Fisheries Research Report No. 246, 2013

Status of nearshore finfish stocks in south-western Western Australia

Part 1: Australian herring

NRM Project 09003 Final Report

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Correct citation:

Smith, K., Brown, J., Lewis, P., Dowling, C., Howard, A., Lenanton, R., and Molony, B. 2013. Status of nearshore finfish stocks in south-western Western Australia Part 1: Australian herring. Fisheries Research Report No. 246. Department of Fisheries, Western Australia. 200pp.

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ISSN: 1035 - 4549 ISBN: 978-1-921845-66-6

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Executive Summary

The status of the popular nearshore finfish resource in the West Coast Bioregion (WCB) of Western Australia (WA) was largely unknown prior to this study. Previously, declining catches of several nearshore species had highlighted the risk to their sustainability and the need for greater certainty about their status. Recently, the risk further increased due to management changes in the WCB aimed at reducing the catch of demersal scalefish, which are likely to result in a shift in targeting towards nearshore species. This increase in fishing pressure on nearshore species will be on top of any increase due to the continuing human population growth in the WCB.

The status of the Australian herring (*Arripis georgianus*) stock was assessed using a 'weight-of-evidence' approach, which incorporated all available historical and current information about the stock. This species forms part of a small group of indicator species that is used to monitor the status of the nearshore finfish resource in the WCB. The status of the other WCB nearshore indicators tailor (*Pomamtomus saltatrix*), southern garfish (*Hyporhamphus melanochir*) and whiting (Sillaginidae) will be the subject of later reports.

The 'weight of evidence' assessment of Australian herring considered all available information, including past and present levels of fishing mortality, catch composition, catch rates trends, recruitment trends and the inherent vulnerability of the stock to exploitation due to biological characteristics. This assessment identified a severe risk to the sustainability of the Australian herring stock. To reduce this risk, additional management action will be required.

Australian herring is endemic to southern Australia, occurring from Shark Bay (WA) southwards to Port Phillip Bay (Victoria). The breeding stock occurs only in the WCB. Other areas, including the south coast of WA, South Australia (SA) and Victoria, contain immature/pre-spawning fish, which migrate to the WCB prior to spawning. Adults remain in the WCB after spawning (i.e. there is no return migration back to the south coast). Due to this life cycle, the composition of fishery landings varies between regions. Landings along the southern coast of Australia are dominated by juveniles and young adults, whereas fishery landings in the WCB are comprised of a wider range of ages and sizes that is representative of the entire breeding stock.

In the past five years (2007–2011), annual commercial landings of Australian herring in WA ranged from 147 to 272 t per year. The catch in 2011 of 147 t was the lowest since records commenced in 1951 and was substantially below the historical peak of 1,545 t reported in 1990/91.

Precise estimates of the total recreational catch of Australian herring are not available due to the lack of recent catch estimates for the shore-based sector. The 2000/01 National Recreational and Indigenous Fishing Survey has been the only state-wide recreational fishing survey conducted in WA. Results of this survey provide the only basis for 'scaling up' catch estimates from other more spatially limited recreational fishing surveys to Bioregion or state level. For example, the total recreational catch in each Bioregion can be calculated from partial catch estimates from boat-based surveys in recent years by applying the catch shares (boat v. shore) from the 2000/01 survey. Using this approach, which assumes that catch shares have not changed since 2000/01, current recreational landings are estimated to be approximately 100–150 t in the WCB and 30–70 t in the South Coast Bioregion (SCB) per year.

The current total recreational catch is estimated to be approximately equal to the current total commercial catch in WA. However, these sectors are spatially separated – the majority (~85%) of commercial landings are taken in the SCB, while the majority (~85%) of recreational landings are taken in the WCB.

The 2000/01 survey estimated that shore-based fishers in the WCB take the largest share (about

50%) of the total WA recreational catch of Australian herring. WCB boat-based fishers take the next largest share (25–30%) with the remainder taken in the SCB (mainly by shore-based fishers). Australian herring is the most commonly retained species in the WCB, comprising about 65% of all finfish retained by WCB shore-based recreational fishers and 25–30% of finfish retained by WCB boat-based fishers. In addition, approximately 10–12% of all Australian herring caught by recreational fishers in the WCB are released.

Catch rate trends in the major commercial herring fisheries suggest a steady decline in the abundance of Australian herring commencing in the mid to late 1990s. The current stock level appears to be the lowest since the mid-1970s, when catch rate records commenced. Historical trends in recreational catch rates (albeit based on limited data) suggest a similar decline in stock level to that suggested by the commercial fisheries. The decline is likely to be a consequence of a period of sustained low recruitment.

The annual recruitment of juvenile (age 0+ years) Australian herring has been monitored in two of the four management zones (Metropolitan, South-west) of the WCB and in both zones (South, South-east) of the SCB since 1996/97, and previously in SA (1981 to 2000). While there are annual differences among zones, the long-term trend has been similar, with a peak in recruitment occurring during the late 1990s, followed by relatively low recruitment since 2000.

Variations in the Leeuwin Current appear to influence 0+ recruitment levels within each zone, possibly by regulating the supply of larvae which are transported by the current from the WCB spawning area to nursery sites in each zone. In the WCB and western part of the SCB, high recruitment tends to occur during years of weak current, whereas in the eastern part of the SCB and in SA high recruitment tends to occur during years of strong current. Other factors such as wind-driven surface currents and spawning stock levels in the WCB may also partly determine the supply of new recruits to each zone.

The age and length structure of Australian herring in commercial and recreational catches was sampled during 2009–11 and compared against historical samples collected since the 1970s. These comparisons suggest that the age and size composition of the population has become more truncated over time, i.e. the proportion of larger and older fish in the catch has declined. The 2009–11 catches were dominated by 2 and 3+ female fish, despite a maximum age of 12 years for this species. The overall catch of juvenile (pre-spawning) fish during 2009–11, including all commercial and recreational landings in Australia (WA and SA), was estimated to be high (57% of landings). These findings suggest that the Australian herring stock has been heavily fished over the past two decades and is now predominantly based on young fish entering the fishery. This is supported by estimates of current fishing mortality (F), which are approximately two times greater than the estimated natural mortality (M), and well above the limit reference point determined for this species.

Three key areas within the WCB (where the spawning stock is located) were identified as a focus for future monitoring. Firstly, the recreational catch rate of Australian herring in the WCB was identified as the most reliable fishery-dependent index of spawning stock abundance, which is important information for assessing stock status. Catch rates of Australian herring estimated during boat-based surveys are not considered reliable since the effort spent specifically targeting herring cannot be quantified, and so in the absence of shore-based surveys, WCB recreational catch rates of Australian herring are available only from voluntary logbooks. The voluntary logbook program should therefore be maintained. Secondly, in the WCB, the largest catch share of Australian herring is considered to be taken by shore-based recreational fishers although the actual catch level (or trend) is unknown. Regular surveys of WCB shore-based recreational fishing that provided robust estimates of catch and catch rate by this sector would provide valuable information for effective management of this sector and would increase the certainty of stock assessments. However, a better sampling frame will need to be developed to make shore-based surveys cost-effective. Thirdly, the age composition of WCB recreational fishery landings should be monitored annually because this data source currently yields the most reliable estimate of fishing mortality.

1.0 Introduction

1.1 Background

Nearshore fish species such as Australian herring (*Arripis georgianus*), tailor (*Pomatomus saltatrix*), whiting (Sillaginidae) and southern garfish (*Hyporhamphus melanochir)* have historically dominated shore-based and inshore boat-based landings by recreational and commercial fisheries in the West Coast Bioregion (WCB) of Western Australia (WA) (i.e. Kalbarri to Augusta, including the Perth Metropolitan Zone). Yet, despite their popularity, the status of key nearshore stocks of finfish in the WCB are largely unknown. Results from a boat-based recreational fishing survey in 2005/06, revealed substantial declines in annual catches of Australian herring and tailor of 21% and 80%, respectively, since an earlier survey in 1996/97 (Sumner *et al.* 2008). These declines demonstrated the need for greater certainty about the status of these and other nearshore species, and highlighted the current risk to their sustainability, along with the recreational and commercial fisheries that they support.

The risk to the sustainability of nearshore species has further increased as a consequence of recent management changes to the West Coast Demersal Scalefish Fishery, which were introduced to ensure the ongoing sustainability of inshore demersal stocks. These measures, including an annual two-month closure to recreational fishing for demersal species (commenced in 2009), were designed to achieve a 50% reduction in catch by all sectors (Wise *et al.* 2007, Department of Fisheries 2008). One likely consequence of these changes is that there will be an effort shift, with more recreational fishers targeting nearshore fish during the closed demersal season. This sustainability risk increase will be on top of any increase due to the continuing human population growth in the Perth area and WA in general.

To date, limited management action has been focussed on the sustainability of nearshore stocks. In commercial fisheries, licence buy-backs and fishery closures over a period of decades have successfully reduced the number of operators in temperate nearshore and estuarine fisheries, although the primary focus of these measures was removal of latent effort and resource reallocation, not sustainability. In the recreational fishery, only blunt management tools have been applied (e.g. bag limits and/or size limits), which limit individual catches but do not constrain total catch.

These low-level management approaches are a result of an earlier sustainability risk assignment of 'low' (e.g. Australian herring, sand whiting, mullet, skipjack trevally) or 'medium' (e.g. tailor, King George whiting) to many nearshore species (Prokop 1994). However, there are now many indications (e.g. declining catch levels and low recruitment) that the risk level and the status of the nearshore finfish resource within the WCB should be reviewed.

1.2 Need

The Department of Fisheries uses an indicator species approach to monitor the status of finfish resources throughout the State (Department of Fisheries 2011). Therefore, the Department's research activities are strongly focused on determining the stock status of the indicator species identified.

Within each Bioregion of WA, finfish resources are assigned to one of five ecological suites: estuarine, nearshore, inshore demersal, offshore demersal or pelagic. Indicator species for each suite have been identified using a risk-based approach, based on the vulnerability of the species/ stock to fishing, as well as social, economic and cultural values (Department of Fisheries 2011). The collective status of the indicator species is used to indicate the status of an entire finfish suite. The following indicators have been selected to represent the nearshore finfish resources of the WCB: Australian herring, tailor, southern garfish, whitebait (*Hyperlophus vittatus*) and whiting (various species). The whiting species complex has been provisionally selected, subject to resolution of the taxonomic uncertainty about these species in fishery landings. Australian herring is also an indicator species for the nearshore finfish resources of the South Coast Bioregion (SCB).

Concerns about the status of the WCB nearshore indicators, especially Australian herring and tailor, from evidence of declining fishery catches and declining recruitment, combined with the likelihood of increased targeting within the WCB, has highlighted the need for greater detail and precision of assessments to ensure the ongoing sustainable management of the nearshore finfish resource (Smith *et al.* 2012).

1.3 Resource assessment framework – indicator species

Completing stock assessments for use in the sustainable management of multi-species, multi-sectoral fisheries presents many challenges in both scale and complexity. These were recently addressed in the assessments of demersal finfish resources in the WCB and Gascoyne Coast Bioregion (GCB) that focused on a limited number of indicator species (Wise *et al.* 2007; Marriott *et al*. 2012). In the WCB, a precautionary management approach was applied whereby the indicator species with the poorest status determined the status of the entire inshore demersal suite. In the GCB, a more spatially explicit management approach is being taken. Due to the wide range of species with varying biological traits in the nearshore suite of the WCB, and the diverse range of fisheries that target them, a spatially explicit management approach may also be appropriate.

The benefits of assessing and managing stock suites based on indicator species are twofold: (i) if resources are limited they can be prioritised to allow more frequent assessments of the indicators in order to determine the status of the entire suite; and (ii) management of fishing on the species that comprise the suite is simplified by focusing on management of the indicators.

1.4 Weight of evidence assessment

For fisheries that are considered 'data limited', a 'weight-of-evidence' approach is now considered to be best practice (Wise *et al.* 2007, Marriott *et al*. 2012). This approach increases the robustness of the assessment, and thereby reduces the uncertainty, by considering all available data sources.

The 'weight-of-evidence' approach allows all available biological, fishery-dependent and fishery-independent data to be considered, such as trends in catch, catch rate and recruitment, and other relevant biological, ecological and anthropogenic data (Marriott *et al*. 2010). This approach develops indicators that allow the performance of a stock to be assessed relative to management reference levels. A range of management outcomes are possible – from broad, precautionary actions to very specific actions – depending on the precision of, and level of risk associated with, the estimate(s) of stock status and the inherent vulnerability of the species involved.

For the nearshore indicator species of the WCB, current data limitations meant it was not possible to develop integrated stock assessment models that could reliably estimate spawning stock biomass. Instead, a 'weight-of-evidence' approach was taken, allowing the full range of available information to be considered in each stock assessment.

1.5 Objectives

This State Natural Resource Management funded project was conducted from 2009/10 to 2012/13. The project aimed to assess the status of Australian herring and tailor stocks, and provide preliminary assessments of the status of southern garfish and whiting stocks, in the WCB and SCB. This project aimed to collaborate with key recreational and commercial stakeholders, including Recfishwest and the Western Australian Fishing Industry Council, to assist in data collection and the establishment of a collaborative, long-term monitoring programme for nearshore finfish resources in the WCB and SCB.

In this report, a 'weight-of-evidence' assessment of the status of the Australian herring stock is presented. Assessments of other nearshore indicator species (tailor, whiting and southern garfish) are presented in other reports.

Specific objectives:

1. Develop methods for collecting representative age samples in order to generate robust estimates of fishing mortality.
2. Develop ageing methodologies (if not already available).
3. Estimate fishing mortality and compare the current level with that determined from historical data sets (where available) to determine if the current status is unique or has occurred in the past.
4. Determine catch and catch rate trends from commercial and recreational fishery data.
5. Develop recruitment indices.
6. Evaluate the influence of key environmental variables on recruitment strength and examine relationships between recruitment strength and catch rates of adults.
7. Review, and estimate where required, key biological parameters (growth, reproduction, natural mortality) required to assess inherent vulnerability.
8. Develop an ongoing monitoring regime for assessment of the stock.

1.6 Overview of biological characteristics of Australian herring

Australian herring is a small, relatively short-lived species, attaining a maximum total length of 41 cm and a maximum reported age of 12 years (Hutchins and Swainston 1986, Ayvazian *et al.* 2000). Adults and juveniles form pelagic schools over a range of habitats (reef/sand/weed) in nearshore coastal waters and the lower reaches of estuaries. The species is endemic to southern Australia, inhabiting nearshore coastal waters and estuaries from Shark Bay (WA) southward to the Gippsland Lakes (Victoria) (Hutchins and Swainston 1986). The species constitutes a single breeding stock across this range (Ayvazian *et al.* 2004, Moore and Chaplin 2013).

Australian herring spawn annually during a 2–3 week period in May/early June in coastal waters of south-western WA, mainly between Perth and Augusta (Fairclough 2000a, Section 5 this report). The pelagic eggs and larvae are transported southwards and then eastward along the southern coast by prevailing currents (especially the Leeuwin Current) before settling into nursery habitats in sheltered nearshore waters in WA, SA and Victoria. Higher levels of recruitment to the eastern section of the WA south coast and in SA tend to occur during years of strong Leeuwin Current flow due to the increased advection of larvae. At maturity, fish undertake a pre-spawning migration back to the spawning area in south-western WA during February to April (Ayvazian *et al*. 2000). There is no return (post-spawning) migration, and thus the spawning stock occurs only in WA (Ayvazian *et al*. 2004).

Over 50% of males are mature at the end of their 2^{nd} year and over 50% of females are mature at the end of their 3^{rd} year (Section 5 this report). Over 95% of all fish are mature by the end of their 4^{th} year. Australian herring are multiple spawners, i.e. individuals spawn more than once during the breeding season. Each female is estimated to release between 32,000 and 207,000 eggs per year, depending on female body size (Fairclough *et al.* 2000a). Individuals do not change sex.

Juveniles and adults of *A. georgianus* are opportunistic carnivores, feeding on a wide range of invertebrates and fish (Lenanton *et al.* 1982, Department of Fisheries unpubl. data).

2.0 Australian herring recruitment dynamics

Summary

- The annual rate of recruitment by 0+ Australian herring was monitored in two Zones of the West Coast Bioregion (Metropolitan, South-west) and two Zones of the South Coast Bioregion (South, South-east) in Western Australia, from 1996/97 to 2009/10. Annual recruitment varied between Zones. However, a similar long-term trend occurred in all Zones, i.e. annual recruitment followed a declining trend in each Zone between 1996/97 and 2009/10.
- The factors that determine recruitment strength are not fully understood. The strength of the Leeuwin Current may partly determine recruitment in each Zone. In the Metropolitan, South-west and South Zones, high recruitment tended to occur during years of weak current, whereas in the South-east Zone high recruitment tended to occur during years of strong current. Other factors such as wind-driven surface currents and spawning stock levels on the west coast may also partly determine the supply of new recruits to southern regions. Recruitment is presumably also related to the spawning stock level, although the stock-recruitment relationship is currently unknown for Australian herring.
- The average growth rate of juvenile herring in the Metropolitan, South-west and South Zones is substantially faster than in the South-east Zone (and probably South Australia), possibly due to cooler temperatures in the South-east Zone. The differences in growth between regions estimated here are greater than those estimated previously by Fairclough *et al.* (2000b).
- Variations in juvenile growth result in regional differences in age-at-maturity. Herring in the West Coast Bioregion (WCB) typically mature at the end of their 2nd year, whereas a high proportion of fish from the South Coast Bioregion (SCB) mature at the end of their 3rd year. These differences have implications for the composition of fishery landings. For example, in 2009–2011 pre-spawning fish (i.e. individuals that are yet to spawn for the first time) comprised approximately 60% of all landings in the SCB, but only 20% in the WCB.

2.1 Introduction

Australian herring (*Arripis georgianus*) occurs from Shark Bay (WA) southwards, including the south coast of WA, South Australia (SA) and Victoria (Hutchins and Swainston 1986). Spawning occurs along the southern west coast during a discrete 2–3 week period in May/early June (Fairclough *et al.* 2000a, Section 5 this report). This timing coincides with the peak flow of the Leeuwin Current, which flows southward and then eastward along the southern Australian coast. The current transports the eggs and larvae of herring to sheltered coastal nursery sites along the west coast and south coast, as far as Victoria. Juvenile herring are believed to remain in these nursery areas until they attain maturity at approximately 2 years of age (Fairclough *et al.* 2000a, Section 5 this report). In the months immediately prior to their first spawning, fish form large schools that migrate westwards along the south coast and northwards along the lower west coast (Section 3). Tagging studies and decades of observations by commercial fishers indicate that adults remain on the west coast after spawning (i.e. there is no return migration back to the south coast) (Ayvazian *et al*. 2004). Due to this life cycle, the immature and mature components of the Australian herring stock are essentially spatially separated – the breeding stock is located along the west coast, while the majority of the juveniles (and some non-breeding adults) are located along the south coast.

In 1993, the Western Australian Department of Fisheries (DoF) commenced large scale, annual surveys of 0+ juvenile fish abundance at numerous coastal sites along the lower west and south coasts of Western Australia (WA) (Ayvazian *et al.* 2000). In SA, similar annual surveys of juvenile fish recruitment had commenced in 1980 (but ceased in 2000 (Jones 2008)). These surveys aimed to monitor the annual recruitment of juveniles of various recreationally and commercially important species, in order to assess relative stock abundance and potentially predict fishery landings. In WA, annual recruitment levels subsequently proved effective in predicting fishery catch rates and have assisted in stock assessments for various species, including Australian herring (Gaughan *et al.* 2006).

Since 1993, the WA recruitment monitoring program has sampled at a total of 52 sites along the south-western coast of WA (Gaughan *et al.* 2006, Smith *et al.* 2008a) (Fig. 2.1). No sampling was undertaken from 2002/03 to 2004/05, due to lack of resources. In mid-2005, an 'optimised' sampling program was implemented, based on a reduced number of months and number of sites being sampled annually, compared to previous years. This new 'optimised' sampling regime was designed to provide cost-effective monitoring of the annual recruitment of seven key fishery species (Australian herring, tailor (*Pomatomus saltatrix*), western Australian salmon (*A. truttaceus*), King George whiting (*Sillaginodes punctata*), yellowfin whiting (*Sillago schomburgkii*), sea mullet (*Mugil cephalus*), yelloweye mullet (*Aldrichetta forsteri*)). The methodology was developed during two major DoF projects (Ayvazian *et al.* 2000, Gaughan *et al.* 2006).

Recruitment indices for Australian herring and the other key species were initially developed by Ayvazian *et al.* (2000). Preliminary analyses of the relationships between annual recruitment trends, fishery catch rates and environmental factors were conducted after 6 years of recruitment monitoring (1996/97 to 2001/02) (Gaughan *et al.* 2006). With a further 4 years of recruitment data now available (2005/06 to 2009/10), a re-examination of these relationships can be undertaken.

The objectives of this Section are to:

- Revise and document the methods for calculating annual recruitment indices for Australian herring at each site.
- Describe trends in annual recruitment of Australian herring from 1996/97 to 2009/10.
- Describe the relationships between Australian herring annual recruitment rates and Leeuwin Current strength.
- Describe differences in the juvenile growth rate of Australian herring between Bioregions and discuss implications for attainment of maturity and fishery catch composition.

2.2 Methods

2.1.1 Environmental data

The lower west coast and south coast of WA is strongly influenced by the tropical Leeuwin Current, which flows southward along the west coast throughout the year. In autumn/winter (April–August), the current typically strengthens and extends southwards along the full length of the west coast and then eastwards along the south coast (Smith *et al.* 1991). This process transports warmer water and various pelagic species to the more temperate region of the south coast (Maxwell and Cresswell 1981, Caputi *et al.* 1996, Gopurenko *et al.* 2003). Transport potential varies according to substantial interannual variations in current strength. The Leeuwin Current is typically stronger during a *La Niña* year and weaker during an *El Niño* year (Feng *et* *al.* 2003). There is a strong linear relationship between Leeuwin Current volume transport and sea level deviation at Fremantle, WA (Feng *et al.* 2003).

Mean monthly sea level at Hillarys (near Fremantle) and Esperance, WA, and the annual Southern Oscillation Index (SOI) were used as indices of annual Leeuwin Current strength. In addition, mean monthly sea surface temperature (SST) in continental shelf waters along the south coast during February–September was used as an annual indicator of local influence of the Leeuwin Current. Ocean temperature since 1982 were available from satellite-derived monthly mean SST for 1-degree latitude x 1-degree longitude blocks (Reynolds and Smith 1994).

Sea level data were downloaded from the Australian National Tidal Centre (http://www.bom.gov.au/oceanography/projects/abslmp/abslmp.shtml). Ocean temperature data were provided by CSIRO Marine and Atmospheric Research, Hobart. SOI data were downloaded from the Bureau of Meteorology website (http://www.bom.gov.au/climate/current/soihtm1.shtml.).

Correlations were used to investigate relationships between the annual Australian herring recruitment index at each site and three proxies of annual Leeuwin Current strength. These proxies were i) the annual deviation of SOI from the long-term annual mean (1980–2009), ii) the annual deviation of mean monthly Fremantle sea level from the long-term annual mean (1993–2009) and iii) the annual deviation of mean monthly sea surface temperature (SST) (detrended) during February–September from the long-term annual mean (1982–2009) in the 1-degree latitude x 1-degree longitude block adjacent to Albany (i.e. 34–35º S, 118–119º E).

Mean monthly sea level at Esperance in 2000 was excluded from correlations due to missing data in several months. A warming trend was clearly evident in the SST data, consistent with the linear warming trend that has been occurring in ocean waters around south-western Australia for the past 50 years (Pearce and Feng 2007). Therefore, SST data was detrended prior to determination of deviations.

Annual recruitment indices were plotted against Leeuwin Current proxies. After inspection of residuals, a Ln(x+1) transformation was applied to recruitment indices at each site. Relationships between the transformed recruitment index at each site and Leeuwin Current proxies were investigated by correlations.

2.1.2 Fish collection

A full description of the methodology used for the recruitment sampling can be found in Ayvazian *et al*. (2000) and Gaughan *et al*. (2006) and is summarised below.

Sampling was conducted during daylight. Fish were collected using a beach seine net (total length 60.6 m, height 2.0 m), composed of two wings of length 29.1 m (22 mm stretched mesh) and a bunt of length 2.4 m (8 mm mesh). The net was deployed from a small dinghy rowed in an arc from/to the beach. The area swept by the net was approximately 592 m² per haul. Both ends of the net were hauled back onto the beach, where the catch was sorted. At all sites, the area swept by the net was predominantly bare sand, sometimes interspersed with small patches of drifting or fixed vegetation (seagrass or algae).

At each site, 3 or 4 replicate hauls were undertaken each month at each site. Replicate hauls were completed within a single day and swept adjacent, but non-overlapping, areas of habitat at each site. Captured fish and macro-invertebrates were held in an aerated tub of seawater. Fish were identified to the lowest possible taxon (usually species), measured (total length, to the nearest mm) and then released alive. Very abundant species were subsampled before being counted and measured. Fish were released after all hauls were completed to avoid any recaptures. Temperature, salinity and weather conditions were recorded during sampling.

Seine netting catch and effort data was stored within the Department of Fisheries PISCES Database (a Microsoft Access database).

Recruitment sampling was commenced by DoF in 1993. The 'optimised' annual sampling regime that has been employed since mid-2005 includes 6 sites, each sampled during multiple months from September to April, following the methods recommended by Gaughan *et al.* (2006). The number of months sampled each year varies between sites, ranging from 4 to 7 months per site. Sampling occurs at 3 sites within the Metropolitan Zone (Pinnaroo Point, Mangles Bay, Warnbro Sound – all located in Perth), 1 site within the South-west Zone (Koombana Bay – located in Bunbury), 1 site in the South Zone (Emu Point – located in Albany) and 1 site in the South-east Zone (Poison Creek – east of Esperance) (Fig. 2.1).

2.1.3 Analysis of length frequencies

Catches taken since 1993 were grouped by month to generate monthly length frequency distributions of Australian herring in each Bioregion or Zone. Inspection of length frequencies was used to define the length range of 0+ fish in each month in each Bioregion or Zone. The catch rate of 0+ fish was then used as a recruitment index at each site (Table 2.1).

The monthly mean length and standard deviation of the 0+ cohort was estimated using the NORMSEP function within the FiSAT II program, which uses a maximum likelihood method to fit normal distributions to a user-defined number of cohorts within a sample. Progression of the mean monthly cohort length was used to estimate juvenile growth rates in each Bioregion or Zone.

2.1.4 Recruitment indices

Annual recruitment indices for Australian herring were calculated for 4 sites – Poison Creek, Emu Point, Koombana Bay and Warnbro Sound (Fig. 2.1). Recruitment indices were not calculated at the other sampling sites (Mangles Bay and Pinnaroo) because catch rates of 0+ herring at these sites were very low.

At Koombana Bay, Emu Point and Warnbro Sound, the catch rate (number of fish per haul) of 0+ herring per month was calculated from the summed catch during all hauls (n=4) taken that month. At Poison Creek, the monthly catch rate was calculated from the summed catch during the first 3 hauls taken that month. The 4^{th} haul was often not undertaken at Poison Creek due to unfavourable beach conditions in this part of the beach.

Monthly catch rate = $\frac{\sum_1^i C_i}{i}$ where C= catch, i = number of hauls

The annual recruitment index (R) at each site was equal to the average of monthly catch rates, for specified months only (Table 2.1). Where data from a month was missing, the average of remaining months was used. Missing data occurred in 11 of 66 sampling months (17%) at Poison Creek, 12 of 77 months (16%) at Emu Point and 3 of 36 months (8%) at Warnbro Sound. At Koombana Bay there were no missing data.

Annual recruitment indices were derived from the average monthly catch rate of the 0+ age class over a financial year (July–June). For example, the recruitment strength of juveniles spawned in autumn 2000 (i.e. the '2000 year class') was determined from sampling during the 2000/01 financial year.

2.3 Results

From 1993/94 to 2009/10, a total of 21,500 Australian herring were captured during seine netting by DoF. These fish were caught at 29 inshore marine sites extending from Cervantes (Mid-west Zone) to Poison Creek (South-east Zone) (Fig. 2.1). The majority of captures occurred at Poison Creek (68% of fish) and Koombana Bay (23%). The highest average catch rates over this period were also at these two sites (182 and 25 fish/day, respectively). The average catch rates at other sites were <10 fish/day.

The smallest length class of 0+ fish captured by seine netting was 30–40 mm total length (TL) in the Metropolitan, South-west and South Zones and 50–60 mm in the South-east Zone (with the exception of a single 48 mm fish captured in November in the South-east Zone) (Figs. 2.2, 2.3, 2.4). In each Zone, the smallest fish were caught in June. June was also the earliest month of capture of 0+ fish in each Zone (with the exception of a single 0+ fish captured in May in the South-west Zone).

In the South-east Zone, pooled monthly length frequency distributions suggested two pulses of recruitment by Australian herring, arriving in June and August, respectively (Fig. 2.4). The timing and mean length of the earlier recruitment pulse matched closely that of western Australian salmon (*A. truttaceus*) (DoF unpub. data). It is likely that these fish were actually western Australian salmon but were mis-identified as Australian herring during the initial years of the sampling program (J. Brown, DoF, pers. comm.). If so, then annual recruitment by Australian herring to the South-east Zone was first represented in samples by the 50–60 mm TL size class in August. Any accidental inclusion of western Australian salmon in the early years of sampling, which potentially occurred during June–August, would not affect the value of the annual recruitment index for Australian herring, which was derived from catch rates during September–April (Table 2.1).

In each Zone, the 0+ age class formed a discrete length cohort that could be clearly distinguished in samples for 12 months after recruitment (i.e. until the following June/July). The abundance of the cohort then declined abruptly, suggesting emigration of 1+ fish from the sampling area. Despite the low abundance of older fish in samples, the 1+ age class could still be identified as a discrete length cohort in some months in the Metropolitan, South-west and South-east Zones. Hence, in these regions the average growth rate of 0+ and 1+ juvenile Australian herring could be estimated from the increase in mean monthly cohort length (i.e. modal progression).

A comparison of the monthly length frequency distributions at individual sites in the WCB (Koombana Bay, Perth and Cervantes) suggested that juvenile growth did not vary significantly among sites within this Bioregion (DoF unpubl. data, not shown). Hence monthly length frequencies from all WCB Zones were pooled prior to estimating growth rates. Monthly increases in the mean length of each cohort suggested faster juvenile growth in the WCB (Zones pooled), compared to the South-east Zone (Fig. 2.5). At age 11 months (which occurs in April, assuming a birth date of 1 June for all fish), fish recruiting to the South-east Zone attained an average total length of 118 mm whereas fish recruiting to the WCB attained 144 mm. After 22 months, South-east and WCB recruits attained average lengths of 156 mm and 214 mm, respectively. Limited data from the South Zone suggested a growth rate of 0+ herring similar to that in the WCB (not shown).

Annual recruitment indices at key sites were calculated during two periods (1995/96 to 2002/03 and 2005/06 to 2009/10). No sampling was undertaken between 2002/03 and 2004/05.

At all sites, higher levels of annual recruitment were observed early in each time series, prior to 2000 (Fig. 2.6). At Koombana Bay and Warnbro Sound, where annual recruitment trends were similar, the peak in recruitment occurred in 1997/98. At Emu Point, the peak occurred in

1998/99, although recruitment in 1997/98 was also relatively high. At Poison Creek, the peak in annual recruitment occurred in 1999/00.

From 2005/06 to 2009/10, annual recruitment increased steadily at Poison Creek but remained low at other sites throughout this period.

Recruitment at Warnbro Sound, Koombana Bay and Emu Point was higher during years of weak or average Leeuwin Current strength (Figs. 2.7, 2.8). The highest annual recruitment at each of these sites occurred during years when the SOI, Hillarys sea level and Esperance sea level were at or below average. However, there was no trend between recruitment at these sites and SST along the south coast.

At Poison Creek, higher recruitment tended to occur during years of strong Leeuwin Current, as suggested by a positive correlation with south coast SST ($r = 0.766$, d.f. = 9, $p < 0.10$). However, there was no relationship between recruitment at this site and the SOI or sea level.

2.4 Discussion

2.4.1 Use of nursery areas by Australian herring

Juvenile Australian herring are widely distributed around south-western WA and are relatively abundant in many different types of inshore habitats (Ayvazian and Hyndes 1995, Gaughan *et al.* 2006, Smith *et al.* 2008a). Despite this widespread distribution, large and persistent differences in the average catch rates between sites suggest substantial differences in their value as nursery areas for 0+ herring. For example, the long-term average catch rates of 0+ herring at Poison Creek and Koombana Bay were more than twice that observed at any of the other 27 sites sampled by DoF since 1993.

The reasons for such variations between sites in the abundance of 0+ herring are unclear. Catch rates of Australian herring can differ markedly between sites with apparently similar physical attributes or between sites in close proximity. For example, DoF has captured 0+ herring at only three of the seven sites that have been sampled in the Perth area. Within this area, the presence of juveniles at both sheltered (Mangles Bay) and wave-exposed (Warnbro Sound) sites suggests that various types of shallow inshore habitats can function as nurseries for this species.

The presence of aquatic vegetation appears to be an important factor influencing the distribution of juvenile Australian herring. Although 0+ herring are often captured over bare sand, they appear to benefit from nurseries with adjacent vegetation. At coastal sites along the west coast, the abundance of 0+ herring is positively correlated with the level of detached macrophytes, which appear to be an important source of shelter and food (especially amphipods) for juveniles (Lenanton 1982, Lenanton *et al*. 1982). The recruitment by 0+ fish in late winter/spring occurs at the peak in the level of detached macrophytes in local surf zones and 0+ fish remain associated with detached macrophytes throughout summer on the west coast (Lenanton *et al*. 1982). Thus, it appears that recruitment by Australian herring is timed to allow newly settled fish to derive maximum benefit from the abundant food and shelter associated with seasonal accumulations of detached macrophytes in surf zones throughout south-western WA. This suggests that loss of marine vegetation adjacent to nurseries could negatively impact on local recruitment success by Australian herring due to a reduced availability of food and shelter.

The presence of a single, clearly defined length cohort of 0+ fish that is first detected in samples in June each year is consistent with the timing of spawning by Australian herring. Spawning occurs on the west coast and possibly also in the western-most part of the south coast of WA, but not in the South-east Zone (Fairclough *et al.* 2000a). Spawning occurs over a relatively short period (April–June), with a pronounced peak in activity during late May/early June (Lenanton 1978, Fairclough *et al.* 2000a, Section 4 this report).

Differences between regions in the minimum observed lengths of 0+ Australian herring and the timing of their occurrence suggest a larger length-at-recruitment and later arrival at south-east nurseries, compared to south-west nurseries. The smallest length class of 0+ fish captured by seine netting was 30–40 mm TL in the WCB and in the South Zone of the South Coast Bioregion (SCB), which was first observed in June at each site. In the South-east Zone, the smallest length class was 50–60 mm TL which was first observed in August. In South Australia (SA), juveniles are usually first observed at a length of >60 mm in October/November (Jones *et al.* 1990, Jones 2008).

A minimum observed size of 30 mm TL is consistent with other observations about the growth and development of larval Australian herring. The transformation from larva to juvenile occurs between 12–27 mm standard length and pre-settlement fish (larvae or juveniles) have been caught in offshore plankton samples at lengths up to 37.5 mm (Fahlbusch 1995). These observations suggest that Australian herring are competent to settle into nursery areas at or slightly below 30 mm TL.

Given the peak in spawning in late May/early June, the arrival of 0+ fish in June at south-western nurseries implies an age-at-recruitment of 3–4 weeks for at least some fish. This is consistent with ages estimated from the enumeration of daily increments in otoliths, which suggest that fish are approximately 1–2 months old at 30–40mm TL and 2–3 months old at 50–60mm TL (Ayvazian *et al.* 2000). These observations are also consistent with modelling of ocean dispersal that suggests eggs/larvae spawned on the lower west coast would take approximately 60–80 days to reach the South-east Zone (Ayvazian *et al.* 2000).

Overall, the timing, length and age at recruitment to coastal nurseries appear to vary between regions, increasing with distance from the spawning area on the lower west coast. A longer larval duration (and thus greater size- and age-at-settlement) is experienced by fish that are transported to more remote nurseries in the South-east Zone and in SA.

In each region, 0+ herring recruit in a short 'pulse' of recruitment, resulting in the formation of a single, well defined length cohort each year. This cohort can be easily identified in samples for 12 months after settlement and occasionally up to 24 months after settlement.

The relative abundance in samples of each annual cohort for 12 months after settlement suggests that juveniles typically remain in shallow inshore nursery sites for at least the 1st year of their life. The abrupt decline in the catch rate of fish approximately 12 months after recruitment (in July), which was evident in all regions, suggests that herring typically emigrate from shallow waters at the start of their 2nd year, possibly into deeper adjacent waters.. The arrival of the next year class may provide a cue for older fish to move. This behaviour would reduce competition between year classes. A small number of older herring in samples indicated that they continue to use these shallow sites occasionally.

2.4.2 Variations in juvenile growth

Monthly increases in the modal lengths of annual cohorts indicated substantially faster growth by juvenile Australian herring in the WCB compared to the SCB (especially the South-east Zone). SA nursery sites were not sampled by the DoF recruitment monitoring program. However, Fairclough *et al.* (2000b) previously noted that juvenile herring in SA exhibited similar growth rates to fish in the South-east Zone of WA during their first year of life. On this basis, it is assumed that Australian herring in SA typically grow at a similar rate to those in the South-east Zone.

The average lengths-at-age of juveniles in the WCB estimated in this report are consistent with those reported by Fairclough *et al.* (2000b), who used a modal progression method to estimate growth and additionally validated the age of cohort members by enumerating increments in their otoliths. In this report, recruits in the WCB are estimated to attain an average length of 144 mm at 11 months (i.e. during April) and 214 mm at 22 months. Similarly, Fairclough *et al.* (2000b) reported that WCB fish reached 140–149 mm at 11 months and 210–219 mm at 24 months.

In the South-east Zone, the average lengths-at-age of Australian herring estimated here are also consistent with that reported by Fairclough *et al.* (2000b) in the 1st year of life (118 mm at 11 months versus 110–119 mm at 11 months). However, growth during the 2nd year is estimated to be considerably slower than that reported by Fairclough *et al.* (156 mm at 22 months versus 190–199 mm at 24 months). The low number of 1+ fish sampled by Fairclough *et al.* (2000b) may have contributed to this discrepancy.

A gradient in growth rate has also been observed in juveniles of the closely related western Australian salmon (Nicholls 1973, Cappo *et al.* 2000). Growth of this species is slowest in SA, intermediate along the south coast of WA and fastest along the west coast.

2.4.3 Variations in age- and length-at-maturity

Such pronounced differences in juvenile growth between regions are likely to result in differences in the age or size at which individual Australian herring attain maturity in each region. Specifically, slower juvenile growth in the SCB (especially in the South–east Zone) implies that maturity will be attained at a higher age and/or length in this region, compared to the WCB. This is supported by the consistently higher values of $A_{50\%}$ and $L_{50\%}$ that have been estimated for fish in the SCB.

In 1996–1998, $A_{50\%}$ was estimated to be 2.4/2.6 years (male/female) in the SCB and 1.8/1.9 years in the WCB (Table 5.8 in Section 5). In 2009–2011, $A_{50\%}$ was estimated to be 1.9/2.8 years in the SCB and 1.8/2.2 years in the WCB.

In 1996–1998, $L_{50\%}$ was estimated to be 217/228 mm (male/female) in the SCB and 185/203 mm in the WCB (Table 5.8 in Section 5). In 2009–2011, $L_{50\%}$ was again estimated to be higher in the SCB, at 196/220 mm, compared to 174/194 mm in the WCB.

Given these region-specific $L_{50\%}$ values, the juvenile growth rate suggested by length frequency data indicates that virtually all Australian herring in the WCB attain maturity between 12 and 24 months of age. Therefore, the majority of individuals derived from WCB nurseries are likely to spawn for the first time during May/June (the spawning period) at the end of their 2nd year. This age is consistent with the estimated values of $A_{50\%}$ (~ 2 years) for both males and females in the WCB. In contrast, length frequency data indicates that only a small proportion of herring from the South-east Zone would reach a sufficient length to spawn at end of their 2nd year and that the majority would do so at the end of their 3rd year. This age is consistent with $A_{50\%}$ estimates for females (~ 3 years) in the SCB, although not for males (~2 years).

The closely related western Australian salmon exhibits a similar increase in age-at-maturity from west to east, due to faster juvenile growth rate in western regions (Cappo *et al.* 2000). Western Australian salmon attain maturity approximately 3–4 years along the west coast of WA and 4–6 years in SA (Cappo 1987).

Evidence from fishery landings is consistent with Australian herring in the South-east Zone typically attaining maturity in their 3rd year. The commercial South Coast trap net fishery exclusively targets Australian herring during their westwards pre-spawning migration (Section 3). The age composition of the catch by this fishery (predominantly aged 2+ and 3+ years) suggests that fish on the south coast (including the SCB and SA) attain maturity and commence their pre-spawning migration at the end of their 3rd or 4th year. The 3 or 4 year lagged correlation between annual recruitment in the South-east Zone and trap net CPUE (Section 3, Fig. 3.24) also suggests that juvenile herring in the South-east Zone attain maturity at the end of their 3rd or 4th year.

Given the similar growth rates of juvenile Australian herring in SA to those in the South-east Zone, it is likely that SA herring attain maturity at the same age. Indeed, commercial landings in SA are comprised almost exclusively of 1+ and 2+ fish (Ayvazian *et al.* 2000, Fairclough *et al*. 2000b). The rarity of 3+ and older fish suggests that they mature and emigrate from SA waters at the end of their 3rd year.

Within WA, regional variations in growth rate result in differences between Bioregions in the composition of fishery landings. Although the age at which Australian herring become vulnerable to capture by both commercial and recreational fisheries is similar in each Bioregion (2+ years, see Section 5), the proportion of immature fish being caught differs greatly. In 2009–2011, pre-spawning fish (i.e. individuals that are yet to spawn for the first time) comprised 59% of commercial landings in the SCB, but only 21% in the WCB. Similarly, pre-spawning fish comprised 67% of recreational landings in the SCB, but only 17% in the WCB.

2.4.4 Trends in annual recruitment

Annual recruitment by 0+ Australian herring was monitored in four Zones of south-western Australia from 1996 to 2009. Differences in the strength of annual recruitment experienced in each Zone indicates that the annual supply of new recruits varies markedly between Zones in south-western WA. For example, peak recruitment occurred in 1997 on the west coast but occurred in 1999 on the south coast. Also, since 2005 recruitment has followed an increasing trend in the South-east Zone but remained low in other Zones. However, despite some regional variations, the same long-term trend was seen in all Zones - peak recruitment occurred during the late 1990s, followed by relatively low annual recruitment after 2000.

The level of annual recruitment in each region of WA may be partly determined by the strength of the Leeuwin Current. In the WCB and South Zone of the SCB, high recruitment tended to occur during years of below-average Leeuwin Current strength, whereas in the South-east Zone high recruitment tended to occur during years of above-average current strength. These trends suggest that the advection of planktonic eggs and larvae by the Leeuwin Current is an important factor regulating the supply of new recruits to each region in WA.

Advection by the Leeuwin Current has also been implicated in regulating the supply of recruits to SA nurseries. Recruitment by 0+ Australian herring to Gulf St Vincent in SA was measured annually from 1981 to 2000 (Jones and Westlake 2003). Sea level height at Albany during June (a proxy of Leeuwin Current strength) was found to explain 66% of the variation in annual recruitment strength of Australian herring into this area.

Despite a clear tendency towards higher recruitment in the South-east Zone of WA and in SA during years of strong Leeuwin Current, a substantial amount of the variation in annual recruitment in these regions was not explained by Leeuwin Current variation. This indicates that other factors were also important.

Preliminary modelling of larval dispersal has previously suggested that larvae spawned in the WCB could be transported to nurseries in the SCB and SA by the combined effects of the Leeuwin Current, wind-driven surface currents and swimming behaviour (Ayvazian *et al.* 2000).

Since the Leeuwin Current typically flows along the shelf edge, factors that increase cross-shelf transport of larvae towards the south coast are likely to be important for successful recruitment. These factors may include wind-driven surface currents and meanders/eddies of the Leeuwin Current. The positive correlation between Poison Creek (South-east Zone) recruitment and coastal SST may be due to the across-shelf transport of recruits within a warm eddy or meander of the Leeuwin Current.

The annual rate of recruitment by Australian herring is presumably also related to spawning stock biomass. Unfortunately, a reliable index of spawning stock level is not yet available and so the stock-recruitment relationship is currently unknown (see other Sections).

Whilst the factors that determine recruitment strength are not fully understood, it is clear that the annual rate of recruitment by Australian herring followed a declining trend in each region of WA between 1996 and 2009. This decline was correlated with a decline in the commercial catch rates of herring in the SCB and lower WCB, which suggests that these fisheries are largely recruitment driven (Section 3).

Table 2.1. Length range of age 0+ juvenile Australian herring determined from visual inspection of monthly length frequency distributions at each site. Length data from 1993/94 to 2009/10 pooled at each site (see Figs. 2.2, 2.3, 2.4).

