) than other crustaceans (27%). Crab zoea, other decapods, copepods, polychaetes, fish eggs and larvae, and gelatinous zooplankton were also dietary components (Daly 2007).

5.1.7 Age, Growth and Size

Sardines have been aged using growth increments in scales (Blackburn 1950) and otoliths (Butler et al. 1996, Fletcher and Blight 1996) and by modelling marginal increment formation in otoliths (Kerstan 2000). Several methods show that translucent zones form annually in otoliths of 1 year old fish off South Africa (Waldron 1998), 2 year olds off North America (Barnes et al. 1992) and 4 year olds off Western Australia (Fletcher and Blight 1996). Ageing sardine from southern Australia has been challenging due to difficulties associated with interpreting and counting growth zones (Rogers and Ward 2007).

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

5.1.8 Reproduction

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

The peak spawning season is variable across the Australian distribution of Sardine. For example, in South Australia, spawning occurs during the summer-autumn upwelling from January to April (Ward et al. 2001c, Ward and Staunton-Smith 2002). Similarly, along the south coast of Western Australia spawning peaks between January and June (Gaughan et al. 2002), whereas Sardines off Fremantle have maximum GSI values during June (Murhling et al. 2008). Off southern Qld and northern NSW, Sardine GSI values peak in winter to early spring (Ward and Staunton-Smith 2002, Ward et al. 2015c), whereas off southern New South Wales the peak occur between July and December (Stewart et al. 2010, Ward et al. 2011). In Victoria, GSI values of Sardine are greatest from spring to early summer (Hoedt and Dimmlich 1995, Neira et al. 1999).

The size and age at of sexual maturity in Sardine varies between locations, and ranges from 100 to 180 mm FL and 1.8 to 2.8 years (Blackburn 1950, Fletcher 1990, Staunton-Smith and Ward 2000). In South Australia, 50% of males are sexually mature at 146 mm FL and females at 150 mm FL (Ward and Staunton-Smith 2002).

5.1.9 Early Life History and Recruitment

Sardines have a relatively long larval phase: eggs hatch approximately two days after fertilization and yolk-sac larvae are 2.2–2.5 mm TL (Neira et al. 1998). Larvae metamorphose at 1–2 months of age and at lengths of 35–40 mm TL. Larvae are known to undertake vertical migrations to prevent passive transport away from regions with favourable environmental conditions for survival (Watanabe et al. 1996, Logerwell et al. 2001, Curtis 2004). Survival rates of sardine eggs and larvae strongly affect recruitment success (Louw et al. 1998). Large variations in abundance that characterise sardine populations worldwide are attributed to fluctuations in recruitment, which can be influenced by environmental factors, regime shifts and over-fishing (Galindo-Cortes et al. 2010). Larval survival is a key determinant of recruitment success, but factors affecting survivorship may vary spatially and temporally. The effects of food availability on larval survival have been discussed at length (Galindo-Cortes et al. 2010), but there has been less consideration about how predation on eggs and larvae may affect recruitment success.

In South Australia, Sardine larvae are highly abundant at temperature and salinity fronts that form near the mouths of the two Gulfs during summer and autumn (Bruce and Short 1990) and in mid-shelf waters of the eastern and central Great Australian Bight (Ward et al. 2014b). Juvenile sardine occupy nursery areas that include shallow embayments and semi-protected waters. The factors affecting recruitment success of Sardines are poorly understood.

5.1.10 Stock Assessment

The DEPM was developed to assess the status of northern anchovy (*Engraulis mordax*) stocks off the coast of California (Parker 1980, Lasker 1985) and is widely used for for assessing spawning-stock biomass of sardine worldwide (see review in Barangé et al. 2009), e.g. Atlanto-Iberian Sardine (*Sardina pilchardus*) (Bernal et al. 2011a, Bernal et al. 2011b). This approach provides direct estimates of spawning biomass for the basis of management decisions. The DEPM has been used extensively to estimate the spawning biomass of Australian Sardine in South Australia since 1995 (Ward et al. 2017). During 2014, two DEPM surveys were undertaken for to Sardine off eastern Australia (Ward et al. 2015a). Prior to 2014, a preliminary DEPM was applied to Australian Sardine in 2004 using samples collected along the southern Queensland and northern New South Wales coast during a survey of Blue Mackerel (Ward et al. 2007).

5.1.11 Recreational fishing

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

5.1.12 Biomass Estimates

<u>East</u>

An early application of the DEPM to Australian Sardines off eastern Australia in 2004 produced a spawning biomass estimate of 28,809 t (Ward et al. 2007). This estimate was calculated from the 'best' estimate of each parameter, and 'minimum' and 'maximum' estimates ranged from 7,565 to 116,395 t. The 'best' estimate was considered conservative and likely negatively biased as spawning season and area varies temporally and spatially on the east coast of Australia (Ward and Staunton-Smith 2002); it was unlikely that the entire spawning area was sampled during peak spawning season (Ward et al. 2007).

During 2014, two DEPM surveys were applied to Sardine off eastern Australia: a summer survey and a winter/spring survey (Ward et al. 2015a, 2015b). The summer DEPM survey, undertaken in January 2014 between Eden, New South Wales and Triabunna, Tasmania, estimated the spawning biomass for Australian Sardine off south-eastern Australia to be 10,962 t over a spawning area of 11,906 km^2 (Ward et al. 2015a). It is important to note that this was not considered an estimate of the total adult biomass off eastern Australia, only an estimate of the portion of the population that was spawning in the southern part of the range during summer. The main spawning area for Australian Sardine East occurs off northern New South Wales and southern Queensland during late winter and early spring (Ward and Staunton-Smith 2002). The study by Ward et al. (2015a) provides unequivocal evidence that Sardine occur off eastern Tasmania and in Bass Strait, at least in some years, and provides insights into the quantum of catches that may be suitable for any developmental fishery established in the region.

The second DEPM survey, undertaken in August/September 2014 off eastern Australia by Ward et al. (2015b), estimated spawning biomass of Australian Sardine East to be ~49,600 t (95% CI = 24,200–213,300 t). The estimated spawning area was 22,400 km^2, comprising 34.2% of the total area sampled (65,528 km^2). Most Sardine eggs were collected between Sandy Cape, Queensland and just south of Newcastle, New South Wales where sea surface temperatures were 17– 22°C. The highest densities of eggs were collected from sites with SSTs of 18–21°C. All DEPM parameters were estimated from a large number of samples and were considered robust. These parameters included: mean daily egg production (P_0): 52.6 eggs·day^{-1}·m^{-2}; mean sex ratio: 0.54; mean female weight: 38.8 g; mean batch fecundity: 11,942 eggs; and mean spawning fraction: 0.14.

The 2014 winter/spring estimate of spawning biomass for Australian Sardine East, i.e. 49,600 t, is considered suitable for setting recommended biological catches as outlined by the SPF HS. Most of the estimates of spawning biomass obtained in the sensitivity analyses were between approximately 30,000 and 110,000 t. Credible values for only one parameter (spawning fraction, 0.04) provided estimates outside that range (i.e. ~175,000 t). The proportion of total adult biomass of Australian Sardine East that occurred outside the survey area during the winter/spring survey period is unknown.

5.1.13 Management Strategy Evaluation

2010

For Australian Sardine East, the DEPM estimate of spawning biomass based on surveys in 2004, was 96% of the model calculated estimate of spawning biomass. All Tier 1 scenarios reached equilibrium around B_{60} by the end of the 30 year simulation period. The Tier 2 and Tier 3 results suggest that these harvest levels were 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.