Bioregion & Zone	Site	Month(s)	0+ length range (mm)	Months used to calculate annual recruitment index
SCB (South-east Zone)	Poison Creek	May–Jun	<80	Sept, Oct, Nov, Feb, Mar, Apr.
		Jul–Aug	<90	
		Sep–Oct	<100	
		Nov–Dec	<120	
		Jan–Feb	<150	
		Mar–Apr	70–149	
SCB (South Zone)	Emu Point	May–Sep	<90	Sept, Oct, Nov, Jan, Feb, Mar, Apr.
		Oct–Jan	<120	
		Feb–Mar	<140	
		Apr	70–149	
West Coast (Metropolitan & South-west Zones)	Warnbro Sound & Koombana Bay	May–Jun	<75	*Warnbro Sound* : Sept, Oct, Nov.
		Jul–Oct	<110	
		Nov–Dec	<130	
		Jan–Feb	60–159	*Koombana Bay* : Oct, Nov, Dec.
		Mar–Apr	80–174	

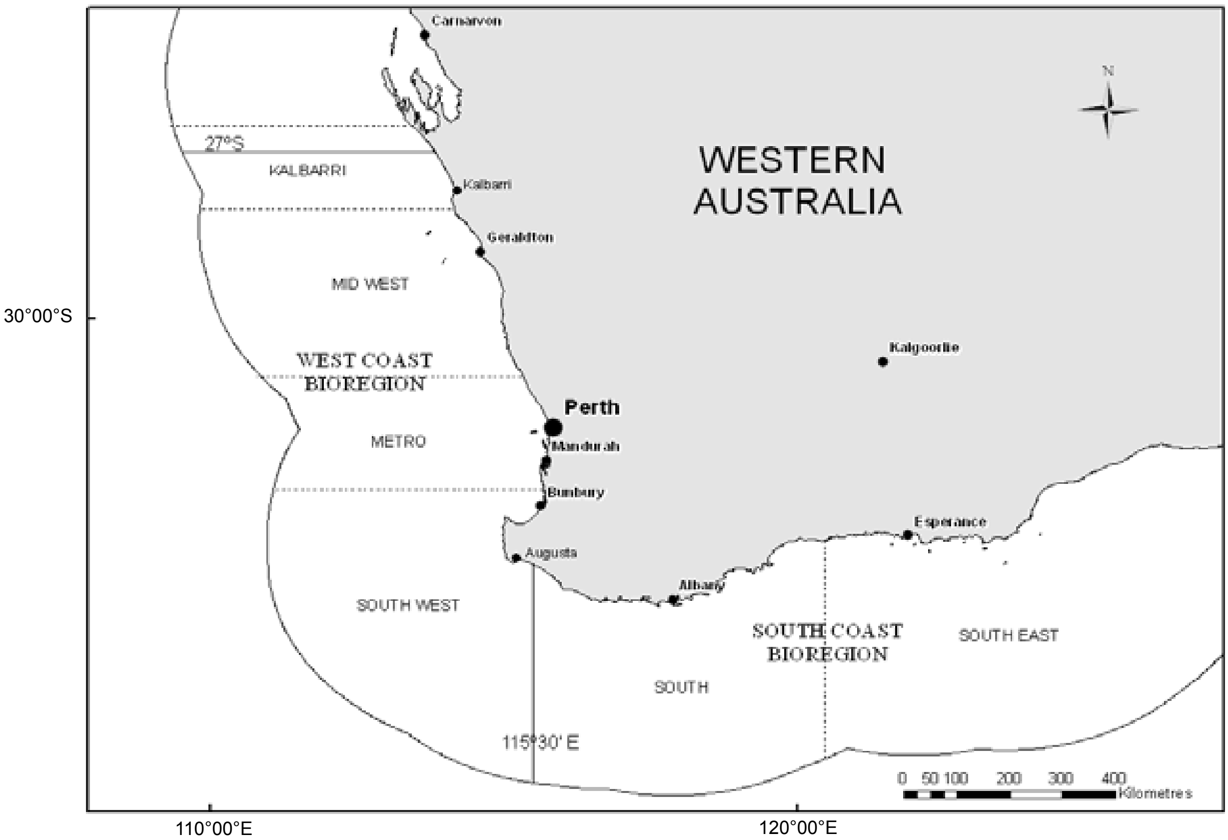

Figure 2.1. Locations of main recruitment monitoring sites and boundaries of Bioregions (West Coast, South Coast) and Zones within Bioregions (Kalbarri, Mid-west, Metropolitan, South-west, South, South-east) of south-western Australia.

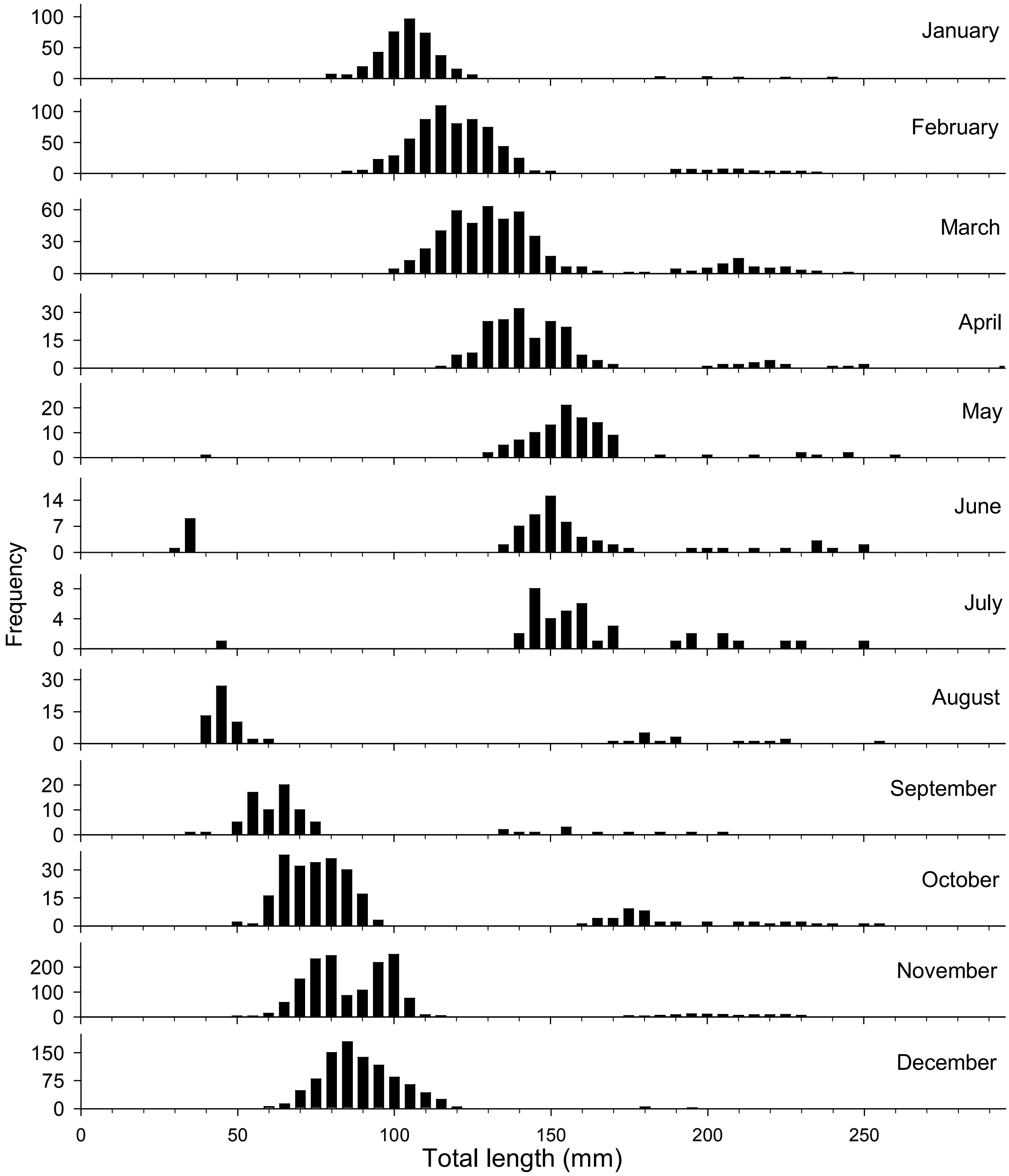

Figure 2.2. Monthly length frequency distributions of Australian herring in the West Coast Bioregion (Zones pooled), summed from all samples taken 1993/94 to 2009/10.

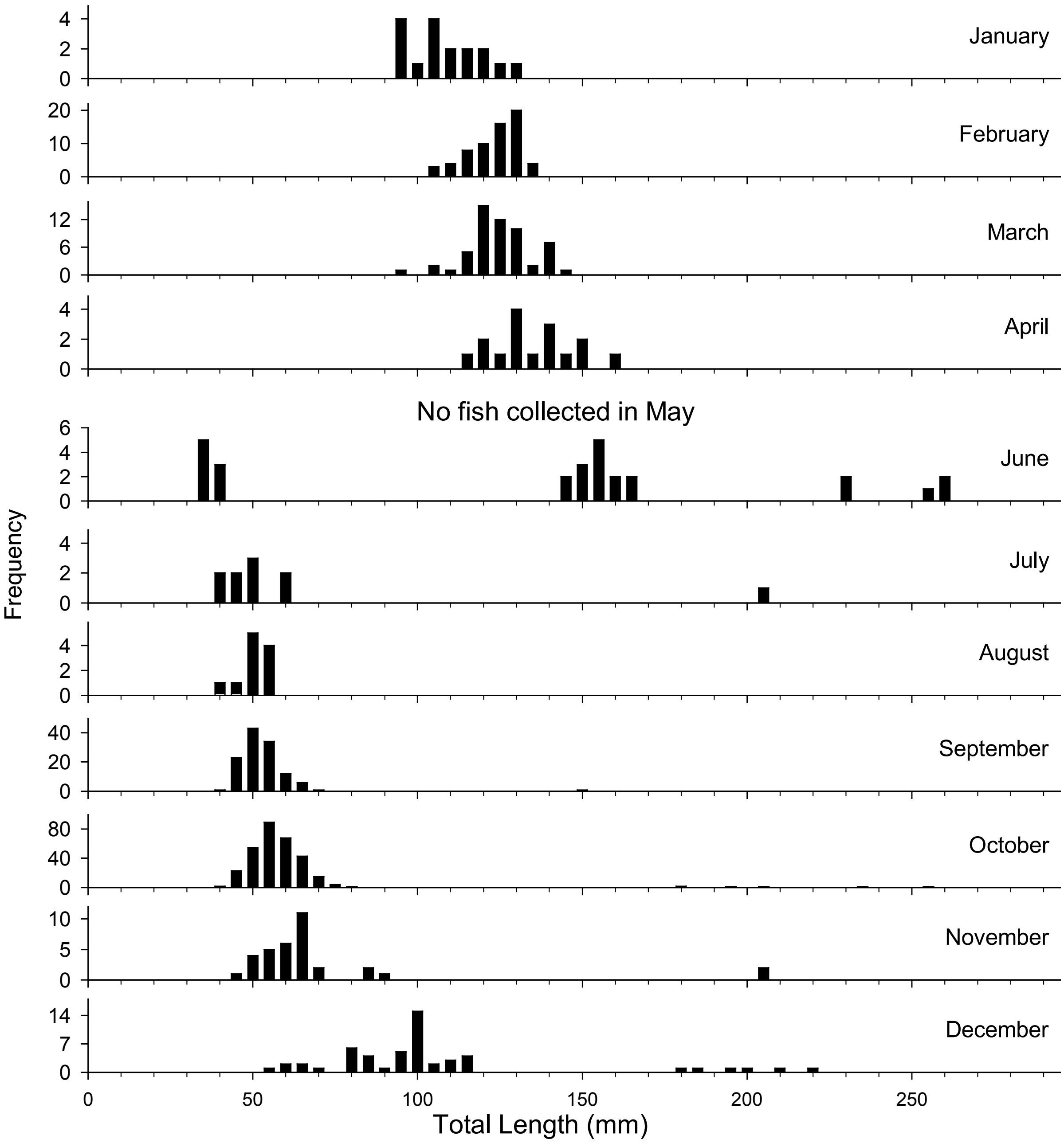

Figure 2.3. Monthly length frequency distributions of Australian herring in the South Zone of the South Coast Bioregion, summed from all samples taken 1993/94 to 2009/10.

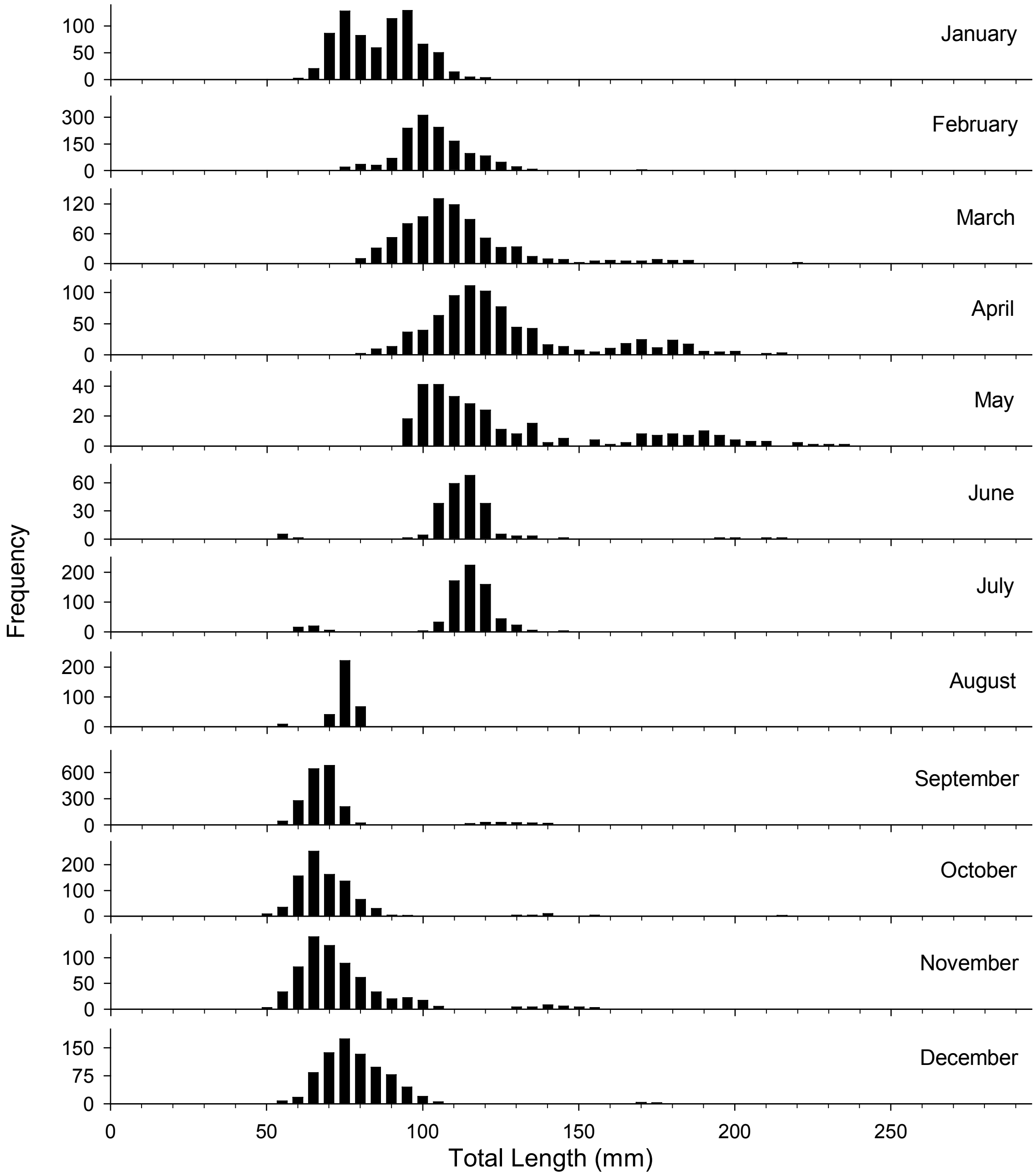

Figure 2.4. Monthly length frequency distributions of Australian herring in the South-east Zone of the South Coast Bioregion, summed from all samples taken 1993/94 to 2009/10.

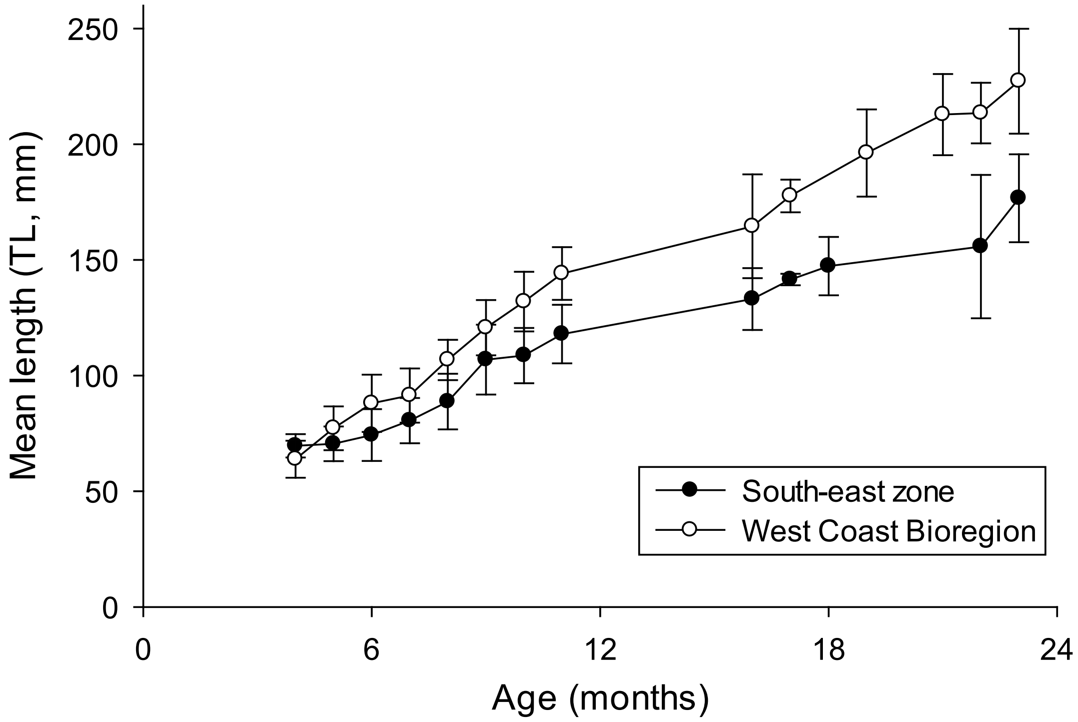

Figure 2.5. Mean (+ s.d.) length-at-age of Australian herring in the West Coast Bioregion (Zones pooled) and South-east Zone of the South Coast Bioregion, estimated from modal progression of monthly length frequencies.

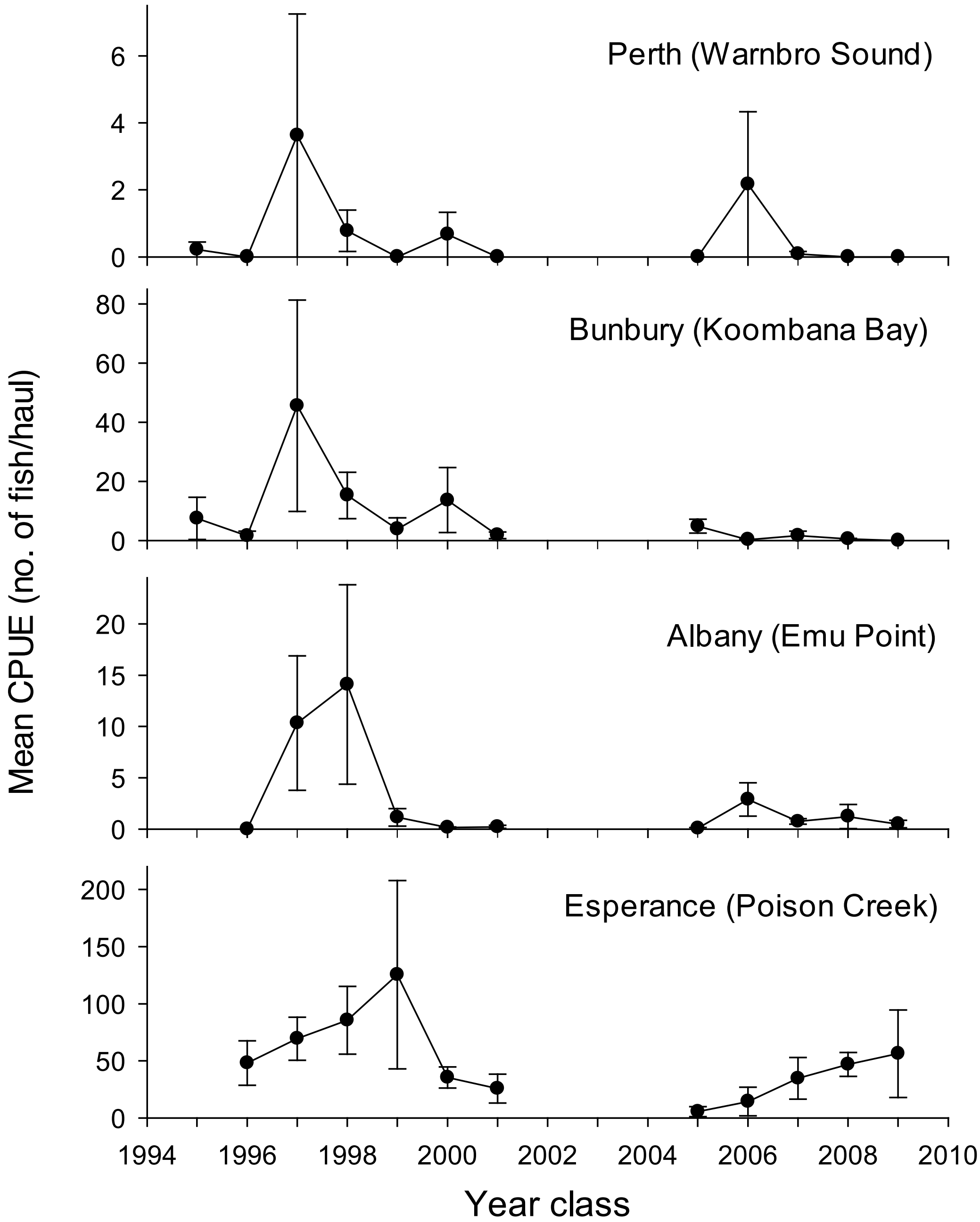

Figure 2.6. Australian herring annual recruitment indices (mean CPUE ± s.e.) at Warnbro Sound, Koombana Bay, Emu Point and Poison Creek from 1995/96 to 2009/10. 'Year class' refers to birth year. Year classes were sampled in the following financial year, e.g. the '2000 year class' was spawned in autumn 2000 and sampled throughout 2000/01.

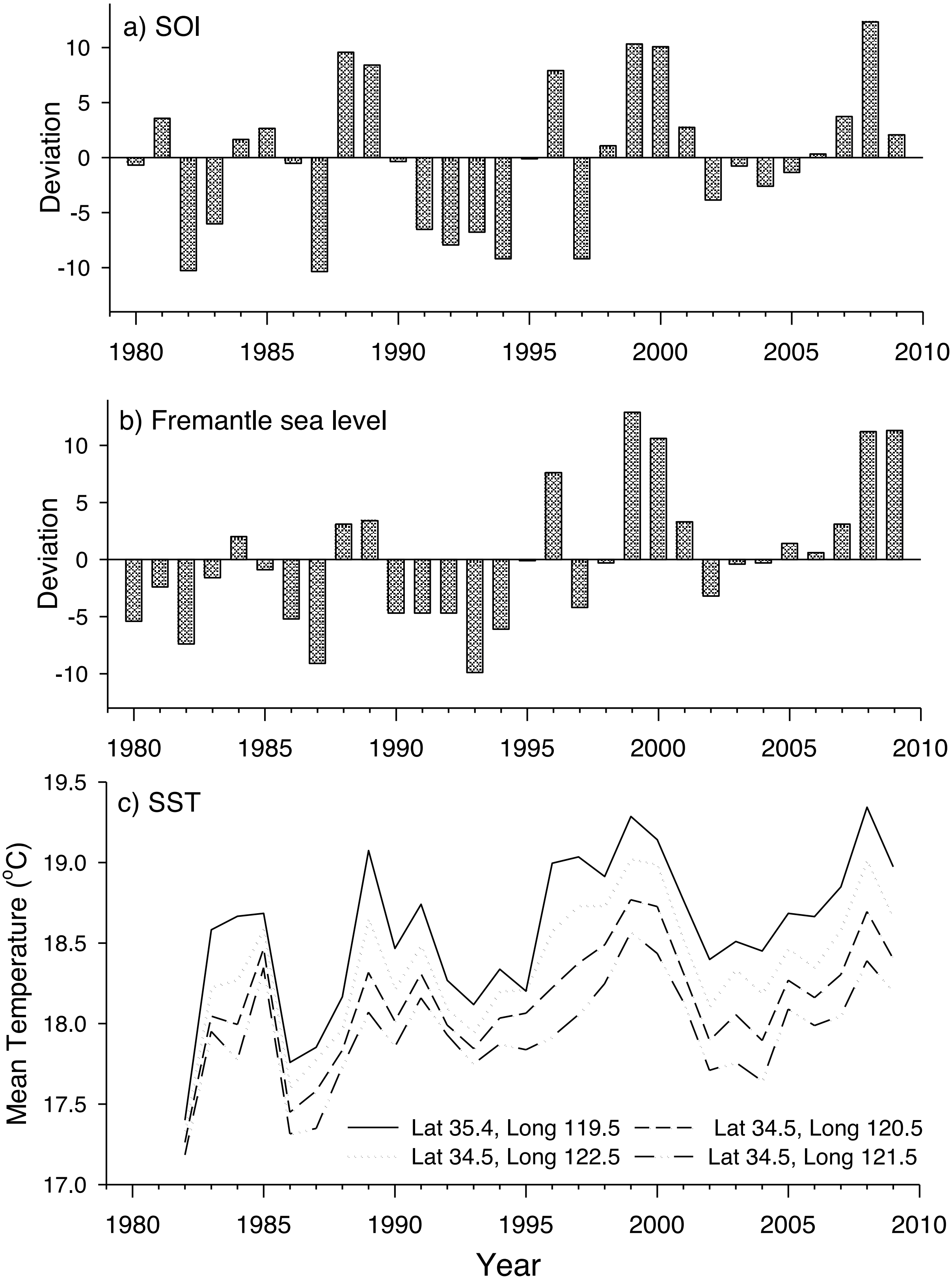

Figure 2.7. Proxies of annual Leeuwin Current strength : **a)** deviation from average annual Southern Oscillation Index (SOI) 1980–2009, **b)** deviation from average annual sea level at Fremantle 1980–2009, **c)** average sea surface temperature (SST) during February–September in various 1 x 1 degree ocean blocks along the south coast of WA (labels refer to mid-point of block).

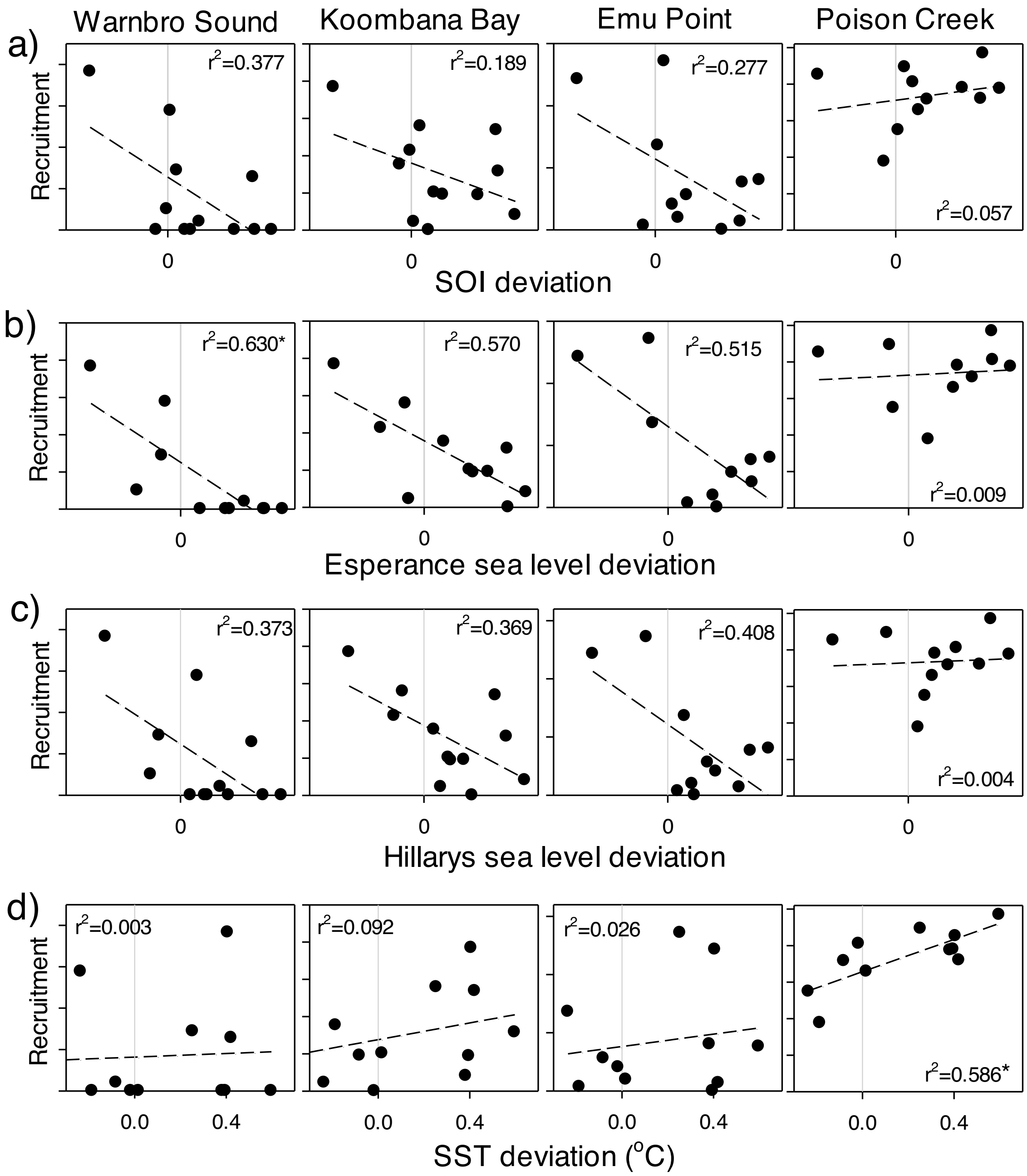

Figure 2.8. Australian herring annual recruitment indices at 4 sites (Warnbro Sound, Koombana Bay, Emu Point, Poison Creek) versus 3 proxies of Leeuwin Current strength : **a)** deviation from average annual Southern Oscillation Index (SOI) 1980–2009, **b)** deviation from average annual sea level at Esperance 1993–2009, **c)** deviation from average annual sea level at Hillarys 1993–2009 and **d)** deviation from detrended average sea surface temperature (SST) during February–September 1982–2009 in the 1 x 1 degree block adjacent to Albany (i.e. Lat 34–35º S, Long 118–119º E). Recruitment indices based on Ln(x+1) transformed catch rates of 0+ herring. (*correlation significant at p<0.10)

3.0 Australian herring commercial fishery catch and effort trends

Summary

- Recent commercial landings of Australian herring in WA were 200–250 t per year, with approximately 85% of the landings each year reported in the SCB. These total catch levels were substantially below those reported prior to 2000, including an historical peak of 1,545 t in 1990/91.
- After 2000, total commercial fishery landings of Australian herring followed the same downward trend in the South Coast Bioregion (SCB) and West Coast Bioregion (WCB) of Western Australia (WA) and in South Australia (SA), suggesting a similar decline in stock availability in all regions. The decline was consistent with low juvenile recruitment along the southern Australian coast since 2000.
- Commercial fishery catch rates in WA displayed similar long-term (decadal) trends, which suggest a high abundance of Australian herring in the 1980s, a moderately high abundance in the 1990s and a low abundance since 2000. Overall, trends in both catch and catch rate suggest a long-term decline in the abundance of Australian herring since the mid to late 1990s in each WA Bioregion and in SA. The current abundance appears to be at the lowest level reported in each Bioregion since the mid 1970s.
- The commercial Australian herring fisheries in WA each displayed different short-term (1–5 year) trends in catch and catch rate. Short-term fluctuations may reflect differences in local Australian herring abundance or reflect local social, economic and environmental factors. Catch rates in these fisheries may be an unreliable index of Australian herring abundance over short (less than 5 year) time scales.
- The catch and catch rate trends in southern areas (i.e. southern WCB, SCB and SA), where all of the major commercial fisheries for Australian herring are located, suggest low and/or declining abundance since 2000. This trend reflected declining recruitment in southern areas. In contrast, catch rate trends in the northern part of the species range (i.e. north Metropolitan and Mid-west Zones of the WCB), which hosts minor commercial Australian herring fisheries, suggest stable or increasing abundance after 2000. An increasing trend after 2000 was also evident in recreational catch rates of Australian herring in northern areas. These trends suggest that the annual abundance of Australian herring in northern areas is not directly related to annual recruitment indices, unlike abundance in southern areas.
- Despite the increasing trend in northern areas, the low catch levels and catch rates still suggest a much lower abundance of Australian herring in these areas compared to the abundance in southern areas.
- Relationships between recruitment and fishery catch rates suggest that the South-east Zone and SA are the main source of recruits to the commercial South Coast trap net fishery. Catch rates in the trap net fishery, and in SA commercial fisheries, appear to be primarily recruitment-driven.

3.1 Introduction

Australian herring (*Arripis georgianus*) is widely distributed in coastal waters and estuaries across southern Australia, from Western Australia (WA) to Victoria. Throughout this range Australian herring forms large and predictable aggregations, especially during spawning periods. It is vulnerable to capture by line and netting methods and is targeted by numerous commercial and recreational fisheries throughout southern Australia. The histories of the herring fisheries in WA, SA and Victoria are described in detail by Walker and Clarke (1987) and Ayvazian *et al.* (2000).

Although there is very little historical information about recreational catches of herring in Australia, there are reliable records of commercial catches since the 1950s in some regions, and detailed records of commercial catch and effort in all regions from the 1970s onwards. Hence, there is a relatively long time series of commercial data relating to this species, some of which may provide insights into the historical abundance of this species.

Commercial fishery catch rates are the only available indicator of Australian herring abundance in many regions of WA (due to the lack of fishery-independent or recreational fishery data), but can be unreliable for various reasons. For example, all of the commercial netting fisheries that capture Australian herring in WA have experienced reductions in effort via voluntary or compulsory licence buy-backs. Changes in overall fishery activity as a result of these effort adjustments (e.g. spatial and temporal shifts in the distribution of effort, shifts in target species) have the potential to affect annual catch and catch rate of herring. In addition, most fisheries that capture herring are multi-species fisheries and the catch of herring may be reduced when other, more valuable target species are available. Environmental factors that affect gear efficiency or alter fish behaviour can also influence catch rates. The potential of the annual catch rate to provide a reliable index of abundance must be critically evaluated in each fishery, based on knowledge of the social, economic and environmental factors that may influence the fishery.

Objectives of this Section;

- Describe the main sources of commercial catch and effort data relating to Australian herring and evaluate the potential of each source to provide a reliable index of Australian herring abundance.
- Describe trends in Australian herring abundance as suggested by catch rates.
- Describe the relationships between Australian herring annual recruitment and fishery catch rates.

3.2 Methods

3.2.1 Sources of commercial catch data

Catch and effort data used in this report was obtained from compulsory monthly returns submitted by commercial fishers. All commercial fishers in WA are required to submit a monthly summary of their catch and effort (except those completing other types of compulsory returns). Effort associated with zero catch is reported.

Published records kept by the Australian Bureau of Statistics (ABS) commenced in 1951. This later became known as the Catch and Effort System (CAES) in 1989, after data collection and analysis was taken over by the Research Division of the WA Department of Fisheries (DoF). Commercial catch and effort records from July 1975 onwards are held within the DoF CAES database.

Prior to 1990, the compulsory monthly catch and effort returns submitted by all WA commercial netting fisheries, which includes all Australian herring fisheries, provided limited detail about the netting methods used. Hence, landings reported prior to 1990 cannot always be accurately assigned to particular methods. In particular, the returns did not distinguish between various types of haul nets (specifically beach seine, haul net, ‘G-trap’). After 1990, the format of monthly returns issued by DoF was altered to provide more detailed information about catches by each of these methods.

New compulsory monthly catch and effort returns introduced after 1990 were also accompanied by the introduction of additional CAES reporting blocks and so more detail about the location of catches is available after 1990. For example, a specific block number was assigned to Geographe Bay and various individual estuaries (Fig. 3.1).

From 1973 to 2001, catch disposal records from fish processing factories provided an alternative source of catch and effort data for Australian herring. Factories provided the DoF with a summary of the total catch (weight) per species received from each fisher. Since 2001, factories have instead provided a summary of the total weight and value of each species, usually with no information about individual fishers (M. Cliffe DoF pers. comm.). Therefore, factory returns no longer provide information suitable to determine Australian herring catch rates.

Previously, some Australian herring commercial fishers supplied supplementary catch and effort data to the DoF via a voluntary daily logbook. Voluntary logbooks were first distributed to western Australian salmon fishers in 1962, many of whom also recorded catches of Australian herring. However, logbooks have never been used to formally assess total commercial catch and effort because only 30–85% of logbooks distributed were returned each year. The voluntary logbook program has effectively ceased due to low recent catch and effort in the Australian herring and western Australian salmon fisheries.

Catch and effort data reported by fishers are checked for errors/inconsistencies prior to entry into the CAES database. Data are again checked for errors/inconsistencies after extraction from the database and prior to any analysis.

3.2.2 Calculation of catch-per-unit-effort (CPUE)

In all fisheries described in this Section, 'catch' refers to live weight of landed fish.

Three measures of monthly fishing effort can be calculated from compulsory monthly data submitted by commercial fishers in net-based fisheries that catch Australian herring;

1) Number of block days (Bdays) per month = a day spent using a particular method within a particular CAES reporting block (Fig. 3.1) . In compulsory monthly returns, the number of block days is reported as a total for each month.

2) Number of registered vessels or teams = the total number of boats or teams registered in the fishery. However, it may overestimate actual effort expended because it includes inactive boats or teams.

3) Monthly number of active vessels or teams = the number of boats or teams that fished (i.e. recorded some effort) per month.

Due to the multi-species nature of most commercial netting fisheries and the monthly aggregation of data reported by fishers, it is often not possible to determine precisely the effort spent specifically targeting Australian herring by a particular method. In multi-species fisheries, a single method can be used to target Australian herring and several other species within a month. In the absence of daily or 'shot-by-shot' catch and effort information, the target species and the effort directed towards a particular species cannot be ascertained[1].

1 This problem can be illustrated with a hypothetical example – in a single month, a fisher reported 20 days of gill netting and a total catch of 500 kg of herring and 200 kg of sea mullet. From this limited data, the number of days spent specifically targeting each species cannot be determined. In the absence of any other information, 20 days of effort could be (and usually is) allocated to each species, and the estimated monthly catch rates would be (500 ÷ 20 =) 25 kg.day^{-1} and (200 ÷ 20 =) 10 kg.day^{-1}, respectively. However, if 19 days was actually spent targeting herring and only 1 day spent targeting mullet, then the actual catch rates would be (500 ÷ 19 =) 26 kg.day^{-1} and (200 ÷ 1 =) 200 kg.day^{-1}, respectively

The problem of the lack of knowledge of targeted effort can be partly overcome by restricting the calculation of catch rates to times/areas where Australian herring is a large proportion of the catch. This increases the likelihood that reported effort was actually spent targeting Australian herring.

In the following sections, annual CPUE was calculated for various commercial fisheries in WA that have historically captured a significant quantity of Australian herring. For each fishery, annual CPUE was calculated as the total annual catch (C) by the fishery, divided by the total annual effort (E) by the fishery. The exception was the Cockburn Sound fish net fishery, where annual CPUE was calculated as the mean of individual fisher CPUEs (see below). Specific definitions of total catch and total effort are outlined below for each fishery. None of the fishery catch rates discussed below have been formally validated by fishery-independent surveys.

South Coast trap net fishery CPUE

Three measures of annual catch rate in the South Coast trap net fishery are described here:

1. Average catch per licenced team, $CPUE_{licenced} = C_1/E_1$, where;

    C_1 = *total annual catch by trap net fishery*

    E_1 = *number of licenced teams (i.e. Condition 42 holders).*

The total annual catch by trap net fishery is available from 1993/94 onwards. Hence $CPUE_{licenced}$ was determined for the years 1993/94 to 2008/09.

2. Approximate average catch per licenced team, $CPUE_{approx} = C_2/E_1$, where;

    C_2 = *total annual catch in South Coast ocean waters*

    E_1 = *number of licenced teams (i.e. Condition 42 holders).*

The trap net catch comprises the vast majority of total South Coast ocean landings each year (~90%). Therefore, total South Coast ocean catch was used as a proxy for the trap net catch in earlier years. This catch was used to calculate an approximate trap net catch rate ($CPUE_{approx}$) for the years 1975/76 to 2008/09.

3. Average catch per active team, $CPUE_{active} = C_1/E_2$, where;

    C_1 = *total annual catch by trap net fishery*

    E_2 = *total number of active licenced teams (i.e. those that reported effort).*

A relatively high proportion of teams were inactive in recent years. Records of which teams were active/inactive are available from 1994 onwards. Hence $CPUE_{active}$ was determined for the years 1993/94 to 2008/09.

South Coast Estuarine Managed Fishery CPUE

The majority of Australian herring landings by the SCEF are taken in three estuaries – Oyster Harbour, Broke Inlet and Wilson Inlet.

Oyster Harbour is permanently open to the ocean. Most Australian herring caught in this estuary have been taken by seine and/or haul netting. Historically, most of the annual catch was taken during the warmer months (October–February) although some catches were also taken in other months. The average annual catch rate of herring by seine/haul netting in Oyster Harbour was calculated as $CPUE_{Haul} = C_{Haul}/E_{Haul}$, where;

C_{Haul} = *sum of Australian herring catches by haul nets and seine nets in CAES block 9505. All vessels included. All months included.*

E_{Haul} = sum of Bdays by haul nets and seine nets in CAES block 9505. All vessels included. All months included.

A small proportion of historical herring landings in Oyster Harbour have been taken by gill netting. Gill net landings of herring are taken in all months. The average annual catch rate (CPUE) of herring by gill netting in Oyster Harbour was calculated as $CPUE_{Gill} = C_{Gill}/E_{Gill}$, where:

C_{Gill} = sum of Australian herring catches by gill nets in CAES block 9505. All vessels included. All months included.

E_{Gill} = sum of Bdays by gill nets in CAES block 9505. All vessels included. All months included.

Broke Inlet typically opens to the ocean during spring each year. Australian herring is primarily taken by gill netting in this estuary. The estuary is open to commercial fishing from May to October. Australian herring are caught in all these months. The average annual catch rate of herring by gill netting in Broke Inlet was calculated as CPUE = C/E , where;

C = sum of Australian herring catches by gill nets in CAES block 9508, from Oct–May inclusive. All vessels included.

E = sum of Bdays by gill nets in CAES block 9508, from Oct–May inclusive. All vessels included.

Wilson Inlet is usually open to the ocean during spring each year. The mouth remained closed in 2007 and 2010 due to low water levels following low annual rainfall. Australian herring is primarily taken by gill netting in this estuary, mainly during the warmer months. The average annual catch rate of herring by gill netting in Wilson Inlet was calculated as CPUE = C/E , where;

C = sum of Australian herring catches by gill nets in CAES block 9508, from Oct–May inclusive. All vessels included.

E = sum of Bdays by gill nets in CAES block 9508, from Oct–May inclusive. All vessels included.

Geographe Bay/Bunbury CPUE

In the Geographe Bay/Bunbury area, commercial fishers target Australian herring during the warmer months (mainly Nov–Apr). The vast majority of these landings are taken by seine nets and haul nets. The average annual catch rate of herring was calculated as CPUE = C/E , where;

C = sum of Australian herring catches by haul nets and seine nets in CAES blocks 3315, 33151 and 9601, from Nov – Apr inclusive. All vessels included.

E = sum of Bdays by haul nets and seine nets in CAES blocks 3315, 33151 and 9601, from Nov – Apr inclusive. All vessels included.

Cockburn Sound CPUE

In Cockburn Sound, commercial fishers have historically targeted Australian herring during all months. The majority of pre-1990 landings were recorded as taken by gill nets. More recent landings are known to have been mainly taken by garfish nets. Catches of herring by gill nets and garfish nets are combined here due to difficulties in determining from DoF records which method was used[2]. Annual trends in gill/garfish netting catch and effort in Cockburn Sound changed markedly after 1996 in response to the restructuring of the gill net fishery to exclude

2 The abbreviation 'GN' was used for both gill net and garfish net.

targeting of crabs. Hence, annual catch rates of herring by gill/garfish netting were calculated from 1996 onwards.

Since 1980, the vast majority of herring landings in Cockburn Sound have been taken by 4 vessels. These vessels reported 96% of gill/garfish net landings of herring in Cockburn Sound since 1996.

The annual catch rates of these vessels varied markedly in magnitude. Therefore, the annual CPUE of each vessel was standardised (i.e. divided by the mean of their respective annual CPUEs) prior to calculating an average standardised CPUE for herring in Cockburn Sound. The annual CPUE of an individual vessel was calculated as CPUE = C/E , where;

C = sum of Australian herring catches by gill/garfish netting in CAES block 9600. All months included.

E = sum of Bdays by gill/garfish netting in CAES block 9600. All months included.

The average annual standardised CPUE for herring in Cockburn Sound was calculated from the average of the standardised CPUEs of the 4 main vessels.

Peel-Harvey Estuary CPUE

Small quantities of Australian herring are taken each year by gill nets and haul nets in the Peel-Harvey Estuary. Gill net landings are seasonal whereas haul net landings are taken throughout the year. The average annual catch rate of herring in this estuary was calculated for gill netting ($CPUE_{Gill} = C_{Gill}/E_{Gill}$) and haul netting ($CPUE_{Haul} = C_{Haull}/E_{Haul}$), where;

C_{Gill} *= sum of Australian herring catches by gill nets in CAES blocks 9502 from Jul–Sept inclusive.*

E_{Gill} *= sum of Bdays by gill nets in CAES block 9502 from Jul–Sept inclusive.*

C_{Haul} *= sum of Australian herring catches by haul nets in CAES blocks 9502. All months included.*

E_{Haul} *= sum of Bdays by haul nets in CAES block 9502. All months included.*

Mandurah/southern metropolitan ocean CPUE

Historically, small quantities of Australian herring were taken by haul and seine netting in ocean waters within CAES block 3215 (includes Mandurah and the southern metropolitan region), usually from December to April. The average annual catch rate of herring in CAES block 3215 was calculated for haul/seine netting as CPUE = C/E **,** where;

C = sum of Australian herring catches by haul and seine nets in CAES block 3215 from Dec–Apr, inclusive.

E = sum of Bdays by haul and seine nets in CAES block 3215 reported from Dec–Apr, inclusive.

Northern WCB ocean CPUE

Historically, minor quantities of Australian herring have been taken by haul and/or seine netting in ocean waters of the WCB north of Perth (latitudes ≥28º and <32º, inclusive). The average annual CPUE of herring in this area was calculated for haul/seine netting as CPUE = C/E **,** where;

C = sum of Australian herring catches by haul and seine nets caught from latitude 28º to 31º. All months. All vessels.

E = sum of Bdays by haul nets and/or seine nets from latitude 28º to 31º. All months. All vessels.

3.2.3 Recruitment

To investigate relationships between annual recruitment and fishery catch rates, recruitment indices at Poison Creek (SCB) and Koombana Bay (WCB) (see Section 2.1) were correlated against the annual catch and catch rate of Australian herring in the commercial South Coast trap net fishery. The annual catch (tonnes) and annual CPUE (tonnes per active team) of the trap net fishery generally follow a similar trend and either could potentially provide an index of fish availability in this fishery. Therefore, both catch and CPUE were both correlated against recruitment. Recruitment indices were also correlated against the total annual commercial catch of herring in South Australia. Fishery catch/catch rates were lagged from –3 to +5 years.

Poison Creek and Koombana Bay were considered to provide the most robust of the available indices of annual recruitment, due to consistently higher catch rates of 0+ Australian herring compared to other sites where recruits were sampled.

The following four versions of the annual recruitment index at each site were correlated against CPUE:

R_n , recruitment index in year *n*,

$\ln(R_n + 1)$, natural logarithm transformed value of recruitment index in year *n*, and

$R_{n,n+1}$, average of recruitment index in year *n* and *n+1* (i.e. a 2-point moving average),

$\ln(R_{n,n+1})$, average of natural logarithm transformed recruitment index in year *n* and *n+1* (i.e. a 2-point moving average).

The 2-year recruitment indices ($R_{n,n+1}$) and $\ln(R_{n,n+1})$ were intended to reflect the composition of commercial fishery landings, which are frequently dominated by two consecutive year classes.

The recruitment indices that resulted in the highest correlation coefficients were plotted.

3.3 Results

3.3.1 National and state landings

Australian herring is targeted commercially and recreationally in WA and SA. Minor quantities are taken in Victoria. Records of commercial landings in both WA and SA are available annually since the 1950s (Fig. 3.2).

In Victoria, commercial landings of Australian herring have always been low (<60 t per year). In recent years, only 1–5 t per year was harvested commercially in Victoria, with the exception of 2009/10 when 11 t was landed.

In SA, commercial landings of Australian herring increased from 100–200 tonnes (t) per year in the 1950s to 300–400 t in the 1990s. Landings have been 100–200 t since 2001 (Figs. 3.2, 3.3). Details of recent annual commercial catches, targeted catches, targeted effort and targeted catch per unit effort in SA are available in Fowler *et al.* (2011). Since 1970, the proportion of national annual landings of herring taken in SA has been relatively constant (average 27%, range 16 – 44%).

The reported commercial catches of Australian herring in SA between 1951 and 1975 are probably underestimates of the total state catch. During these years, catches handled by selected fish processors and the Adelaide fish market were recorded, but catches by many small netting operators who processed and sold their catches locally were not included (K. Jones, pers. comm.). Catch records are more accurate in SA after 1975, when compulsory logbooks were introduced for all fishers.

In SA, Australian herring are landed in nearshore waters by multi-species net fisheries located throughout the state. Various management changes in these fisheries, often intended to reallocate resources from net fisheries to commercial and recreational line fisheries, are likely to have constrained the total catch level of Australian herring (Ayvazian *et al.* 2000). These included: restriction of net fishers to depths of 5 metres or less since the 1970's, netting closures around southern Eyre Peninsula and in northern Spencer Gulf in 1983, further closures around the southern Eyre Peninsula in the mid 1990's and around southern Yorke Peninsula in 2004/05. With other factors such as net licence freezes and net licence buy backs, the number of licenced multi-species net fishers decreased from 280 in 1989 to about 40 in 2011 (K. Jones, pers. comm.).

In WA, recorded landings of Australian herring underestimate total commercial landings during the 1960s and 1970s. Prior to 1974, commercial fishers in WA were not required to report their bait catches. Rock lobster fishers in the WCB commenced harvesting Australian herring for bait in the 1950s. During the late 1960s and early 1970s, particularly the period 1969–1973, substantial quantities of Australian herring were harvested in the metropolitan area (at Rottnest Island and Rockingham) for rock lobster bait. At the time it was estimated that 60–200 t per year of unreported Australian herring were being taken as bait (WFRC 1973, 1975).

With the inclusion of unreported commercial bait catches and estimated recreational landings in WA and SA (discussed below), the national total harvest of Australian herring is likely to have reached about 1,770 t in 1972 and well over 2,000 t annually during the late 1980s and early 1990s (Figs. 3.2, 3.3).

Commercial landings of Australian herring in WA are essentially restricted to the WCB and SCB, which reflects the geographic range of this species. Historically, the SCB typically contributed 80–90% of annual landings and the WCB contributed 10–20%. An exception to this pattern occurred in 2005, when 29% of landings occurred in the WCB. In both the SCB and WCB, the vast majority of landings are taken in ocean waters.

Prior to 1990, small quantities (0–6 t per year) of Australian herring from the Gascoyne Coast Bioregion were occasionally recorded in the CAES database. However, it is likely that these catches were misreported and were actually Perth herring (*Nematalosa vlahmingi*).

In the 1950s and 1960s, the WA annual catch ranged between 240 and 619 t (Fig. 3.2). After the late 1960s, WA annual landings increased rapidly to peak at 1,187 t in 1972/73 (plus unreported catches taken as bait). Landings declined to 503 t in 1975/76 and then steadily increased to reach an historical peak of 1,545 t in 1990/91. Total annual landings dropped abruptly from 1,322 t in 1991/92 to 784 t 1992/93 and then remained relatively stable until 2000/01 (range 744–1,083 t).

After 2000, the total WA state annual commercial catch of Australian herring steadily declined from 818 t in 1999/00 to 147 t in 20010/11 (Fig. 3.2). Annual landings in both Bioregions followed a similar downward trend – declining from 705 t in 2000 to 183 t in 2010 in the SCB and from 143 t (in 2001) to 29 t in 2010 in the WCB (Fig. 3.3). Commercial fishery landings in SA also followed this downward trend.

Correlations between total annual landings in each Bioregion indicated that the annual catch in SCB followed a very similar trend to the annual catch in SA, with a lag of about 2 years (Fig. 3.4a). However, the relationship between annual landings in the WCB and SA was unclear (Fig. 3.4b). Within WA, the WCB catch trend followed the SCB catch trend, with a lag of 0 to 1 years (Fig. 3.4c).

The relationships between annual landings in each region became clearer when the effect of short-term (annual) variability was removed. Catch trends between Bioregions over longer time scales (e.g. 5 years) were highly correlated. The 5-year moving averages of annual catch in the SCB and in the WCB each followed the trend in the 5-year averaged South Australian total catch, with a lag of 1 to 3 years (Figs. 3.4d, e). Within WA, the 5-year averaged WCB catch followed the same trend as the 5-year averaged SCB catch, with a lag of 0 to 1 years (Fig. 3.4f). Overall, correlations between 5-year averaged catch levels suggested similar long-term trends in stock availability in all regions.

The lagged relationships between WA and SA annual landings are consistent with the progressive migration of Australian herring between Bioregions, with fish migrating from SA to the SCB and then to the WCB. This trend is reflected in the age structure of commercial landings from each region. The age at capture was typically 1–2 y in SA during the 1990s (Ayvazian *et al.* 2000) and 0–1 y in more recent years in SA (K. Jones, pers. comm.), 2–3 y in the SCB and 2–4 y in the WCB (see Section 5).

3.3.2 South Coast Bioregion (SCB) – catch and effort

Commercial landings of Australian herring in the SCB peaked at 1,427 t in 1991 (Fig. 3.3). The annual catch declined sharply to 633 t in 1993, and then fluctuated between 626–1,001 t per year from 1993 to 2000. Annual landings declined rapidly from 705 t in 2000 to 203 t in 2005. The decline continued at a slower rate after 2005, reaching an historical low of 151 t in 2009. The catch was 183 t in 2010.

Since 1976, 92% of herring landings in the SCB have been taken by the South Coast Herring Trap Net Fishery, 3% have been taken in estuaries and the remainder taken by other fishers in nearshore waters.

Ocean landings of Australian herring in the SCB are highly seasonal, occurring mainly in March and April (Fig. 3.5a). This is largely determined by the autumn pre-spawning migration of this species (approximately February to June) but also reflects the timing of the trap net fishing season. There is a trap net fishing closure from 10 February to 25 March each year to limit effects on western Australian salmon landings, which immediately precede and overlap the Australian herring-fishing season. In the SCB, ocean landings of Australian herring are essentially restricted to a region between 16 and 20 longitude, which is centred around Albany (Fig. 3.5b). The spatial and monthly distribution of ocean landings in the SCB has remained largely unchanged since 1976.

South Coast Herring Trap Net Fishery

The trap net fishery originated as a secondary activity of the western Australian salmon (*Arripis truttaceus*) fishery, which commenced operation along the south coast of WA in the 1940s. WA salmon fishers caught herring using the seine/haul nets that had previously been used to capture salmon. During the 1950s and 60s, targeting of herring tended to increase when the availability or price of salmon was poor. Hence the herring catch was influenced by factors within the western Australian salmon fishery, as well as the demand and price for herring itself. During this period, the majority (~95%) of commercial herring landings were canned for human consumption, with the remainder used as shark bait or retailed through the Perth wholesale markets. From the 1970s, a market for herring as Western rock lobster (*Panulirus cygnus*) bait was developed, and catches rose in response to the increased demand (White 1980).

During the late 1970s and early 80s, the demand and price for Australian herring as bait increased, while the price and abundance of western Australian salmon decreased. This led to an increase of fishing effort directed towards herring, including a shift in effort by salmon fishers towards herring and the entry of new fishers that exclusively targeted herring. The use of the ‘G-trap’ net method, specifically used to target herring, increased over this period. Usually set in a ‘6’ or ‘G’ shape off a beach, this fishing method herds and traps fish migrating along the beach. The seaward end of the net is pulled to the shore after an overnight set. In mid-

1991, the use of herring trap nets was restricted to licensed fishers using a fishing boat with the appropriate condition (i.e. *Fishing Boat Licence Condition 42*) at 10 separately nominated south coast ocean beaches.

After 1995/96, there was a significant drop in the average price of Australian herring, mainly due to the decreased demand for herring as bait in the rock lobster fishery, following the importation of cheaper North Sea herring (*Clupea harengus*). Following the decline in demand for herring as bait, attempts to develop herring as a high-volume product for human consumption have met with limited success, largely due to the short season of this fishery. Other market influences have also affected the catch and catch rate in this fishery. For example, catches are occasionally released by fishers when the factory is too busy to receive the catch.

The trap net fishery was historically divided into the same four statistical areas as previously used in the South Coast Salmon fishery (Area 0 = Point Charles east; Area I = Point Charles – Cape Riche; Area II = Cape Riche – Albany east; Area III = Albany west – Windy Harbour). However, these areas have not been used for research purposes in recent years. The majority of landings were historically taken in Areas I and II.

The trap net fishery has historically been the major commercial fishery for Australian herring in Australia, landing 45–70% of the national commercial catch per year. Since 2000, this fishery has landed 75% of the total WA commercial catch (range 60–90% per year). Trap net fishers target herring during the annual autumn spawning migration as fish move from nursery areas on the south coast of Australia to the spawning areas on the lower west coast. The fishery season typically only lasts around one to two months.

The annual catch of Australian herring by the South Coast trap net fishery can be difficult to determine precisely[3]. Reasonably precise estimates are available from 1994 onwards. Since 1994, the trap net fishery catch has contributed between 74 and 97% (average 89%) of total commercial landings in the SCB. Therefore, the total SCB annual catch provides a reasonable proxy for annual landings by the trap net fishery in earlier years (Fig. 3.3).

Catch and effort levels in the trap net fishery are affected by the abundance and prices of species targeted by the South Coast Salmon and South Coast Estuarine commercial fisheries. Many Australian herring trap net fishers also participate in these other fisheries and may vary their effort within each fishery to maximise overall annual profitability. Therefore, a decline in the Australian herring trap net fishery catch level can be the result of a shift in effort towards targeting of a more valuable species in another fishery.

3 The estimation of the South Coast trap net fishery catch is confounded due to several factors. Although trap netting is the main method used to target herring in WA, it evolved from the modified use of seine nets and was only formally recognised in CAES as a separate method after 1989. From 1975 to 1988, the method of capture recorded in the CAES database for 95% (live weight) of ocean landings of herring on the south coast was 'beach seine/haul net'. From 1989 onwards, landings by 'G-trap nets', 'beach seine' and 'haul nets' were specifically reported.

From 1989 to 2000, the proportion of ocean landings on the South Coast taken by each method were reported as 52% trap nets, 41% seine nets and 6% haul nets. From 2000 to 2009, ocean landings on the south coast beach taken by each method were reported as 73% trap nets, 26% seine nets and <1% haul nets. Minor amounts of Australian herring are also taken in ocean waters by gill nets and other methods. The statistics in most years may not precisely reflect the actual use of trap nets.

In practise, a commercial fisher may deploy the same net either as a seine net or a trap net on a single beach within a single month, depending on the fishing conditions. Occasionally, fishers report their total monthly catches under one method, even when both methods are used. Therefore, various 'rules of thumb' are applied during the analysis of CAES data. Catch is usually assigned to the trap net fishery if i) the fisher holds a trap net endorsement (Condition 42), and ii) the catch is taken during the trap netting season (late March–Jun) on their designated beach as stated in licence condition 42, and iii) the monthly catch is relatively large (usually >1000 kg). Where possible, data is confirmed with licence holders.

The estimation of fishing effort by the trap net fishery is problematic for various reasons[4]. Historically, the 'number of licenced teams' that existed during each trap net fishing season has been used as the best available measure of total effort by the trap net fishery. In recent years, some teams have chosen not to fish during a particular year and so the 'number of active teams' has been used as a measure of total effort.

Since 1990, effort in the trap net fishery has been reduced via a Voluntary Fishery Adjustment Scheme (i.e. licence buy-backs). The removal of licences has eliminated some latent effort (inactive licences) that previously existed in the fishery. From 1982 to 1994, the number of licenced trap net teams ranged from 24–30 per year (Fig. 3.6). The number of licenced teams declined from 1994 to 2001. Since 2001, there have been 10 or 11 licenced teams in the fishery per year, who are entitled to take Australian herring using trap nets set on 10 nominated South Coast beaches. The number of active teams was relatively stable from 1985 to 1996, ranging from 16 to 21 (Fig. 3.6). Since 1996, the number of active teams has steadily declined to reach three in 2007. In 2008 and 2009 there were five active teams. In 2009, approximately 16 commercial fishers were employed directly in the trap net fishery.

Commercial fishers report that recent historically low effort levels have been in response to the lack of markets and low wholesale prices paid for Australian herring.

From 1990 to 2009, trap nets have ranged between 200 and 1,400 m in length. Shorter trap nets can be more effective under certain beach conditions, such as in small bays. Therefore, the net length is not strongly related to catch rate in this fishery.

Since 2000, about 75% of the catch has been reported by four teams (and >50% of the catch was reported by 2 teams, both of which operate at Cheynes Beach). These four teams have consistently taken the majority of landings each year since the early 1990s.

South Coast Estuarine Managed Fishery (SCEF)

The South Coast Estuarine Managed Fishery (SCEF) includes all estuaries on the south coast of WA between Cape Beaufort and 129º east longitude. Since 2005, 13 south coast estuaries have been open to commercial fishing.

The SCEF has always contributed a minor share (2–11% per year) to total commercial landings of Australian herring in the SCB (Fig. 3.7). The SCEF is a multi-species fishery, with herring typically comprising only 5–10% by weight of the total annual SCEF catch. From 1976 to 2009, total estuarine landings ranged from 16 t (in 2003–06 and in 2008–09) to 88 t (in 1977). Although the SCEF annual catch of herring has been at a low level (<20 t) since 2002, the proportion of the SCB catch derived from the SCEF has increased slightly over this period due to a greater rate of decline in trap net landings (Fig. 3.7).

Historically, the estuaries around Albany (Princess Royal Harbour[5], Oyster Harbour) contributed

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4 Trap net fishers operate as a team, typically comprised of a registered fishing vessel and 2–6 associated crew. Fishers are not required to record which team they belonged to when submitting monthly catch returns. Several fishers from a single team may submit a catch return, describing their portion of the catch. Therefore, the number of teams operating per year cannot be determined from returns and must be determined from licencing data and/or by contacting fishers directly.

Fishing effort by trap net teams includes time spent searching for fish. Search time is difficult to quantify and is estimated differently by each team. Therefore, the total reported fishing days (Bdays) are not a precise measure of effort by trap net fishers.

5 Prior to 1993, Princess Royal Harbour and King George Sound were grouped together and assigned CAES block number 9504. It is possible to roughly estimate pre-1993 catch levels in the two areas by examining the fishing methods used, e.g. trap nets are only used in King George Sound. In 1993, additional CAES block numbers were introduced to separately describe Princess Royal Harbour (9509) and King George Sound (9603) and so landings in each location after 1993 are better known. In this report, herring catch and effort from block 9504, 9509 and 9603 (i.e. Princess Royal Harbour and King George Sound) are combined and analysed as a single multi-block location.

the majority of estuarine landings of Australian herring in the SCB, although this contribution has gradually declined since 2000 (Fig. 3.8). The Albany estuaries/harbours contributed 76% of all South Coast estuarine landings during 1976–1990, 61% during 1991–2000 and 44% during 2001–2009.

Minor annual catches of Australian herring are also taken in Wilson Inlet (3–24 t per year), Broke Inlet (0–12 t per year), and Irwin Inlet (0–4 t per year) (Fig. 3.8). Other estuaries collectively have contributed < 600 kg per year since 1976. The main commercial method used to catch herring in the estuaries/harbours around Albany is seine/haul nets, whereas the main method used in other estuaries is gill netting.

The seasonality of Australian herring landings varies among South Coast estuaries (Fig. 3.9). Landings in Broke and Irwin Inlets occur from May to October, which is the period when these estuaries are open to commercial fishing. In Wilson Inlet, which is open to fishing all year, landings mainly occur in the warmer months. The lowest monthly landings of herring occur during June–September in Wilson Inlet. During these months, herring aggregate immediately behind the sand bar and then emigrate from the inlet after the sand bar is breached, following the onset of winter rain. The area behind the sand bar is closed to commercial fishing. Consequently, herring are least vulnerable to capture by commercial fishing during these months.

In the Albany estuaries, Australian herring landings are mainly taken during the warmer months. The combined catch from Princess Royal Harbour and King George Sound displays a very pronounced peak in April, mirroring the trend in the trap net fishery operating in adjacent ocean waters.

In Oyster Harbour, Australian herring landings by all methods typically reach a minimum in autumn/winter, mainly due to low effort expended in the estuary at this time. Some Oyster Harbour fishers shift their effort to ocean waters in autumn/winter to target migrating schools of Australian herring and western Australian salmon at this time.

In Oyster Harbour, the majority of annual Australian herring landings were historically taken by haul netting, with small quantities taken by gill netting. Gill net landings were approximately 4 t per year from 1982 to 1991 (including a peak of 5 t in 1983) and then steadily declined until 1999 (Fig. 3.10a). From 1999 onwards, the annual gill net catch was negligible (0–0.5 t). Haul net landings peaked at 19 t in 1987 and then rapidly declined to low levels during the early 1990s (Fig. 3.10b). Catch levels recovered to reach 10 t in 1999 and then declined to low levels from 2004 onwards.

Annual gill net landings of Australian herring in Wilson Inlet and Broke Inlet have been highly variable. In Wilson Inlet, annual landings during October–May (the main herring capture period) have ranged from 1.5 t to 18 t since 1976/77 (Fig. 3.10c). In Broke Inlet, landings have ranged from 0.5 to 6.7 t per year since 1988 (Fig. 3.10d). In both estuaries, no long-term directional trend is evident in annual landings.

Annual gill netting effort in Oyster Harbour gradually increased after 1980 to peak at 117 days per year in 1991 (Fig. 3.10a). Annual effort then gradually declined to a minimum of 197 days in 2007 but increased to 380 days in 2009. Haul netting effort in Oyster Harbour gradually increased after 1980 to peak at 461 days in 1993 (Fig. 3.10b). Haul netting effort then steadily declined to a minimum of 21 days in 1995 and remained very low (< 75 days) in subsequent years.

In Wilson Inlet, annual gill netting effort during October–May (the main Australian herring capture period) gradually increased from 954 days in 1978/79 to a peak of 1,882 days in 1992/93 (Fig. 3.10c). Between 1994/95 and 2008/09, annual gill net effort was relatively stable ranging from about 1,200 to 1,600 days per year.

In Broke Inlet, annual gill netting effort was highly variable with a slight declining trend between 1988 and 2009 (Fig. 3.10d). Annual effort ranged between 35 days (in 2003) and 257 days (in 1997).

Since 1990, the effort spent targeting Australian herring in south coast estuaries is likely to have declined as a consequence of a decline in total fishery effort. The number of licences in the SCEF was substantially reduced via a Voluntary Fishery Adjustment Scheme (i.e. licence buy-backs). The removal of licences eliminated a significant amount of latent effort (inactive licences) that previously existed in this fishery. The number of licensees declined from a peak of 66 in 1987 to 25 in 2002 and subsequent years.

3.3.3 West Coast Bioregion (WCB) – catch and effort

In the WCB, the total annual commercial catch of Australian herring reached an historical peak of 211 t in 1988 and has since gradually declined to reach an historic low of 29 t in 2010 (Fig. 3.3). The downward trend in total WCB landings is a consequence of declines in most areas, including in the Geographe Bay/Bunbury area[6] where the largest proportion of the WCB catch has historically been taken. Landings in the Peel-Harvey estuary and in ocean waters north of Perth are the only WCB areas where commercial landings have increased since the late 1990s.

Previously, the WCB Australian herring fisheries were divided into 2 main statistical areas. South-West Coast = Windy Harbour to Bunbury (same as South-West Coast Salmon fishery); West Coast = Bunbury to Geraldton. However, these areas have not been used for research purposes in recent years.

Since 1975, the Geographe Bay/Bunbury area (CAES blocks 9601, 3315 and 33151) has contributed the largest share of WCB commercial Australian herring landings (Fig. 3.11). The next largest shares were from Cockburn Sound (block 9600), Mandurah/southern metropolitan region (block 3215) and the West Coast Estuarine Managed Fishery (blocks 9501, 9502, 9503). Coastal waters south of Geographe Bay (the 'Capes region') (blocks 3314, 3414, 3415, 3515) and to the north of Perth between latitudes 28 and 32 (blocks 2813, 28142, 29142, 3014, 3015, 3115) contributed minor landings of herring.

Geographe Bay/Bunbury seine net fishery

Historically, 40–75% of annual WCB landings of Australian herring were reported from the Geographe Bay/Bunbury area, where they were taken by fishers who also targeted salmon in this area. Since 2006, the catch share from this area has fallen to 30–40% per year. From 1980 to 2000, Geographe Bay/Bunbury area landings averaged 80 t per year, including an historical peak of 151 t in 1988 (Fig. 3.11). Since 2001, the catch in this area has declined steadily to reach an historical low of 8 t in 2009. In 2010, the southern part of Geographe Bay was closed to commercial fishing. This included part of CAES block 9601 which typically produced the majority of the herring landings by this fishery.

The majority (~90%) of annual Australian herring landings from the Geographe Bay/Bunbury area are taken by beach seine and haul nets and the remainder taken by gill nets. Beach seine and haul net fishing in the Geographe Bay/Bunbury area is collectively known as the 'South-west Beach Seine Fishery'. This fishery landed approximately 10% of the total WA catch of herring and 57% of the WCB catch between 2000 and 2010.

6 In this report, the 'Geographe Bay/Bunbury area' refers to CAES blocks 9601, 3315 and 33151. In 1990, Geographe Bay was allocated a specific CAES block number (9601). Since then, approximately 75% of landings of Australian herring in the 'Geographe Bay/Bunbury area' have been from block 9601.

The *South West Beach Seine Fishery Notice (1990)* was recently revoked and replaced by *Prohibition On Commercial Fishing (South-West Coast Beach Bait Net) Order (2010)*. The new notice permits fishing with a beach seine net within 800 m of the high water mark between Tim's Thicket and Port Geographe Marina (33°37.56' S). The previous notice (No. 416 of 1990) permitted fishing with a beach seine net (ring net and small purse seine nets were also used) between Tim's Thicket and Point D'Entrecasteaux (34° 50.50' S). The new notice effectively closed a large section of Geographe Bay that was previously used by commercial fishers to target Australian herring. A large component of the historical WCB Australian herring catch came from this section. The closure was intended to reduce conflict with recreational fishers and other beach users.

About 90% of Australian herring caught by seine/haul netting in the Geographe Bay/Bunbury area is taken from November to April each year (Fig. 3.12). This period overlaps with the main fishing seasons for western Australian salmon (March–May) and whitebait (December–March). Australian herring is often taken as a byproduct while targeting other species, especially western Australian salmon and whitebait, although the proportion of Australian herring in total annual landings varies greatly. For example, herring comprised 32% of the total seine/haul net catch in 1999/00, but comprised only 2–6% per year of the total catch from 2003/04 to 2008/09.

From 1980/81 to 2002/03, the total catch of Australian herring by seine/haul netting in the Geographe Bay/Bunbury area during the months November–April ranged from 24 to 134 t per year (Fig. 3.13). The November–April catch exhibited a slight increasing trend over this period. Peak catches of >100 t were reported in 1987/88, 1988/89 and 2000/01. After 2000/01, the November–April catch declined rapidly to reach 2 t in 2009/10.

Total annual effort by seine and haul netting in the Geographe Bay/Bunbury area increased from about 500 days during the early 1990s to approximately 2,200 days from 2000/01 to 2002/03. Effort then gradually declined to 972 days in 2008/09.

From 1980/81 to 1998/99, total seine/haul net effort during the main Australian herring capture months (November–April) in the Geographe Bay/Bunbury area ranged from 598 to 1,448 days per year (Fig. 3.13). From 1999/00 to 2005/06, November–April effort was significantly higher and ranged from 1,548 to 1,850 days. After 2005, seine/haul net effort declined sharply to an historic low of 222 days in 2009/10. The effort reduction was largely due to a Voluntary Fishery Reduction Scheme (licence buyback) in Geographe Bay.

Since Australian herring is taken in the Geographe Bay/Bunbury area as a byproduct while targeting other species, it is impossible to estimate effort spent specifically targeting Australian herring using information within the CAES database. The majority of annual effort is usually spent targeting western Australian salmon and whitebait.

Cockburn Sound Fish Net Managed Fishery

The Cockburn Sound Fish Net Managed Fishery has landed 4% of the WA commercial catch of Australian herring since 2000. This fishery was gazetted in 1995. The *Cockburn Sound (Fish Net) Limited Entry Fishery Notice (1995)* permits the use of gill nets, haul nets and garfish nets in Cockburn Sound. Each net type has specific length, depth and mesh size restrictions.

Commercial landings of Australian herring in Cockburn Sound (CAES block 9600) gradually increased from zero in the late 1970s to 50 t in 1994 (Fig. 3.11). Landings fell abruptly to 32 t in 1995, and then declined gradually reaching 8 t in 2008 and 2009. Prior to 1990, Cockburn Sound contributed about 10% of commercial herring landings in the WCB. From 1990 to 2009, Cockburn Sound contributed about 25% of WCB landings. This change largely reflect fluctuations in landings elsewhere in the Bioregion (mainly in Geographe Bay) rather than in Cockburn Sound itself.

Historically, the majority (70–100% per year) of Australian herring landings in Cockburn Sound have been taken by gill net or 'garfish net'. The exception was a 9-year period from 1986 to 1994 when landings by haul/seine nets contributed 35–65% of total Cockburn Sound landings per year (Fig. 3.14). Annual landings by haul/seine nets were 6–20 t per year in this period but have been <5 t in other years. Catches of Australian herring by gill nets and garfish nets are combined here due to difficulties in determining from DoF records which method was used. The gill/garfish net catch of Australian herring in Cockburn Sound peaked at 32 t in 1994 and has since undergone a gradual decline, falling to less than 10 t since 2008.

Total annual landings of Australian herring in Cockburn Sound are seasonal, with a peak in summer/autumn and a minimum in winter (Fig. 3.12). However, this seasonality essentially reflects the monthly distribution of catches by the most active net fisher, who has been the most productive net fisher in Cockburn Sound (i.e. highest annual landings) since the mid 1990s and has been the only net fisher operating in Cockburn Sound since June 2008. Australian herring landings by other fishers previously operating in Cockburn Sound were non-seasonal.

Australian herring and southern garfish (*Hyporhamphus melanchir*) are the primary target species of net fishers in Cockburn Sound. Together they comprise about 95% of the annual gill net/garfish net catch. Since 1999, Australian herring has comprised 35–55% of the annual gill net/garfish net catch.

In Cockburn Sound, total commercial gill/garfish netting effort fell dramatically from about 2,000 days per year during the late 1980s to 301 days in 2000/01, and then declined at a more gradual rate to reach 157 days in 2008/09 (Fig. 3.15). In the 1980s and early 1990s, the majority of the gill net catch in Cockburn Sound was comprised of blue swimmer crabs (*Portunus armatus*) and the majority of gill netting effort until 1995 was spent targeting crabs. The large decline in gill netting effort in the early 1990s was mainly due to a reduction in the level of targeting of crabs by this method as fishers in this area shifted to trapping to capture crabs. After 1995, Australian herring and southern garfish became the dominant components of the gill/garfish net catch in Cockburn Sound.

From 1980 to 2009, 36 vessels reported catches of Australian herring by gill/garfish netting in Cockburn Sound but 92% of the Australian herring catch (by weight) in this period was taken by just 4 vessels. In all years, these four vessels primarily targeted finfish, not crabs. In contrast to the declining trend in total gill netting effort in Cockburn Sound, the combined annual gill/garfish netting effort by these four vessels increased during the 1990s and then declined gradually in the 2000s (Fig. 3.15). The decline was due to cessation of gill/garfish netting by one vessel in 1999/00 and another two vessels in 2007/08, leaving only one vessel operating from 2008/09 onwards.

West Coast Estuarine Interim Managed Fishery (WCEF)

The *West Coast Estuarine Fishery (WCEF)* comprises two estuaries (Swan-Canning Estuary and Peel-Harvey Estuary) in the WCB. Previously, this fishery also included Leschenault Inlet until it was closed to commercial fishing in 2001. Although not formally part of the WCEF, the Hardy Inlet is often included in the fishery for reporting purposes. Australian herring are mainly caught in the Peel-Harvey Estuary, although landings were historically also taken in the Swan-Canning and Leschenault fisheries. The main methods used to capture herring are haul and gill nets. The WCEF landed 1% of the WA commercial catch of herring between 2000 and 2010.

From 1976 to 2009, the proportion of WCB landings of Australian herring taken in estuaries ranged from 5 to 25% per year. Prior to 1996, the majority of estuarine landings of herring in the WCB were taken in the Leschenault Estuary (Fig. 3.11). After 1996, WCB estuarine landings were mainly derived from the Peel-Harvey Estuary. Annual commercial landings of herring in the Swan-Canning Estuary have always been low relative to landings in other estuaries.

In the Leschenault Estuary, Australian herring landings fell from an historical peak of 19 t in 1976 to <2 t per year after 1996 (Fig. 3.11). The estuary was closed to commercial fishing in January 2001. The majority (~80%) of herring landings in the Leschenault Estuary were caught using seine/haul netting. The monthly distribution of total landings from 1976 to 1999 was similar to that reported in nearby ocean waters in Geographe Bay, i.e. a peak in late summer/autumn and a minimum in winter (Fig. 3.12).

WCEF landings were relatively low during the 1990s, and then increased significantly after the mid-1990s as a result of an increase in landings in the Peel-Harvey Estuary (Fig. 3.11). Prior to 1994, when the Dawesville Cut was opened, landings of herring in the Peel-Harvey Estuary were relatively low (0–4 t per year) but subsequently increased to 4–9 t per year. The increase probably reflects the increased intrusion of ocean waters (and marine species such as Australian herring) into the estuary following the Cut's implementation.

Overall, Australian herring is a minor byproduct species in the Peel-Harvey Estuary. Since 1994, herring has contributed only 0–5% per year (by weight) of the total commercial catch (including crabs and other invertebrates) and 0–9% per year of the total finfish catch (excluding invertebrates) in this estuary. The main finfish species caught commercially in the Peel-Harvey Estuary are sea mullet (*Mugil cepahlus*) and yellow-eye mullet (*Aldrichetta forsteri*), which together comprise 40–55% per year of the total catch and 65–85% of the finfish catch.

Since 1994, haul/seine nets have taken 67% of Australian herring landings in the Peel-Harvey Estuary, with the remainder landed by gill nets. Australian herring has comprised about 8% of total annual commercial haul/seine net finfish landings in the Peel-Harvey estuary in recent years. About 85% (by weight) of haul/seine net landings are sea mullet and yellow-eye mullet. Haul/seine net landings of herring are not strongly seasonal and occur during all months of the year (Fig. 3.12).

Australian herring and mullet species are captured during the same months and so specific effort spent targeting a particular species cannot be determined. The total haul/seine netting effort (i.e. the combined effort spent targeting all species) in Peel-Harvey Estuary has been stable since 2000, averaging 596 days per year (Fig. 3.16).

Gill net landings of Australian herring in the Peel-Harvey Estuary are mainly taken June–September (Fig. 3.12). Australian herring has comprised about 10% of total gill net catches in Peel-Harvey Estuary within this period in recent years. Other species captured by gill netting in the same period include sea mullet, yellow-eye mullet, cobbler (*Cnidoglanis macrocephalus*) and whiting (*Sillago* sp.). The total gill netting effort (i.e. the combined effort spent targeting all species) in the Peel-Harvey Estuary during July–September has been stable since 2000, averaging 139 days per year (Fig. 3.16).

Mandurah/southern metropolitan fishery

From 1976 to 1992, a significant quantity (6–35 t per year) of Australian herring was reported from block 3215 (i.e. coastal waters around Mandurah and the southern metropolitan region) (Fig. 3.11). During this period, annual landings in this block represented 14% of total herring landings in the WCB. Herring were taken by seine/haul nets (~70% by weight) and gill nets (~30%).

From 1993 to 2002, 1–5 t per year of Australian herring were taken by seine/haul nets in CAES block 3215. After 2002, annual herring landings declined due to effort reductions and have been negligible since 2004. Total seine/haul netting effort in CAES block 3215 declined steadily after 2000 and reached very low levels in 2008 (43 days) and 2009 (94 days).

In all years, Australian herring was taken as a byproduct and comprised only 2–12% of total seine/haul net landings per year in block 3215. Seine/haul net fishers in this area have historically mainly targeted whitebait.

Historically, seine/haul net landings of Australian herring in block 3215 primarily occurred during December–April (Fig. 3.12). Annual landings of herring during these months increased from almost zero in 1978/79 to 14 t in 1984/85, and then remained relatively high until 1991/92 when 18 t was reported (Fig. 3.17a). From 1992/93 until 2000/01, annual landings in this period were low (1–5 t) and were negligible after 2000/01. From 1975/76 to 2003/04, haul net effort during December–April fluctuated, ranging from 135 to 915 days per year (Fig. 3.17a). Effort declined after 2003/04 and reached a negligible level (18 days) in 2009/10.

The fishery in this region is currently known as the West Coast Beach Bait Fishery. *The West Coast (Beach Bait Fish Net) Limited Entry Fishery Notice (1995)* includes all waters of the Indian Ocean between Moore River (31°21.13' S) and Tim's Thicket (32°39.08' S). Permitted fishing gears are beach seine nets or small purse seine nets.

Northern WCB fisheries

Minor quantities of Australian herring have historically been taken within the northern Perth area ('metro north', CAES block 3115) and to the north of Perth (latitudes ≥28º and <32º) (Fig. 3.11). The annual catch level and trend has been similar in both regions. To the north of Perth, the total annual catch of herring gradually declined from a peak of 7 t in 1977/78 to <1 t in the mid-1990s. After 2004/05, landings gradually increased and reached 2 t in 2009/10. Recent landings were mainly taken near Dongara (CAES block 29142) and Jurien (blocks 3014, 3015). Previously, herring landings north of Perth were mainly taken from blocks 3014, 3015 and 3115.

Australian herring is taken by haul/seine nets and gill nets in these northern regions, but is a minor component of the total catch by both methods. In recent years, herring has comprised < 1% per year of the total gill net catch. The majority of the gill net catch in northern areas is taken offshore, where herring is not caught (sharks and demersal finfish are the main offshore targets). A small number of inshore gill net fishers operate in northern areas, targeting sea mullet, whiting, herring and other inshore species.

From 1999 to 2009, haul/seine landings were mainly sea mullet (~90% by weight) and whiting (~6%), while Australian herring comprised only 1–4% of seine/haul net landings per year. The majority of herring landings by haul/seine net are taken between November and April, which is the main capture season for sea mullet. Fishing effort is also concentrated during this period each year.

From 1975/76 to 1998/99, Australian herring landings by haul/seine nets fluctuated, ranging from almost zero to 7 t per year (Fig. 3.17b). From 1999/00 to 2009/10, annual landings of herring were relatively low (<1.3 t). Annual haul/seine net effort declined from 1,174 days in 1979/80 to 128 days in 1992/93. Effort then increased briefly to a peak of 1,196 days in 1995/96 before declining to 199 days in 1999/00. After 1999/00, annual haul/seine net effort was relatively low, ranging from 185 to 443 days.

3.3.4 Catch rates in key WA fisheries

South Coast trap net fishery CPUE

The approximate annual catch rate ($CPUE_{approx}$) of the trap net fishery, using total SCB ocean catch as a proxy for trap net catch, gradually increased after 1980 until 2001, when an historical peak was reached (Fig. 3.18). The catch rate declined very sharply between 2001 and 2005 and then continued to decline at a more gradual rate until 2010.

Other versions of the trap net annual catch rate ('tonnes/licenced team' and 'tonnes/active team') displayed similar trends from 1994 to 2002 (Fig. 3.18). After 2002, the proportion of inactive teams in the fishery increased. Therefore, the catch rate of active teams shows less of a decline than that of the total fishery after 2002.

The catch rate of the trap net fishery can be influenced by many factors, in addition to the abundance of Australian herring, and so may be an inaccurate index of the abundance of Australian herring. These factors include

- Real fishing effort is difficult to accurately quantify.
- Trap net fishers capture Australian herring selectively, depending on market demand. Fishers will sometimes release all/part of a captured school, depending on market demand. The decline in catch rate after 2000 may be partly due to a decline in targeting due to low market demand.
- Nets are set from the beach and are therefore only able to catch schools swimming adjacent to the shore. Offshore schools are not captured.
- Trap net fishers report that environmental factors such as water temperature can affect the behaviour and distribution of Australian herring, thus affecting catchability.
- Increases in fishing efficiency during the development of the trap net fishery may have contributed to an increase in annual landings in the 1970s and 1980s.
- Unfavourable weather or weed accumulation along the beach may reduce trap net efficiency.

Given these problems, it can be argued that the total annual catch by the fishery is equally likely to provide an index of Australian herring abundance as catch rate. Trends in both catch and catch rate suggest that the availability of Australian herring has undergone a pronounced decline in ocean waters of the SCB since about 2001. However, the catch trend suggests that the decline commenced about a decade earlier, in the early 1990s, rather than after 2001 as suggested by the catch rate trend.

South Coast Estuarine Managed Fishery CPUE

The average annual catch rate of Australian herring by gill nets in Oyster Harbour peaked at 11.9 kg/day in 1983. The catch rate then gradually declined to 0.3 kg/day in 1999 and remained low in subsequent years (Fig. 3.19a).

After 1999, the proportion of black bream, and to a lesser extent cobbler, in total gill net landings in Oyster Harbour increased. Targeting of bream occurs in the upper estuary, where Australian herring are less abundant. Therefore, changes in fishing location within the estuary and in gear deployment associated with a shift in the main target species, could have contributed in the very low gill net catch rate of herring after 1999 in Oyster Harbour.

The average annual catch rate of herring by haul/seine nets in Oyster Harbour was relatively high throughout the 1980s, peaking at 59 kg/day on three occasions (Fig. 3.19b). After 1989, the catch rate declined sharply and was relatively low from 1990 to 1993, ranging from 3 to 12 kg/day. The haul/seine catch rate then recovered rapidly to reach 53 kg/day in 1996. After 1996, the catch rate gradually declined to 5 kg/day in 2005. It remained low in subsequent years.

The reason for the sudden 4-year period of low catch rate of herring by haul/seine nets in Oyster Harbour from 1990 to 1993 is unclear. Exceptionally high catches of herring in adjacent ocean waters (i.e. in the trap net fishery) during these years may have discouraged fishers from targeted herring in Oyster Harbour at this time.

The average annual catch rates of herring in Oyster Harbour by haul/seine nets and by gill nets were strongly correlated over the period 1980 to 2009 (r^2=0.509, d.f. = 28, P<0.01). The similarity of the catch rates by these independent methods (separate groups of fishers use these methods) suggests that the trend is indicative of the availability of herring within Oyster Harbour over this period. This suggests that the abundance of herring in Oyster Harbour was highest during the 1980s and has been very low since 2000.

In Wilson Inlet, the average annual gill net CPUE of Australian herring (based on total annual catch and effort levels during October–May each year) has been variable since 1975 (Fig. 3.19c). Despite peak catch rates during the 1980s, there was still an overall downward trend from 1975/76 to 1995/96. From 1995/96 to 2009/10, the annual catch rate followed a gradual upward trend. Relatively high catch rates in recent years could be a consequence of herring being retained in the estuary as a result of non-openings of the sand bar in 2007 and 2010.

In Broke Inlet, the average annual gill net CPUE of Australian herring (based on total annual catch and effort levels during May–October each year) was calculated from 1988 onwards (insufficient data prior to 1988). CPUE was relatively low over an extended period from 1988 to 1998 (Fig. 3.19d). CPUE increased sharply to a peak in 1999 and then gradually declined until 2005. From 2006 to 2009 CPUE was consistently low.

Not surprisingly, the average annual Australian herring CPUE in three key SCB estuaries (Broke Inlet, Wilson Inlet, Oyster Harbour) followed different trends. The abundance of herring in Wilson Inlet and Broke Inlet, which are seasonally closed estuaries, is partly determined by the timing and duration of the annual opening of the sand bar. Openings provide opportunities for juvenile recruitment into the estuary and adult emigration from the estuary. Therefore, catch rates in these estuaries are unlikely to reflect regional herring abundance. Catch rates in Oyster Harbour, which is permanently open to the ocean, is more likely to reflect regional stock abundance.

Geographe Bay/Bunbury seine net CPUE

From 1980/81 to 1990/91, the average annual catch rate of Australian herring by haul/seine nets (based on catch and effort from November to April only) in the Geographe Bay/Bunbury region was relatively high (10-year average 58 t/day) and highly variable (range 30–97 t/day) (Fig. 3.20). Over the next decade (1990/91 to 2000/01), the average catch rate was again relatively high (10-year average 52 t/day) but was much less variable (range 43–58 t/day). After 2000/01, the average annual catch rate of herring by haul/seine nets declined rapidly until 2005/06. From 2005/06 to 2009/10, catch rates were at historically low levels (range 9–16 t/day).

Low and declining levels in recent years probably partly reflect management changes to commercial seine net fishing in this area since 2000. A Voluntary Fisheries Adjustment Scheme operated from mid-2004 until mid-2009, resulting in the buy-back of three licences in the South West Coast Salmon Fishery. A section of Geographe Bay was permanently closed to western Australian salmon fishing in mid-2009 and then closed to all commercial seine netting in mid-2010. Seine netting was only permitted north of Busselton after mid-2010.