2015

Smith et al. (2015) concluded the harvest rate of 15% may be too low for Australian Sardine East and suggested a Tier 1 harvest rate of 33%, with the Tier 1 rate being applied for not more than 5 years. Tier 2 harvest rates for Australian Sardine East were recommended to be 50% of Tier 1 rates and should not be applied for more than 5 years. The study results also indicated it is not safe to apply Tier 2 harvest rates unchecked for long periods of time (Smith et al. 2015). The Atlantis-SPF biomass estimate for Australian Sardine East is 147,000 t (typical range: 32,000–184,000 t) (Smith et al. 2015).

5.1.14 Management

Sardine in the Australian Sardine sub-area of the East sub-area in the SPF are currently managed at the Tier 1 level based on the 2014 DEPM assessments.

5.2 Methods

5.2.1 Fishery Statistics

Fishery statistics from 1984/85 to 2016/17 have been supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported in fishing seasons (May 1 to April 30) rather than financial years as was done in previous assessments (e.g. Ward et al. 2013, 2014c, 2015c).

Estimates of total annual catch supplied for Australian Sardine East include data from the NSW Ocean Fisheries (Hauling, Trap and Line, Trawl), NSW Estuary Fisheries (General and Prawn Trawl), Victorian Ocean Purse Seine Fishery and the Commonwealth SPF. Mean annual CPUE of Australian Sardine East in the Commonwealth SPF is calculated for purse-seine ($\text{tonnes}\cdot\text{net-set}^{-1}$ ±SE) from 2000/01 to 2016/17.

5.2.2 Biological Information

Length-frequency data for Australian Sardine sampled from commercial catches taken in New South Wales were supplied by New South Wales DPI from 2004/05 to 2016/17. Additional samples were collected from commercial catches taken from the north (Iluka) and south-central (Eden) coast of New South Wales between March 2009 and January 2010 for biological analysis. These fish were dissected and morphometric data collected by New South Wales DPI, while otoliths were interpreted for age by SARDI Aquatic Sciences using the methods of Rogers and Ward (2007).

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

Ages were derived from the otolith weights in 2012/13 using the relationship calculated from South Australian commercial catches (Rogers and Ward 2007). In all other years, ages were based annual growth increment counts in whole otoliths.

Summarised biological data from New South Wales DPI are presented in financial years and all other biological data are presented in fishing seasons (1 May to 30 April).

The number and spatio-temporal coverage of the biological samples of Australian Sardine East are limited in comparison to the magnitude of catches since the mid-1990s, and may not provide a good representation of the catch.

5.3 Results

5.3.1 Australian Sardine East

5.3.1.1 Fishery Statistics

<u>Number of vessels</u>

Prior to 1999/00, >90 vessels annually reported catches of Australian Sardine East; 97% were from New South Wales. Since then, vessel numbers taking Australian Sardine East declined to 15 vessels in 2012/13 and have averaged 29 per year over the last 3 years (80% from New South Wales).

<u>Annual patterns: Total catch</u>

Total catches of Australian Sardine have varied over the last 32 years (Figure 5.1a). Catches dropped from ~2,100 t to ~150 t in the mid- to late-1980s, increased to ~1,800 t in 1992/93 and again fell to low levels in the early 2000s. The low catches of the late 1990s and early 2000s resulted from the widespread die-off of Sardine from the Pilchard herpesvirus that spread through the Australian population in 1995 and 1998 (Ward et al. 2001b, Whittington et al. 2008). The stocks recovered, and catches increased to 4,619 t in 2007/08 and declined to 894 t in 2014/15 (Figure 5.1a). Total catch increased to 2,887 t in 2016/17, primarily driven by large catches in eastern Victoria. The main fisheries taking Australian Sardine East have been the NSW Ocean Hauling Fishery, the SPF and the Victorian Ocean Purse Seine Fishery.

Annual patterns: Catch, Effort and CPUE

Purse seining has been the main method used to take Australian Sardine East. In the SPF, catches of Australian Sardine East have been solely taken by purse seine (Figure 5.1b, c). Historically, annual purse seining effort in the SPF has been substantially less than in the NSW fishery but with only slightly lower catch. For example, in 2007/08, effort and catch in the NSW fishery was 1,948 t with 354 boat days compared to 1,759 t and 52 net-sets (46 boat days) in the SPF (Figure 5.1b, d). Catch trends in the SPF are similar to those in the NSW fishery, with the highest catches in the mid to late 2000s (Figure 5.1 b, d). Temporal effort in the SPF was relatively stable, averaging 50 net-sets annually from 2004/05 to 2010/11. Both effort and catch of Australian Sardine East in the SPF decreased to low levels between 2011/12 and 2013/14 (Figure 5.1b). Fishing effort and catch increased in 2014/15 (57 net-sets, catch: 152 t) and remained steady through 2016/17 (effort: 57 net-sets, catch: 131 t) (Figure 5.1b). Mean annual CPUE of purse seining in the SPF for Sardine declined from 34 $t \cdot net\text{-}set^{-1}$ in 2007/08 to 7 $t \cdot net\text{-}set^{-1}$ in 2010/11 (Figure 5.1c). Mean annual CPUE has been <3 $t \cdot net\text{-}set^{-1}$ from 2011/12 to the present.

In the NSW fishery, purse seining effort for Australian Sardine has been highly variable among years; in 2000/01, effort was 108 boat days with a catch of only 18 t (Figure 5.1d). Fishing effort remained low in the early 2000s and increased to a peak of >350 boat days in the late 2000s. Catches also peaked at ~1,950 t during that time (Figure 5.1d). Annual catch and effort data are confidential in the NSW fishery from 2011/12–2013/14 due to the low number (<5) of license holders reporting catch.