Cockburn Sound gill/garfish net CPUE

Prior to 1996, the majority of gill netting effort in Cockburn Sound was spent targeting crabs. After 1996, crab fishers in Cockburn Sound adopted traps as the only method of capture, leaving a small number of remaining gill net fishers who exclusively targeted finfish. After 1996, <5 vessels used gill nets to capture significant quantities of Australian herring in Cockburn Sound. Most recent landings were taken by garfish netting.

From 1996 to 2009, the average annual gill/garfish net catch rate of herring in Cockburn Sound (based on the standardised annual catch rates of the main four vessels) displayed a slight downward trend, although this was not statistically significant (d.f. = 12, r = 0.242, P>0.05). This may reflect a relatively stable availability of herring to gill/garfish net fishers in Cockburn Sound over this period (Fig. 3.21). However, daily catch levels are sometimes regulated by individual fishers to supply a limited local market for herring. Therefore, the stable catch rate over this period may reflect market demand rather than availability.

Peel-Harvey Estuary CPUE

Prior to the opening of the Dawesville Cut in April 1994, the catch rate of Australian herring in the Peel-Harvey Estuary was negligible. A marked increase in the annual catch rate by haul/seine nets and by gill nets in this estuary in the late 1990s almost certainly reflected an increase in the abundance of herring in this estuary as a result of increased connectivity with the ocean via the Dawesville Cut. The opening of the Cut increased the flow of ocean water into the estuary, creating more opportunities for herring to move into the estuary. Also, the salinity of the lower estuary became more oceanic which may have been more favourable to herring.

The average annual gill net CPUE of herring in the Peel-Harvey Estuary was negligible (0–1 kg/day) from 1994 to 1998 (Fig. 3.22a). From 1999 to 2009, the annual gill net CPUE ranged from 6 to 26 kg/day. The average annual haul net CPUE of herring gradually increased from zero kg/day in 1994 to reach 7–10 kg/day in 2005–2009 (Fig. 3.22b).

The abundance of Australian herring within this estuary appeared to increase dramatically during the late 1990s following the opening of the Dawesville Cut. Ongoing environmental changes (due to declining rainfall, eutrophication, habitat modification, etc.) may continue to influence the abundance of herring in this estuary. Therefore, catch rates of herring in this estuary do appear to reflect local abundance but are unlikely to reflect regional herring abundance.

Mandurah/southern metropolitan ocean seine/haul CPUE

The average annual catch rate of Australian herring by haul/seine nets in block 3215 (based on catch and effort from December to April only) increased rapidly after 1978/79 to reach a peak in 1991/92 (Fig. 3.23a). The average catch rate then gradually declined and reached zero in 2006 and subsequent years, reflecting the negligible effort levels in this fishery recently.

After 2000/01, the continuing decline in CPUE coincided with a period of effort reduction and restructuring of commercial fishing activity in this area. Therefore, the most recent, very low CPUE level may reflect changes in fishing behaviour (e.g. the level of targeting of Australian herring) rather than a decline in the availability of Australian herring. Earlier trends suggest that the abundance of Australian herring in this area increased during the 1980s and then gradually declined during the 1990s.

Northern WCB ocean seine/haul CPUE

Since 1975/76, the average annual catch rate of Australian herring by haul/seine nets in ocean waters north of Perth has been very low, ranging from 0–9 kg/day (Fig. 3.23b).

Australian herring is a minor byproduct in this fishery, and so catch and effort levels are partly determined by the location and timing of fishing for other species, especially sea mullet. Therefore, trends in the catch rate of herring may be an artefact of changes in the targeting of other species rather than reflecting changes in the availability of herring. Nonetheless, the average annual catch rate of herring by haul/seine nets in this region followed a broadly similar trend to catch rates of herring in other regions – increasing during the 1980s and then declining during the 1990s. From 2001/02 to 2009/10, the catch rate suggested a slight increase in the abundance of Australian herring in coastal waters north of Perth.

3.3.5 Relationships between recruitment and catch rate

Four versions of the annual recruitment index, R_n , $R_{n,n+1}$, $\ln(R_n)$ and $\ln(R_{n,n+1})$, were correlated against the commercial trap net fishery catch and CPUE. Log transformed values of the annual recruitment index ($\ln(R_n$) and $\ln(R_{n,n+1}$)) were consistently more highly correlated against catch/CPUE, compared to untransformed values (R_n , $R_{n,n+1}$). The correlations with log transformed values are described below.

The annual CPUE (tonnes/active team) of the commercial South Coast trap net fishery was correlated with the log transformed recruitment index, $\ln(R_n)$, at Poison Creek three years earlier ($p<0.01$) (Fig. 3.24). CPUE in the trap net fishery was also significantly correlated with the 2-year log transformed recruitment index, $\ln(R_{n,n+1})$, at Poison Creek three years earlier ($p<0.01$) (i.e. there was a strong correlation between CPUE and the average of recruitment 2 and 3 years earlier). The annual catch by the fishery was correlated with the 2-year recruitment index at Poison Creek four years earlier.

The relationship between the trap net fishery catch/CPUE and recruitment at Koombana Bay was ambiguous (Fig. 3.24). Annual catch displayed no clear relationship with the log transformed 1-year recruitment index, $\ln(R_n)$, at Koombana Bay. Multiple significant correlations occurred due to the declining trend in both data series. Although CPUE was not correlated with the 1-year recruitment index at this site, it was significantly correlated with the 2-year recruitment index, $\ln(R_{n,n+1})$, when CPUE was lagged by +3 years ($p<0.01$).

Four versions of the annual recruitment index, R_n , $R_{n,n+1}$, $\ln(R_n)$ and $\ln(R_{n,n+1})$, were also correlated against the lagged annual commercial catch of Australian herring in SA (not shown). The SA commercial catch was mostly strongly correlated with the annual recruitment index R_n at Poison Creek in the same year, i.e with a 0–1 year lag between recruitment and catch ($r^2 = 0.532$, d.f. = 9, $p<0.02$).

3.4. Discussion

Since 2000, total commercial fishery landings of Australian herring have followed the same downward trend in each Bioregion of WA and in SA. Despite the independence of the fisheries operating in each region, the long-term catch trends are highly correlated which suggests a similar decline in stock availability in all regions since 2000. The decline in stock availability was due to a decline in recruitment across southern Australia. In both WA and SA, reductions in effort, including spatial closures and licence buy-backs, may also have contributed to declines in catch levels.

In the SCB of WA, the trap net fishery is responsible for the vast majority of landings of Australian herring. A correlation between annual 0+ juvenile recruitment (measured by fishery-independent sampling) and trap net catch indicates that trends in this catch can be used to infer approximate trends in herring abundance, especially in earlier years of the fishery when catch rate is not available. The correlation with recruitment provides further confirmation that the catch trend in the SCB reflects declining abundance or, more specifically, declining recruitment. A stronger correlation between recruitment and trap net catch rate implies that catch rate is probably a more accurate index of Australian herring abundance and should be used when available.

To facilitate a comparison of the long-term trends in catch rates in the trap net fishery and other commercial fisheries in WA, the average annual catch rate of Australian herring in each fishery was standardised (i.e. divided by the mean of their respective annual CPUEs) and then smoothed by a 3-point moving average (Fig. 3.25). The catch rates in the Peel-Harvey Estuary (where major environmental changes associated with the Dawesville Cut have probably affected herring abundance) and in the Broke and Wilson Inlets (where the sand bar openings are likely to affect herring abundance) were excluded from these comparisons.

The commercial fisheries examined here displayed different short-term (1–5 years) trends in catch rate. These fluctuations may reflect real differences in fish local abundance between regions. Alternatively, they may be a response to the numerous social, economic or environmental factors that can influence the catch level in these fisheries. It is unclear whether catch rates in these fisheries provide a reliable index of abundance over short (less than 5 year) time scales.

On the other hand, the catch rates of these fisheries displayed similar long-term (decadal) trends (Fig. 3.25). The catch rates in most fisheries suggested a relatively high abundance of Australian herring in the 1980s, a moderately high abundance in the 1990s and a relatively low abundance since 2000. These long-term trends occur in fisheries in both the West Coast and South Coast Bioregions.

Catch rates examined here are essentially independent of each other because the fisheries in each Bioregion are comprised of separate, independent groups of fishers who are affected by different market forces and other local factors. Also, gill nets and haul nets are discrete methods – they are employed by different subsets of fishers (even within a fishery), they are used to target different suites of species and are deployed at different times and in different habitats. Therefore the similar long-term trends displayed by the catch rates of these independent fisheries suggest that they are reflecting trends in the stock abundance of Australian herring. Assuming this, there has been a long-term decline in the abundance of Australian herring since the 1990s in each Bioregion. The current abundance of Australian herring appears to be at the lowest level reported in each Bioregion since the mid 1970s.

The catch and catch rate trends in the southern part of the species range (i.e. southern WCB, SCB and SA), where all of the major commercial fisheries are located, indicated a low and/or declining abundance since 2000. This trend reflected declining recruitment in southern areas. In contrast, catch and catch rate trends in the northern part of the species range (i.e. Metropolitan and Mid-west Zones of the WCB), which hosts minor commercial Australian herring fisheries, suggested a stable or increasing abundance of Australian herring after 2000. An increasing trend after 2000 was also evident in recreational catch rates of Australian herring in northern areas (see Section 4). These trends suggest that the annual abundance of Australian herring in northern areas is not directly related to annual recruitment indices, unlike abundance in southern areas.

3.4.1 Influence of recruitment on fishery catch rates

The South Australian commercial catch of Australian herring was correlated with the annual recruitment index at Poison Creek (SCB) in the same year. This suggests that the South Australian catch trend is recruitment-driven with a 0 year lag between recruitment and catch.

For example, strong recruitment by the 2000 year class at Poison Creek is likely to be followed by higher catches in South Australia in 2000/01. This is consistent with the age composition of commercial landings in SA, which have been dominated by 0–1 y old fish in recent years (K. Jones, pers. comm.).

The very strong correlation between the Poison Creek annual recruitment index and the annual catch rate of the commercial trap net fishery 3 years later suggests that the catch rate of this fishery is also largely recruitment-driven. The 3 year lag between the 1-year recruitment index at Poison Creek and commercial catch rate suggests that juveniles in the South-east Zone typically recruit to the trap net fishery at the end of their 3rd year, i.e. fish are aged 2+ years at capture. Furthermore, an even stronger correlation with the 2-year recruitment index at Poison Creek suggests that the annual catch by the trap net fishery may often comprise a mixture of 2+ and 3+ fish. These conclusions are consistent with the observed age composition of the trap net fishery catch, which is dominated by the 2+ and/or 3+ age classes each year (see Section 5).

A 0 year lagged relationship with recruitment in the SA fishery and a 3 year lagged relationship with recruitment in the SCB fishery is consistent with the migration of fish from SA to the SCB at the attainment of maturity after approximately 3 years (see Section 5). The migration of maturing fish from SA to SCB is also reflected in the 3 year lagged relationship between the catches in these fisheries.

The strong lagged correlation between trap net fishery CPUE and recruitment at Poison Creek, which was corroborated by the age composition of the trap net fishery catch, strongly suggests that nurseries in the South-east Zone (and presumably also in South Australia) are the main source of recruits to this major commercial fishery. This is also consistent with the observed movements of tagged fish, which indicates that movement by Australian herring along the southern Australian coast is exclusively westward (WFRC 1973, Ayvazian *et al.* 2000).

There was no clear relationship between the Koombana Bay (WCB) recruitment and the catch of the trap net fishery. However, there was a significant correlation between the 2-year recruitment index at Koombana Bay and the catch rate of the trap net fishery 3 years later. The ambiguous relationship between the catch/CPUE of the trap net fishery and recruitment at Koombana Bay is consistent with observed movements of tagged fish indicating that Australian herring do not migrate southwards from west coast nurseries to the south coast (WFRC 1973, Ayvazian *et al.* 2000). Under this scenario, there would be no direct relationship, although coincidental correlations could occur in periods when Koombana Bay experiences similar recruitment trends to Poison Creek.

Previously, it was unclear whether either the annual catch (tonnes) or annual CPUE (tonnes per team) by the commercial South Coast trap net fishery provided a meaningful measure of fish availability in this fishery and, therefore, whether either measure provided a meaningful index of Australian herring abundance on the south coast. A very strong correlation with recruitment implies that trap net CPUE is a more reliable index of Australian herring abundance than trap net catch. However, the moderately strong correlation with catch suggests that trends in catch level could be used to infer approximate trends in Australian herring abundance, especially in earlier years of the fishery when CPUE is not available.

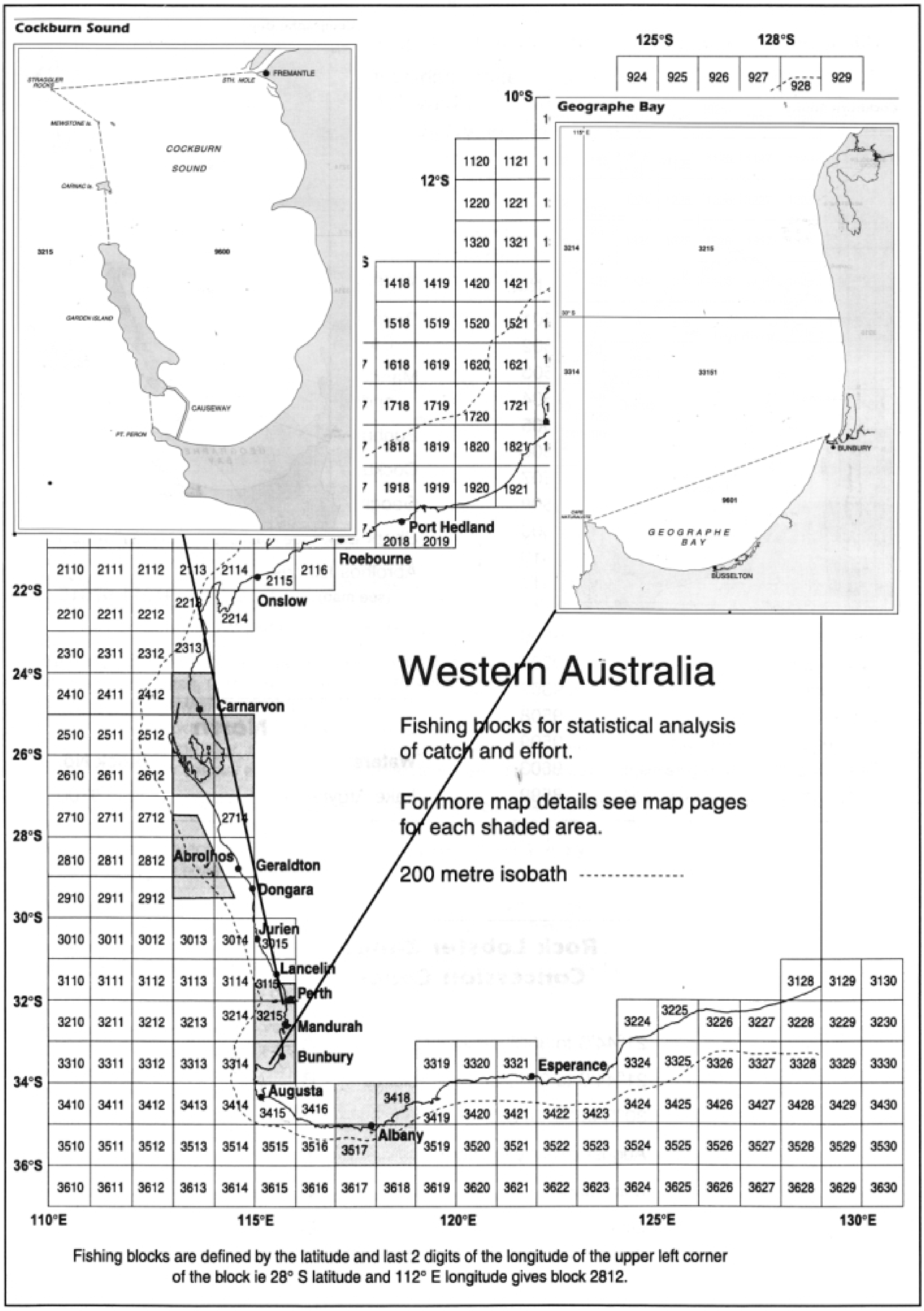


Figure 3.1. CAES block maps used by commercial fishers in the reporting of monthly catch and effort.

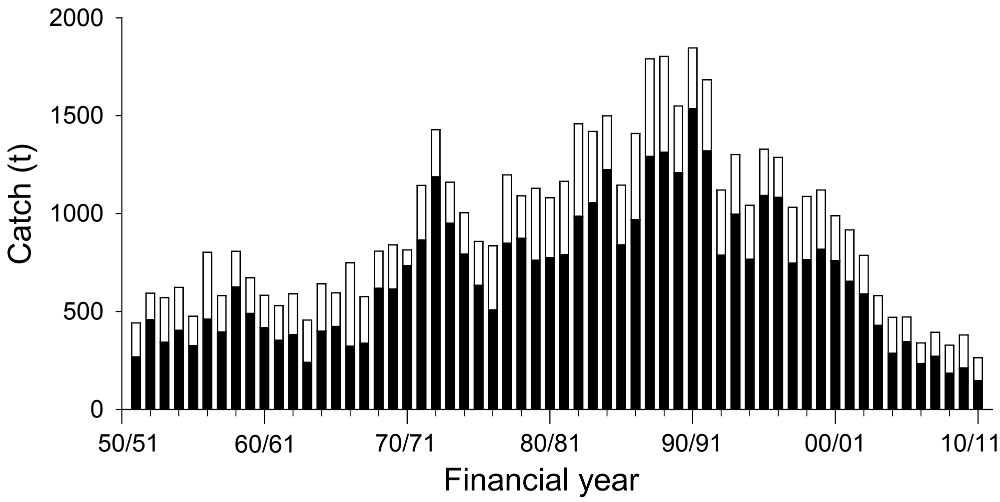


Figure 3.2. Total annual commercial landings of Australian herring in Western Australia and South Australia, 1951/52–20010/11 (white – SA; black – WA).

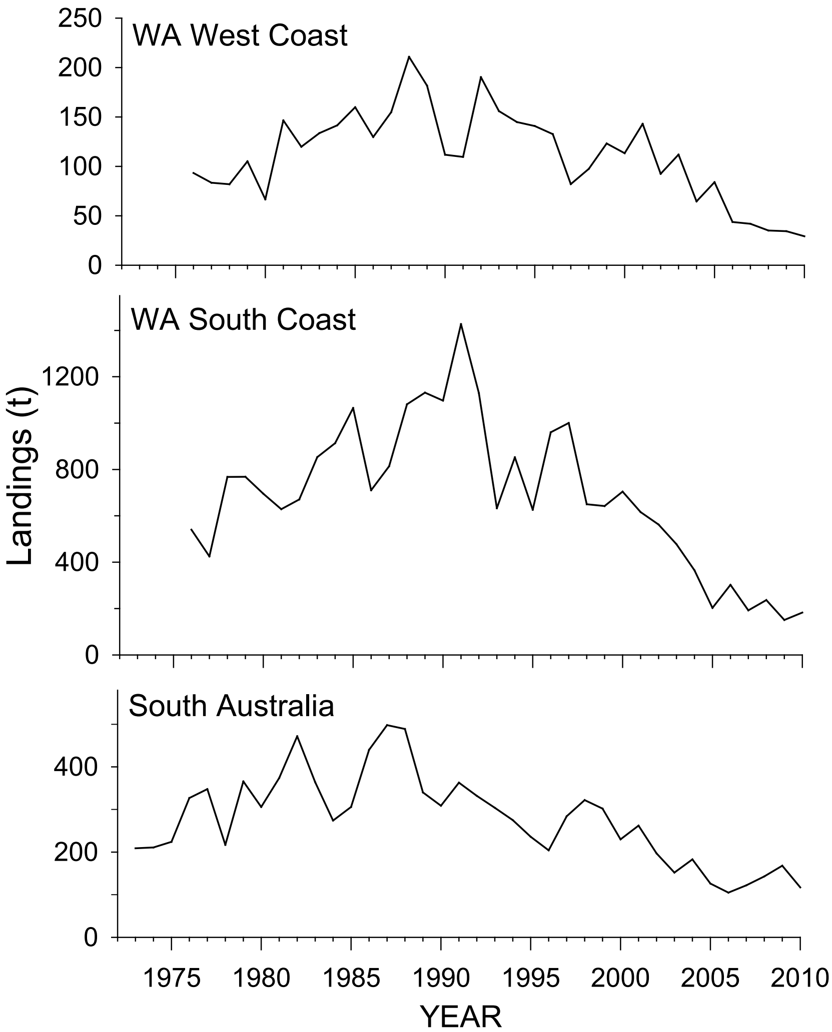


Figure 3.3. Total annual commercial landings of Australian herring in the main fishery regions, 1976 to 2010 in Western Australia (WA), 1973/74 to 2009/10 in South Australia.

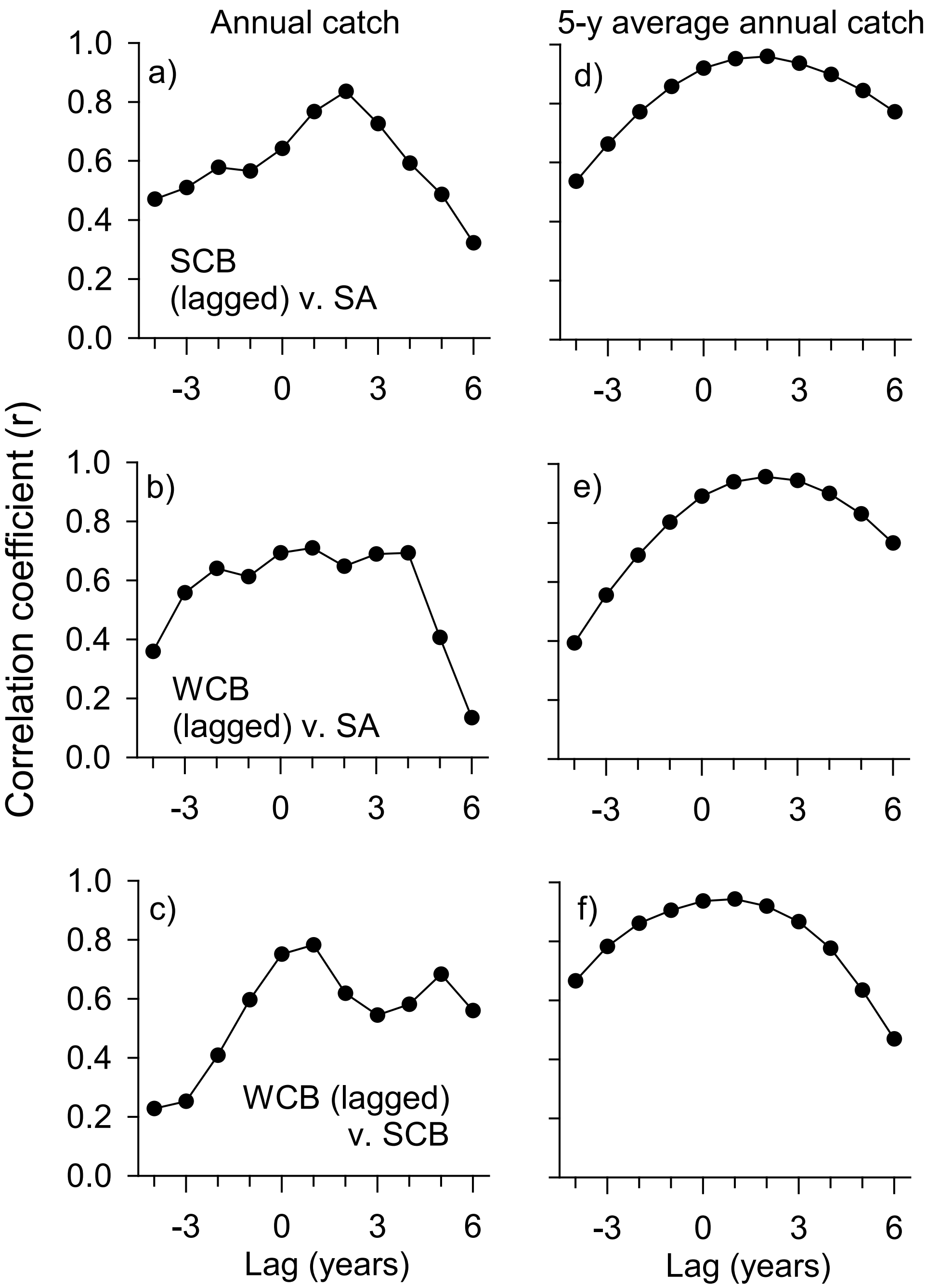


Figure 3.4. Correlations between Australian herring commercial landings in each Bioregion. **a)** WA South Coast Bioregion (SCB) annual catch (lagged by –4 to 6 years) versus South Australian (SA) annual catch; **b)** WA West Coast Bioregion (WCB) annual catch (lagged by –4 to 6 years) versus SA annual catch; **c)** WCB annual catch (lagged by –4 to 6 years) versus SCB annual catch; **d)** SCB 5-year averaged annual catch (lagged by –4 to 6 years) versus South Australian 5-year averaged annual catch; **e)** WCB 5-year averaged annual catch (lagged by –4 to 6 years) versus South Australian 5-year averaged annual catch; **f)** WCB 5-year averaged annual catch (lagged by –4 to 6 years) versus WCB 5-year averaged annual catch. All figures include annual landings from 1976/77 to 2008/09.

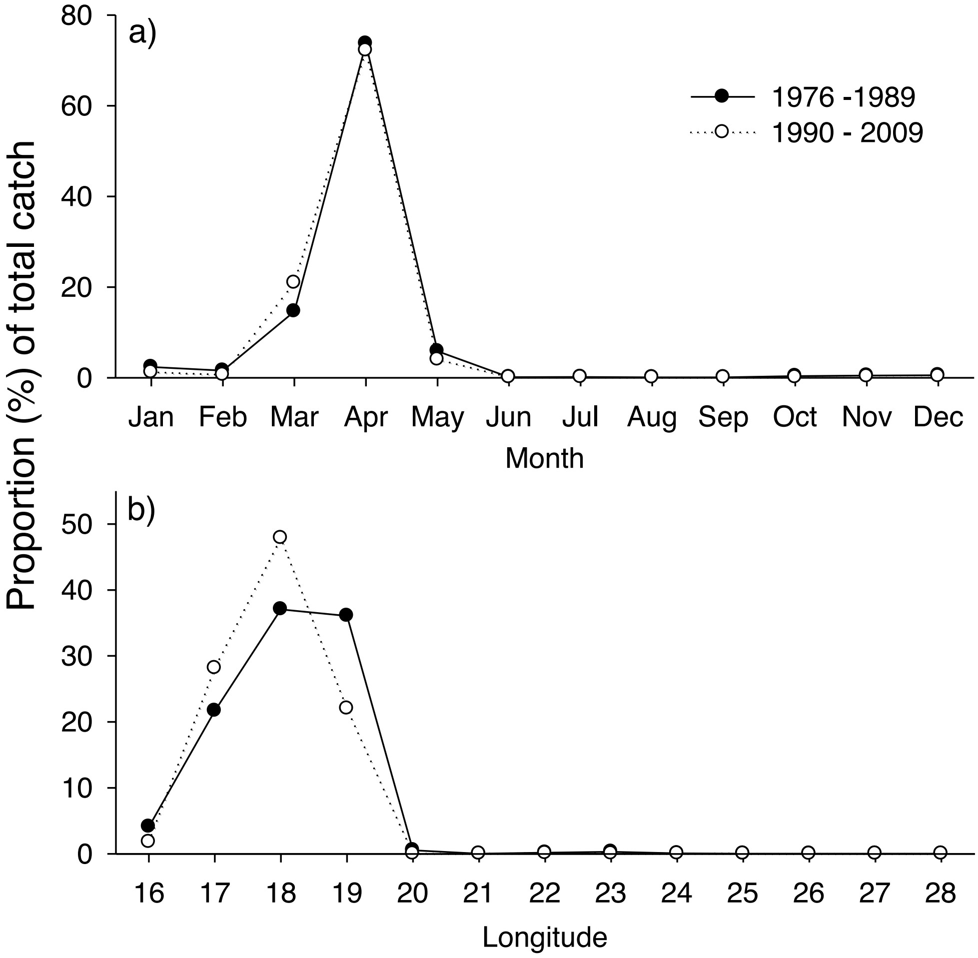


Figure 3.5. Proportion (%) of total Australian herring landings in ocean waters of the South Coast Bioregion during the periods 1976–1989 and 1990–2009, grouped by **a)** month and **b)** latitude.

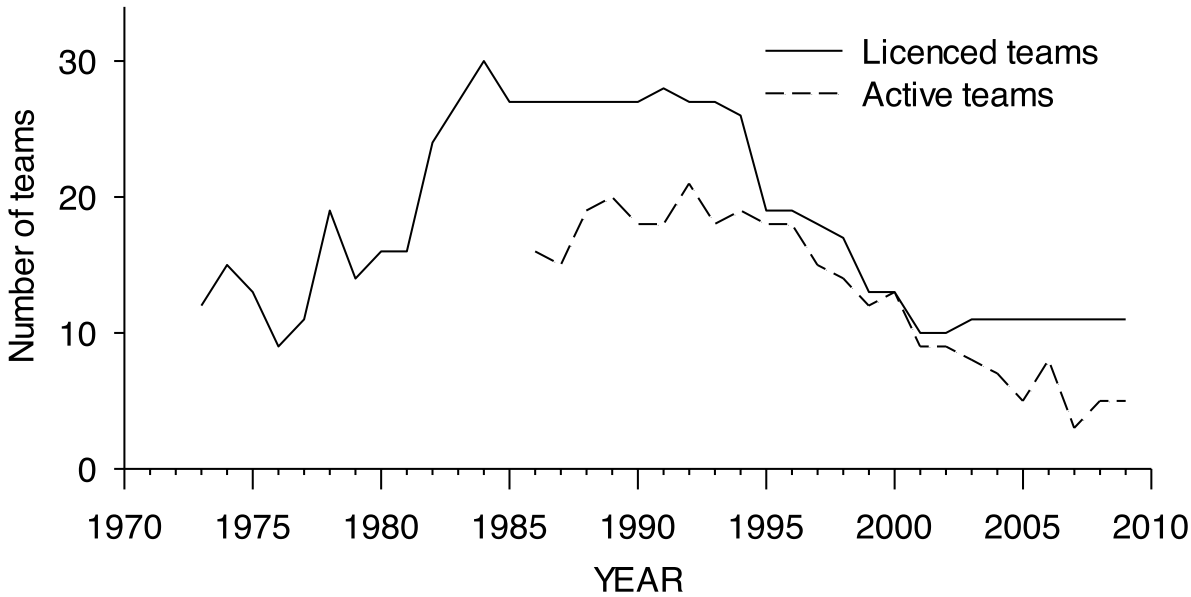


Figure 3.6. Number of licensed south coast trap net teams per year, 1973–2009, and number of active trap net teams per year, 1985–2009.

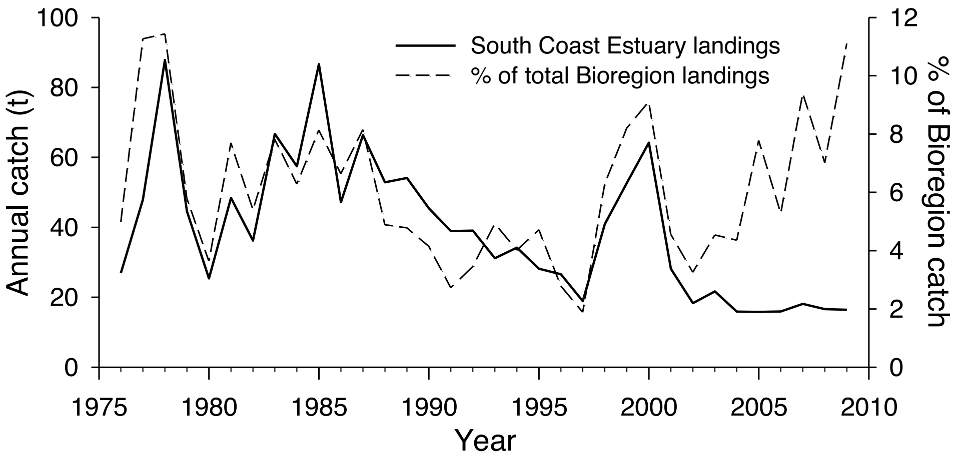


Figure 3.7. Total annual landings of Australian herring in South Coast Bioregion estuaries – live weight and as a percentage of total South Coast Bioregion commercial landings of Australian herring – 1976 to 2009.

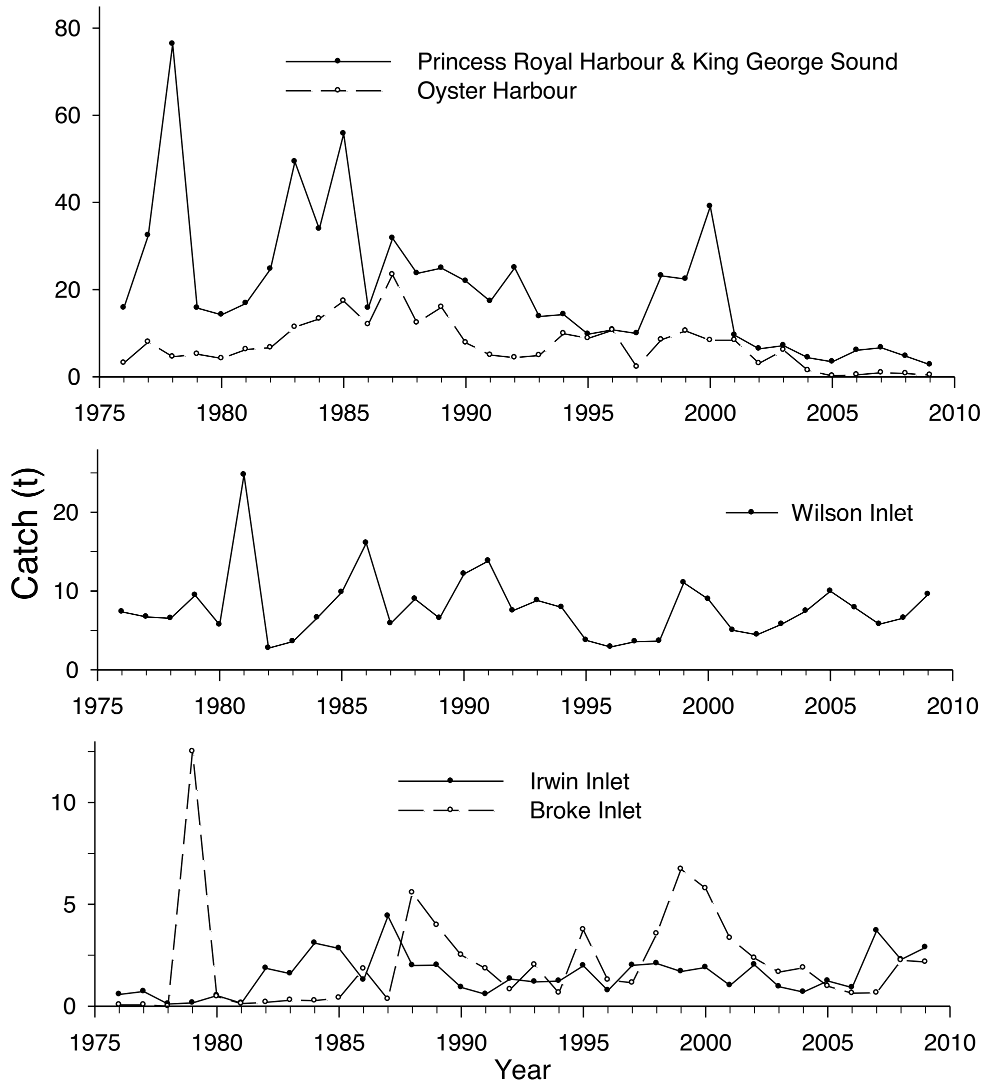


Figure 3.8. Total annual landings of Australian herring from 1976 to 2009 in South Coast Bioregion estuaries: Princess Royal Harbour/King George Sound and Oyster Harbour, Wilson Inlet, Broke Inlet and Irwin Inlet.

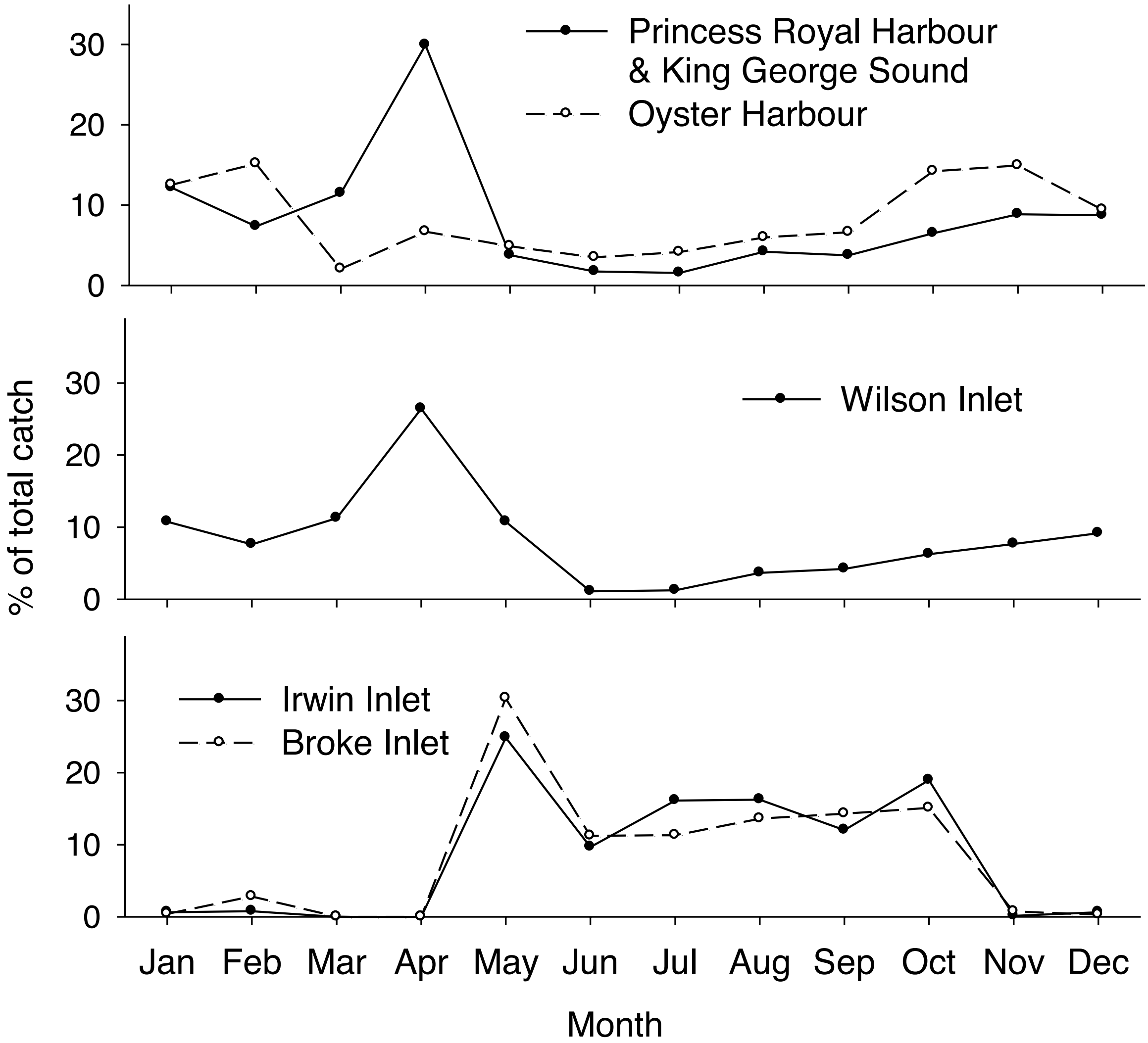


Figure 3.9. Monthly distribution of total landings of Australian herring from 1990 to 2009 in South Coast Bioregion estuaries: Princess Royal Harbour/King George Sound and Oyster Harbour, Wilson Inlet, Broke Inlet and Irwin Inlet.

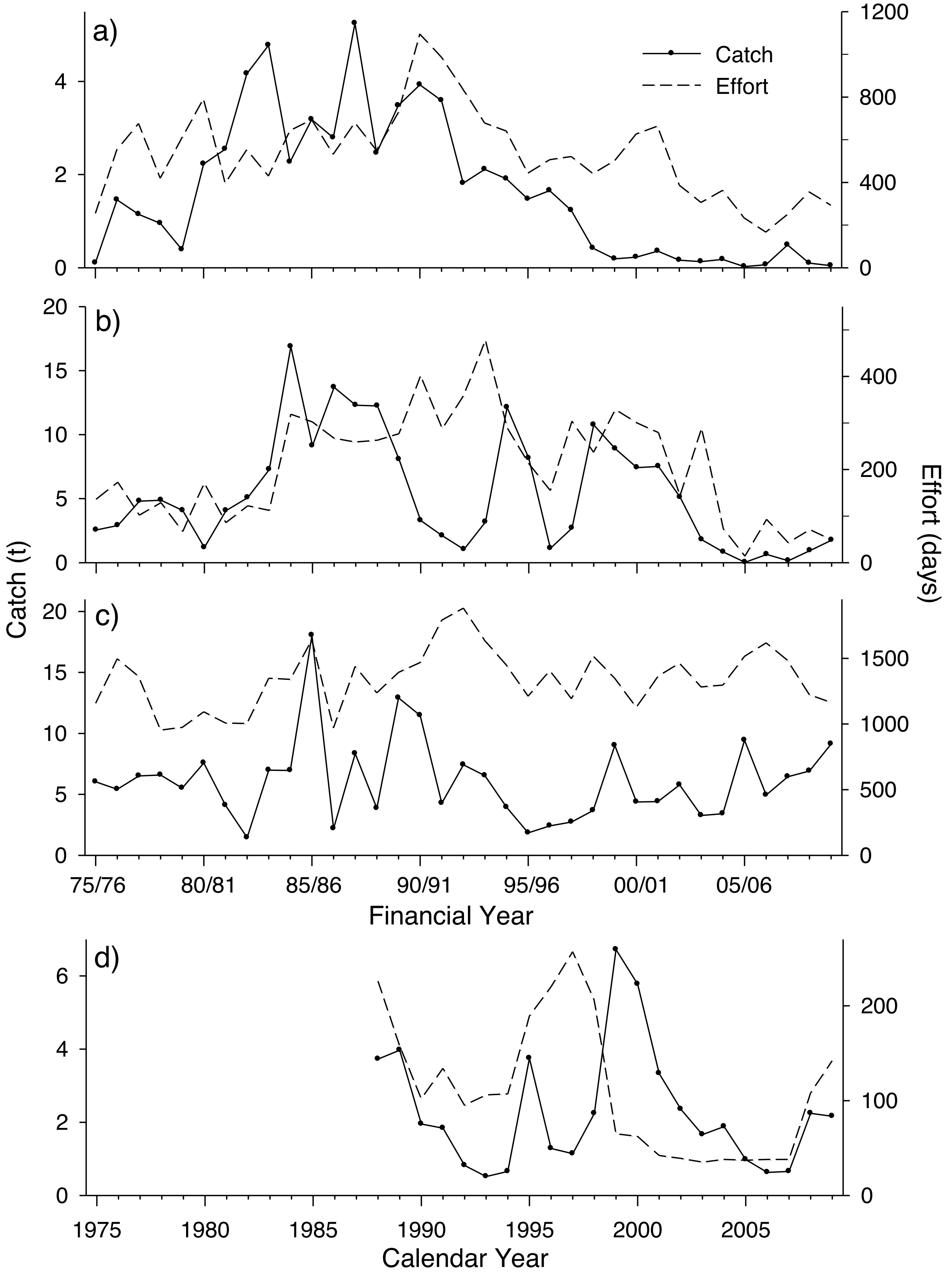


Figure 3.10. Total annual catch of Australian herring and total annual effort by **a)** gill netting and **b)** haul/seine netting in Oyster Harbour, 1975/6–2009/10. Total annual catch of Australian herring by gill netting and total gill net effort (May–October only) in **c)** Wilson Inlet 1975/76–2009/10, and **d)** Broke Inlet 1988–2009. (effort relates to landings of all species by all vessels using specified method).

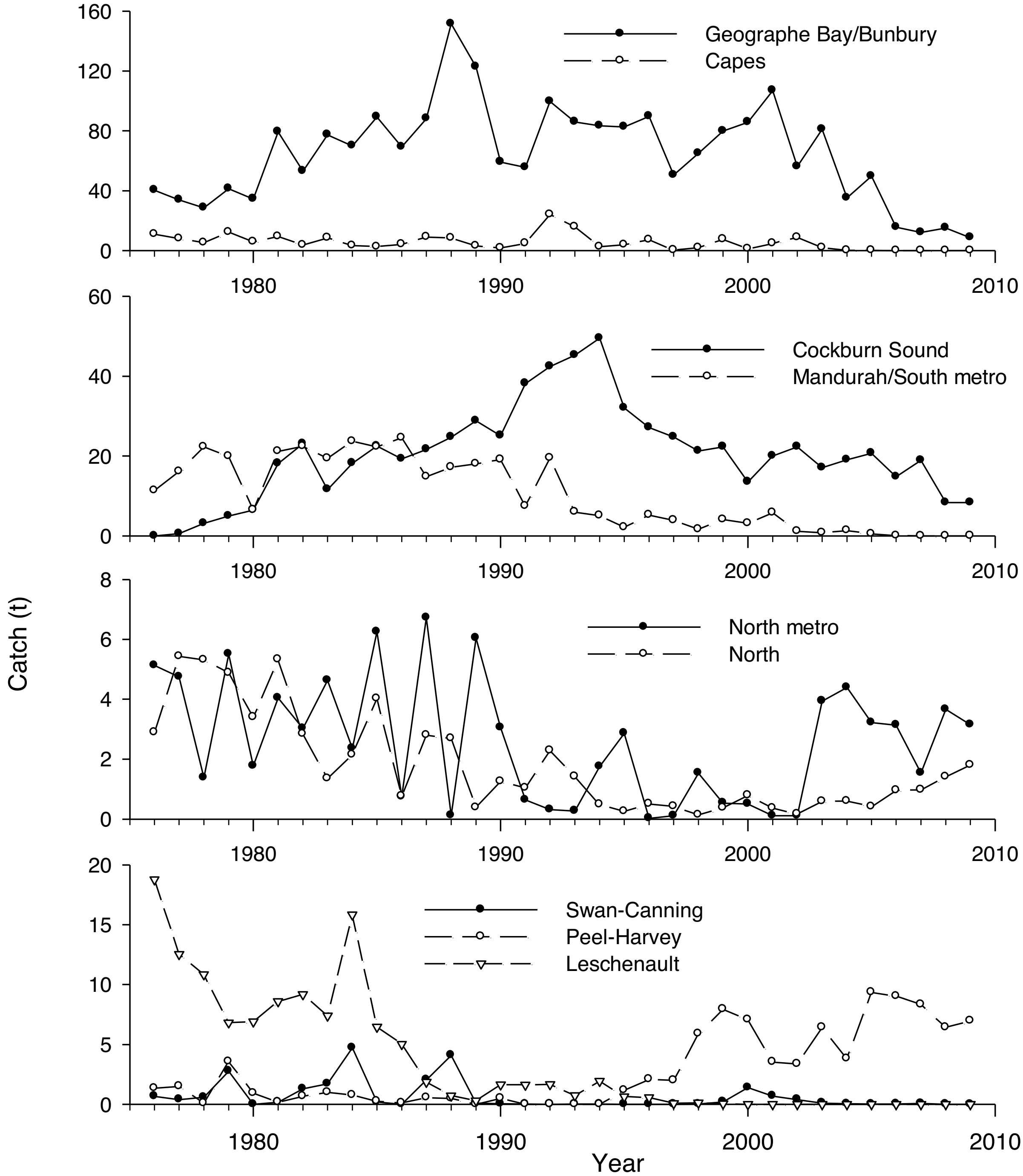


Figure 3.11. Total annual commercial landings of Australian herring in each region of the West Coast Bioregion, 1976 to 2009. (Geographe Bay/Bunbury = CAES blocks 3515, 35151, 9601; Capes region = blocks 3314, 3414, 3415, 3515; Cockburn Sound = block 9600; Mandurah/South metropolitan = block 3215; North metropolitan = block 3115; North= latitudes ≥28° to <31°).

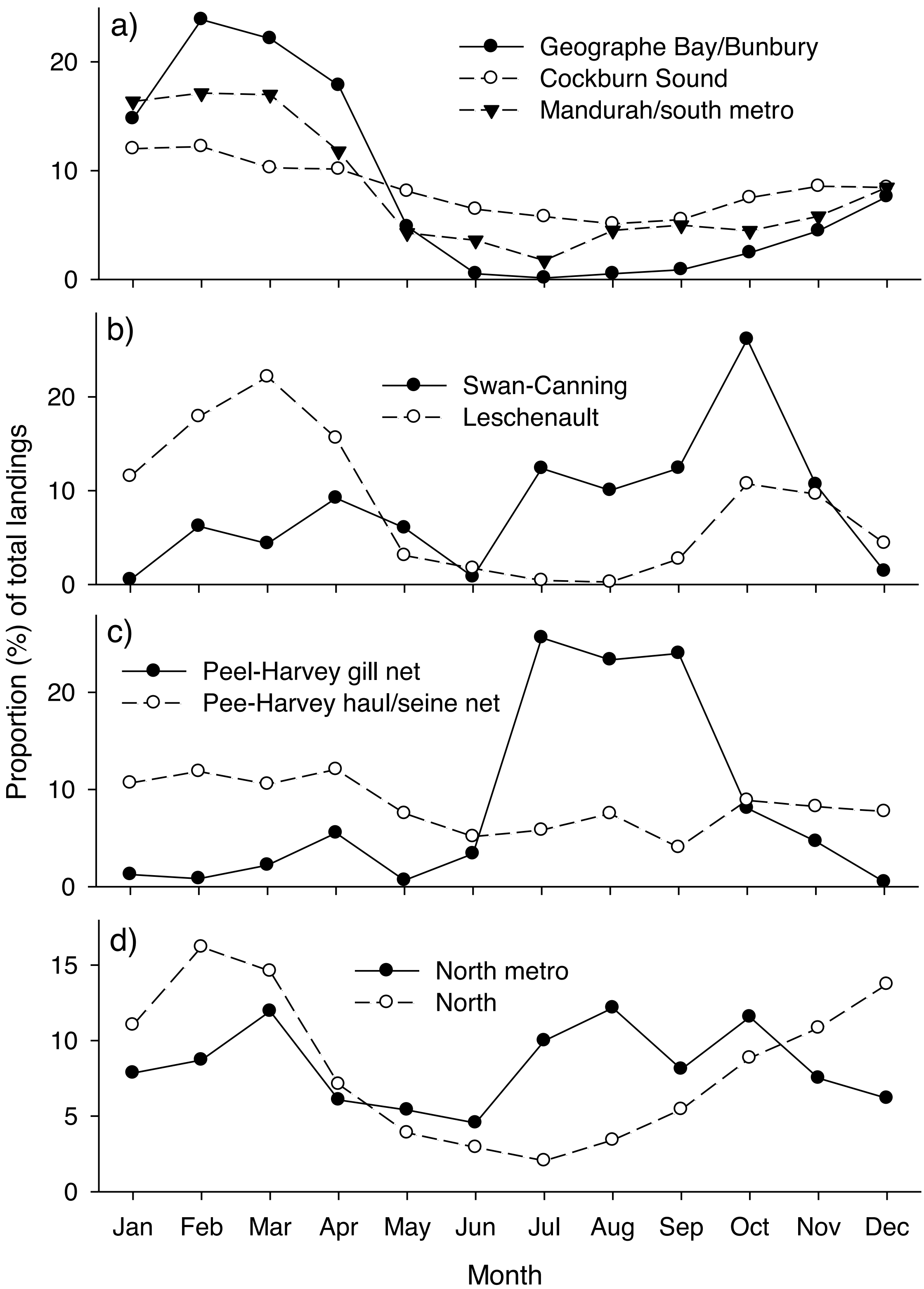


Figure 3.12. Monthly distribution of total landings of Australian herring from 1976 to 2009 in **a)** Geographe Bay/Bunbury (blocks 3315, 33151, 9601), Cockburn Sound (block 9600) and Mandurah/south metropolitan area (block 3215), **b)** Swan-Canning Estuary and Leschenault Inlet, **c)** Peel Harvey Estuary – gill net landings and haul/seine net landings (1998 to 2009 only), and **d)** north metropolitan area (block 3115) and waters north of Perth (latitudes ≥28° to <31°).

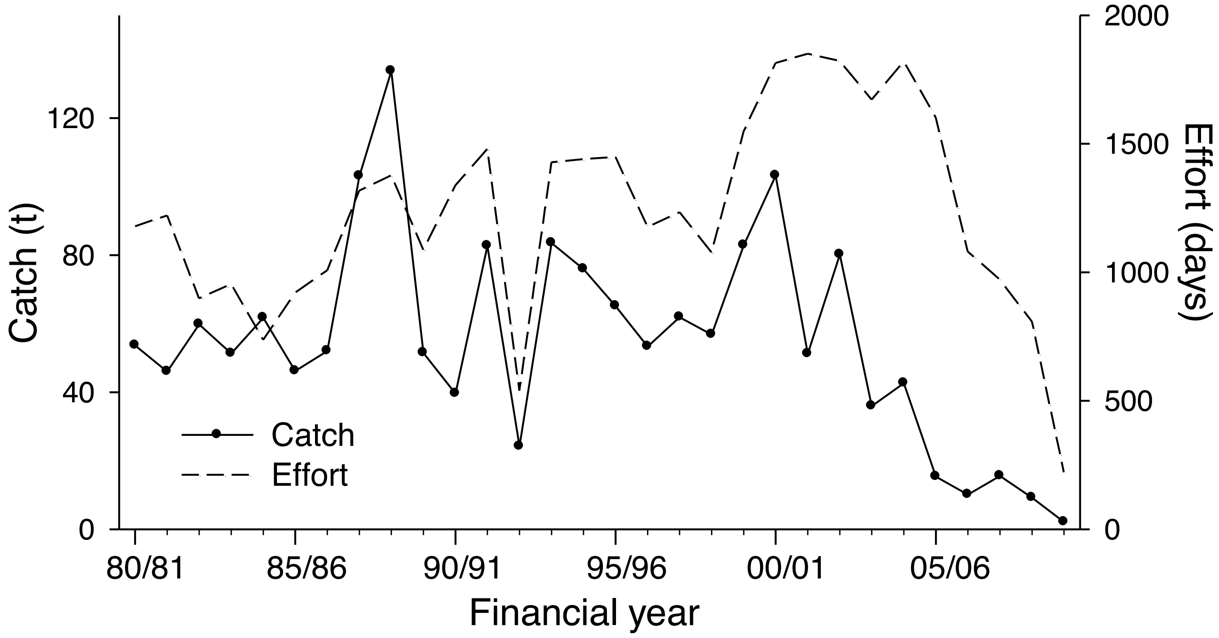


Figure 3.13. Total annual catch of Australian herring taken by seine/haul nets and total seine/haul net effort in the Geographe Bay/Bunbury area (CAES blocks 3315, 33151, 9601), November–April only, 1980/81–2009/10 (effort relates to landings of all species by all vessels).

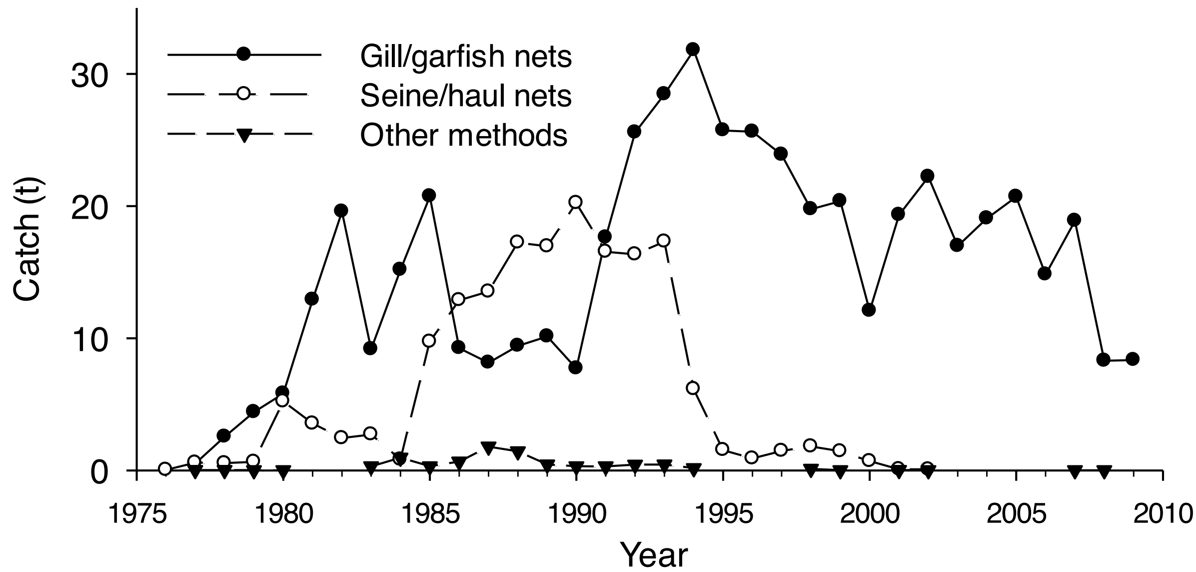


Figure 3.14. Total annual commercial catch of Australian herring in Cockburn Sound (CAES block 9600) by method, 1976 – 2009.

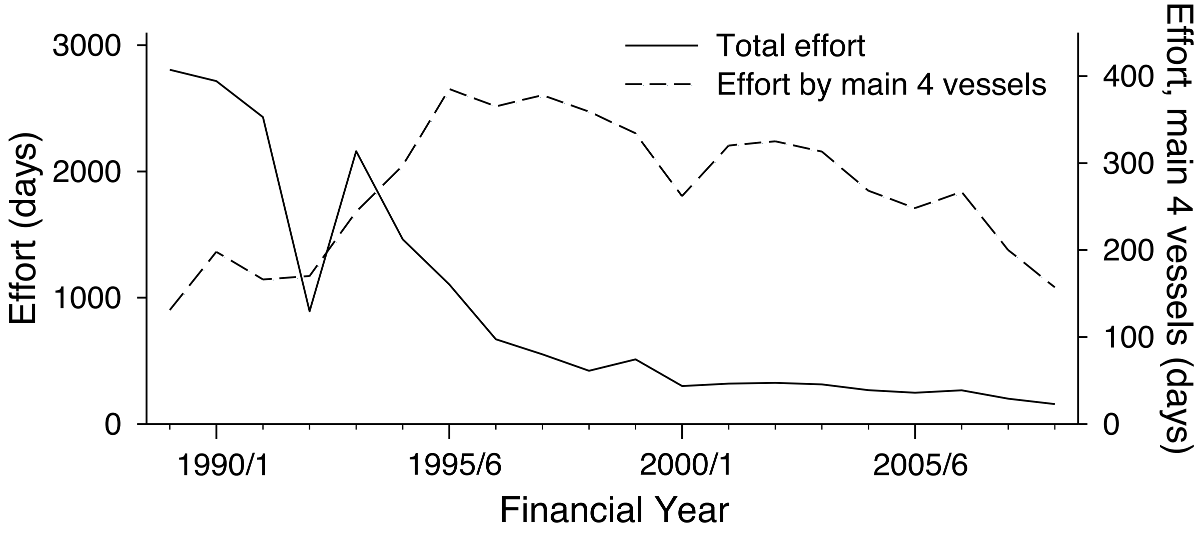


Figure 3.15. Total annual gill/garfish netting effort (all vessels) and annual gill/garfish netting effort by main 4 vessels capturing Australian herring in Cockburn Sound (CAES block 9600), 1989/90 to 2008/09.

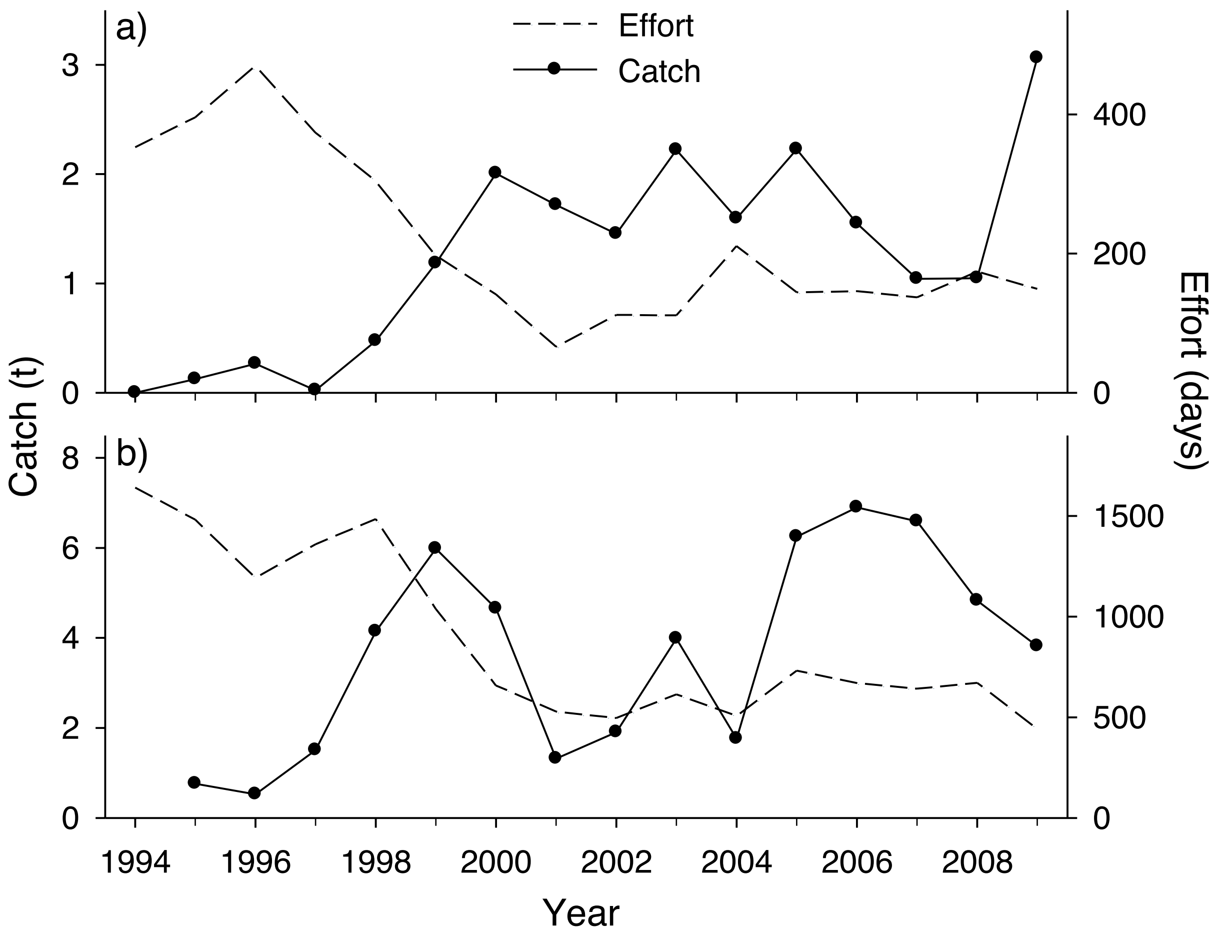


Figure 3.16. Total annual catch of Australian herring and effort by **a)** gill nets (Jul–Sept only) and **b)** by haul/seine nets (all months) in the Peel-Harvey Estuary, 1994 to 2009 (effort relates to landings of all species by all vessels).

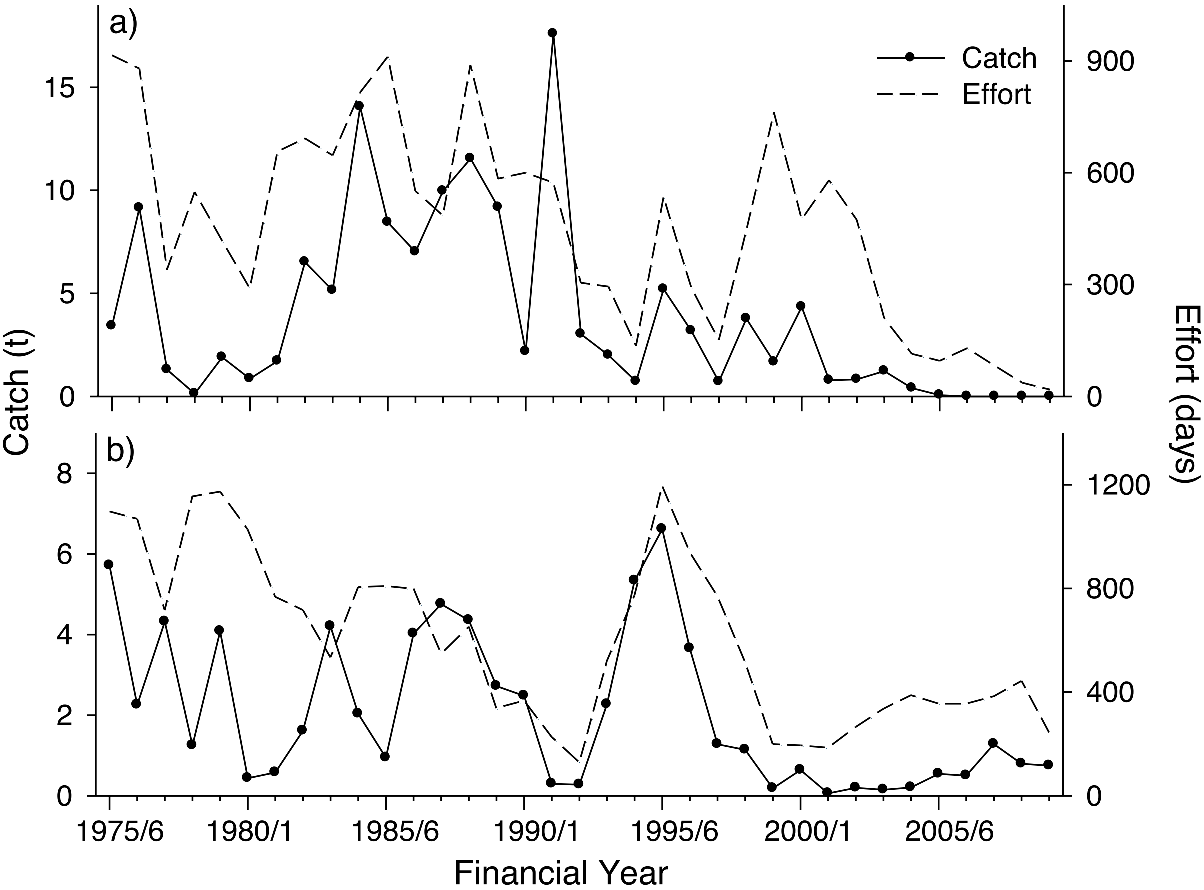


Figure 3.17. Total catch of Australian herring and total effort by haul/seine nets **a)** in CAES block 3215 (Mandurah/south metropolitan) December–April only, and **b)** in waters of the West Coast Bioregion north of Perth (latitudes ≥28° to <32°), 1975/76 to 2009/10.

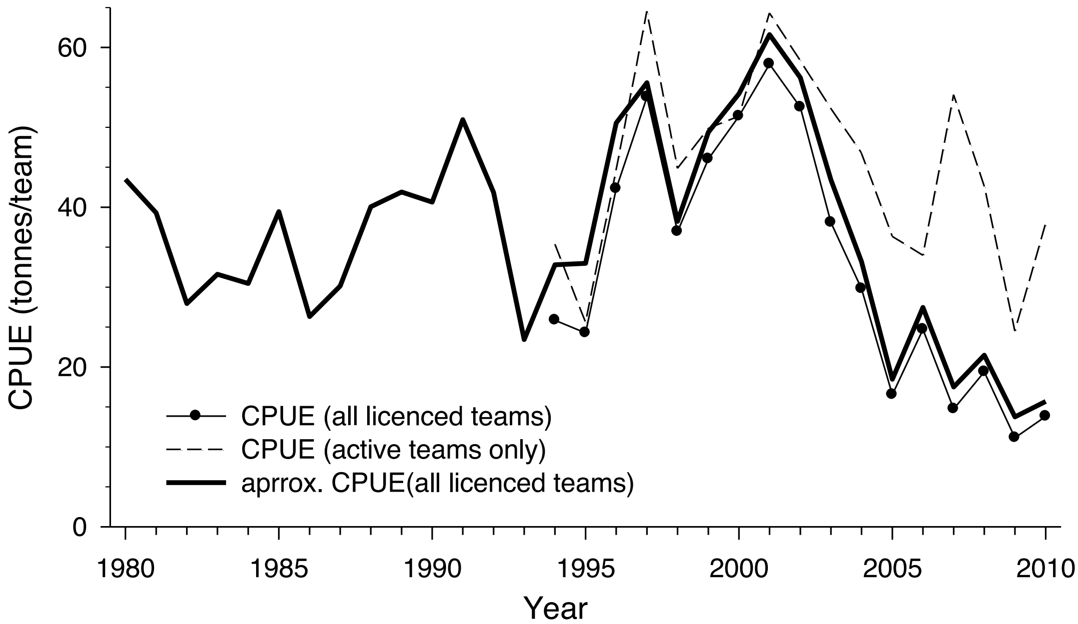


Figure 3.18. Average annual catch rate (CPUE) of all licensed teams and mean annual catch rate of active teams in the South Coast trap net fishery, 1994 to 2010. Approximate average annual catch rate of all licensed teams in the South Coast trap net fishery, 1980 to 2010, using South Coast total annual catch as a proxy for trap net catch.

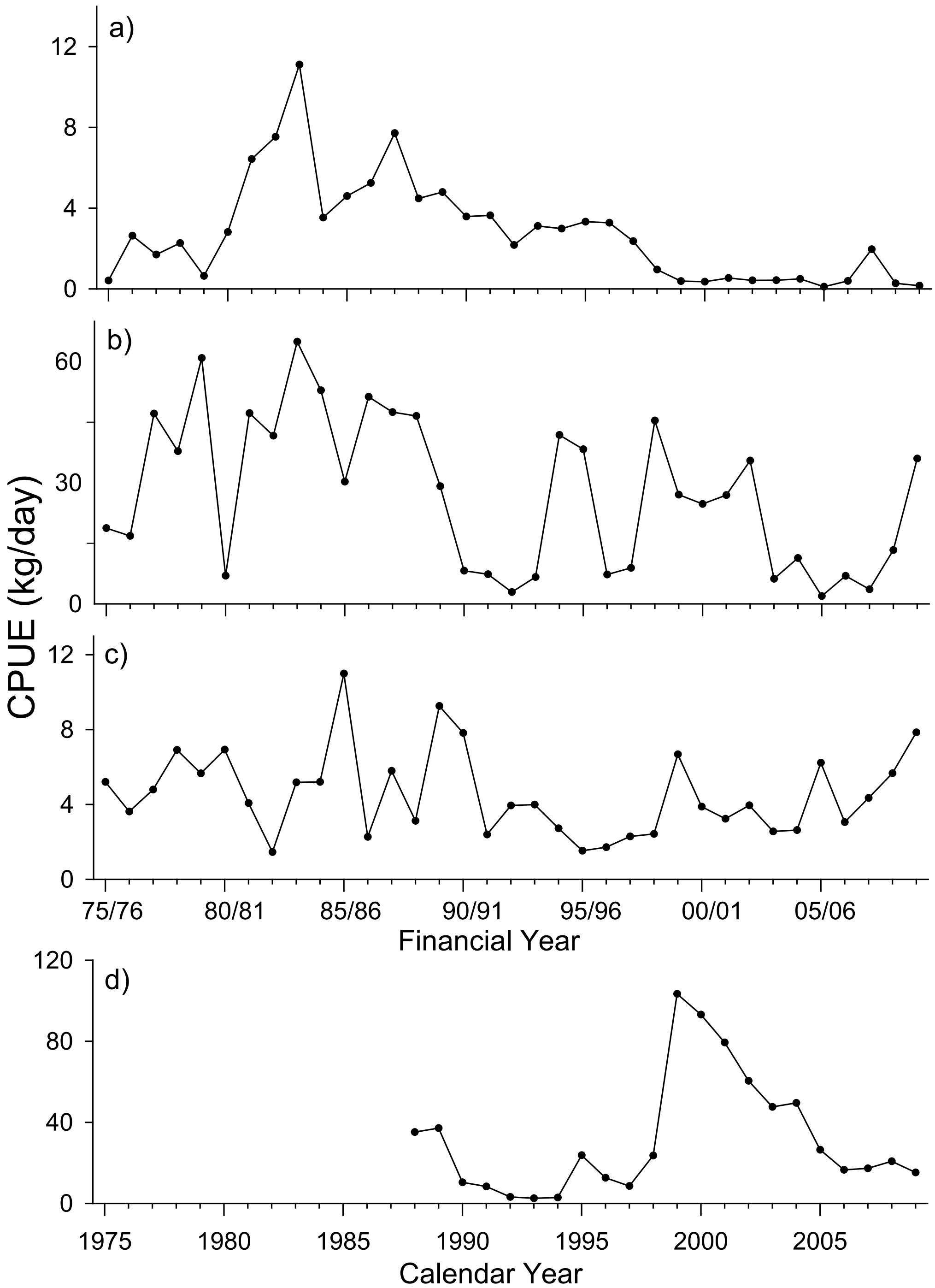


Figure 3.19. Average annual catch rate (CPUE) of Australian herring by **a)** gill netting in Oyster Harbour 1975/76–2009/10 **b)** haul and/or seine netting in Oyster Harbour 1975/76–2009/10, **c)** gill netting in Wilson Inlet (October–May only) 1975/76–2009/10, and **d)** gill netting in Broke Inlet (May–October only) 1988–2009.

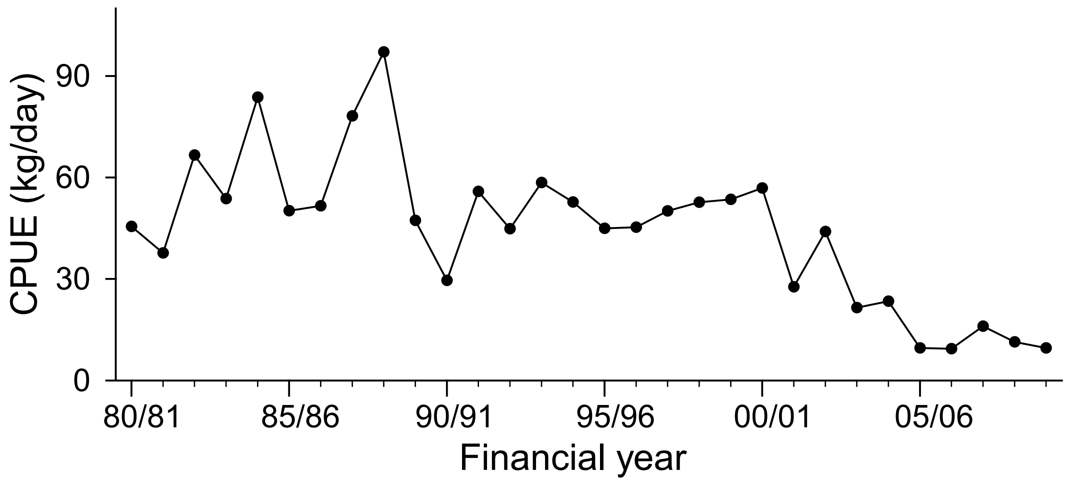


Figure 3.20. Average annual catch rate (CPUE) of Australian herring taken by seine/haul nets in the Geographe Bay/Bunbury area (CAES blocks 3315, 33151, 9601), November–April only, 1980/81–2009/10.

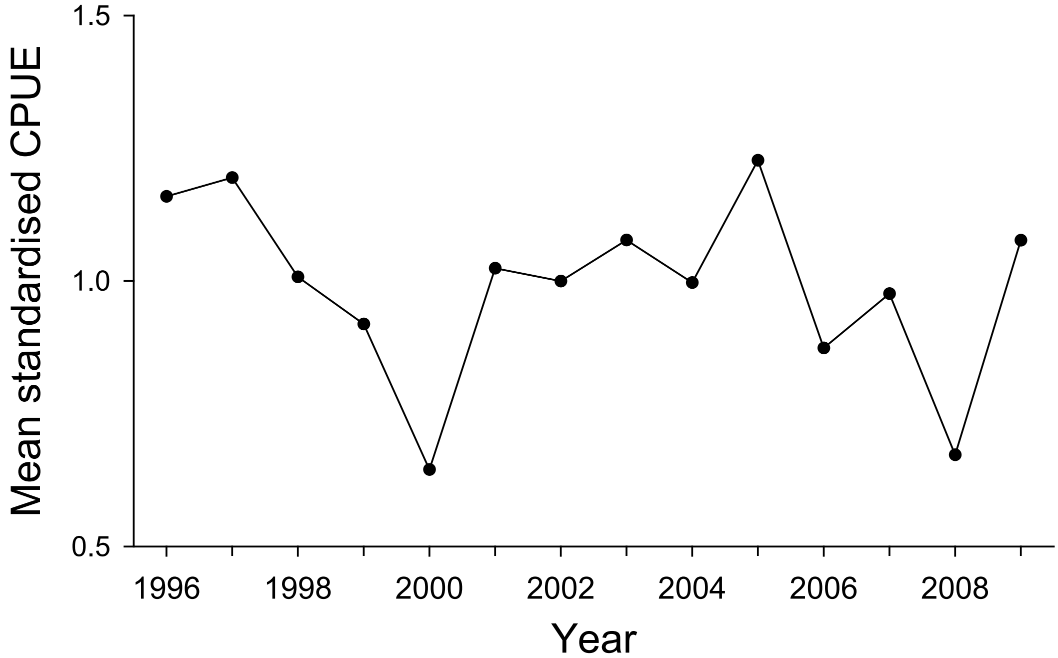


Figure 3.21. Average annual standardised catch rate (CPUE) of Australian herring by gill/garfish netting by the 4 main vessels capturing Australian herring in Cockburn Sound (CAES block 9600), 1996–2009. Note: y-axes do not start at zero.

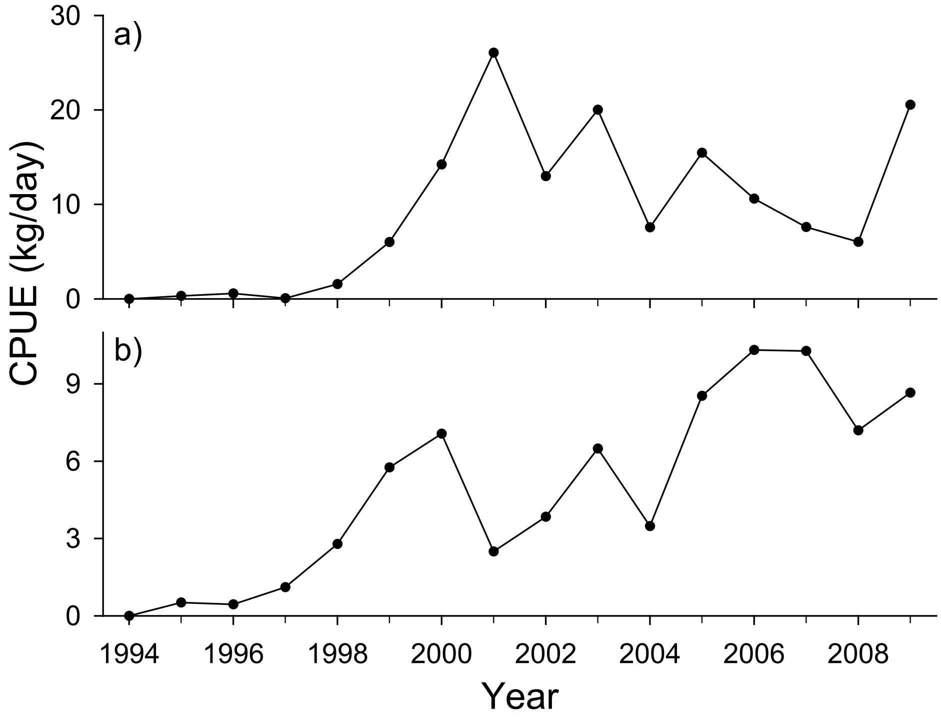


Figure 3.22. Average annual catch rate (CPUE) of Australian herring by **a)** gill nets (Jul–Sept only) and **b)** by haul/seine nets (all months) in the Peel-Harvey Estuary, 1994 to 2009.

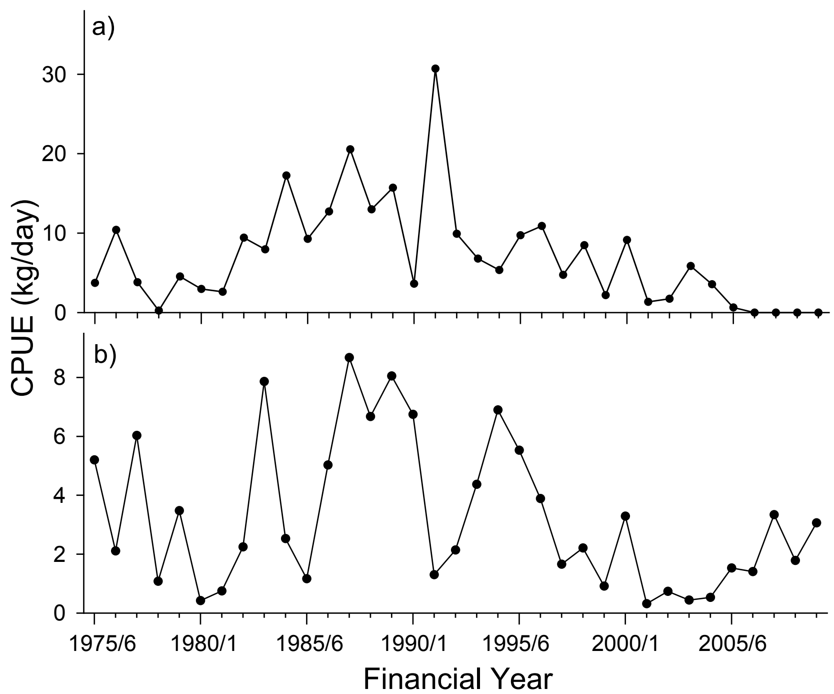


Figure 3.23. Average annual catch rate (CPUE) of Australian herring by haul/seine nets in **a)** CAES block 3215 (Mandurah/south metropolitan) (Dec–Apr only) and **b)** waters of the West Coast Bioregion north of Perth (latitudes ≥28º to <32º), 1975/76 to 2009/10.

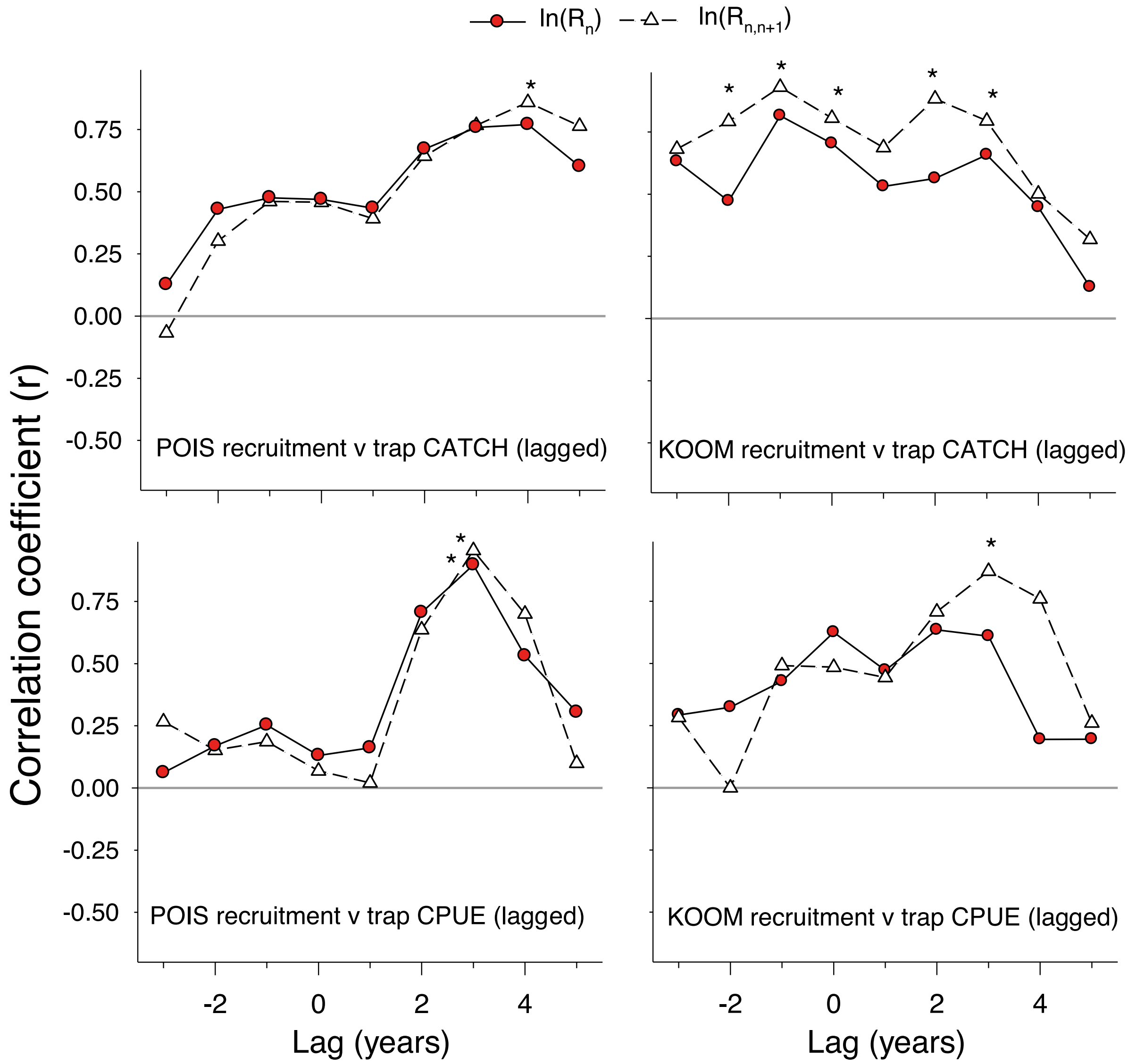


Figure 3.24. Correlation coefficients of Australian herring annual recruitment indices ($\ln(R_n)$ and $\ln(R_{n,n+1})$), at Poison Creek (POIS) and Koombana Bay (KOOM) versus annual catch and annual CPUE (t/active team) by the commercial trap net fishery. Catch and CPUE lagged by –3 to +5 years. Recruitment indices based on natural logarithm transformed catch rates of 0+ Australian herring. (*correlation significant at p<0.01) (negative r value indicates negative correlation)

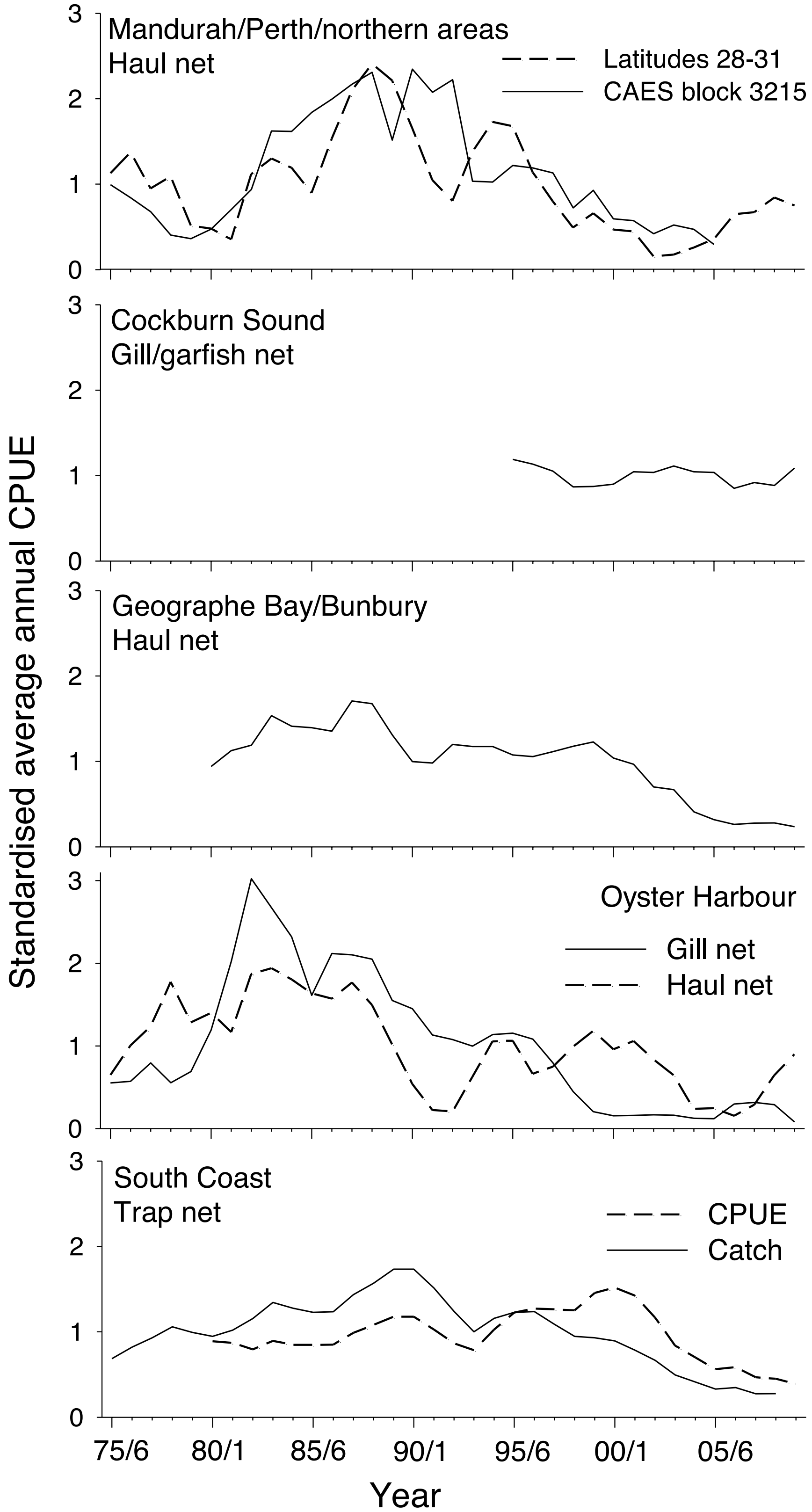


Figure 3.25. Summary of commercial fishery catch rates of Australian herring abundance. Standardised and smoothed (3-point moving average) average annual CPUE of Australian herring by selected commercial fisheries in the West Coast Bioregion and South Coast Bioregion, 1975/76 to 2009/10. Total annual catch (3-point moving average) by the South Coast trap net fishery is also shown.