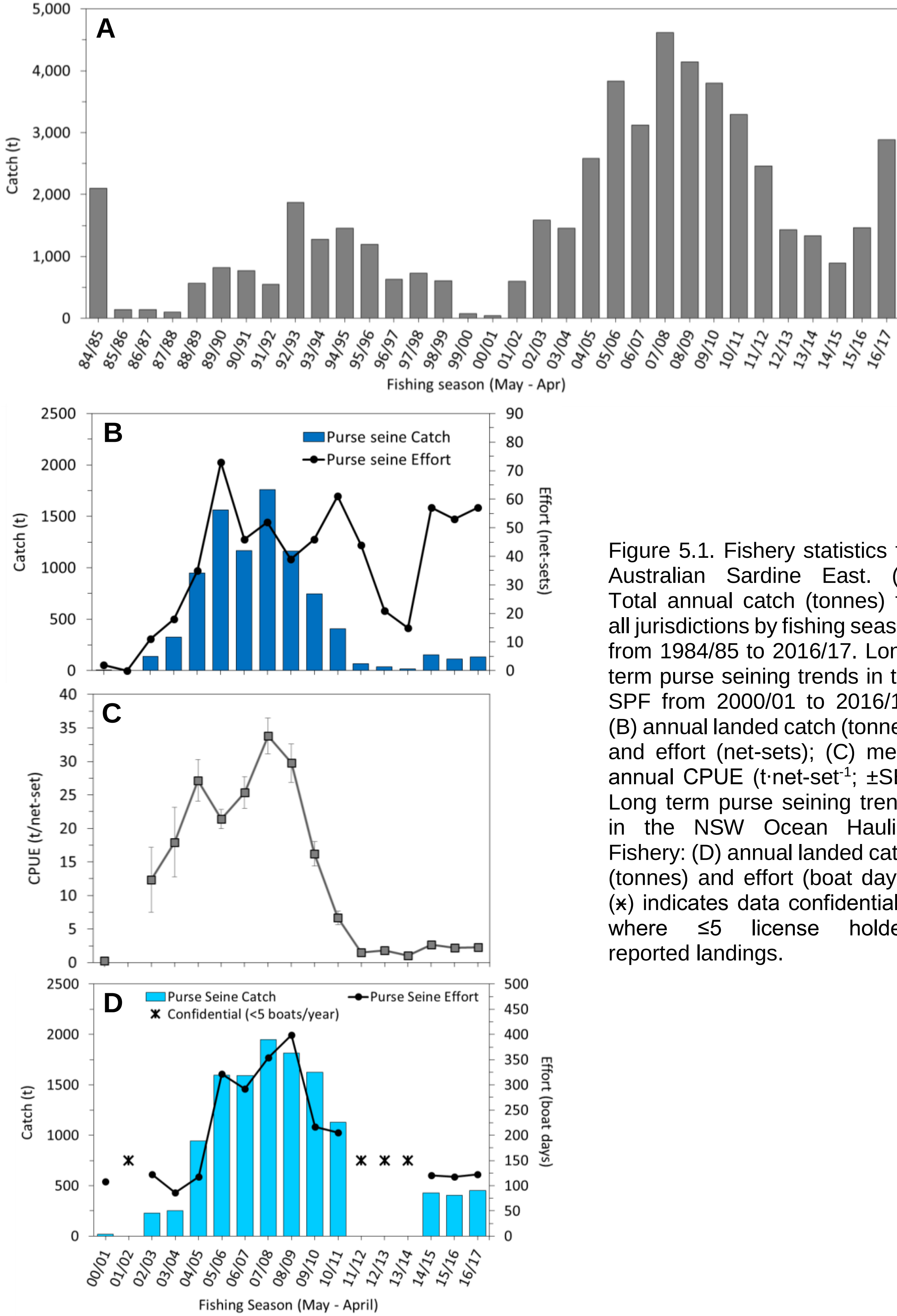


Figure 5.1. Fishery statistics for Australian Sardine East. (A) Total annual catch (tonnes) for all jurisdictions by fishing season from 1984/85 to 2016/17. Long-term purse seining trends in the SPF from 2000/01 to 2016/17: (B) annual landed catch (tonnes) and effort (net-sets); (C) mean annual CPUE (t·net-set^{-1}; ±SE). Long term purse seining trends in the NSW Ocean Hauling Fishery: (D) annual landed catch (tonnes) and effort (boat days). (⁎) indicates data confidentiality where ≤5 license holders reported landings.

5.3.1.2 Biological Information

Length-frequency data were collected from 18,610 Australian Sardine East sampled from purse seine catches in the NSW Ocean Hauling Fishery between 2004/05 and 2016/17 (Table 5.1). The number of samples collected in each year ranged between 2 (2004/05) and 54 (2009/10). In 2016/17, 8 catch samples were collected (733 fish).

In the SPF, length-frequency data were collected from 4,068 Australian Sardine East taken by purse seining off New South Wales between 2009/10 and 2014/15 (Table 5.2). Of these samples, age-frequency data were collected from 1,215 individuals (Table 5.2).

Table 5.1. Summary of Australian Sardine East samples collected from commercial New South Wales State purse seine catches between 2004/05 and 2016/17 (data supplied by New South Wales DPI).

Season	No. of samples	No. of fish	Size range (mm FL)
2004/05	2	249	90–210
2005/06	7	592	80–240
2006/07	31	3,098	70–230
2007/08	12	1,209	90–230
2008/09	8	860	110–210
2009/10	54	5,579	50–230
2010/11	5	473	100–220
2011/12	6	691	100–200
2012/13	4	538	100–180
2013/14	30	2,075	120–190
2014/15	12	1,223	120–200
2015/16	12	1,186	90–200
2016/17	8	733	120–210

Table 5.2. Summary of Australian Sardine East catch samples collected from commercial SPF landings off New South Wales from 2009/10 to 2014/15.

Season	NSW Region	No. of samples	Length-frequency n	Age-frequency n	Size range (mm FL)	Age range (years)
2009/10	North	15	240	155	120–190	0–3
2009/10	South	6	330	167	127–213	0–5
2012/13	North	3	208	32	120–175	1–3
2013/14	North	40	1,840	492	68–175	0–5
2014/15	North	32	1,450	369	124–195	0–6

Size Structure

Annual size distributions for Australian Sardines sampled between 2004/05 and 2016/17 from the NSW Ocean Hauling Fishery were mainly between 100 and 200 mm FL, although the modal length varied among years (Figure 5.2). For some years (i.e. 2004/05 to 2006/07, 2011/12), the size structure was bimodal with a dominant mode at ~130 to 140 mm FL (i.e. the approximate size at sexual maturity for Australian Sardine) and a smaller mode at ~170 to 190 mm FL. In all other years, the size structures contained a single dominant mode between 130 and 180 mm FL. The length mode has increase since 2012/13 from 140–150 mm FL to 180 mm FL in 2016/17 (Figure 5.2).

Size structures of catches off New South Wales in 2009/10 Australian Sardine East were larger on average in the south than in the north (Figure 5.3). Purse seine catch samples taken in the SPF between 2012/13 and 2014/15 indicated an increase in the size structure over time but a consistent modal length at 150 mm FL (Figure 5.3).

Age structure

Ages of Australian Sardine East collected from purse seine catches in the SPF along the south coast of New South Wales in 2009/10 ranged from 0+ to 5 years, whereas catches from the northern region contained fish aged 0+ to 3 years (Figure 5.4). Commercial catch samples from the north in 2012/13 mostly consisted of 2 year old fish. In 2013/14 and 2014/15, the range of ages in age structures in the northern region continued to increase, with more fish in the 3 and 4 year old age classes. Fish reached a maximum age of 6 years in 2014/15 (Figure 5.4).

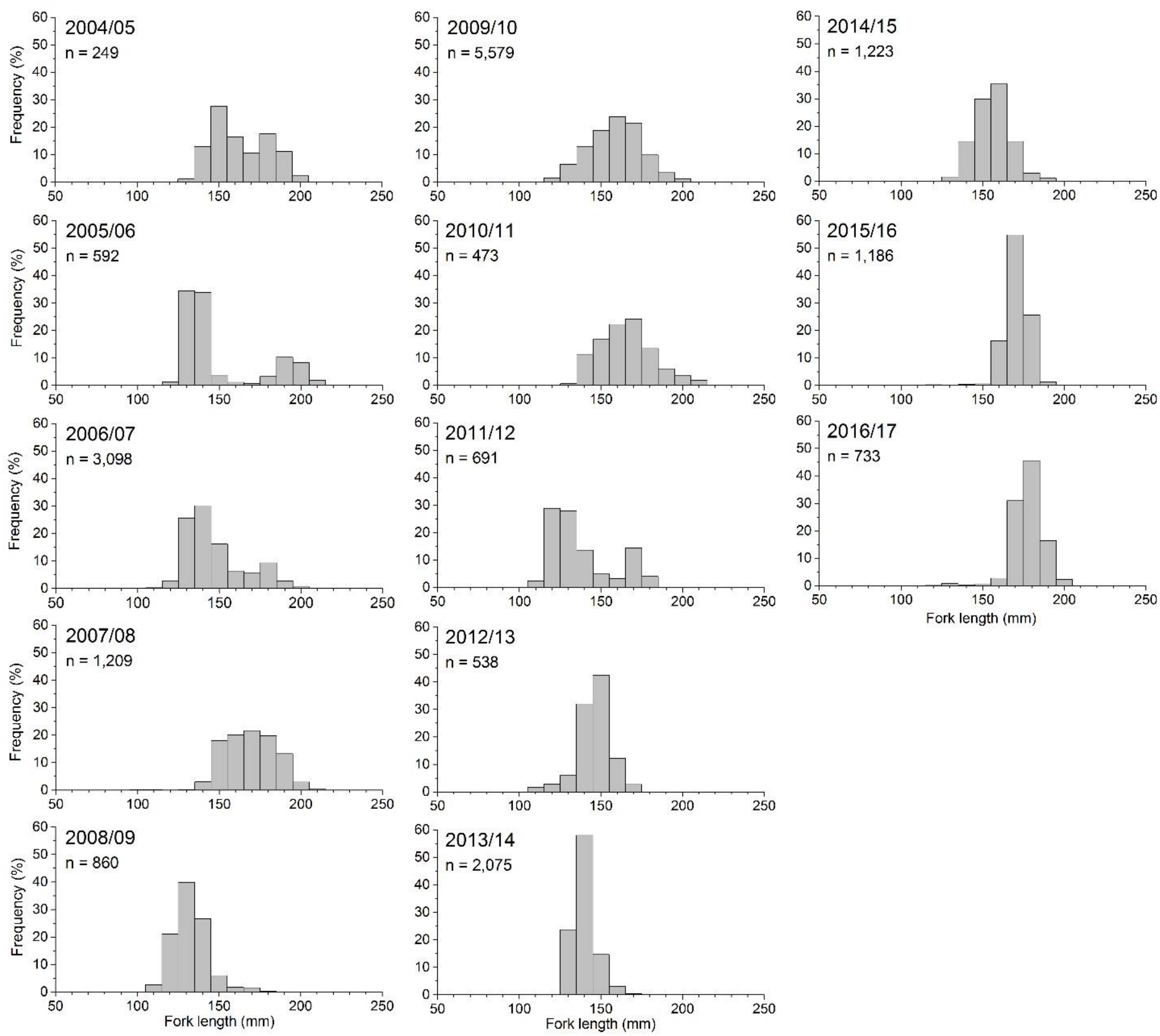


Figure 5.2. Length-frequency distributions of Australian Sardine East sampled from purse seine catches taken in New South Wales from 2004/05 to 2016/17. Data supplied by New South Wales DPI; n = number of fish. See Table 5.1 for sample N.

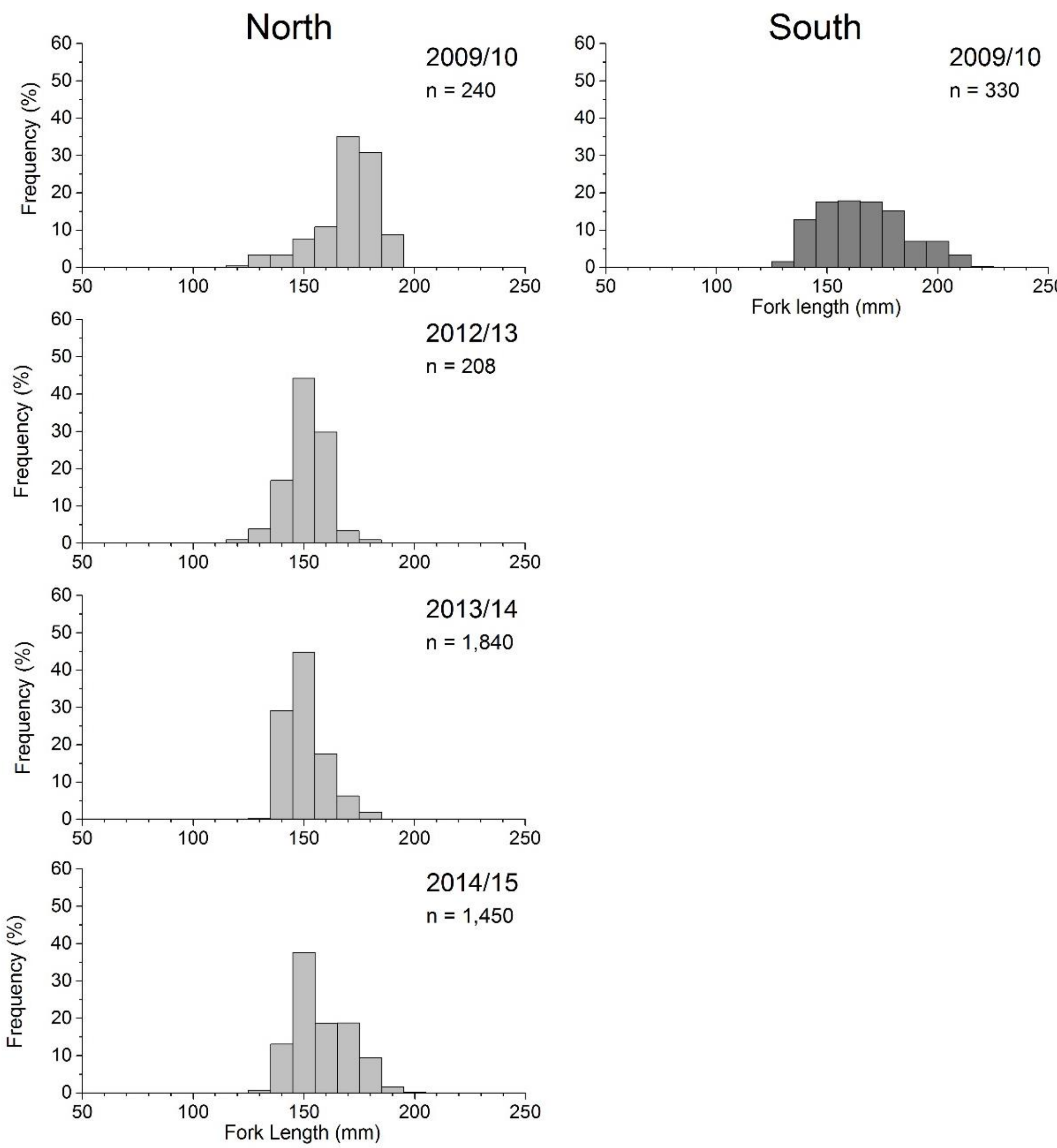


Figure 5.3. Length-frequency distributions of Australian Sardine East caught in the SPF by purse seine along the northern and southern New South Wales coastline; n = number of fish. See Table 5.2 for sample N.