4.0 Australian herring recreational fishery catch and effort trends

Summary

- A precise estimate of the total recreational catch, or catch share, in Western Australia (WA) is not available due to the lack of recent catch estimates for the shore-based fishery. Limited available data suggests current recreational landings of Australian herring are approximately 100–150 t in the West Coast Bioregion (WCB) and 30–70 t in the South Coast Bioregion (SCB) per year. At these levels, the total recreational catch was approximately equal to the total commercial catch in WA in recent years.
- Shore-based fishers in the WCB are estimated to take the largest share (about 50%) of the total WA recreational catch of Australian herring. WCB boat-based fishers take the next largest share (25–30%).
- Within the WCB, Australian herring comprise about 65% of all finfish retained by shore-based recreational fishers and 25–30% of finfish retained by boat-based fishers. Approximately 10–12% of all Australian herring caught by recreational fishers in the WCB are released.
- In the WCB, the recreational catch rate of Australian herring peaks in autumn. However, the total recreational catch probably peaks in summer, or is equally high in summer and autumn, in response to peaks in effort levels.
- Historical trends in recreational catch rates, from various independent sources, suggest that Australian herring abundance in the WCB increased between the mid-1970s and mid-1980s, declined steadily until the late 1990s and then followed a stable or slightly increasing trend until 2011. The catch rates of some commercial fisheries in the Metropolitan and Mid-west Zones of the WCB also suggest a slight increase in Australian herring abundance since 2000.
- Despite the recent increase, catch rates suggest that the abundance of Australian herring in the WCB in recent years was still very low relative to the abundance during the 1980s.
- The catch rate of adult Australian herring in the WCB is essentially an index of spawning stock biomass and, as such, provides important information for assessing stock status. In the foreseeable future, catch rates of Australian herring in the WCB are likely to be available only from voluntary logbooks and surveys of boat-based recreational fishing.
- The majority of Australian herring caught in the WCB are taken recreationally, and predominantly by shore-based fishers. Regular surveys of WCB shore-based fishers that provided robust estimates of catch and catch rate would provide valuable information for the effective management of this sector. Catch rates from shore-based surveys would also provide an index of spawning stock biomass. However, a better sampling frame needs to be developed to make shore-based surveys cost-effective.
- Relationships between recruitment and fishery catch rates suggest that the WCB recreational fishery probably comprises a mixture of recruits from the west coast and south coast regions.

4.1 Introduction

In Western Australia (WA), Australian herring (*Arripis georgianus*) is the most common finfish species retained by recreational fishers (Henry and Lyle 2003). Australian herring is also commonly caught by recreational fishers in South Australia (SA) and occasionally by recreational fishers in

Victoria. Australian herring is targeted by shore- and boat-based recreational fishers in coastal and estuarine waters. Due to its accessibility and ease of capture, Australian herring is a very popular target species, especially with shore-based fishers, and has high social value in WA.

Despite the popularity of Australian herring in WA, estimates of recreational catches or catch rates are very limited. The only state-wide survey of recreational fishing in WA was conducted in 2000/01 (Henry and Lyle 2003). Most previous recreational fishing surveys in WA have been spatially or temporally limited and were not designed to estimate the state-wide Australian herring catch (but see Lenanton and Hall 1976, Ayvazian *et al.* 1997). Surveys in WA have also been too infrequent to provide information about long-term trends in the catch or catch rate of Australian herring, making it difficult to assess the status of the recreational fishery.

Shore-based recreational fishers in the WCB are believed to take the largest single share of the recreational catch of Australian herring. However, despite high levels of shore-based catch and effort and the very high social value of this fishery, relatively little quantitative information about this sector exists. Few surveys of shore-based recreational fishing have been undertaken in WA (but see Lenanton and Hall 1976, Ayvazian *et al.* 1997, Smallwood *et al.* 2011). Therefore, the largest share of the recreational Australian herring catch and the associated effort levels are currently unquantified. Furthermore, trends in the annual catch rate and catch composition of Australian herring taken by shore-based fishers and the characteristics of these fishers are unknown. A lack of information about virtually all aspects of the shore-based recreational catch makes it difficult to develop appropriate monitoring and effective management programs for Australian herring.

The need for more information on shore-based fishing prompted a recent pilot study to investigate methods of estimating shore-based catch and effort in the WCB (Smallwood *et al.* 2011). Since phone/diary surveys of shore-based fishing in the WCB are currently not cost-effective due to the lack of a known sampling frame (e.g. there is no shore-based recreational fishing licence or licence-holder database), the pilot study focused on field-based techniques (angler interviews, aerial surveys, remote cameras) to estimate catch and/or effort. The 3-month study, which was restricted to the Perth metropolitan area, highlighted the challenges of surveying shore-based fishers in the WCB, including surveying large numbers of fishers at a large number of locations, often with limited access. This study concluded that obtaining annual estimates of shore-based catch and effort at a bioregion-wide level with acceptable levels of confidence would be costly.

Given the relatively high recreational catch of Australian herring and its potential impact on the sustainability of the stock, there is an urgent need for a better understanding of this fishery, especially in the WCB. Data from the recreational sector, in conjunction with fishery-independent studies and data from the commercial sector, is required to assess the current status of the Australian herring stock and formulate effective future management of each sector. Due to the high cost, future surveys of shore-based recreational fishing in the WCB are likely to be conducted infrequently. Therefore, a range of other potential sources of information such as surveys of boat-based recreational fishing, voluntary recreational logbooks and historical records from fishing clubs should be investigated to supplement the infrequent data from shore-based surveys. Hence, the aims of this section are to:

- Collate available estimates of recreational catch and catch rate of Australian herring, including unpublished data from previous WA Department of Fisheries surveys.
- Describe the distribution of the recreational Australian herring catch and effort in the WCB.
- Estimate the proportion of Australian herring released by recreational fishers.

- Examine annual trends in recreational catch rates for evidence of historical changes in Australian herring availability in the WCB.
- Describe the relationships between Australian herring annual recruitment and fishery catch rates.

4.2 Methods

4.2.1 West Coast Bioregion boat-based fishing surveys

Survey of boat-based recreational fishing catch and effort in the WCB were conducted by the WA Department of Fisheries (DoF) in 1996/97, 2005/06, 2008/09 and 2009/10. Boat-based fishers were interviewed at various boat ramps between Kalbarri and Augusta. Catch information was obtained using the bus route method between ramps within districts, with complete trip information obtained at the time of the interview. Estimates of total catch and effort in the Bioregion were calculated using weightings derived from the distribution of effort observed in the survey. For more information on the survey design and the methods used to estimate the mean (and variance) of catch and effort in WCB boat-based recreational fishing surveys see Sumner *et al.* (2008).

The effort spent specifically targeting Australian herring during these surveys cannot be accurately determined because only the total number of boating hours per boat was estimated during each survey. Total boating time included time spent travelling and time spent fishing at all locations during a trip (including offshore locations where herring was not targeted). Therefore, the total number of boating hours is only an approximate measure of boat-based fishing effort spent targeting Australian herring during each survey. In addition, the total number of boating hours provides an unstandardised measure of fishing effort, i.e. effort was not adjusted to account for any differences between surveys in fishing efficiency due to technological improvements or any increases in targeting of Australian herring.

The unstandardised average annual catch-per-unit-effort (CPUE) of Australian herring by boat-based fishers in the WCB was calculated as $CPUE = C/E$, where

C = *total annual catch of Australian herring by boat-based fishers*

E = *total annual number of boating hours.*

To examine seasonal trends in Australian herring availability, the average monthly catch rate of Australian herring by boat-based fishers in ocean waters of the WCB was calculated for each month in 2008/09 and 2009/10 as $CPUE_{month} = C_{month}/E_{month}$, where

C_{month} = *total monthly catch of Australian herring taken by boat-based fishers*

E_{month} = *total monthly number of boating hours.*

Catch included retained fish only. Effort included all line fishing effort by boat-based fishers in ocean waters (effort within estuaries and effort by other methods was excluded).

4.2.2 Individual angler diaries

Although potentially non-representative of the general recreational fishery, the catch rates reported by individual diary anglers and fishing clubs are the only available long-term series of recreational catch rates of Australian herring and trends may provide useful information.

Personal diaries containing long-term catch and effort data were donated to the DoF by three individual recreational anglers. Australian herring was among the most common species caught by each fisher. Catch was reported as number of fish. Only retained catches were recorded (i.e. released fish not recorded). Lengths of fish were not recorded. The effort data reported by each angler is summarised below:

Angler 1 (Busselton): Undertook shore-based fishing at various beaches in Busselton area from 1981/82–2009/10. Typically fished 1–5 days per month from October to April. No fishing was undertaken May–September each year. Effort was reported in hours. Each fishing session was typically 2 hours duration. A single session occurred per day. Low annual effort was reported from 1986/87 to 1993/94.

Angler 2 (Perth): Undertook shore-based fishing at various beaches in the Perth area and sites at the mouth of the Swan-Canning Estuary from 1977/78 to 2005/06. Fishing effort tended to occur on beaches during summer and at the estuary mouth in winter. Data from all sites were pooled after inspection of catch rate trends suggested no significant difference in annual trends. Effort was reported as number of fishing days. The number of hours fished per day was not recorded. Low annual effort was recorded from 1987/88 to 1995/96.

Angler 3 (Geraldton): Undertook shore-based fishing at various beaches in the Geraldton area from 1976/77 to 2007/08. Lower catch and effort levels were experienced in the last few years, which could reflect his declining health (died in 2010). Effort was reported in hours. Fishing sessions were of variable duration. Typically a single session occurred per day. No effort was recorded from 1986/87 to 1994/95. Annual fishing effort was distributed relatively evenly among all months within each year.

Initially, catch and effort data reported by each angler were aggregated by season and year, due to evidence of seasonal differences in the recreational catch rate of Australian herring within the WCB. However, for Angler 2 and Angler 3, the seasonal catch rates were of similar magnitude within each year and followed similar annual trends. Therefore, catch and effort data for these Anglers were aggregated by year.

Catch and effort data reported by Angler 1 suggested two distinct periods of activity: October–December and January–April. There were strong differences in the magnitude of the average monthly catch rate between these periods. Average CPUE during January–April was nearly twice that during October–December. However, since both catch rates followed a similar annual trend and data from both periods were represented each year, data for Angler 1 were also aggregated by year.

For each angler, an average annual catch rate of Australian herring (CPUE) was calculated as CPUE = C/E, where:

C = total annual catch of Australian herring.

E = total annual fishing effort.

For each angler, CPUE was not calculated for a particular year if E was <20 hours (Angler 1 and 3) or <10 days (Angler 2). Fishing effort was not adjusted to account for any differences between years in fishing efficiency.

4.2.3 Melville Amateur Angling Club

The Melville Amateur Angling Club (MAAC) runs two shore-based fishing competitions – estuary and ocean. Estuary fishing occurs within the Swan-Canning Estuary. Ocean fishing occurs at various locations in the WCB and in the western part of the SCB. The majority of ocean effort to date has occurred in the WCB.

Monthly catch and effort records from the estuary competition have been kept by this club since 1986/87 and are ongoing. Monthly catch and effort records from the ocean competition have been kept by the MAAC since the 1970s and are ongoing.

Each of the above competitions typically fished one weekend per month throughout the year. Estuary fishing did not occur in December. Weekend fishing events (referred to by the club as 'trips' or 'field days') were typically of a standard duration (~24 hours). The duration of weekend fishing events has remained constant throughout the history of the club. Hence, the number of participating fishers provided a measure of fishing effort in 'fisher days'. Recorded information included i) the number of individuals of each species presented at the monthly competitive 'weigh-in' (released fish were not recorded), ii) the number of fishers participating in each event, and iii) the location of the event.

Although the MAAC scoring system provides an incentive to retain all sizes of fish (points are awarded for number of fish and diversity of species caught, as well as weight of fish), some 'high-grading' of catch may still occur to maximise competition points within allowable bag limits, particularly in the estuary competition where limits are relatively low. Therefore, recorded catches may underestimate the actual catch rate.

The MAAC has self-imposed, bag limits for individual species that are more conservative that the legal limits. The MAAC bag limits are applied per trip and throughout the history of the club have typically been lower than the contemporary legal daily bag limit. In 1991/92, the estuary competition adopted a new bag limit of 3 Australian herring per fisher per day. Prior to this the bag limit was 2 Australian herring per fisher per day. Due to this change, estuary catch rates were calculated from 1991/92 onwards.

Initial inspection of data indicated no significant differences in estuary catch rates of Australian herring between seasons. Fisher attendance levels were usually similar throughout the year (slightly higher in warmer months). Therefore, catch and effort data for the MAAC estuary competition were aggregated by year. The average annual catch rate of Australian herring (CPUE) was calculated as CPUE = C/E, where:

C = total annual catch of Australian herring.

E = total annual fishing effort.

Fishing effort was not adjusted to account for any differences between years in fishing efficiency.

Trends in the ocean catch rate of Australian herring were previously analysed by Pember (2009) and his results are reproduced in this report.

4.2.4 Voluntary recreational logbooks

A voluntary recreational fisher logbook program (part of the DoF Research Angler Program (RAP)) commenced in 2005/06 and is ongoing. Recreational fishers were asked to record fishing date, location, start and finish times of each fishing session, captured species, whether fish were retained or released and the total length (TL) of each fish to the nearest millimetre. Australian herring are easily identified by recreational fishers. Therefore, mis-identification of Australian herring by logbook fishers was assumed to be negligible.

Monthly catch rates of Australian herring were calculated only for shore-based logbook fishers in the Perth area because i) shore-based fishers in Perth are believed to take the largest share of the total WCB recreational Australian herring catch and ii) catch and effort data was available from these logbook fishers for all months. Catch rates were not calculated for boat-based fishers or non-Perth shore-based fishers due to low levels of monthly catch data.

For the purpose of this analysis, the 'Perth area' was defined as logbook reporting blocks BN56-BN64, BO56-B064, BP56-BP64, BQ56-BQ64 and BR56-BR64 (Fig. 4.1). Shore-based catch and effort at Rottnest Island was excluded.

The average monthly catch rate ($CPUE_{month}$) of Australian herring by shore-based logbook fishers operating in ocean waters of the Perth area was calculated from July 2005 until June 2011. $CPUE_{month} = C_{month} / E_{month}$, where

C_{month} = total monthly catch of Australian herring taken by shore-based fishers, including retained and released fish.

E_{month} = total monthly number of hours fished by all shore-based fishers, including fishing trips resulting in non-Australian herring catches and nil catch.

To examine annual trends in logbook data, monthly values of C_{month} , E_{month} and $CPUE_{month}$ within each year were averaged to generate an annual mean catch, effort and catch rate. This method of calculation was used to ensure equal weighting of data from each month. If CPUE had been derived from the total annual catch (C) and total annual effort (E), i.e. CPUE = C/E, then the highly variable amounts of effort between months would have biased the annual average CPUE, given the evidence of monthly variations in catch rate.

To examine monthly trends in logbook data, values of C_{month} , E_{month} and $CPUE_{month}$ within each year were first standardised (divided by the mean value for that year) to remove any effect of annual variation. The average standardised value was then calculated for each month.

The annual and monthly logbook CPUE described above included all shore-based fishers in the Perth area, irrespective of effort level. To examine the effect of changes in skill level due to changes in the individual fishers participating in the logbook program from year to year, an average annual catch rate was calculated for only those fishers who participated in all years from 2005/06 to 2010/11. Only 4 shore-based fishers in the Perth area participated over this entire period. These 'avid' individuals expended effort in nearly every month of this period. The average catch rate (CPUE) of Australian herring by each of these fishers was calculated for each year. CPUE = C /E , where

C = total annual catch of Australian herring, including retained and released fish.

E = total annual number of hours fished, including fishing trips resulting in non-Australian herring catches and nil catch.

To examine average annual trends, the annual CPUEs of each fisher were first standardised (divided by the mean value for all years). The average standardised value was then calculated for each year.

4.2.5 Voluntary Fisheries Liason Officer surveys

From 1995 to 2007, on-site interviews with shore-based recreational fishers were conducted by Voluntary Fisheries Liaison Officers (VFLOs), which were co-ordinated by the Department of Fisheries (Smallwood *et al.* 2010). The majority of interviews each year were conducted in the WCB, and predominantly in the Perth and Mandurah areas. During interviews, recreational fishers were asked to quantify their catch (species, number kept, number released) and effort (number of fishers, number of hours fished, time of day, location, gear type, etc).

Australian herring was the most common finfish species reported during VFLO interviews of shore-based fishers. The average annual shore-based catch rate (number of fish/fisher/hour) of herring caught by line fishing (rods or handlines) in the WCB was calculated from survey data. The catch included retained and released fish. For full details of the survey design and the methods used to estimate catch rates from VFLO survey data see Smallwood *et al.* (2010).

4.2.6 Recruitment

To investigate relationships between annual recruitment and fishery catch rates, recruitment indices at sites Poison Creek (SCB) and Koombana Bay (WCB) (see Section 2) were correlated against the average annual catch rate of shore-based recreational fishers in the southern WCB and at Geraldton (mid-west WCB). Fishery catch rates were lagged from –3 to +5 years.

Catch rates of 0+ Australian herring were consistently higher at Poison Creek and Koombana Bay compared to the other sites where recruits were sampled and so were considered to provide the most robust indices of annual recruitment.

The following four versions of the annual recruitment index at each site were correlated against CPUE:

R_n , recruitment index in year *n*,

$\ln(R_n +1)$, natural logarithm transformed value of recruitment index in year *n*, and

$R_{n,n+1}$, average of recruitment index in year *n* and *n+1* (i.e. a 2-point moving average),

$\ln(R_{n,n+1})$, average of natural logarithm transformed recruitment index in year *n* and *n+1* (i.e. a 2-point moving average).

The 2-year recruitment indices ($R_{n,n+1}$) and $\ln(R_{n,n+1})$ were intended to reflect the composition of recreational fishery landings, which are frequently dominated by two consecutive year classes.

The recruitment indices that resulted in the highest correlation coefficients were plotted.

4.3 Results

4.3.1 Previous recreational fishing surveys

The following is a summary of all recreational fishing surveys that have yielded estimates of recreational landings of Australian herring at local, regional or state level in WA:

- A recreational Australian herring fishery (creel) survey was conducted along the Perth coast and around Rottnest Island in April, May and June of 1973 (Lenanton and Hall 1976). An estimated 711,000 individual Australian herring were taken by recreational fishers in the survey area during this period. This study concluded that the recreational catch was at least equal to, and probably greater than, the commercial catch within the Perth metropolitan area. The surveyed area and period (i.e. Perth area, April–June) was believed to encompass the majority of Australian herring fishing at the time. Therefore, the catch is taken to approximately represent the ocean catch of Australian herring in the WCB in 1973.
- A recreational fishing survey was conducted from May 1974 to April 1975 in the Blackwood River Estuary (Caputi 1976). The survey area encompassed the Hardy Inlet and Blackwood River up to Alexandra Bridge, including Swan Lake and Deadwater. Australian herring was the major species caught in the Hardy Inlet and Swan Lake region during the autumn months. A total of 67,900 Australian herring was estimated to have been taken by recreational fishers during the 12-month survey period.

- A survey of shore-based recreational fishing at Rottnest Island was conducted from January to December 2003 (Smallwood et al. 2006). An estimated 42,085 (7.3 t) of Australian herring was retained during this survey.
- 12-month surveys of recreational fishing in the three most popular WCB estuaries were conducted in 1998 (Leschenault Inlet) and 1998/99 (Swan-Canning and Peel-Harvey estuaries) (Malseed et al. 2000, Malseed and Sumner 2001a, 2001b). The estimated number of Australian herring caught during each survey was 47,540 (Peel-Harvey), 1,674 (Swan-Canning) and 822 (Leschenault). However, the main aim of these surveys was to determine recreational landings of blue swimmer crabs and so these surveys may have substantially underestimated finfish catches.
- A recreational fishing survey was conducted from January 1994 to June 1996 to determine the catch levels of Australian herring and western Australian salmon (A. truttaceus) in the WCB and SCB (Ayvazian et al. 1997). Shore- and boat-based fishers were surveyed (excluding estuaries). In the WCB, an estimated 1,268,000 and 1,061,600 individual Australian herring* were caught in 1994 and 1995, respectively. In the SCB an estimated 707,200 and 356,000 individuals, respectively, were retained. (*the total catch (kept and released) was estimated by this part of the survey).
- 12-month surveys of boat- and shore-based recreational fishing in Cockburn Sound and Owen Anchorage were conducted in 1996/97 and in 2001/02 (Sumner and Malseed 2004). However, the main aim of these surveys was to determine recreational landings of blue swimmer crabs and so finfish catches may have been underestimated.
- The National Recreational and Indigenous Fishing Survey (phone diary survey) was conducted in 2000/01 (Henry and Lyle 2003). In this survey, Australian herring was the finfish species most commonly retained by WA recreational fishers. Australian herring were estimated to have comprised 46% and 43% of all finfish retained in the WCB and SCB, respectively. An estimated 3,244,732 individual Australian herring were retained in the WCB and 624,812 in the SCB during the survey.
- A survey of the most popular recreational fishing estuaries (n=17) in the SCB was conducted from December 2002 to November 2003. (Smallwood and Sumner 2007). Australian herring was among the ten most popular retained species in SCB estuaries in the survey period. Australian herring was mainly caught in estuaries permanently open to the sea. An estimated 32,930 individual Australian herring were retained during the survey
- 12-month surveys of boat-based fishing in the WCB were conducted in 1996/97, 2005/06, 2008/09 and 2009/10 (Sumner and Williamson 1999, Sumner et al. 2008, DoF unpubl. data). An estimated 319,355, 276,824, 261,969 and 272,924 individual Australian herring were retained during each survey, respectively. These surveys used similar methods and so the catch estimates are comparable among surveys. A survey of boat-based fishing in the Perth area was also conducted in 2007/08.
- A 12-month survey of recreational fishing in SA was conducted in 2007/08 (Jones 2009). In this survey, Australian herring was the third most commonly captured and retained finfish species. An estimated 865,864 individual Australian herring were captured in SA during the survey. Approximately 31% of these individuals were released.
- A pilot study was conducted during April–June 2010 to examine the relative benefits of different survey techniques for measuring shore-based recreational fishing catch and effort in the Perth area (Smallwood et al. 2011). From April–June 2010, an estimated 211,447 Australian herring were kept and 25,858 released by shore-based fishers in the Perth area.

4.3.2 Total catch

Western Australia

To date, the 2000/01 National Recreational and Indigenous Fishing Survey has been the only state-wide survey of Australian herring conducted in WA (Henry and Lyle 2003). Results of this survey provide the only basis for 'scaling up' catch estimates from other more spatially limited surveys to Bioregion or state level. In other years when surveys were conducted, the total catch in each Bioregion was calculated by applying the catch proportions from the National Survey to the partial catch estimates from shore-based and/or boat-based creel surveys in those years.

In 2000/01, an estimated 84% of the WA retained recreational catch (number of fish) of Australian herring was taken in the WCB and 16% in the SCB (Table 4.1). This is believed to approximately represent the spatial distribution of the catch in all years. Occasional catches are also taken in the Gascoyne Coast Bioregion (GCB). In 2000/01, shore-based ocean fishers in the WCB caught an estimated 49% of the total WA recreational Australian herring catch (51% of the WCB catch). Boat-based fishers in the WCB caught an estimated 27% of the total WA catch (33% of the WCB catch). Estuary fishers (boat and shore) caught the remainder.

Catch estimates derived from various surveys suggest that the total recreational catch of Australian herring (number of individuals) in the WCB has been relatively constant since 1973, ranging from approximately 799,000 to 1,268,000 fish (Fig. 4.2). The exception was in 2000/01 when total catch was estimated to be approximately 3,245,000. A limited number of surveys suggested that the total number of Australian herring retained in the SCB is substantially less than that retained in the WCB. Estimates of total annual retained Australian herring catch in the SCB range from 296,000 to 625,000 fish (Fig. 4.2).

The conversion of total Australian herring catch (number of fish) to total weight is problematic. The average weight per fish that was assigned to Australian herring during previous recreational fishing surveys ranged from 70 g to 200 g. In most cases, the size distribution of Australian herring during the survey was not documented and/or not rigorously sampled and so the catch weights are uncertain. Size composition data from the voluntary recreational daily logbook suggest an average weight of 126 g per fish caught in ocean waters (and 153 g per fish in estuaries) (Appendix 1, DoF unpubl. data), which is similar to the average weight of 125 g suggested by Ayvazian *et al.* (1997). Assuming 125 g per fish, the total WCB recreational catch weight estimated by each survey was 100–150 t per year, except for 2000/01 when the estimated catch was approximately 400 t. The total SCB recreational catch level was estimated to be 30–70 t per year.

The WCB catch level estimated by the 2000/01 national phone survey was substantially higher than that estimated by other surveys. It is unclear to what extent this difference is an artefact of differences in survey methodology (phone v. on-site survey). Problems with this methodology have been identified (Lyle *et al.* 2010). All other surveys conducted between 1994/95 and 2009/10 yielded relatively similar, and much lower, estimates of total WCB catch, suggesting that the 2000/01 national survey did overestimate the catch to some extent. A pronounced peak in the catch rate of Australian herring was reported in 2000/01 by various recreational fishers (see elsewhere in this Section) and so there may have been a relatively high abundance of Australian herring in 2000/01.

The WCB boat-based surveys provide the most comparable series of data. These four surveys yielded similar estimates of total retained Australian herring catch in 1996/97, 2005/06, 2008/09 and 2009/10, suggesting a relatively stable boat-based catch level (Fig. 4.3).

Within the WCB, about 65% of shore-based catches and 80% of boat-based catches of Australian herring are taken in the Metropolitan Zone (Table 4.2).

South Australia and Victoria

In 2000/01, an estimated 2,535,404 Australian herring (= 253 t, assuming 100 g per fish) were retained by recreational fishers in SA (Henry and Lyle 2003, Jones 2009) (Fig. 4.2). A further 745,063 Australian herring (i.e. 23% of total catch) were estimated to have been released.

In 2007/08, an estimated 598,774 Australian herring (= 93 t, assuming 155 g per fish) were retained by recreational fishers in SA (Jones 2009) (Fig. 4.2). A further 267,090 Australian herring (i.e. 31% of total catch) were estimated to have been released.

Australian herring was the most commonly retained finfish species in the SA recreational catch in 2000/01 and the 3rd most commonly retained finfish species in the SA recreational catch in 2007/08.

In Victoria, an estimated 11,354 Australian herring were retained by recreational fishers in 2000/01 (Henry and Lyle 2003). Release rates are likely to be similar to those in SA.

4.3.3 Catch Rates

Recreational fishing methods for Australian herring have changed little since the 1970s, when the earliest estimates of recreational catch and effort became available. Australian herring is caught by recreational fishers using baited hook and line methods, including rods and handlines. Since Australian herring are primarily caught in shallow coastal waters and often from the shore, technological advancements (e.g. GPS, depth sounders) which have increased efficiency in other fisheries are unlikely to have impacted on the catchability of Australian herring. Therefore, catch rates calculated below were not adjusted for increases in efficiency.

There have been various changes to the legal possession limits applying to recreational fishers in WA that may have affected their catch rates of Australian herring. In WA, legal minimum lengths (LML) have applied to Australian herring since at least 1913, with variations as follows: 6 inches (implemented in 1913), 7 inches (1937), 7.875 inches/ 177.8 mm (1973) and 180 mm (1975). These limits applied to both commercial and recreational fishers until 1991 when the LML for recreationally-caught Australian herring was removed. There is currently no size limit on recreationally caught Australian herring. A state-wide recreational daily bag limit of 40 Australian herring[7] was introduced in June 1991. On 15 October 2009, the daily bag limit in the WCB was reduced to 30 fish, while remaining at 40 fish in the SCB.

West Coast Bioregion boat-based surveys

In the WCB, the estimated total annual catch of Australian herring retained by boat-based fishers in ocean waters was similar in 2005/06, 2008/09 and 2009/10 (276,824, 261,969 and 272,924 individual Australian herring, respectively) (Sumner *et al.* 2008, DoF unpubl. data). These catch levels were less than that estimated in 1996/97 (319,355 individuals) (Sumner and Williamson 1999) (Fig. 4.3). The weight of the total annual catch of Australian herring was estimated to be 40 t in 1996/97, 35 t in 2005/06, 33 t in 2008/09 and 34 t in 2009/10 (assuming 125g per fish).

The estimated total number of boating hours increased markedly from 525,464 hours in 1996/97

7 Herring are subject to a mixed species daily bag limit of 30 'low risk' fish in the WCB (40 in the SCB).

to 729,903 hours in 2005/06, then gradually declined to 681,260 hours in 2008/09 and 626,935 hours in 2009/10 (Fig. 4.3). The average annual catch rate of Australian herring by the boat-based fishery decreased from 0.608 fish per boating hour in 1996/97 to 0.379 fish per boating hour in 2005/06 (with a similar rate of 0.389 fish/hour in 2008/09). The catch rate increased to 0.449 fish/hour in 2009/10 (Fig. 4.3).

During the most recent surveys, Australian herring was retained by 1,588 (12%) of the 13,197 interviewed fishing trips in 2008/09 and 1,550 (13%) of the 11,836 interviewed fishing trips in 2009/10 (DoF, unpubl. data). Over these 2 years, the proportion of boat-based fishing trips in which Australian herring was retained ranged from 10% to 25% per month.

In 2008/09 and 2009/10, the total retained catch of Australian herring was estimated to range from 3,326 to 54,117 fish per month, while boating effort was estimated to range from 19,037 to 108,261 hours per month. Each year, the monthly total catch level of Australian herring peaked in April (plus a minor peak in January) and reached a minimum in September (Fig. 4.4a). Monthly catch levels were largely a function of monthly effort, which also peaked in April (and January) each year, presumably reflecting popular fishing times associated with holiday periods and favourable weather.

The monthly catch rate peaked in autumn (May–July) each year, slightly later than the peak in catch (April) (Fig. 4.4b). The minimum monthly catch rate occurred in September, coinciding approximately with the minimum levels of catch and effort. Monthly catch rates of Australian herring by boat-based fishers were estimated to range from 0.17 to 0.70 fish/boating hour (retained fish only) during the 2-year survey period.

West Coast diary anglers and MAAC estuary competition

Diary records from Angler 1, who fished in the Busselton area, were available from 1981/82 until 2009/10. Relatively low catch and effort was reported between 1986/87 and 1993/94. No effort was reported in 1987/88 (Fig. 4.5a). The average annual catch rate of Angler 1 ranged from a minimum of 0.4 fish/hour in 1998/99 to a maximum of 4.5 fish/hour in 2000/01.

Diary Angler 2, who fished in the Perth area, reported two discrete periods of relatively high Australian herring catch and total effort – the first in the early 1980s and the second in the late 1990s. Relatively low catch and effort was reported in the intervening years from 1986/87 to 1995/96 (Fig. 4.5b). No effort was reported in 2003/04 or after 2005/06. The average annual catch rate of Angler 2 ranged from a minimum of 0.2 fish/day in 1978/79 and 1980/81 to a maximum of 3.5 fish/day in 2000/01 and 2004/05.

The MAAC recorded retained Australian herring catch and total effort in the Swan-Canning Estuary from 1986/87 to 2009/10 (Fig. 4.5c). Over this period, the annual catch displayed an increasing trend whereas the effort trend was non-directional. From 1986/87 to 2008/09, the total annual MAAC fishing effort ranged from 77 to 310 fisher days, while the total annual catch of Australian herring ranged from 0 to 163 fish. From 1991/92 to 1998/99, the MAAC estuary catch rate was relatively low (range 0.1-0.4 fish/fisher day). The catch rate then followed an increasing trend until 2009/10, when a maximum of 1.4 fish/fisher day was reached.

Due to their geographic proximity (within the southern WCB) and the similarity of catch rate trends between Angler 1, Angler 2 and the MAAC, an average of these annual catch rates (after standardisation) was calculated to provide an average relative annual catch rate of Australian herring in the southern WCB (Fig. 4.6a). This average catch rate of Australian herring in the southern WCB was higher during recent years (i.e. 1999/2000 to 2009/10) than in earlier years (1977/78 to 1998/99), and displayed a pronounced peak in 2000/01.

Diary Angler 3, who fished in the Geraldton area (in the northern WCB), reported two discrete periods of Australian herring catch and total effort – 1976/77 to 1985/86 and 1995/96 to 2007/08. No catch and effort was reported in the intervening years from 1986/87 to 1994/95 (Fig. 4.5d). No effort was reported after 2007/08. The average annual catch rate of Angler 3 ranged from a minimum of zero in 1978/79 to a maximum of 5.7 fish/hour in 1998/99 (Fig. 4.6b).

The annual catch rate of Angler 3 in the northern WCB followed a different trend to the average catch rate in the southern WCB. The catch rate of Angler 3 was relatively low in recent years and displayed a pronounced peak in 1998/99. Differences in catch rate trends may reflect geographic differences in the availability of Australian herring between Zones within the WCB.

Melville Amateur Angling Club – ocean beach competition

Trends in the MAAC ocean catch rate of Australian herring were previously analysed by Pember (2009) and the results of that analysis are summarised below.

The MAAC recorded the retained catch (number of fish) of individual fishers and the total fishing effort (number of fishers attending each trip) during 377 field trips in the WCB and SCB held between July 1976 and November 2008. Field trips occurred at various shore-based ocean sites mainly within four regions: Rottnest Island, the Capes Region (Busselton to Augusta), lower west coast (Mandurah to Bunbury) and the south coast (Walpole to Bremer Bay).

Australian herring was the most frequently caught species during MAAC ocean field trips. From 1976 to 2008, a total of 143,890 Australian herring were retained, representing 66.18% of the total retained catch by number and 36.17% by weight.

The bag limits (including club-imposed and legal limits) for individual species kept by MAAC ocean fishers changed four times between 1976 and 2008 (Fig. 4.7). Prior to 1980, there was no limit (either legal or club-imposed) on the number of Australian herring that fishers were allowed to retain. In mid-1980, the club voluntarily imposed a limit of 50 Australian herring per fisher per trip. The bag limit was reduced to 40 fish in June 1991 (legal limit), 20 in June 2000 (voluntary) and 8 in June 2007 (voluntary).

The average annual catch rate of Australian herring was first calculated as the average number of fish per fisher per trip, including data from all trips in all regions. Then, to address the potentially confounding effect of changes in bag limits, the annual availability of Australian herring was also measured by i) average catch per fisher per trip, as a percentage of the bag limit and; ii) percentage of fishers attaining the bag limit.

Trends displayed by the various MAAC annual catch rates were generally in good agreement. Catch rates increased from the mid 1970s to reach an historic peak in the mid-1980s (Fig. 4.7). Catch rates then steadily decline until the late 1990s. Lower catch rates during 1976–1980 compared to 1980–1984, despite the absence of a bag limit prior to 1980, suggests that the availability of Australian herring was increasing over this period. A decline in annual catch rates from 1984 to 1990 (while the bag limit remained constant at 50 fish) and then another decline from 1991 to 1998 (while the bag limit remained constant at 40 fish) suggest an almost continuous decline in the availability of Australian herring from 1984 until 1998. There was a short period of stability in catch rates from 1992 to 1995 (Fig 4.7).

MAAC annual catch rates increased from 1998 to 2000. The spike in catch rates in 2000 is difficult to interpret due to the confounding effect of the bag limit reduction in mid-2000. Similarly, a spike in the percentage of fishers attaining the bag limit in 2007 may have been an artifact of the bag limit reduction in mid-2007. However, in the intervening years from 2001 to

2006 (while the bag limit remained constant at 20 fish), catch rate trends suggests a stable or slightly increasing trend in the availability of Australian herring.

The MAAC annual catch rates between 1999 and 2006 were low compared to catch rates during the 1980s. During the 1980s, a bag limit of 50 Australian herring per fisher per trip was attained during 15–25% of trips. In contrast, a bag limit of 20 was attained during only 5–10% of trips during 2001–2006.

West Coast Bioregion voluntary logbooks

Australian herring was the most common finfish species captured by shore- and boat-based volunteer logbook fishers in ocean waters of the WCB. From 2005/06 to 2010/11, Australian herring comprised 66% (by number) of all finfish retained by shore-based logbook fishers and 22% by boat-based logbook fishers. Australian herring comprised 52% and 14%, respectively, of the total (retained or released) finfish catch of these fishers.

From 2005/06 to 2010/11, shore-based logbook fishers in the WCB captured 15,007 Australian herring while boat-based logbook fishers captured 2,688 Australian herring (retained or released).

The majority (77%) of Australian herring caught by all WCB logbook fishers were taken in the Perth area. Among shore-based fishers, 78% of Australian herring retained in the WCB were taken in the Perth area. The distribution of the shore-based catch partly reflected the distribution of shore-based fishing effort. The majority of shore-based ocean fishing effort in the WCB (65% of sessions and 67% of hours) was reported from the Perth area.

Within the Perth area, Australian herring comprised 73% of all finfish retained by shore-based logbook fishers and 58% of all finfish captured (retained or released). From 2005/06 to 2010/11, Australian herring ranged between 40 and 75% of all finfish retained by shore-based fishers within any particular month.

A very high proportion of the total effort expended by shore-based logbook fishers in the Perth area resulted in the capture of Australian herring. Sixty percent of shore-based fishing sessions conducted between 2005/06 and 2010/11 captured Australian herring (retained or released). The effort (hours) expended during shore-based logbook fishing sessions that captured Australian herring ranged from 38% to 100% of the total monthly shore-based effort (average 67% ± 14% s.d.) in the Perth area.

A relatively low proportion of the total effort expended by boat-based logbook fishers resulted in the capture of Australian herring (retained or released). From 2005/06 to 2010/11, only 15% of boat-based sessions by logbook fishers in the WCB captured Australian herring.

In the Perth area, the total annual catch of Australian herring (retained or released) by shore-based logbook fishers ranged from 1,293 fish in 2008/09 to 2,565 fish in 2006/07. The total annual effort expended by these fishers ranged from 520 hours in 2008/09 to 941 hours in 2006/07. The total monthly catch ranged from 5 to 444 fish per month, while the monthly effort ranged from 12 to 122 fisher hours (Fig. 4.8a). Monthly CPUE ranged from 0.37 to 6.45 fish/hour (Fig. 4.8b).

Catch, effort and CPUE levels reported by shore-based logbook fishers in the Perth area displayed strong seasonality within each year. Each year, total monthly catch was relatively high during summer and autumn and relatively low in winter and spring (Fig. 4.9a). Total monthly effort typically peaked during summer and reached a minimum in winter (Fig. 4.9b). Monthly average CPUE peaked in autumn (May-June) and typically reached a minimum in winter (September) each year (Fig 4.9c).

Despite strong seasonal variations, the average annual CPUE exhibited a stable (non-directional) trend from 2005/06 to 2010/11, ranging from 2.3 to 3.1 fish/hour (Fig. 4.10a).

During the 6-year period 2005/6 to 2010/11, a total of 61 Perth shore-based fishers participated (i.e. recorded effort, including nil and non-herring catches) in the logbook program. In any single year, between 14 and 22 participated. In any single month between 2 and 12 (but typically between 4 and 9) participated. Over this period, 44 fishers participated for one year, 12 fishers participated for 2–5 years and five participated during all six years. Of these five long-term fishers, one recorded very low levels of annual effort and so, effectively, there were only four long-term fishers. Each of these relatively 'avid' fishers recorded effort in nearly every month over the 6-year period, but with a tendency to expend more effort (hours) during warmer months.

The average annual CPUE of the four long-term fishers displayed a different trend to the annual CPUE of all logbook fishers. The CPUE of these long-term fishers followed an increased trend from 2005/6 until 2009/10, and then declined markedly in 2010/11 (Fig. 4.10b).

Voluntary Fisheries Liason Officer surveys

From 1995 to 1998, a relatively low average catch rate of Australian herring (0.3 to 0.6 fish/fisher/hour) was reported by shore-based recreational fishers during interviews with Volunteer Fisheries Liaison Officers in the WCB. The average annual catch rate increased between 1998 and 2007, reaching 2.1 fish/fisher/hour in 2007 (Fig. 4.11).

4.3.4 Released catch

Data from various surveys of recreational fishing and data reported in voluntary fisher logbooks suggest that between 4–15%, but typically 10–12%, of all Australian herring caught in the WCB are released (Table 4.3). In the SCB, a higher proportion of Australian herring appear to be released (10–32%). In SA, where the average age and size of Australian herring is smaller than in WA (Fairclough *et al*. 2000b), a relatively high proportion (20–30%) of all Australian herring caught are released.

From 2005/06 to 2010/11, shore-based logbook fishers in the WCB released a relatively small proportion of all Australian herring caught, ranging from 1% to 9% of the annual catch per year. The rate of release of Australian herring by boat-based logbook fishers in the WCB was higher than shore-based fishers (6–14% per year).

Within the Perth area, shore-based logbook fishers released between <1% to 7% of the annual catch, indicating that fewer fish were released in the Perth area by logbook fishers compared to elsewhere in the WCB. Overall, between 2005/06 to 2010/11, Perth shore-based logbook fishers released 2% of their total catch, whereas non-Perth shore-based fishers released 19% of their total catch. The non-Perth catch contained a higher proportion of small (<19cm) fish than the Perth catch (12% versus 2%), which may explain the higher rate of release (Appendix 1).

4.3.5 Relationship with recruitment and catch rates

Four versions of the annual recruitment index, R_n , $R_{n,n+1}$, $\ln(R_n)$ and $\ln(R_{n,n+1})$, were correlated against recreational fishery catch rates. Untransformed values of the annual recruitment index (R_n , $R_{n,n+1}$) were more highly correlated against recreational CPUE compared to log transformed values ($\ln(R_n)$ and $\ln(R_{n,n+1})$). The correlations with untransformed values are described below.

There were no significant (at $p<0.01$) correlations between average recreational CPUE in the southern WCB and the 1-year recruitment (R_n) index at either Koombana Bay or Poison Creek (Fig. 4.12). There were also no significant (at $p<0.01$) correlations with the 2-year recruitment (R_n) index at Koombana Bay. Recreational CPUE in the southern WCB was significantly correlated with the 2-year recruitment index ($R_{n,n+1}$) at Poison Creek when CPUE was lagged by -1 or -2 years (i.e. there was a strong negative relationship between CPUE and annual recruitment 1 to 3 years later).

There were no significant (at $p<0.01$) correlations between recreational CPUE at Geraldton and the 1-year recruitment (R_n) index at either Koombana Bay or Poison Creek (Fig. 4.12). However, CPUE was significantly correlated with the 2-year recruitment index ($R_{n,n+1}$) at Poison Creek when CPUE was lagged by 0 years (i.e. there was a strong relationship between Geraldton CPUE and the average of recruitment 1 and 2 years earlier) and with 2-year recruitment index at Koombana Bay when CPUE was lagged by +1 year (i.e. there was a strong relationship between Geraldton CPUE and the average of recruitment 0 and 1 year earlier).

4.4 Discussion

4.4.1 Recreational catch and effort

Surveys of recreational fishing conducted in WA since 1990 suggest that the total annual recreational catch of Australian herring is approximately 100–150 t in the WCB and 30–70 t in the SCB. At these levels, the total annual recreational catch in WA was approximately equal to the total annual commercial catch in WA in recent years.

A significant recreational catch of Australian herring is also taken outside WA waters, mainly in SA (negligible quantities are also taken in Victoria). Limited data suggests that the annual recreational catch of Australian herring in SA is typically about 75% (by weight) of the total WCB recreational catch each year. In 2007/08, an estimated 93 t of Australian herring were retained by recreational fishers in SA (Jones 2009).

Shore-based recreational fishers in the WCB contribute the largest single share of the recreational catch of Australian herring in WA. In 2000/01, the shore-based catch in the WCB comprised 49% (by number) of the total retained recreational Australian herring catch in WA (Henry and Lyle 2003). The next largest share was taken by boat-based fishers in the WCB (27%).

In various surveys, Australian herring has consistently emerged as the most common finfish species retained by shore-based fishers in the WCB. In 2000/01, Australian herring were estimated to comprise 54% of all shore-caught finfish in the WCB (Henry and Lyle 2003). From 2005/06 to 2010/11, Australian herring comprised 66% of the retained shore-based catch by voluntary logbook fishers. In a pilot study of shore-based fishing in the Perth area (excluding Rottnest Island) during April–June 2010, Australian herring comprised 65% (by number) of the total retained finfish catch (Smallwood *et al.* 2011). From 1976 to 2008, Australian herring comprised 66% of the MAAC ocean catch. Herring was also the most common finfish reported by shore-based fishers in the WCB during VFLO interviews conducted annually from 1995 to 2007 (Smallwood *et al.* 2010).