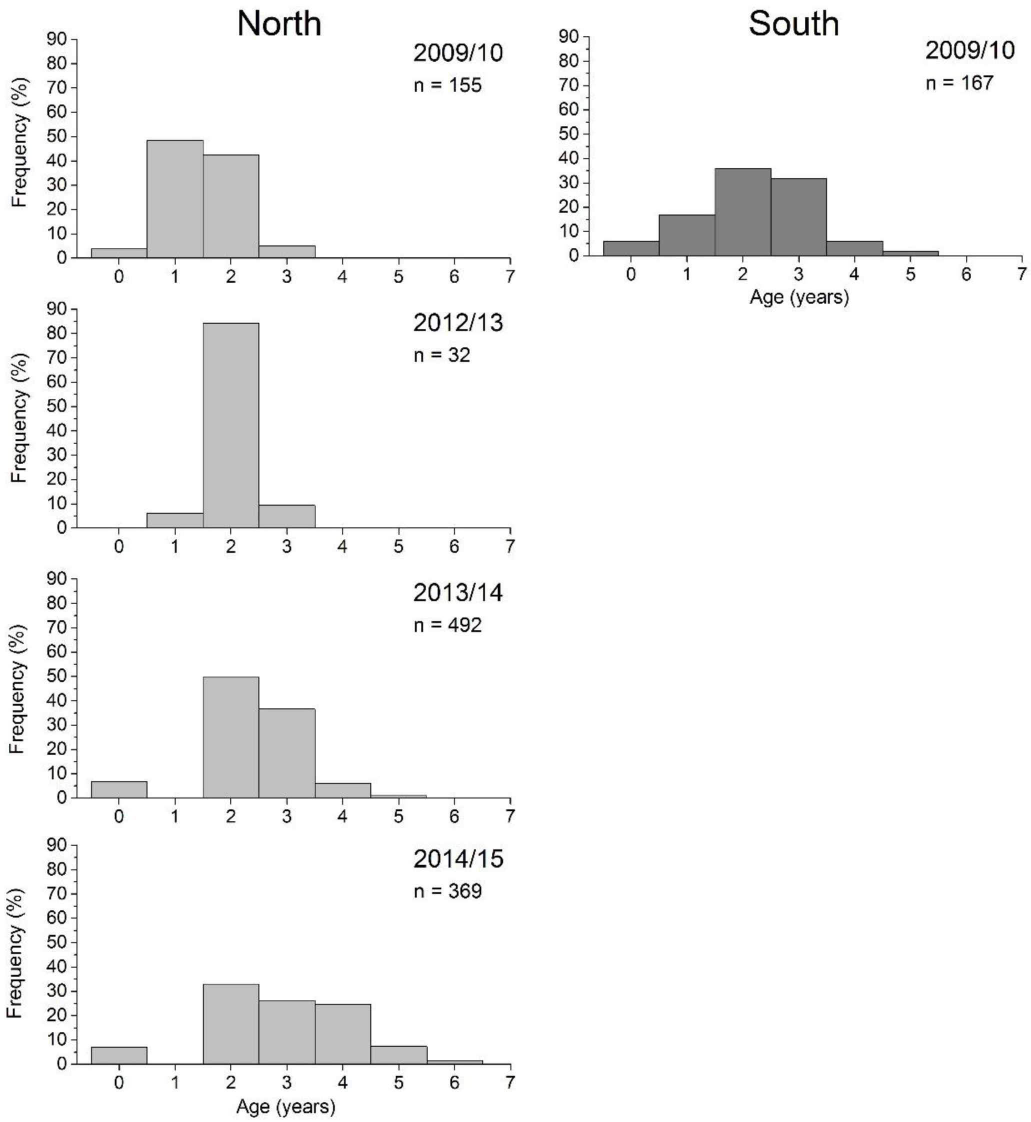


Figure 5.4. Age-frequency distributions of Australian Sardine East caught by purse seine in the SPF along the northern and southern New South Wales coastline; n = number of fish. See Table 5.2 for sample N.

5.4 Summary and Conclusions

5.4.1 Australian Sardine East

The spawning biomass of Australian Sardine East during the main spawning winter/spring spawning period in 2014 was estimated to be ~49,600 t (95% CI = 24,200–213,300 t) (Ward et al. 2015b). This estimate is larger than the 2004 estimate of 28,809 t for Australian Sardine off eastern Australia, which did not cover the entire spawning area (Ward et al. 2007). Ward et al. (2015b) suggested the 2014 estimate of spawning biomass during winter/spring was robust, as it was based on reliable estimates of all DEPM parameters. However, a portion of the adult population may have been outside the survey area during the survey period.

Total annual catches of Australian Sardine East peaked at 4,619 t in 2007/08 and declined to 894 t in 2014/15; total catches increased to 2,887 t in 2016/17. Catches were mainly taken by purse seine, and since 2000/01, annual fishing effort in the SPF has been substantially less than in the NSW Ocean Hauling Fishery but with only slightly lower catch. Both effort and catch of Australian Sardine East in the SPF decreased to low levels between 2011/12 and 2013/14, but have increased since 2014/15. There has been a general reduction in total catch since 2008/09 that reflects a significant reduction in the size of the fishing fleet. Less than 35 vessels annually have reported catch since 2011/12, compared to >90 vessels prior to 2000. Other factors that may have contributed to the reduction in catch and effort include a fire in a major fish processing factory in Eden (southern New South Wales) and apparent movement of Sardines from inshore to offshore waters (AFMA 2014). Substantial catches of Australian Sardine in eastern Victoria contributed to the increase of annual catch in 2016/17.

Size structures of Australian Sardine East in purse seine catches since 2004/05 have varied among years, with the modal length ranging from 130–180 mm FL. The length mode of commercial purse seine catch samples increased from 150 mm FL in 2012/13 to 180 mm FL in 2016/17. Australian Sardine East caught have been at or above the mean size at 50% maturity of ~150 mm FL (Ward and Rogers 2007) with age classes of mainly 2–4 years. Age and length structures are difficult to interpret due to changes in fishing effort over time, differing ageing methods and regional stock differences (i.e. north and south coasts of New South Wales).

Current catches of Australian Sardine East are assessed as sustainable, as they are 6% of the estimated spawning biomass for 2014 (Ward et al. 2015b), and below the Tier 1 exploitation rate for this stock of 20% (Smith et al. 2015). Stewardson et al. (2016) classified the biological stock of

Australian Sardine East as sustainable. The Australian Sardine stock in the East is classified as 'not overfished' and 'not subject to overfishing' by Patterson et al. (2017).

The spawning biomass of the north-eastern sub-population of Australian Sardine East during the main winter/spring spawning period in 2014 was estimated to be ~49,600 t (95% CI = 24,200–213,300 t). The total catch for the entire East sub-area was 2,887 in 2016/17, up from 1,461 t in 2015/16. In the Sardine sub-area of the East sub-area, total catches were 601 t in 2016/17, up from 526 t in 2015/16. Catches have mainly contained fish at or above the mean size at 50% maturity of ~150 mm FL. The modal size of Australian Sardine East was 180 mm FL in 2016/17. Current catches from the Sardine sub-area of Australian Sardine East are assessed as sustainable, because they are <2% of the 2014 estimate of spawning biomass and below the Tier 1 exploitation rate for this species of 20%.

6 YELLOWTAIL SCAD (*Trachurus novaezelandiae*): PERMITTED BY-PRODUCT SPECIES

6.1 Introduction

6.1.1 Background to Fishery

Yellowtail Scad are mainly caught by commercial purse seine in state waters of New South Wales, with a much smaller portion of catch reported in the SPF (Stewart et al. 1998, Bulman et al. 2008, Ward et al. 2015c). Yellowtail Scad and Blue Mackerel are important baitfish and are targets of a purse seine fishery in New South Wales that has been expanding since the 1980s (Stewart et al. 1998, Stewart and Ferrell 2001). The fish are targeted along the coast in inshore waters and destined for human consumption (Stewart et al. 1998, Stewart and Ferrell 2001). Catches steadily increased to a peak in 1999/00, decreased to a low in 2009/10 and have since increased to historical highs in the 2010s (Ward et al. 2015c). Yellowtail Scad are also an important component of the recreational fishery (Stewart et al. 1998, Henry and Lyle 2003, Bulman et al. 2008)

6.1.2 Taxonomy

Yellowtail Scad (*Trachurus novaezelandiae*) belong to the family *Carangidae*, which includes 140 species representing 32 genera (Nelson 2006). The genus *Trachurus* contains 13 species with three inhabiting Australian waters: *T. declivis, T. murphyi* and *T. novaezelandiae* (Gomon et al. 2008).

6.1.3 Distribution

Yellowtail Scad are widely distributed throughout coastal waters of southern Australia and New Zealand. In Australia, they occur in subtropical and temperate waters from Wide Bay, Queensland, along the southern coast to Northwest Cape, Western Australia, but are rare around Tasmania (Gomon et al. 2008). Yellowtail Scad form large schools in bays and estuaries; adults are generally found offshore over rocky reefs, while juveniles occur inshore over soft substrate (Kailola et al. 1993).

6.1.4 Stock Structure

Limited information is available about the stock structure of Yellowtail Scad in Australian waters, but there is evidence supporting the separation of at least two populations of Yellowtail Scad: one in south-eastern Australian waters and one in the GAB. Analysis of morphometric measurements and meristic counts differentiated east Australian fish from those in the GAB (Lindholm and Maxwell 1988).

6.1.5 Movement

No specific studies have examined the movement of Yellowtail Scad. However, a correlation between size and depth is evident, with smaller fish generally found inshore and larger fish offshore (Kailola et al. 1993). Such size-dependent distribution suggests offshore movement with increasing size.

6.1.6 Food and Feeding

Yellowtail Scad are pelagic omnivores that primarily devour krill, carid shrimp, fish (myctophids and anchovies) and the early life stages of crab and shrimp (Bulman et al. 2001, Bulman et al. 2008, Bulman et al. 2011). They also feed on minor quantities of other prey items such as copepods, amphipods, isopods, mysids, cumaceans, tunicate larvae and polychaetes (Bulman et al. 2008).

6.1.7 Age, Growth and Size

Growth of Yellowtail Scad is variable; fish grow to ~200 mm between 2 and 4 years of age (Stewart and Ferrell 2001). In Australia, the maximum reported size of Yellowtail Scad is 330 mm TL (Kailola et al. 1993), and individuals may reach 14 years of age (Stewart and Ferrell 2001). Horn (1993) reported a maximum age and size of 28 years and 440 mm FL for Yellowtail Scad in New Zealand. Along the New South Wales coast, Yellowtail Scad sampled from purse seine catches were larger from the northern region than those from the south (Stewart and Ferrell 2001). However, this size difference could also be related to differing regional fishing practices as opposed to population specific growth rates (Stewart and Ferrell 2001).

6.1.8 Reproduction

The reproductive biology of the Australian population of Yellowtail Scad is not fully understood (Neira 2009). Yellowtail Scad reach 50% sexual maturity at 200 mm FL for females and 220 mm FL for males (Kailola et al. 1993). Mean batch fecundity has been estimated to be ~39,000 eggs based on published values (as eggs·g^{-1}) applied to mean female weight from commercial catch data (Neira 2009). Eggs have been collected in shelf waters off southern Queensland and southern New South Wales during spring, with the majority found in northern New South Wales and southern Queensland (Neira et al. 2015).

6.1.9 Early Life History and Recruitment

Yellowtail Scad eggs are positively buoyant and morphologically similar to Jack Mackerel eggs but slightly smaller in diameter (0.70–0.99 mm; Neira et al. 2015). Larvae have been described in Neira et al. (1998). Significant concentrations of Yellowtail Scad larvae have been found along the mid-

New South Wales coast and shelf in association with the East Australian Current during spring/summer (Smith 2003, Syahailatua et al. 2011)

6.1.10 Stock Assessment

There have been limited stock assessments of Yellowtail Scad in Australia. A provisional DEPM assessment was applied to Yellowtail Scad in 2009 using samples collected off south-eastern Australia in 2002 during a survey of Blue Mackerel (Neira 2009).

6.1.11 Recreational fishing

In Australia, recreational fishers target multiple species of scad (including Yellowtail Scad and Jack Mackerel) using rod and line, and troll lines in New South Wales, Queensland, South Australia, Western Australia and Tasmania. The Australian National Survey of Recreational and Indigenous Fishing (Henry and Lyle 2003) estimated that boat-based recreational fishers harvested 740,260 Jack Mackerel and Scads (combined) in 2000/01, with 37% of these being released back into the water. Of those fish retained, 46% were taken in New South Wales, 26% in Western Australia and 19% in Queensland (Henry and Lyle 2003). Based on the mean length/weight key developed by Stewart and Ferrell (2001), the estimated weight of Jack Mackerel/Yellowtail Scad harvested by the recreational sector annually in Australia was ~94 t (Ward and Rogers 2007).

6.1.12 Biomass Estimates

A provisional DEPM analysis by Neira (2009) estimated the spawning biomass of Yellowtail Scad along the east coast of Australian to be between 2,900 t and 5,900 t (mean ~4,400 t). This estimate was based on samples collected during a survey in October 2002 targeting Blue Mackerel and was dependant on the model used to estimate daily egg production. There is uncertainty around both egg identification and some adult parameters, so this estimate of spawning biomass must be viewed with caution.

6.1.13 Management

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

6.2 Methods

6.2.1 Fishery Statistics

Fishery statistics from 1984/85 to 2015/16 have been supplied by relevant jurisdictions and collated by SARDI Aquatic Sciences. Annual data are reported in fishing seasons (May 1 to April 30) rather than financial years as was done in previous assessments (e.g. Ward et al. 2013, 2014c, 2015c).

Estimates of total annual catch supplied for Yellowtail Scad East include data from the NSW Ocean Fisheries (Hauling, Trap and Line, Trawl), NSW Estuary Fisheries (General and Prawn Trawl), Victorian Ocean Purse Seine Fishery and the Commonwealth SPF. Due to data confidentiality (<5 license holders reporting catch in 2016/17), fishery data from Victoria were not available and are not included in total annual catch statistics for 2016/17.

6.2.2 Biological Information

Annual length-frequency data for Yellowtail Scad, sampled from commercial purse seine catches taken in New South Wales were supplied by New South Wales DPI for the period from 2000/01 to 2014/15. Samples collected in 2011/12 and 2012/13 were sub-sampled, and otoliths were extracted for age estimation. Ages were based on annual growth increment counts in thin-sectioned otoliths. All biological data are presented in financial years.

6.3 Results

6.3.1 Yellowtail Scad East

6.3.1.1 Fishery Statistics

<u>Number of vessels</u>

The number of vessels that reported catches of Yellowtail Scad East ranged from 311 to 597 between 1984/85/98 and 2008/09. Since then, vessel numbers have ranged between 133 and 210, with 133 vessel reporting catches of Yellowtail Scad East in 2016/17. On average, 99% of the vessels reporting catch in each year are from New South Wales.

<u>Annual patterns: Total catch</u>

Total catches of Yellowtail Scad East gradually declined from ~450 t in the late 1990s and early 2000s to 294 t in 2009/10 (Figure 6.1a). Catches increased to 570 t in 2013/14 and have declined slightly to 343 t in 2016/17 (Figure 6.1a). The main fisheries taking Yellowtail Scad East have been the NSW Ocean Hauling and Trawl Fisheries (purse seine and trawl).

<u>Annual patterns: Catch and Effort</u>

Purse seines have been the primary gear used to take Yellowtail Scad East in both the SPF and NSW Ocean Hauling Fishery. Catches of Yellowtail Scad in the SPF have been solely taken by purse seine (Figure 6.1b); there is a lower but consistent use of trawling, along with purse seining, in the NSW fisheries (Figure 6.1 c).

Trends of purse seine effort are similar to annual catch in the SPF for Yellowtail Scad East (Figure 6.1b). However, since 2000/01, purse seining effort has never increased beyond 5 net-sets annually (5 boat days; 2010/11) and catches have remained below a peak of 15 t in 2003/04 (Figure 6.1b). Since 2005/06, SPF catch and effort of Yellowtail Scad East has been low with catches <2 t per year and effort ≤5 net-sets per year (Figure 6.1b). In 2016/17, <1 t of Yellowtail Scad East was taken in the SPF with 4 purse seine net-sets (Figure 6.1b).

In the NSW Ocean Hauling Fishery, trends in annual purse seining effort since 2000/01 for Yellowtail Scad East are also similar to annual catch (Figure 6.1d). Purse seine effort was relatively high in the early 2000s (>900 boat days) then decreased to an averaged of ~600 boat days per year from 2002/03 to 2009/10 before increasing to 971 boat days in 2013/14 (Figure 6.1d). Catch and effort have since declined to 597 boat days of effort in 2016/17 with 288 t of catch (Figure 6.1d).