Logbook data suggests that a very high proportion of total effort (67% of fishing sessions) expended by shore-based recreational fishers in the WCB results in the capture of Australian herring. In comparison, a relatively low proportion (15%) of boat-based effort expended by logbook fishers in the WCB results in the capture of Australian herring. The proportion of boat-based logbook effort is very similar to that seen in surveys of boat-based fishing in 2008/09 and 2009/10, when 12–13% of trips retained Australian herring (DoF, unpubl. data). Comparative data from the recent shore-based survey is not available.

Despite being captured during a minority of boat-based fishing trips within the WCB, Australian herring is still typically the first or second most abundant species in the retained catch. In 1996/97, 2000/01 and 2005/06, Australian herring was estimated to be the second most commonly retained finfish taxon[8] in the boat-based catch in the WCB and comprised 25%, 32% and 27% (by number), respectively, of all finfish retained by boat-based fishers each year (Henry and Lyle 2003, Sumner *et al.* 2008).

It is unlikely that Australian herring is a primary target species for boat-based fishers. The cost per fish (in terms of fuel, gear costs, travel time, etc.) of Australian herring caught by boat-based fishers would be considerably higher than that incurred by shore-based fishers. Similar catch rates of Australian herring (in terms of number and weight of fish per day) can be achieved from the shore (Appendix 1), at lower cost. Therefore, the fact that Australian herring is the second most commonly retained species probably reflects a very high level of opportunistic catch among boat-based fishers.

Estimates of recent catches of Australian herring by WCB boat-based fishers are substantial. The estimated total annual boat-based catch of Australian herring was about 40 t in 1996/97, 35 t in 2005/06, 33 t in 2008/09 and 34 t in 2009/10. (Sumner *et al.* 2008, DoF unpubl. data)

An estimate of the total WCB shore-based annual catch of Australian herring is not available, but limited data suggests that it is considerably higher than the boat-based catch. During April-June 2010, Perth shore-based fishers were estimated to have retained a total of 211,447 Australian herring (26 t assuming 125 g per fish) and released a further 25,858 Australian herring (Smallwood *et al.* 2011). Since Australian herring is taken throughout the year in Perth and other regions of the WCB, the total annual shore-based catch over the entire WCB is probably several times higher than that estimated in April–June 2010.

Total WCB shore-based effort spent targeting Australian herring is also likely to be higher than total boat-based effort. A total of 196,430 fisher hours (s.e. ± 8,662) was estimated to have been expended by Perth shore-based fishers during April–June 2010 (Smallwood *et al.* 2011). This was similar to the estimated total effort expended by boat-based fishers across the entire WCB during April–June in 2008/09 and 2009/10 (219,807 and 184,913 hours, respectively) (DoF, unpubl. data). Given that a much higher proportion of effort by shore-based fishers is spent targeting Australian herring, compared to boat-based fishers, the total annual effort spent targeting Australian herring by shore-based fishers is probably many times higher than that expended by boat-based fishers in the WCB.

Rottnest Island

Rottnest Island appears to be a location of particular significance for recreational targeting of Australian herring in WA. In 2000/01, Australian herring was the most popular species retained by all fishers at Rottnest Island, comprising 88% (by number) of the retained finfish catch by shore-based fishers and 41% by boat-based fishers (Henry and Lyle 2003).

In 2003, Australian herring was again found to be the most popular species retained by shore-based fishers at Rottnest Island, comprising 79% of all retained finfish (60% of all captured finfish, including releases) (Smallwood *et al.* 2006). The majority of Australian herring were caught between April and July. In 2003, 40% of shore-based fishers interviewed at Rottnest Island reported that they were targeting Australian herring.

These values suggest that Australian herring typically comprises a higher proportion of shore-

8 The most abundant finfish taxon retained during these surveys was "whiting", which included ~4 species.

and boat-based catches at Rottnest Island than the average proportions in the WCB.

Interestingly, although Australian herring is highly targeted at Rottnest Island, the average catch rate is apparently not especially high compared to catch rates elsewhere in the WCB. In 2003, the average annual catch rate of Australian herring by shore-based fishers at Rottnest Island was estimated to be 0.97 fish/hour (retained fish only) or 1.10 fish/hour (retained and released fish) during the 12-month survey period.

There is some evidence to suggest that the average size of Australian herring caught recreationally at Rottnest Island may be larger than those caught on mainland beaches in the Metropolitan Zone, i.e. 26 cm versus 23 cm TL (Smallwood *et al.* 2006, Section 5, Appendix 1).

4.4.2 Discarding

Within the WCB, a low proportion of Australian herring caught by recreational fishers is released. Recreational fishing surveys in the WCB have suggested that 10–12% of all Australian herring caught are typically released by shore- and boat-based fishers. The rate of release of Australian herring by boat-based volunteer logbook fishers in the WCB is also at a similar level (6–14% per year). Shore-based logbook fishers appear to have a slightly lower release rate (1–9% per year) than other recreational fishers.

No data is available from surveys regarding the size of released fish. The fish released by volunteer logbook fishers (boat and shore) are almost always small (~20cm TL or less). Larger fish are very rarely released (Appendix 1). In any case, size-related selection probably has a negligible effect on the length distribution of the retained catch because small fish represent <5% of all Australian herring caught (Appendix 1). Size-related selection by other (i.e. non-logbook) fishers is not known, but the similarity in length composition between total recreational catches and logbook catches suggests that size-related selection (or lack of it) by other recreational fishers is similar to that of logbook fishers.

4.4.3 *Seasonal availability of Australian herring in West Coast Bioregion*

Monthly catch rates of shore-based logbook fishers in the Perth area suggest that the availability of Australian herring in this region is seasonal. Over a 6-year period, catch rates consistently peaked in autumn. In both 2008/09 and 2009/10, boat-based Australian herring CPUE also peaked in autumn, mirroring the peak in CPUE reported by shore-based logbook fishers.

This trend is also consistent with the traditional recreational fishing season for Australian herring from March to June. Historically, the majority of the annual recreational catch of Australian herring was taken in this period (Lenanton and Hall 1976).

Autumn is the spawning period for Australian herring, when fish are believed to aggregate in the WCB. Juvenile Australian herring migrate from the SCB and SA, and adults are also likely to emerge from West Coast estuaries, to aggregate in West Coast coastal waters at this time. It is unclear whether the catchability of Australian herring increases at this time due to the formation of denser aggregations and/or some other aspect of fish behaviour (e.g. more intense feeding).

Despite a peak in the catch rate of Australian herring in autumn, the available evidence suggests that total recreational catch level in the WCB may actually peak in summer, or be equally high in summer and autumn, due to higher effort levels in summer.

4.4.4 Long-term trends in Australian herring availability in the West Coast Bioregion

Limited data are available to indicate long-term trends in the recreational catch rate of Australian herring in the WCB. All available data sources suffer from limitations such as small sample sizes, missing data and/or poor survey design. However, despite these limitations, the long-term trends suggested by each source are broadly consistent.

The MAAC ocean competition catch rate provides a long-term index of annual Australian herring availability in the lower WCB with an uninterrupted sequence of annual values from 1976 to 2008. Unfortunately, numerous bag limit changes since the 1970s have limited the use of this data to a qualitative index. Nonetheless, the MAAC ocean catch rate strongly suggests that Australian herring availability increased between 1976 and 1984 and then followed a steady downward trend until 1998.

After 1999, the MAAC ocean catch rate suggests a stable or slightly increasing trend in the availability of Australian herring in the WCB until at least 2006. Three other data sources also suggest an increase in availability after 1999. Firstly, standardised annual recreational catch rates in the southern WCB (Fig 4.6a) were higher after 1998/99 compared to earlier years. Secondly, the shore-based catch rate reported during VFLO surveys (Fig. 4.11) increased after 1998. Thirdly, the catch rate of 'long-term' shore-based logbook fishers (Fig. 4.10b), which commenced in 2005/6, followed an increasing trend until 2010/11.

Relatively high recent catch rates in the southern WCB were also in agreement with anecdotal reports from MAAC members that Australian herring were unusually abundant in the Swan-Canning Estuary in recent years (D. Cox, MAAC, pers. comm.). Club members also reported that the average size of Australian herring was unusually large in recent years.

The annual catch rates of some commercial fisheries in the WCB also suggest a recent increase in Australian herring availability. The catch rate of the commercial haul net fishery in the northern WCB displayed a minor peak in 2000/01 and an increasing trend thereafter (see Fig. 3.23b in Section 3). The catch rate of commercial haul net fishers in the Peel-Harvey Estuary followed an increasing trend between 1998 and 2006 (see Fig. 3.22b, in Section 3).

In addition to the 2000/01 peak in the commercial catch rate in the northern WCB, localised peaks were also evident in the MAAC ocean catch rate in 2000 and in the standardised recreational catch rate in the southern WCB in 2000/01. Together these data suggest a strong recruitment event at this time. This may have been related to a strong pulse of recruitment observed in 1997 in the WCB and/or in 1999 in the SCB (see Section 2). Unfortunately, recruitment strength has been measured during relatively few years and so the relationship between catch rates and recruitment is still unclear (Section 2).

Despite evidence of a recent strong recruitment event, and stable or increasing availability of Australian herring in the WCB since 1999, the long-term MAAC ocean catch rate suggests that the availability since 2000 was still very low relative to the availability during the 1980s.

The sharp decline in the average annual catch rate of herring by long-term logbook fishers in 2010/11 is of concern. At the time of writing this report, recreational fishers in the WCB were reporting a decline in Australian herring availability following a 'heatwave' event along the west coast and western part of the south coast in early 2011 (Pearce et al. 2011). The decline in the logbook catch rate in 2010/11 reflected these anecdotal reports. The 'heatwave' event may have had a negative effect on recruitment or altered migrations patterns of herring. Ongoing monitoring of logbook catch rates, as well as the composition of WCB fishery landings (see Section 5), will be required to determine any long term impact of this event on the herring stock. Catch rates of herring by the MAAC are unlikely to be available in future because the membership of the club is now very low.

4.4.5 Future monitoring

West Coast Bioregion shore-based recreational fishing surveys

The largest recreational catch share of Australian herring is taken by shore-based fishers in the WCB. Surveys of shore-based fishing in the WCB would therefore provide valuable catch and catch rate data. However, these surveys are not likely to be cost-effective until the introduction of a suitable sampling frame (such as a licence holder database) and so are likely to be conducted infrequently in the foreseeable future (Smallwood *et al.* 2011). Therefore, information about the recreational fishery will need to be inferred from other sources, such as voluntary recreational logbooks and surveys of boat-based recreational fishing, that may be supplemented by infrequent data from shore-based surveys.

In the foreseeable future, catch rates calculated from surveys of boat-based recreational fishing and voluntary logbooks are likely to be the only available indices of Australian herring abundance in the WCB.

West Coast Bioregion boat-based recreational fishing surveys

The catch rates of Australian herring by boat-based fishers are difficult to compare directly with catch rates of other fishers due to the difficulty in estimating effort spent targeting Australian herring. During surveys of boat-based fishing in the WCB in 2008/09 and 2009/10, very low monthly catch rates of Australian herring were estimated, ranging from 0.17 to 0.70 fish/boating hour. However, these catch rates were derived from total boating effort, included travelling time and time spent targeting other species (e.g. demersal and offshore pelagic species). Catch rates of Australian herring calculated from boat-based surveys are likely to significantly underestimate the catch rates of boat-based fishers who fished in nearshore waters and specifically targeted Australian herring. Nonetheless, the catch rate during boat-based surveys could still provide a relative index of Australian herring abundance. The close agreement between seasonal trends in the boat-based survey catch rate, the shore-based logbook catch rate and anecdotal information about the abundance of Australian herring, suggest that catch rates of Australian herring estimated during future surveys of WCB boat-based recreational fishing could provide a useful index of Australian herring availability. This is surprising given the low proportion of boat-based fishing effort expended on targeting Australian herring.

The use of existing boat-based surveys to monitor Australian herring would be cost-effective. However, the effects of trip duration and fishing location on boat-based catch rates, which are related to the level of targeting of Australian herring, would need to be quantified before data from boat-based surveys could be confidently used to monitor Australian herring availability (Appendix 1). Due to high uncertainty about the levels of effort associated with catches of Australian herring during previous boat-based surveys, catch rate trends must be interpreted with caution. The differences in the boat-based catch rate of Australian herring between previous surveys may reflect changes in targeting of Australian herring, or other aspects of fisher behaviour, rather than changes in the availability of Australian herring.

West Coast Bioregion voluntary recreational logbooks

Voluntary recreational logbook catch rates could potentially be used as a cost-effective, relative index of annual abundance for Australian herring and many other species. In addition, logbooks could potentially provide information about aspects of recreational fishing behaviour, such as the temporal distribution of effort (commencement time, length of trip) and information about released catches that are difficult to obtain by other survey methods. Hence, logbooks may assist in the design of other surveys and complement other survey data.

Since the commencement of the logbook program in 2005/06, shore-based fishers in the Perth area have contributed the largest share of logbook catch and effort data. Since shore-based fishers in this region are probably the dominant sector within the WCB recreational Australian herring fishery (in terms of % catch and effort), logbook data is well suited to assist in monitoring the status of this fishery.

To use logbook data appropriately it is important to determine whether the catch and effort characteristics of logbook fishers are representative of other recreational fishers. Comparisons with limited data from recent recreational fishing surveys suggest that some characteristics of logbook fishers are not representative of the WCB recreational fishery (Appendix 1). Nonetheless, some data provided by voluntary logbook fishers are likely to be useful for monitoring the status of Australian herring. In particular, trends in logbook catch rates, especially those of shore-based fishers in the Perth area, appear to reflect Australian herring availability. The similarity of monthly trends in the shore-based logbook catch rate, the boat-based survey catch rate and anecdotal information about the abundance of Australian herring, suggest that these seasonal trends are real and that recreational catch rates of Australian herring can provide a useful relative index of availability. Also, the species composition of finfish catches recorded by logbook fishers appears to be similar to those recorded in other surveys. For example, Australian herring comprise a similar percentage of the total catch in logbook and survey records. Furthermore, the length distribution of the Australian herring catch by logbook fishers is similar to that observed in surveys.

When monitoring Australian herring availability, the annual frequency of logbook data represents an advantage over less frequent data from surveys. Australian herring is a relatively short-lived species, with highly variable annual recruitment. Limited historical records of recreational catch rates in the WCB indicate periods of high annual variation in availability in response to recruitment events. An annual index of Australian herring availability, which currently is only available from logbooks, would be desirable to ensure any recruitment-driven spikes in catch rate are distinguished from longer term trends in stock abundance.

The best method of calculating CPUE from logbook data to provide an index of Australian herring abundance is yet to be determined. For example, average CPUE calculated from a subset of catch and effort data provided by frequent or long-term fishers may be more appropriate than average CPUE calculated from the catch and effort of all fishers. Additional years of logbook data will enable comparison with trends in recruitment and other annual data, which will assist in selecting an appropriate method of CPUE calculation.

4.4.6 Influence of recruitment on fishery catch rates

The lack of correlation between the average recreational CPUE in the southern WCB and recruitment during previous years at either Poison Creek (SCB) or Koombana Bay (WCB) suggest that recreational catch rates in the southern WCB are not strongly recruitment-driven. This is in contrast to the commercial fisheries in the SCB and in SA where catch rates are strongly recruitment-driven (Section 3). Interestingly, the correlations between recreational CPUE in the southern WCB and recruitment at Poison Creek 1–3 years later are suggestive of a spawner-recruit relationship. In other words, recreational CPUE in the southern WCB may be an index of future spawner abundance, from which recruitment at Poison Creek is derived.

The correlation between recreational CPUE at Geraldton and Poison Creek recruitment 0–1 year later is also suggestive of a spawner-recruit relationship. Specifically, recreational CPUE at Geraldton may be an index of current spawner abundance in the WCB, from which recruitment at Poison Creek is derived.

The correlation between recreational CPUE at Geraldton and Koombana Bay recruitment 0–1 year earlier is difficult to explain. The capture of recruits derived from Koombana Bay (or another WCB nursery) in Geraldton when aged 0+ or 1+ years is unlikely since these ages are younger than those typically observed in recreational landings on the west coast, although some 1+ fish are caught (see Section 5). Therefore, the evidence does not strongly support a recruitment-driven catch rate in Geraldton. Alternatively, the correlation could reflect a spawner-recruit relationship such that recreational CPUE at Geraldton is an index of current spawner abundance, from which recruitment in the southern WCB is derived.

In summary, the available (albeit limited) evidence suggests that recreational catch rates in some areas of the WCB could function as an index of spawner abundance in the WCB, from which recruits to both the SCB and the WCB are derived.

Overall, the relationships between recruitment indices and recreational fishery catch rates are ambiguous. A number of factors are likely to obscure the influence of recruitment on recreational catch rates in the WCB. First, the WCB recreational catch is typically comprised of a greater number of age classes, compared to the SCB commercial trap net fishery or the commercial fisheries in SA (see Section 5). Secondly, the WCB recreational catch is probably comprised of a mixture of recruits from west coast and southern nurseries, unlike the trap net catch which is entirely comprised of southern recruits. Thus, the WCB recreational catch rate is likely to be a complex function of recruitment during multiple years at west coast and southern nurseries.

4.4.7 Summary

Despite the limitations and potential biases of the recreational catch rates of individual fishers/fisheries examined here, these independently-derived catch rates were generally in agreement and suggested a long-term decline in the abundance of Australian herring in the southern WCB. This trend was also evident in commercial catch rates. Catch rate trends suggested that the abundance of Australian herring in the southern WCB increased in the late 1970s and reached a peak during the early 1980s. Abundance then gradually declined until the late 1990s. A pronounced peak in catch rates occurred in 2000/01, suggestive of a strong recruitment event. Abundance followed an increasing trend from the late 1990s until 2010/11, although current levels still appear to be low relative to abundance during the 1980s.

Since the majority of the spawning stock is located within the WCB, with immature or non-reproductive fish dominating the catches in other regions, the catch rate of adult Australian herring in the WCB is essentially an index of spawning stock biomass. Therefore, the catch rate trend in the WCB is important information when assessing spawning stock status.

The majority of the catch of Australian herring in the WCB is taken recreationally, and predominantly by shore-based fishers. Regular surveys of shore-based fishers that provided robust estimates of catch and catch rate would provide valuable information for the effective management of this sector. Catch rates from shore-based surveys would also provide an index of spawning stock biomass. However a suitable sampling frame will need to be developed to enable cost-effective shore-based surveys. In the foreseeable future, recreational catch rates of Australian herring in the WCB are likely to be available only from surveys of boat-based recreational fishing and voluntary logbooks.

Table 4.1. Estimated proportions (%) of the total retained recreational catch (numbers of fish) of Australian herring in WA in 2000/01, distributed by Bioregion, habitat and fishing platform (Henry and Lyle 2003).

Bioregion	Habitat	% of retained WA catch	
		Boat	Shore
West Coast	Ocean	27.4	49.0
	River/Estuary	1.6	5.8
South Coast	Ocean	2.3	13.2
	River/Estuary	0.6	0.1

Table 4.2. Estimated retained catch of Australian herring (number of herring, weight of herring and herring catch as a proportion of total retained catch of all finfish species) by recreational fishers within each ocean management Zone of the West Coast Bioregion during recreational fishing surveys in 1996/97, 2000/01 and 2005/06 (n/a – negligible catch, not estimated) (Henry and Lyle 2003, Sumner *et al.* 2008). (estuaries excluded).

Platform	Survey period	Zone	Catch (no. of fish)	Catch weight (t) (assuming 125g per fish)	Proportion of total retained finfish (no. of fish, all species) in Zone
Boat	1996/97	Kalbarri	n/a	-	-
		Mid-west	33,743	4.2	31%
		Metropolitan	298,475	37.3	28%
		South-west	32,715	4.1	15%
		TOTAL	364,932	45.6	25%
Boat	2005/06	Kalbarri	n/a	-	-
		Mid-west	23,139	2.9	21%
		Metropolitan	230,372	28.8	30%
		South-west	34,875	4.4	20%
		TOTAL	288,392	36.0	27%
Boat	2000/01	Kalbarri	n/a	-	-
		Mid-west	85,108	10.6	29%
		Metropolitan	846,748	105.8	37%
		South-west	127,989	16.0	20%
		TOTAL	1,059,845	132.5	32%
Shore	2000/01	Kalbarri	1,260	0.2	3%
		Mid-west	150,077	18.8	41%
		Metropolitan	1,244,901	155.6	59%
		South-west	499,360	62.4	49%
		TOTAL	1,895,598	236.9	54%

Table 4.3. Estimated proportion of Australian herring released by recreational fishers in the West Coast Bioregion (WCB), South Coast Bioregion (SCB) and South Australia (SA). Rates are given as the proportion of the total annual catch (retained + released) of Australian herring during various recreational fishing surveys and during fishing sessions by voluntary logbook fishers.

Region	Recreational fishing sector	Year(s)	Released (% of annual catch)
WCB	Boat-based (excludes estuaries)	1996/97	4
		2000/01	10
		2005/06	13
		2008/09	11
		2009/10	10
	Boat-based (excludes estuaries), volunteer logbook fishers	2005/06–2010/11	6–14
	Shore-based (excludes estuaries)	2000/01	12
	Shore-based (excludes estuaries), volunteer logbook fishers	20050/6–2010/11	1–9
	Rottnest Island (shore only)	2003	15
	Estuaries (boat & shore)	2000/01	12
	Shore-based (excludes estuaries)	2010 (Apr–Jun only)	11
SCB	Boat-based (excludes estuaries)	2000/01	16
	Shore-based (excludes estuaries)	2000/01	22
	Shore-based (excludes estuaries), volunteer logbook fishers	2005/06–2010/11	15
	Estuaries (boat & shore)	2000/01	32
	Estuaries (boat & shore)	2002/03	10
SA	Total state	2000/01	23
	Total state	2007/08	31

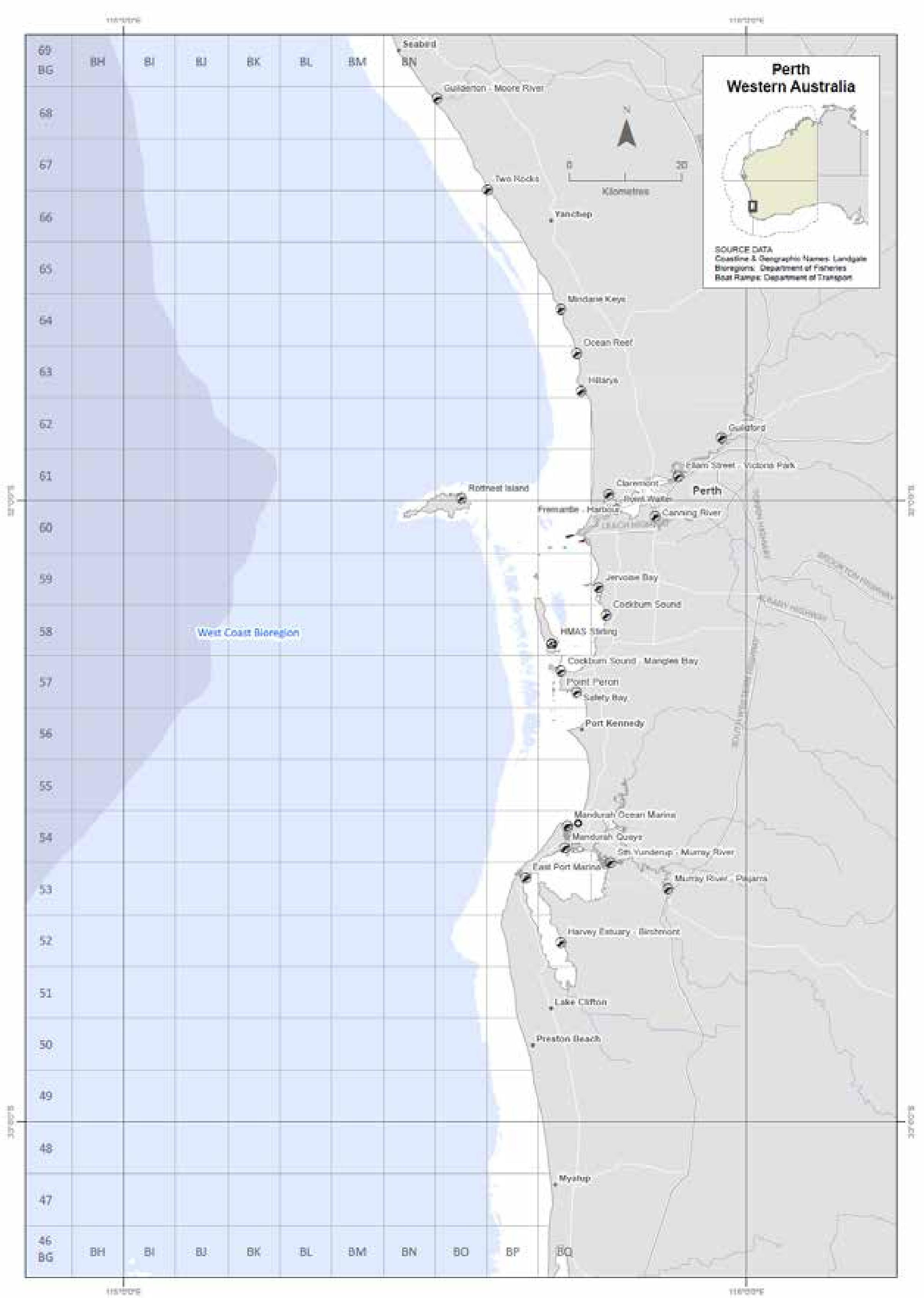


Figure 4.1. Grid map of Perth blocks (5 x 5 nautical miles) used by voluntary logbook fishers to report catch and effort in the West Coast Bioregion.

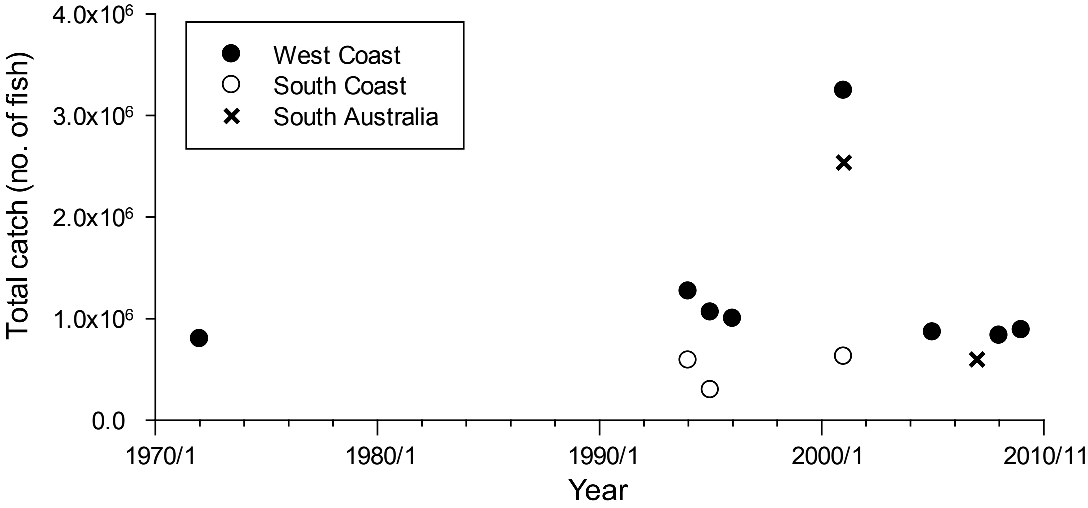


Figure 4.2. Estimated total annual catch (number of individuals) of Australian herring retained by recreational fishers in the West Coast Bioregion, South Coast Bioregion and South Australia, determined by various surveys.

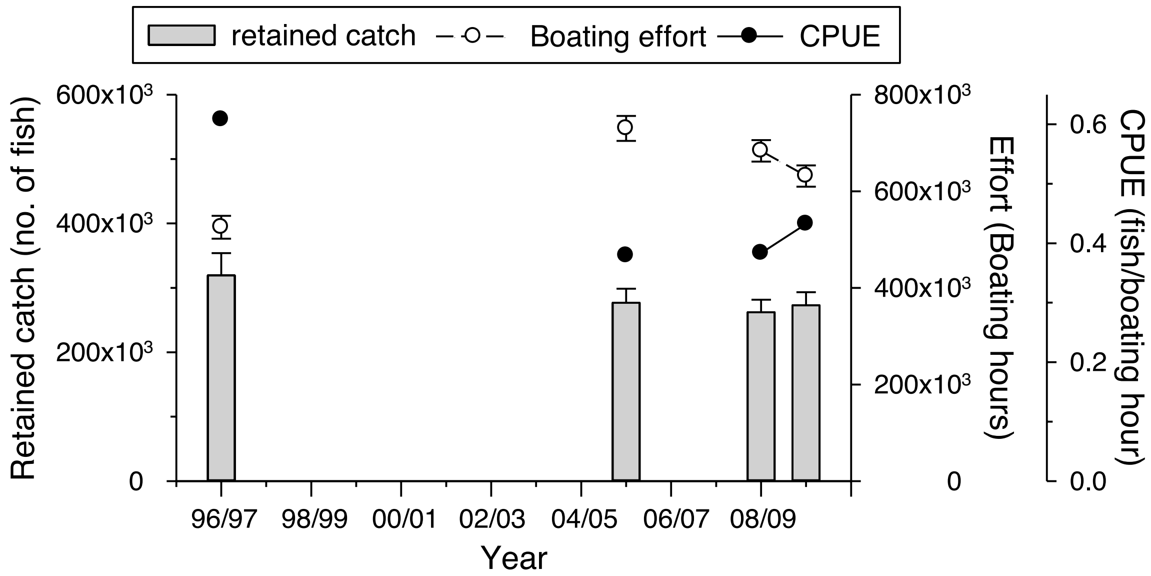


Figure 4.3. Estimated total annual retained catch (number of individuals) (+ 95% confidence intervals), estimated total number of boating hours and unstandardised average catch rate (CPUE) of Australian herring by boat-based recreational fishers in the West Coast Bioregion in 1996/97, 2005/06, 2008/09 and 2009/10.

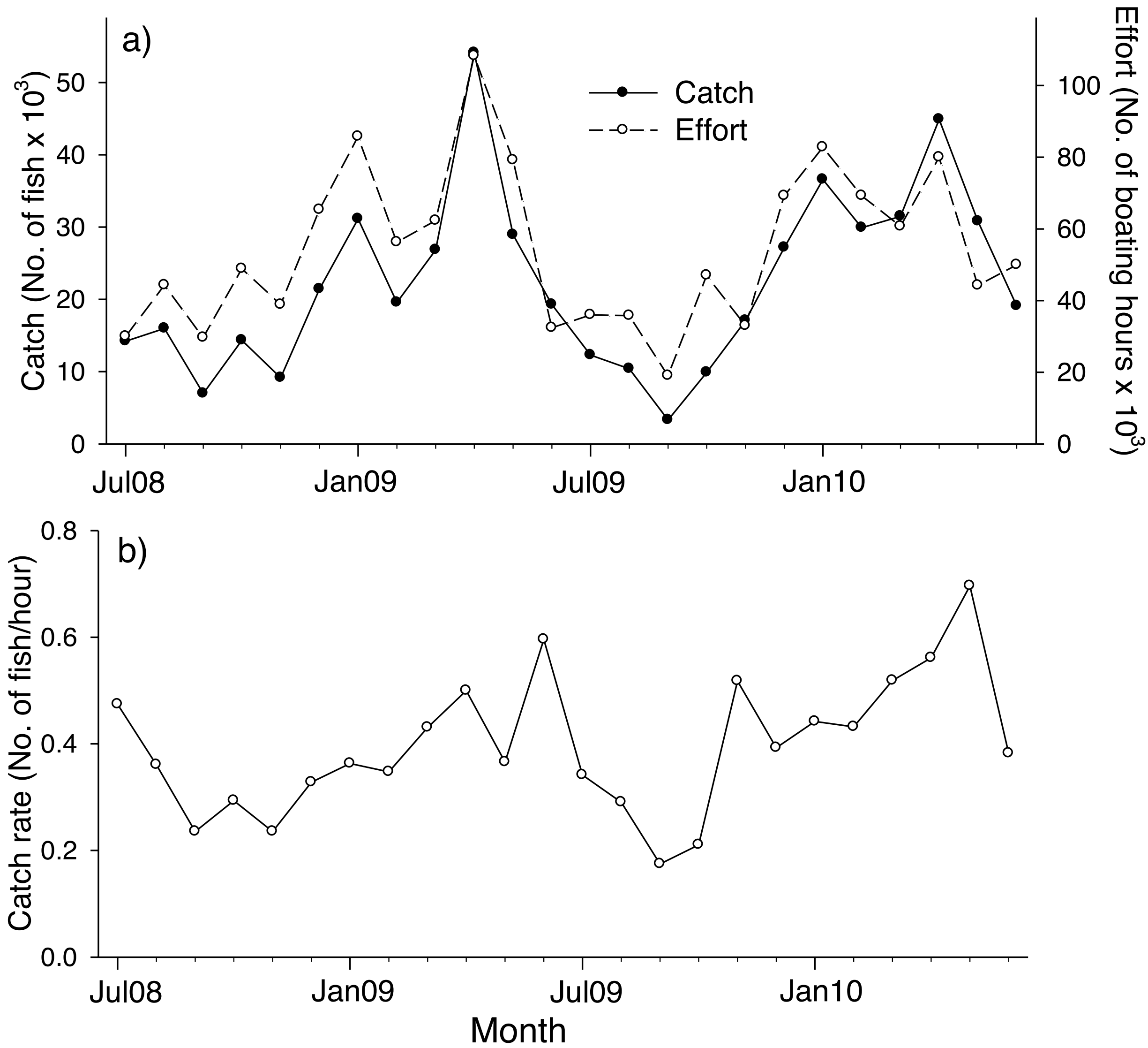


Figure 4.4. a) Total retained catch of Australian herring (number of fish), total boating effort (number of hours) each month, and **b)** average monthly catch rate of Australian herring by boat-based recreational fishers in the West Coast Bioregion, estimated by recreational fishing surveys in 2008/09 and 2009/10.

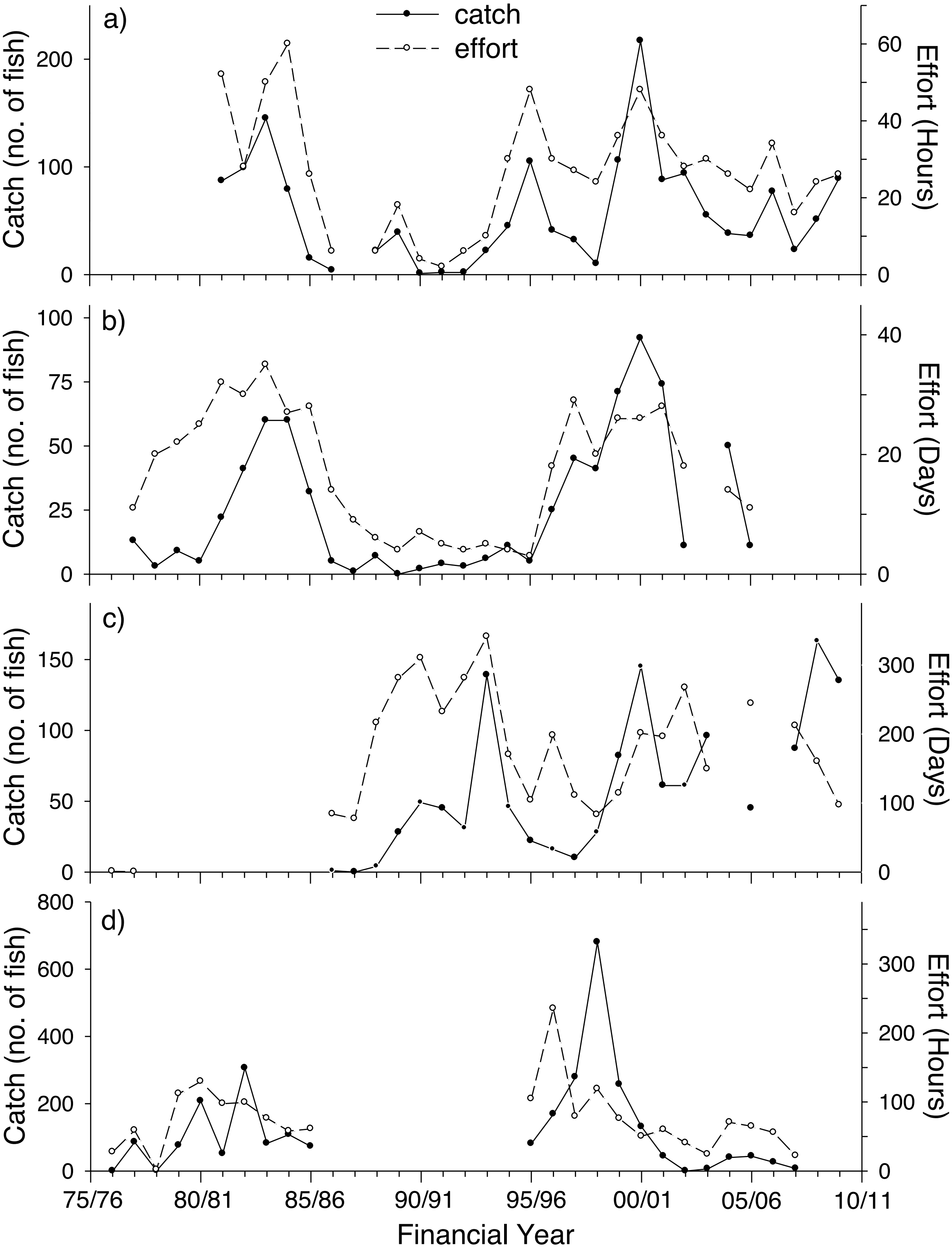


Figure 4.5. Total annual Australian herring catch (number of retained fish) and total annual effort recorded by **a)** Diary Angler 1 (fished in Busselton area), **b)** Diary Angler 2 (Perth), **c)** Melville Amateur Angling Club (Swan-Canning Estuary) and **d)** Diary Angler 3 (Geraldton).

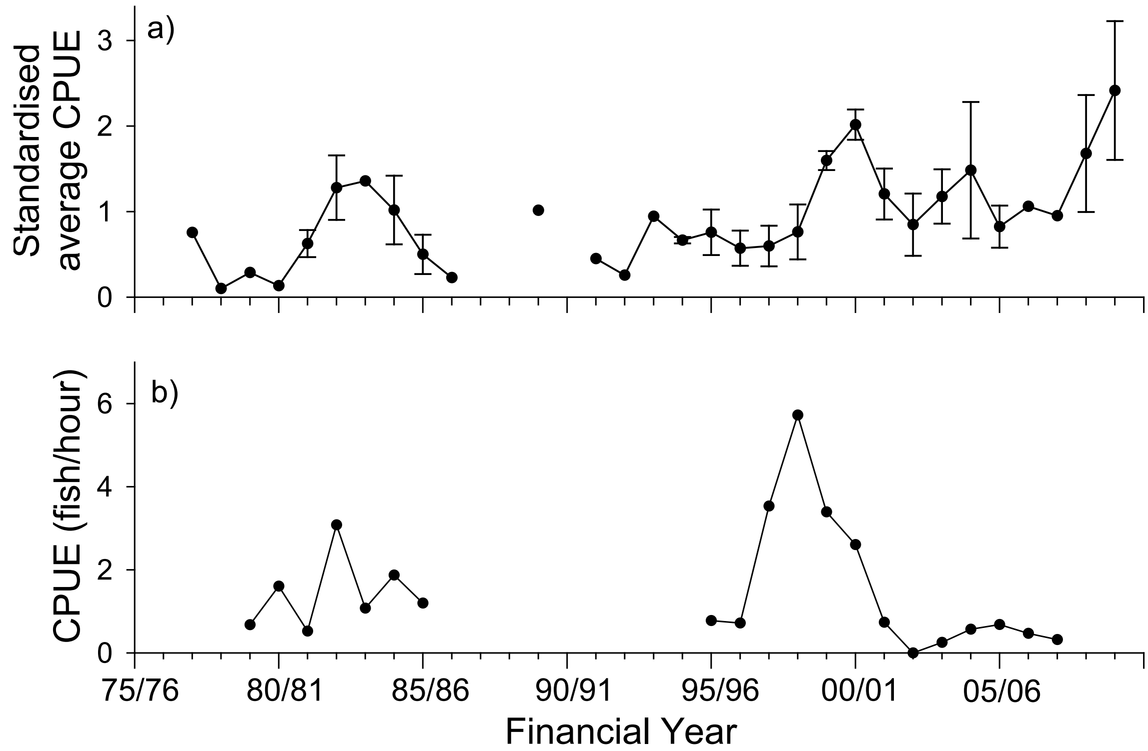


Figure 4.6. **a)** Average (± s.e.) annual standardised catch rate of Australian herring by recreational fishers in the southern West Coast Bioregion, derived from the average of standardised catch rates of Diary Angler 1 (Busselton), Diary Angler 2 (Perth) and the Melville Amateur Angling Club (Swan-Canning Estuary) and **b)** average annual Australian herring catch rate recorded by Diary Angler 3 in the northern West Coast Bioregion (Geraldton).

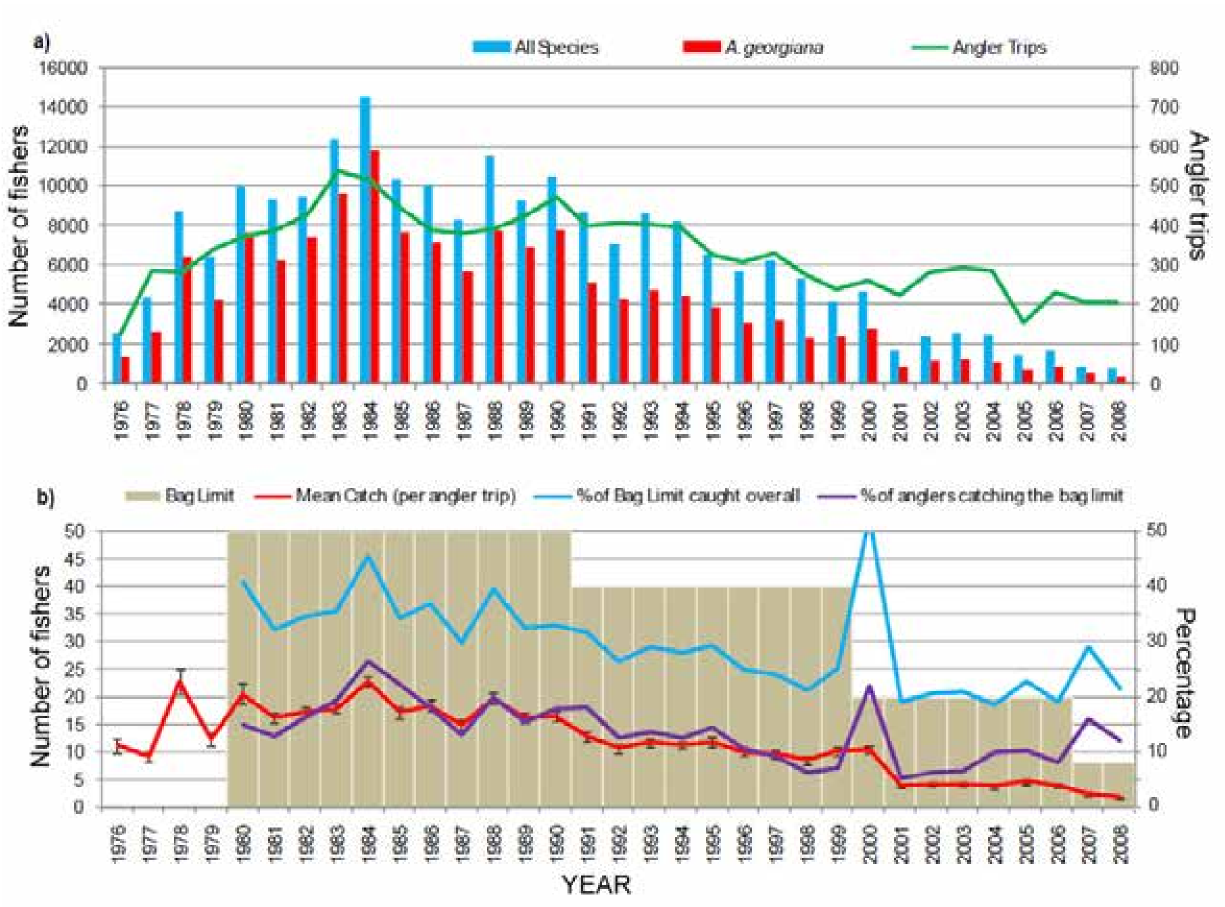


Figure 4.7. Total annual catch, total annual effort and average annual Australian herring catch rate recorded by the Melville Amateur Angling Club (MAAC) at various ocean sites in south-western WA from 1976 to 2008. **a)** the total number of fish retained (all species), total number of Australian herring retained and total number of angler trips each year; **b)** the club-imposed bag limit of Australian herring (fish per fisher per trip), the average (± s.e.) retained catch of Australian herring (number of fish per fisher per trip), the average percentage of the total Australian herring bag limit retained per trip and the percentage of angler trips that resulted in attainment of the bag limit each year. (reproduced from Pember 2009)

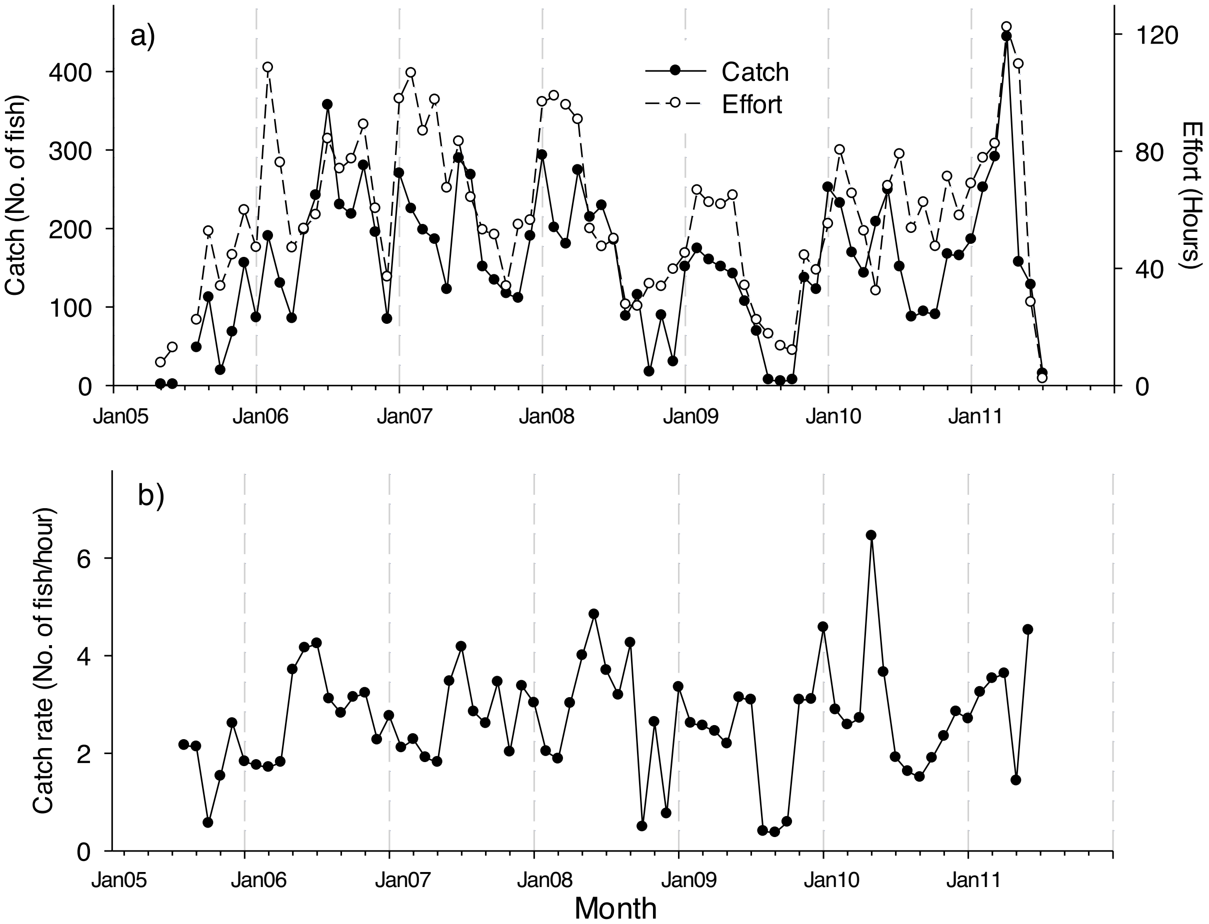


Figure 4.8. **a)** Total catch of Australian herring (retained and released), total shore-based effort (hours fished) and **b)** average monthly catch rate (fish/hour) of Australian herring reported by voluntary logbook fishers each month during shore-based fishing in the Perth area from July 2005 to June 2011.