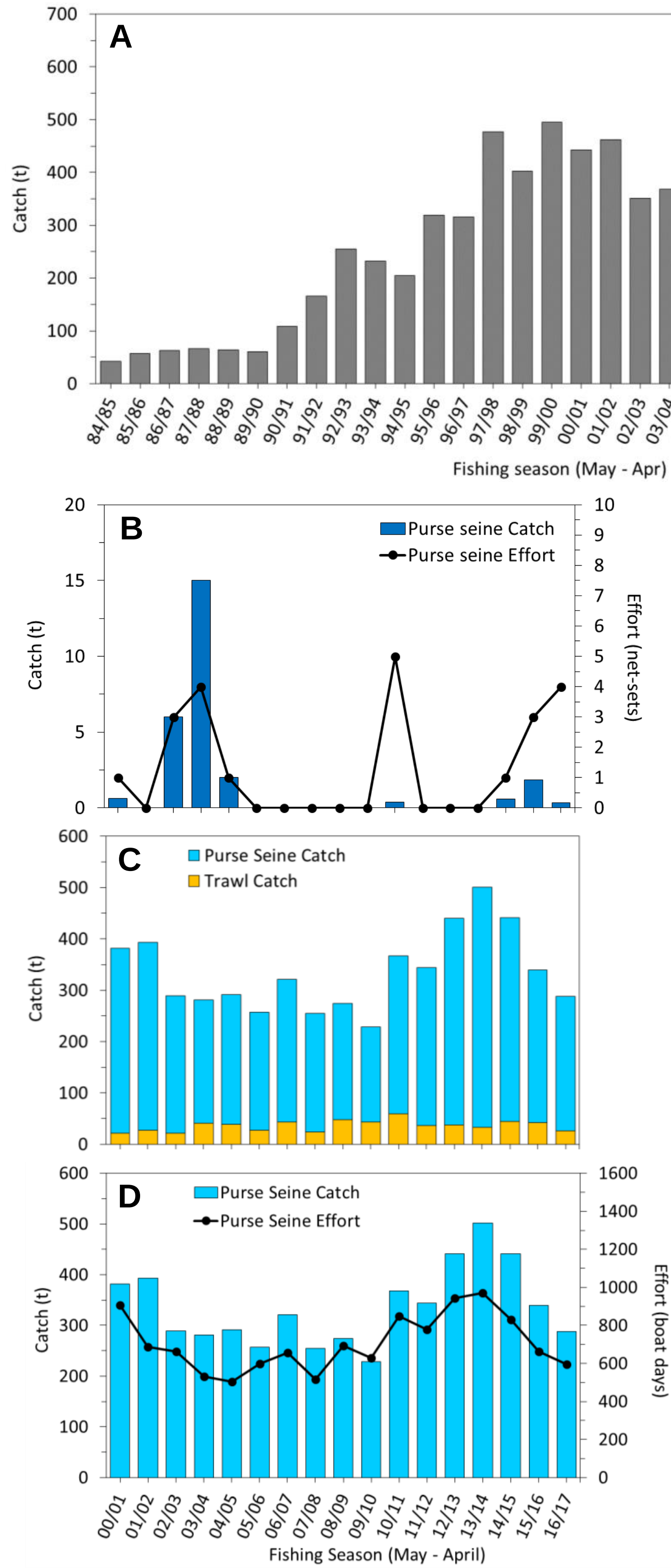


Figure 6.1. Fishery statistics for Yellowtail Scad East. (A) Total annual catch (tonnes) for all jurisdictions by fishing season from 1984/85 to 2016/17. (B) Annual landed catch (tonnes) and effort (net-sets) in the SPF by purse seining from 2000/01 to 2016/17. Long term trends in the NSW Ocean Hauling and Ocean Trawl Fisheries: (C) annual landed catch (tonnes) taken by purse seine and trawl; (D) annual landed catch (tonnes) and effort (boat days) by purse seining in the NSW Ocean Hauling Fishery.

6.3.1.2 Biological Information

Length data were collected for Yellowtail Scad East from a total of 30,775 fish sampled from commercial catches taken in New South Wales between 2000/01 and 2014/15 (Table 6.1). Information on the spatial and temporal coverage of these samples relative to fishery production in New South Wales was not available, although between 8 and 47 catch samples of Yellowtail Scad were taken in each year. Yellowtail Scad otoliths were collected for ageing in 2011/12 (n = 119) and 2012/13 (n = 69).

Table 6.1. Summary of Yellowtail Scad East samples of collected from commercial State catches taken in New South Wales between 2000/01 and 2014/15 (data supplied by New South Wales DPI).

Season	SPF sub-area	Gear type	No. of samples	Length-frequency n	Size range (mm FL)
2000/01	East	purse seine	41	5,078	80–330
2001/02	East	purse seine	47	4,996	80–330
2003/04	East	purse seine	7	1,400	220–325
2004/05	East	purse seine	20	1,499	100–320
2005/06	East	purse seine	31	2,661	110–320
2006/07	East	purse seine	25	3,048	190–310
2007/08	East	purse seine	18	2,429	80–310
2008/09	East	purse seine	8	1,328	100–310
2011/12	East	purse seine	17	2,040	120–290
2012/13	East	purse seine	8	916	180–290
2013/14	East	purse seine	19	2,137	170–300
2014/15	East	purse seine	27	3,243	160–320

Size Structure

Commercial purse seine fishing operations: New South Wales only

Annual size structures for Yellowtail Scad East taken by commercial purse seine between 2000/01 and 2014/15 mainly contained fish between 200 and 280 mm FL (Figure 6.2). The size structures were relatively stable among years, with each containing a narrow dominant mode and varying between 220 and 270 mm FL (excepting 2014/15). For some years, the size structure also included a secondary mode at ~150 mm FL. The modal length of 200 mm FL in 2014/15 is the smallest primary mode recorded in the last 15 years.

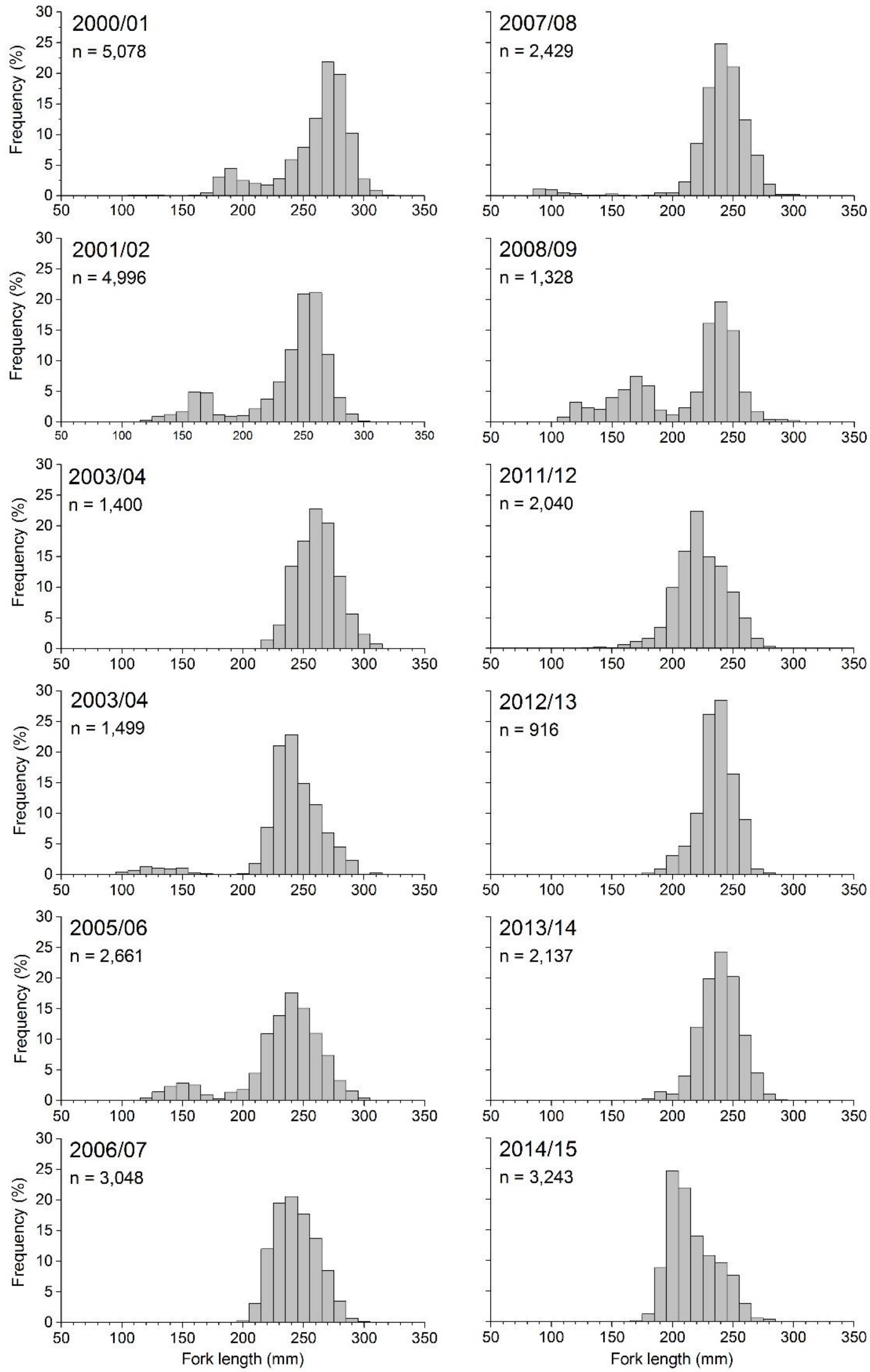


Figure 6.2. Length-frequency distributions of Yellowtail Scad East collected from purse seine net-sets in New South Wales from 2000/01 to 2014/15. Data supplied by New South Wales DPI; n = number of fish. See Table 6.1 for sample N.

Age Structure

Purse seine operations: 2011/12–2012/13

The ages of Yellowtail Scad collected from purse seine catches along the New South Wales coast in 2011/12 and 2012/13 ranged from 2 to 14 years; >59% of the fish in the annual samples were between 4 and 5 years (Figure 6.3).

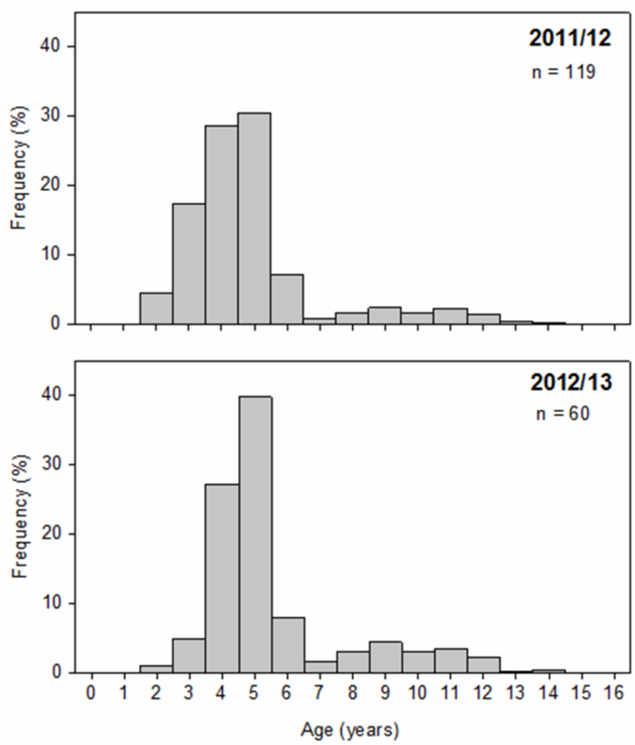


Figure 6.3. Age-frequency distribution of Yellowtail Scad East from purse seine catches taken in 2011/12 and 2012/13 along the New South Wales coast (data supplied by New South Wales DPI).

6.4 Summary and Conclusions

6.4.1 Yellowtail Scad East

Total catches of Yellowtail Scad East declined from ~450 t in the late 1990s and early 2000s to a low of 294 t in 2009/10. Catches peaked at 570 t in 2013/14 and declined to 343 t in 2016/17. The main fisheries taking Yellowtail Scad East have been the NSW Ocean Hauling and Trawl Fisheries. The SPF reports small amounts taken by purse seining. Since 2013/14, <2 t of Yellowtail Scad

East have been taken annually in the SPF. Current total catches of Yellowtail Scad East are 8% of the provisional estimated spawning biomass (Neira 2009).

Size structures of Yellowtail Scad East in purse seine catches have been relatively stable since 2000/01, with a narrow dominant mode varying between 220 and 270 mm FL (except in 2014/15). The modal length of 200 mm FL in 2014/15 is the smallest primary mode recorded in the last 15 years. Limited temporal data is available for age structures; >59% of fish sampled annually have been 4 and 5 years (age range: 2–14 years). Yellowtail Scad East have been above the mean size at 50% maturity of ~210 mm FL (Kailola et al. 1993), excepting 2014/15.

Recent total annual catches of Yellowtail Scad East are similar to or less than catches of the other SPF species since 2014/15. Currently, assessment of the stock status for this species is limited by the lack of biological and demographic data.

7 GENERAL SUMMARY AND CONCLUSIONS

Available evidence suggests that recent catches of all SPF quota species are sustainable. In 2016/17, catches of Blue Mackerel, Jack Mackerel, Redbait and Australian Sardine were relatively low and below the maximum recommended biological catches of each species for both the West and East sub-areas of the SPF. Catch and effort increased during 2014/15 and 2015/16 when a factory-trawler operated in the SPF. Effort and catch decreased in 2016/17 with the exit of the factory-trawler in October 2016. There is no evidence to suggest that the low catches from 2011/12 to 2014/15 for the SPF species were related to low abundance. Changes in fishing effort, and catches, appear to have been driven by factors other than changes in stock abundance.

Age and length structures for the SPF species have varied among years and sub-areas. These are difficult to interpret due to changing fishing effort, small sample sizes, differing ageing methods and changes in fishing locations over time. Standardised protocols are being developed for processing catch samples, particularly with regards to species-specific ageing methods.

The most recent classification of stock status for Jack Mackerel East and West, Blue Mackerel East and West, and Australian Sardine East suggested that the biological stocks are sustainable (Stewardson et al. 2016). Jack Mackerel, Blue Mackerel and Redbait in both sub-areas, and Australian Sardine East were classified as 'not over-fished' and 'not subject to over fishing' (Patterson et al. 2017). The evidence presented in this report suggests that the recent catch levels of Blue Mackerel, Jack Mackerel and Redbait in the East and West sub-areas and Australian Sardine in the East sub-area are sustainable.

Knowledge of the status of SPF species in the East sub-area was enhanced in 2014 with DEPM surveys being completed on Blue Mackerel, Jack Mackerel and Australian Sardine. A DEPM survey for Jack Mackerel in the West sub-area was completed in 2017. A DEPM survey for Redbait West was undertaken in October 2017 and estimates of spawning biomass will be available in late 2018.

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