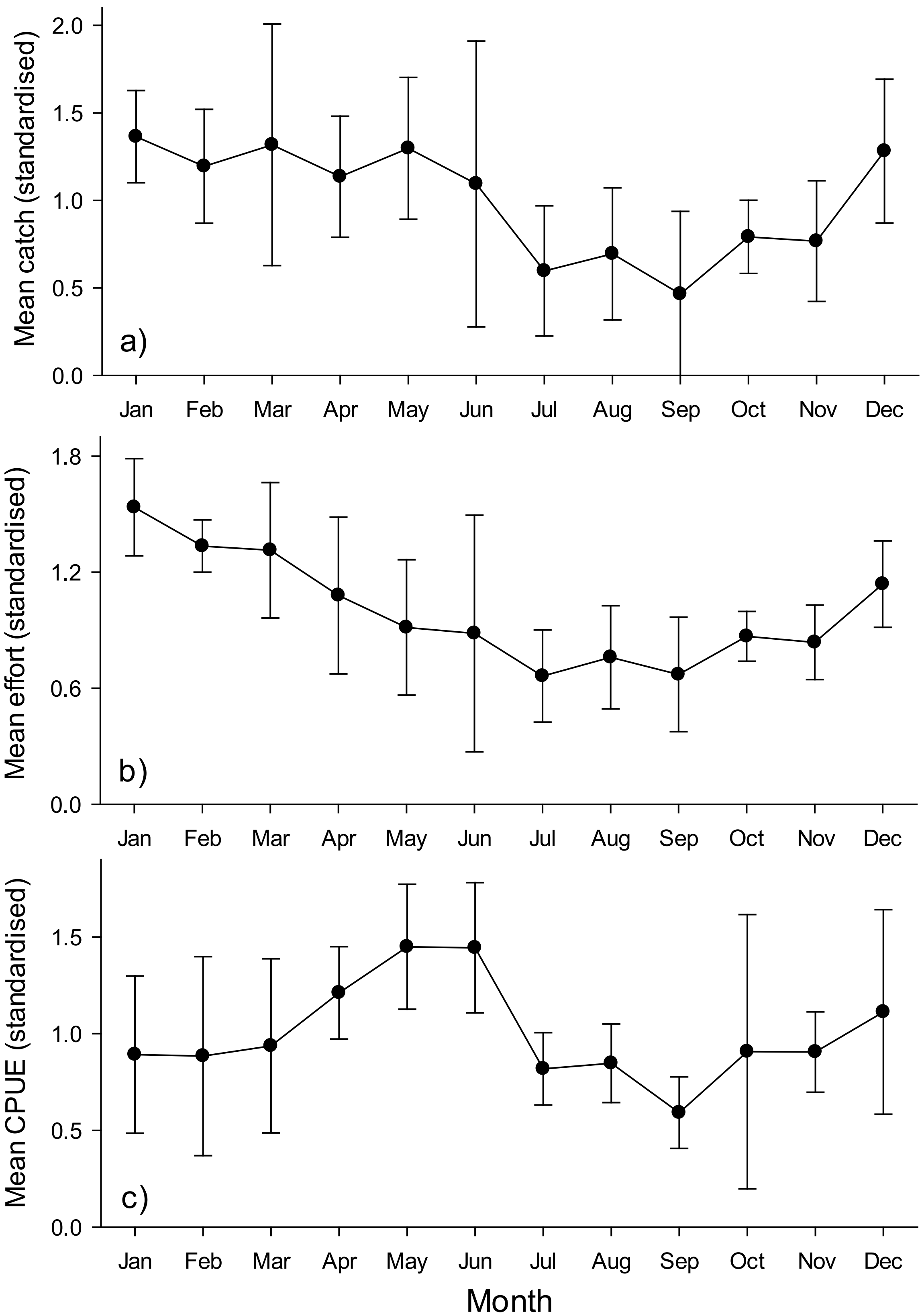


Figure 4.9. Average (± s.d.) standardised monthly **a)** catch (retained and released), **b)** effort and **c)** catch rate of Australian herring reported by voluntary logbook fishers each month during shore-based fishing in the Perth area from July 2005 to June 2011.

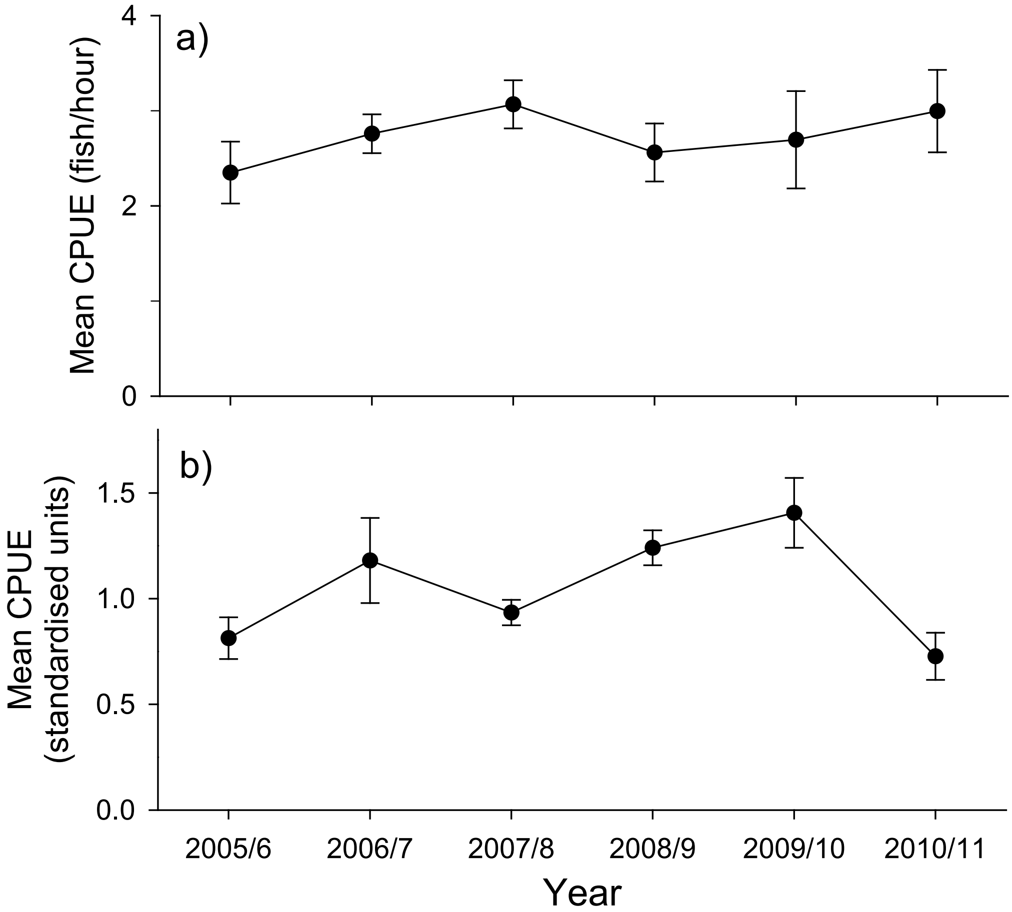


Figure 4.10. Average (± s.e.) annual catch rate of Australian herring during shore-based fishing in the Perth area from 2005/06 to 2010/11 reported by **a)** all voluntary logbook fishers and **b)** four 'avid' long-term fishers who participated in every year of the logbook program. (catches include retained and released fish)

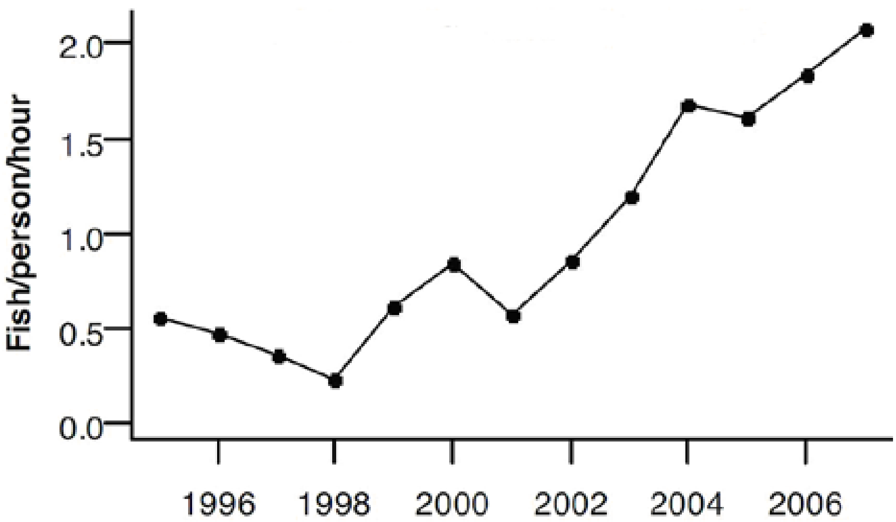


Figure 4.11. Average annual catch rate of Australian herring (retained fish only) reported by shore- and boat-based recreational fishers during interviews with Volunteer Fisheries Liaison Officers in the Metropolitan Zone from 1995 to 2007 (reproduced from Smallwood *et al.* 2010). (n = 5632 retained fished reported during 1995–2007)

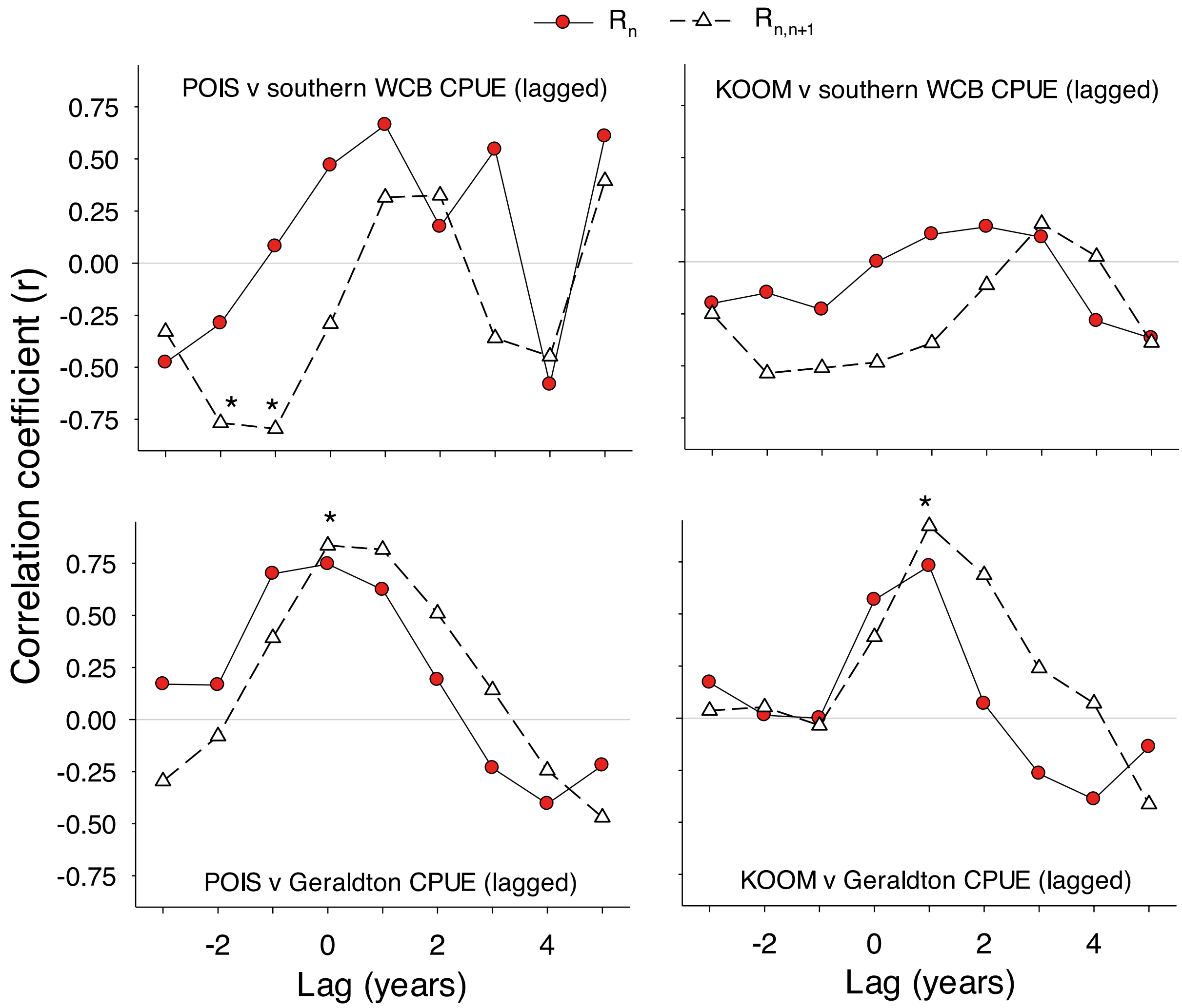


Figure 4.12. Correlation coefficients of Australian herring annual recruitment indices (R_n and $R_{n,n+1}$), at Poison Creek (POIS) and Koombana Bay (KOOM) versus annual recreational CPUE in the southern West Coast Bioregion (WCB) and in Geraldton. CPUE lagged by –3 to +5 years. Recruitment indices based on untransformed catch rates of 0+ Australian herring. (*correlation significant at p<0.01) (negative r value indicates negative correlation)

5.0 Australian herring biology and assessment

Summary

- As part of a 'weight of evidence' approach, this section presents a new suite of tools to monitor and assess the status of the Australian herring stock including determining, for the first time, estimates of fishing mortality from catch curve analyses.
- The age and size structure of Australian herring in commercial and recreational catches during 2009–11 were determined and compared against historical data collected since the 1970s. The comparisons suggest that the Australian herring population is now truncated with respect to age and size. The 2009–11 catches were dominated by 2+ and 3+ female fish despite a maximum age for this species of 12 years. This suggests that the stock has been heavily fished over the past two decades and is now predominantly comprised of young fish.
- The evidence of age truncation is supported by the estimated rate of fishing mortality for the stock, which is two times greater than the estimated natural mortality, and above the limit reference point determined for this species.
- There is also evidence that the size at first maturity has decreased over time, possibly in response to the high rate of exploitation for this species.
- The catch of juvenile (pre-spawning) fish by both the commercial and recreational sectors in Australia during 2009–11 was estimated to be high (57% in total).
- Based upon the high rate of fishing mortality, the high percentage of immature fish in the catch, and the declining mean size of fish in the catch, there is a severe risk to the sustainability of the Australian herring stock.
- To reduce the risk to stock sustainability, additional management actions will be required.

5.1 Introduction

Assessing the current and historical biological characteristics of a fish population is important in determining the stock status of that population, and in turn, supporting the sustainable management of that species. Fishing pressure can impact on the biology of the fished population through changes in age structure, growth and length/age-at-maturity (Law 2000). These impacts can reduce the overall biomass of the stock through lower egg production and quality (Berkeley *et al*. 2004).

In Western Australia (WA), the strategy used by the Department of Fisheries (DoF) to ensure the overall sustainability of finfish resources (i.e suites of species) in each Bioregion is to monitor the stock status of key indicator species representing each resource. Australian herring (*Arripis georgianus*) has been selected by the DoF as an indicator species for the nearshore finfish resource in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) (Department of Fisheries 2011).

Australian herring is a small, short-lived species, attaining a maximum size of 41 cm total length and a maximum reported age of 12[9] years ((Hutchins and Swainston 1986, Ayvazian *et al*. 2000). The species is endemic to southern Australia, inhabiting nearshore coastal waters and estuaries ranging from Shark Bay on the west coast of Australia to Port Phillip Bay (Victoria)

9 Ayvazian *et al*. (2000) previously reported 13 years but a review of the data has updated the maximum age to 12 years.

on the east coast (Hutchins and Swainston 1986). Australian herring spawns annually during autumn, mainly between Perth and Augusta on the lower west coast of WA. Larvae and juveniles are transported southwards and then eastward along the southern coast by prevailing currents and winds before settling during winter and spring into nursery habitats in sheltered nearshore waters in WA, South Australia (SA) and Victoria. At two to three years of age, maturing fish undertake a pre-spawning migration back to the spawning ground on the southwest coast of WA during February to April (Ayvazian *et al*. 2000). Tagging studies of herring indicate that there is no return (post-spawning) migration, and thus the spawning stock is believed to occur only in WA (Ayvazian *et al*. 2004).

Australian herring is an important commercial and recreational species in southern Australia. The majority (~ 75%) of the commercial and recreational catch occurs in WA, with the rest in SA and a negligible amount in Victoria. In WA, the majority (~ 75%) of the commercial catch is taken within the SCB by the South Coast trap net fishery, with the remainder taken by various other commercial netting fisheries (see Section 3).

In WA, Australian herring is the most landed finfish species by both shore- and boat-based recreational fishers (see Section 4). The WCB is the main recreational fishery area for Australian herring, where approximately 84% of the total state recreational catch is taken using line methods. The majority (~ 67%) of the WCB recreational catch is taken by shore- and estuary-based fishing (Henry and Lyle 2003).

There is a distinct seasonal pattern in fishing activity within both fishing sectors. The commercial sector mainly targets the pre-spawning migration of the species, with approximately 84% of the WA catch landed from March to May (see Section 3). Catch and effort in the recreational sector peaks during summer and autumn, encompassing pre- and post-spawning periods (see Section 4).

In recent years, Australian herring has shown signs of reduced abundance, which has generated concerns from some experienced commercial and recreational fishers about its sustainability. Since the late 1990s, the WA commercial catch and catch rate have declined and recruitment has been relatively low in most years (see Sections 2 and 3). A declining trend since 2000 was also evident in the commercial catch in SA. However, these negative signals have been primarily observed within southern regions. Since the degree of connectivity between west and south coast components of the stock are uncertain, it is unclear what these trends are inferring about the total stock abundance and stock status.

Recent management changes designed to reduce targeting of demersal fish in the WCB may result in a shift in recreational effort towards nearshore species such as Australian herring. Given the current uncertainty about stock status, any increase in fishing effort and catch is of concern. The level of assessment therefore needs to be improved to provide more certainty about current stock status and to ensure that future impacts can be monitored and adequately managed.

An age-structured population dynamics model was previously developed to assess the stock status of Australian herring (Wise and Hall 2000). This model required numerous assumptions to overcome the gaps in knowledge that existed at that time, including information about stock structure, biological parameters and recreational catch levels. The model output was inconclusive and it was subsequently recognised that knowledge gaps would need to be addressed and a new model structure would be required before a modelling approach could again be applied (B. Wise pers. comm.).

To address gaps in knowledge about stock structure, differences in the catch composition (age, length and sex structure) spatially (between Bioregions and management zones), temporally (years, months) and by fishing sectors (methods) need to be quantified. Extensive temporal and spatial sampling is also required to estimate biological parameters for all components of the stock. The DoF has been collecting biological information on Australian herring since the 1970s, albeit on an irregular basis. The majority of this data was collected through monitoring the major commercial fishery (South Coast trap net), with occasional collections from other more minor commercial fisheries as well as from the recreational sector.

In this study we investigate the historical and current age, length and sex structure of the WA Australian herring population. We use these data to determine trends in total and fishing mortality levels and to estimate key biological parameters. Total mortality has been identified as one of the key parameters necessary to accurately assess stock status (Gedamke *et al*. 2008, Craine *et al*. 2009), and is most commonly estimated in fish populations by applying a 'catch curve analysis' to age structure information (Dunn *et al*. 2002, Simpfendorfer *et al*. 2005). Determining mortality in fish populations by this method can be problematic since the required assumption of constant recruitment is rarely met. In the case of Australian herring, empirical data demonstrates major annual variations in recruitment (see Section 2). An assumption of constant natural mortality may also be violated, especially in relatively short-lived species such as Australian herring. Despite the inherent uncertainties, the catch curve method is still the best available for determining mortality levels in Australian herring.

In this study, mortality levels are considered in conjunction with other indicators of stock status and biological characteristics, to produce a 'weight-of-evidence' assessment of the status of Australian herring.

The key project output in this section is an investigation of the contemporary and historical stock status of Australian herring. The specific objectives were to:

1. Evaluate the historical and current length and age structure of the main fished populations,
2. Determine the sex-based characteristics of the fished populations,
3. Determine spatial and temporal spawning characteristics,
4. Determine growth and reproductive parameters,
5. Conduct an age-based assessment of fishing mortality and determine appropriate biological reference points, and
6. Develop a sampling strategy to ensure the collection of a representative sample of the age structure of the population for future monitoring purposes.

5.2 Materials and methods

5.2.1 Study location and sampling methods

Historical sample collection (1974–2009 June)

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) recorded length data of Australian herring in WA from 1940 to 1955. In total, 18,863 fish were measured (Western Fisheries Research Committee 1973). All Australian herring sampled during this period were collected from the commercial South Coast trap net fishery (R. Lenanton pers. comm.). The raw data were unavailable for analysis for this assessment, although, a single modal peak of 210 millimetres (mm) fork length (FL) (~ 244 mm total length (TL)) was documented for the commercial catch during this period (Western Fisheries Research Committee 1973).

The DoF has intermittently collected biological and age composition data for Australian herring since the 1970s. Some data collection was for specific research projects on age and reproduction (Lenanton 1978), stock assessment (Ayvazian *et al*. 2000), stock structure (Ayvazian *et al*. 2004) and juvenile recruitment (Gaughan *et al*. 2006).

In the 1970s and 1980s, scales were used for ageing Australian herring although otoliths were also occasionally collected during this period. From the 1990s, the use of otoliths for ageing Australian herring was adopted by the DoF. All otoliths collected prior to the current project were aged or re-aged by the current readers for data consistency. In addition to the DoF historical data collection, access to the ageing and biological data from a University honours project (Fairclough *et al.* 2000a, 2000b) collected during 1996–1999 as part of the DoF stock assessment study (Ayvazian *et al*. 2000) were provided for this assessment. The same methods were used to estimate length- and age-at-maturity, growth and mortality for the historical sample collection and the current sample collection to allow for comparability between collection periods.

The amount of biological data collected varied among projects but in most instances TL and/or FL, weight, sex, gonad weight and gonad stage were recorded. For most of the older records, only FL was recorded and TL was determined via $TL = 6.415 + (1.13 \times FL)$ (Burton 1982).

While the location and source were usually recorded for these historical samples, there was occasionally some uncertainty over the capture method and the representativeness of the sample (i.e. whether or not sub-sampling or grading was performed). For example, some commercial samples contained a large number of juvenile fish (<170 mm) and it was not always clear if these samples were a true representation of the commercial catch on that day, or if juveniles were retained for specific research purposes. A commercial legal minimum length (LML) of 180 mm for Australian herring existed from 1975 to 29 March 2011, so generally very few fish below this size were collected from this sector during this period. However, to reduce bias in estimates of total and fishing mortality, only fish ≥170 mm TL were used. A LML of 180 mm for the recreational sector was removed in 1991. However, the DoF collected very few fish from this sector prior to this year so virtually all the length and age samples from the recreational sector were comparable.

The fishing methods used in the commercial and recreational fisheries for Australian herring have changed little over time so recent and historical samples were assumed to be comparable if the method was known. While a significant amount of historical data has been compiled on this species, only age data that were considered to be representative of the stock are used here to assess fishing mortality.

Length data of Australian herring were also collected from a tagging study conducted in 1997–98 (Ayvazian *et al.* 2004). A total of 18,750 length measurements were recorded but as all fish were tagged and released, no additional biological data (e.g. sex or age) were available. All fish were sampled from a commercial trap net at two sites in the SCB in 1997, and one in each of the SC and WCBs in 1998. Market sampling of the commercial catch during 1999–2002 recorded lengths for 7,123 Australian herring, which were predominantly caught from estuaries on the SCB and WCB. As only length data was recorded from these two projects, this information is used here only to document the length structure of the commercial catch at that time.

Current sample collection (2009–11)

Samples of Australian herring were collected from the south-west of WA in each month between July 2009 and June 2011. Sample collection for this species is currently ongoing, although the stock assessment in this report used data from the 2009/10 and 2010/11 financial years only. Collections during this period were taken from the two spatial assessment/management areas in WA where Australian herring catches have been recorded in the past (WCB – Kalbarri to Augusta, and SCB – Augusta to WA/SA border) (Fig. 5.1). The biology, age structure and estimates of fishing mortality for the commercially and recreationally fished populations in these two Bioregions were assessed separately.

To collect an annual representative sample of the age structure of Australian herring, a minimum sample of 30 fish per month was sought from both the commercial and recreational fishing sectors in the SCB and in each of the four management zones in the WCB (Fig. 5.1). An investigation into the methodology for ongoing age monitoring of scalefish fisheries in WA (Craine *et al*. 2009) recommended a minimum sample size of ~ 300–500 in order to generate a representative age structure from which to estimate total mortality with sufficiently tight confidence limits using 'catch-curve analysis' methods. Thus, a minimum of 30 fish per month per zone was enough to ensure a minimum of 360 fish for each 12-month period.

Commercial samples were purchased directly from fishers or processors and comprised whole fish. As the South Coast trap net fishery lands the majority of the commercial catch of Australian herring in WA, representative samples were collected from this fishery. In the WCB most of the commercial catch of Australian herring is taken by the South-west Beach Seine Fishery (mainly Geographe Bay), Cockburn Sound Fish Net Fishery (Cockburn Sound) and the West Coast Estuarine Fishery (mainly Peel-Harvey estuary) and each of these fisheries were sampled. Commercial samples came from a variety of methods; trap nets from the South Coast fishery (mesh size typically 28–46 mm) and haul nets (28–46 mm), beach seines (28–46 mm) and gill nets (mainly 54–58 mm) from the other fisheries (Ayvazian *et al*. 2000) (see also Section 3). With the exception of the gill net method, which has historically taken a small percentage of the total catch, the type of fishing nets and small mesh sizes used by these fisheries results in uniform selectivity of all size (and age) classes in the population above the recruitment size (~ >170 mm and two years of age). Fishers operating in these areas were asked to provide a random (ungraded) sample of at least 30 fish per month, except for the South Coast trap net fishery where 50 fish per catch day was requested due to the short fishing season (~ one month).

A request for Australian herring frames from recreational anglers was made through media releases, website promotion, tackle store and fishing magazine advertising. To assist with the collection of a representative sample from the recreational sector, prize incentives (donated by members of the fishing industry) were offered to encourage donations from a wide range of fishers. Recreational fishers used traditional line angling methods. Samples donated from the recreational sector were mostly fish frames (fillets removed) so total weight of these fish could not be recorded.

Juvenile Australian herring were collected by fishery-independent surveys using a 61 metre beach seine net with mesh sizes of 8 mm in the bunt and 22 mm in the wings (see Gaughan *et al*. 2006 for methodology). Age estimates from these samples were used for the determination of growth rates and back calculation of birthdates.

For each fish, the TL and FL were recorded to the nearest mm. Total weight (when whole fish were collected) was recorded to the nearest 0.1 gram (g). Gonads were removed and weighed to the nearest 0.01 g, sex was determined and each gonad was assigned to a macroscopic stage (Section 5.2.3). Otoliths were removed, cleaned and stored in paper envelopes.

Representative Sample Study (2010)

To establish if a representative sample of the age structure is obtained, an investigation was conducted into the representativeness of a one-off monthly sample. One hundred fish were requested from every fishing day from a single commercial fisher who was fishing in the same location and using the same method (haul net with panels of 25, 38 and 50 mm mesh) over a period of one month just prior to the spawning period in 2010 (late April to late May). Ten fishing days occurred in this period. Variation in catch composition (mean length, mean age and sex ratio) was assessed between the sampling dates. One-way analysis of variance (ANOVA) was used to assess differences in mean length and age. Type 3 sums of squares were used for testing significance in the ANOVAs since there were an unequal number of replicates per treatment. A χ^2 goodness-of-fit test (Zar 1984) was used to assess differences in sex ratio.

5.2.2 Age and growth

Juvenile age and growth

The otoliths of 103 juvenile Australian herring (TL <136 mm) from the Mid-west and South-west Zones of the WCB and the South and South-east Zones of the SCB were processed to estimate age in days. Data were investigated for temporal and spatial variation in growth rates of Australian herring and used to generate a growth equation to assess ages and birthdates of new Australian herring recruits.

Adult age and growth

The ageing method used in this study was based on the methods described by Fairclough *et al.* (2000a). Fairclough *et al.* (2000a) aged Australian herring by enumeration of validated annual opaque zones visible in whole sagittal otoliths.

While a large number of scales collected from Australian herring in the 1970s and early 1980s were available, these were not used because age estimates from enumeration of scale increments are consistently lower and less precise at all ages, compared with counts from whole otoliths (Fairclough *et al.* 2000a).

Otoliths were read whole after being placed in a small black dish and covered with methyl salicylate. Otoliths were viewed under a dissecting microscope (Nikon SMZ745T) using reflected light. Images were captured using a digital camera (Jenoptik ProgRes® Model C7). The number of opaque annuli was then recorded. A marginal increment category was assigned where 0: opaque zone on edge; 1: <50% translucent edge; 2: >50% translucent edge. A readability index was assigned where 1: poor, 2: fair, 3: good. All otoliths assigned a poor readability were not included in the age analysis. A detailed written description of the methodology used to age Australian herring was compiled (DoF unpublished) and a reference collection (including digital images) was developed for training and quality control purposes.

Fish age was calculated in months based on the count of opaque zones, the marginal increment category, the date of collection and the universal birth date of 1 June. An average birth date of 1 June was assigned to Australian herring by Fairclough *et al.* (2000a) based on monthly trends in gonadosomatic index (GSI), various macroscopic gonad stages and ooycyte development. This birth date was supported by additional data collected in this study (GSI trends and back calculation of birth dates by enumerating daily rings in the otoliths of juvenile fish).

Growth was determined by fitting the von Bertalanffy growth functions (VBGF) (von Bertalanffy 1938) to length-at-age data for each sex separately for both Bioregions (pooled data) and each Bioregion separately, using non-linear least-squares regression. The von Bertalanffy growth equation used was

$$L_t = L_\infty (1 - e^{-k(t - t_0)})$$

where L_t is the predicted mean length (TL in mm) of fish at age t (years), L_∞ is the asymptotic mean length (mm) – the mean length the fish would reach if they were to grow indefinitely, k is the growth coefficient (year^{-1}), or the rate at which L_∞ is approached, t is the estimated age (years) and t_0 is the hypothetical age (years) at which length is equal to zero. Since few Australian herring <170 mm TL were collected from the commercial or recreational sector, the VBGF was fitted with the addition of juvenile fish collected using fishery independent methods. Australian herring <120 mm TL could not be sexed macroscopically, so the lengths at age of these 0+ fish were added equally to the female and male data sets that were used for determining von Bertalanffy growth equations. Growth curve parameters were compared between sexes, Bioregions and years by using a t-test.

Mean length-at-age (by month) (with standard error) was calculated separately for each sex for the WCB in 2009–11. There was insufficient data for the SCB.

5.2.3 Reproduction

A gonadosomatic index (GSI) for each fish was calculated as

$$GSI = W_1/W_2 \times 100$$

where W_1 is wet weight of the gonad (g) and W_2 is total wet weight of the fish (g).

Gonads were staged macroscopically using criteria based on Laevastu (1965). These criteria were also used historically by other researchers at the DoF and Fairclough *et al.* (2000b) when describing the reproductive biology of Australian herring. Gonads were assigned to one of the following macroscopic stages:

1. Virgin/immature
2. Maturing virgin/resting adult
3. Developing
4. Partially developed
5. Pre-spawning
6. Spawning
7. Spent
8. Recovering spent

To establish the timing of spawning, mean monthly GSIs for each sex and each Bioregion were calculated using values from all fish ≥ L50 (see below).

The lengths at which 50% (L50) and 95% (L95) of Australian herring became mature, and the standard error, was estimated for each sex by fitting a logistic function to the proportion of mature fish (defined as possessing gonads at stages III–VIII during the spawning period (April – June)) in 10 mm size categories. Similarly, the proportion of mature fish in each year class was used to estimate the ages at which 50% (A50) and 95% (A95) of female and male fish first became mature, and the standard error. A regression analysis including dummy variables was used to determine whether the length- and age-at-maturity for each sex differed significantly between Bioregion or between years.

A χ^2 goodness-of-fit test was used to assess whether the sex ratios in samples collected by commercial netting and recreational angling were significantly different from parity.

The number of juvenile fish caught by the commercial and recreational sector ('juvenile retention') was defined as the proportion of fish in samples below the mean length-at-maturity (L_{50}) for each sex. Juvenile retention was also estimated by applying the percentage of fish within each age class possessing mature gonads during the spawning period against the age structure sampled. For example, no fish in age classes 0 and 1+ were considered mature, only a proportion of those in age class 2+ were considered mature and all fish in age classes ≥ 3+ were considered to be mature.

5.2.4 Mortality

Total mortality (Z)

Estimates of the instantaneous rate of total mortality were calculated from catch-at-age data using the 'catch curve analysis' equation (Ricker 1975):

$$log_e (N_t) = log_e (N_0) - Zt ,$$

where N_t is the number of Australian herring sampled at age (t) years, Z is the total mortality and N_0 is the number of Australian herring in the zero age class.

The catch curve procedure involved fitting a linear regression equation to the natural logarithm of the frequency of fish from the most abundant age class in each sample (age 2 or 3), up to the maximum age from that sample. The most abundant age class plus 1 year is sometimes used used as the starting point of the regression in a catch curve analysis, but was not used here due to there being a small number of age classes for most samples. Therefore, the most abundant age class was assumed to be fully selected by these fisheries. The inclusion of as many age classes as possible is likely to produce the most accurate estimate of total mortality with the lowest error (Simpfendorfer 1999). In addition, not including all age classes might over estimate total mortality (Wise *et al*. 2007).

The catch curve method assumes that recruitment and mortality are constant through time. However, the Australian herring stock is known to experience variable annual recruitment (Section 2). While the linear catch curve method for determining the instantaneous rate of total mortality has been applied to other short-lived species (e.g. longtail silver biddy (*Gerres longirostris*): maximum age 7+ (Grandcourt *et al*. 2006); stout whiting (*Sillago robusta*): maximum age 5+ (Butcher and Hagedoorn 2003); Australian sharpnose shark (*Rhizoprionodon taylori*): maximum age 7+ (Simpfendorfer 1999); and dusky flathead (*Platycephalus fuscus*): maximum age 11+ (Gray *et al*. 2002)), it has been recommended for short lived species that this method should be applied to aggregated data over consecutive years, and sample sizes need to be large (enough to be representative of the population) for greater precision (Fisher *et al*. 2011). Therefore, catch curve analysis was performed only on data where consecutive years could be pooled. However, this approach is still likely to underestimate mortality (Fisher *et al*. 2011), which suggests that true estimates of total mortality are likely to be actually higher than estimated here. This means advice on stock status is likely to be biased to be more optimistic than the actual status.

A catch curve analysis was performed for each Bioregion, fishing sector and sampling period. Preliminary analyses using Kolmogorov-Smirnov tests (KS-test) showed that age data from the two Bioregions and two sectors were significantly different and therefore could not be aggregated. In addition, while it may be possible to collect representative samples from each of these Bioregions and sectors, it is not possible to determine the appropriate weighting of these groups needed to pool these data and generate an overall estimate of total mortality. Sexes were combined after preliminary analyses demonstrated that total mortality estimates were similar between male and female age samples. Preliminary analysis using KS-tests showed a significant difference between management zones within the WCB. However due to the paucity of data in some zones, it was not always possible to generate separate estimates of total mortality by zone so the age data were aggregated among years for the WCB in these instances. To produce a more robust estimate of total mortality, only samples of >300 ages were used (note: a 'sample' may comprise consecutive years of data). Bootstrap with replacement using 2,000 runs was used to determine upper and lower 95% confidence intervals and median estimates of total mortality.

Natural mortality (M)

Estimating natural mortality has been identified as one of the most difficult and critical elements of a stock assessment (Hewitt *et al*. 2007). A number of approaches have been developed to estimate natural mortality, including using the maximum age of a species (Hoenig 1983), growth parameters (Pauly 1980) and reproductive effort (Gunderson and Dygert 1988). Initially, natural mortality was estimated in this study from the average of the values derived from the above three methods. However, the Pauly (1980) method gave an estimate of natural mortality that exceeded that of the others. This method has been suggested to overestimate natural mortality (Ralston 1987, Russ *et al.* 1998) so was not used here. The more commonly accepted method of Hoenig (1983) was therefore used.

The instantaneous rate of natural mortality (M) was estimated by the general regression equation method of Hoenig (1983) for all taxa, where;

$$\log_e \mathrm{M} = 1.44 - 0.982 \log_e \mathrm{t}_{max}$$

where t_{max} is the maximum age in years either observed in the stock or found in the literature. This method assumes that 1% of individuals reach the maximum attainable age of the species. Hoenig's method is frequently applied for estimations of natural mortality (Jennings *et al*. 2001, Hewitt and Hoenig 2005) and has been used recently to estimate natural mortality for other short-lived, temperate species (Kendall *et al*. 2009, Fisher *et al*. 2011).

Fishing mortality (F)

The instantaneous rate of fishing mortality (F) was calculated by subtracting natural mortality (M) from total mortality (Z), derived from age-based catch curves ($F = Z - M$). A range of F was estimated by subtracting the upper and lower 95% confidence intervals of Z.

5.2.5 Yield and egg per recruit

Yield per recruit (YPR) and egg per recruit (EPR) models were used to compare the relative vulnerability of the Australian herring stock at various levels of F. YPR models have traditionally been used to predict optimal rates of harvest, corresponding to simulated changes in F, and to avoid the prospect of growth overfishing (where the relative yield from catches starts to decline with increasing F). EPR models have traditionally been used to predict effects of simulated changes in F on relative rate of egg production of the fished stock, and to avoid the prospect of recruitment overfishing (where the relative egg production has fallen below some critical reference level).

The YPR model used for Australian herring was:

$$YPR = Fe^{-Mt_r}\int_{t_r}^{t_{\max}} ([w_{male,t}p_{male,t} + w_{female,t}(1 - p_{male,t})]e^{-(M+F)(t-t_r)})dt$$

The EPR model used for Australian herring was:

$$EPR = \sum_{t=0}^{\infty} N_{female,t}Pmat_t fec_t$$

where: N_t is the population size at age t calculated from

$$N_{sex,t+1} = N_{sex,t} e^{-M - S_{sex,t} F},$$

and F is fishing mortality, M is the natural mortality, t is the fish age (yr), t_r is the age (yr) at full recruitment assuming "knife-edged" selectivity, t_{max} is the assumed maximum age (yr) in the fish population, *sex* is either female or male, $p_{sex,t}$ is the proportion of fish at age t for each sex , $w_{sex,t}$ is the average weight at age t for each sex, $Pmat_t$ is the proportion of females mature at age t, fec_t is the fecundity at age t relationship assumed to represent relative egg production and $S_{sex,t}$ is fishing selectivity at age t for each *sex*. For simplicity, this is assumed to be a knife-edged selectivity with full recruitment (S_t = 1) from age t_r.

Importantly, these per-recruit analyses represent very simplistic predictions of how the fish stocks might respond to changing F, and ignore the potential influence of other important aspects of population dynamics, such as the relationship between spawning stock size and subsequent recruitment, annual recruitment variability, environmental changes and other external influences. These analyses also do not assess data sampled from the stock over time, and so cannot model or test for such processes to account for their influence(s) on estimates of stock status and inferred inherent vulnerability.

The YPR and EPR were calculated using a range of different inputted levels of F and the calculated values of F (using the inputted value of M) that corresponded to the target, threshold and limit reference points currently adopted by the DoF (see Table 1 in Wise *et al*. 2007). Given the uncertainty around the proportion of fish in the WCB fishery (which represents the breeding stock) that are derived from southern (SCB or SA) nurseries or local (WCB) nurseries, two scenarios were compared: 1) all fish in the breeding stock were derived from SCB nurseries and 2) all fish in the breeding stock were derived from WCB nurseries. The source of recruitment has implications for the productivity and susceptibility of the stock, due to different growth rates and ages at which fish become vulnerable to capture in each Bioregion (Table 5.1).

Fish derived from SCB nurseries were assigned an age-at-first capture of 2 years. Fishery-independent estimates of growth indicate that SCB juveniles attain a length corresponding to the minimum length in fishery landings (i.e. 180–200 mm) at age 2+ years. Also, the minimum age in SCB landings is typically two years (i.e. assumed t_r = 2 yr). Fish derived from WCB nurseries were assigned an age-at-first capture of 1 year (i.e. assumed t_r = 1 yr). In the WCB, juveniles grow more rapidly than those in the SCB and attain the minimum length in fishery landings at age 1+ years. Yet, the minimum age in WCB landings is typically two years. This apparent contradiction is believed to be due to a dominance of SCB recruits in WCB landings. The available evidence suggests that the majority of fish captured in the WCB are derived from southern nurseries (the spawning strategy of this species maximises the chance of the advection of eggs and larvae to the SCB or SA, and minimise retention in the WCB; highest abundances of 0+ herring have been observed in southern areas; seasonal variations in the length composition of landings (Fig. 5.16) suggest a very high proportion of fish from southern nurseries recruiting to the WCB annually).

A widely regarded limit to indicate a significant prospect of recruitment overfishing is where the spawning stock biomass is reduced to 20% of the estimated unfished virgin level (Goodyear 1993, Mace and Sissenwine 1993). Accordingly, for the EPR analyses we assumed that 20% of the unfished EPR indicated a significant prospect of recruitment overfishing at that simulated level of F. For YPR analyses, the value of F corresponding to the calculated YPR where the rate of change of that function became 10% of its value near the origin, (referred to as $F_{0.1}$ (Deriso

1987)), was referred to as a level of F beyond which the prospect of growth overfishing was likely to occur. This is generally preferred to the calculated F at which the maximum YPR is achieved (F_{max}) (Deriso 1987).

Biological reference points

Biological reference points were developed based on the ratio of fishing mortality (*F*) to natural mortality (*M*). A sustainable reference point of 2/3 *M* (0.67M) has been widely applied to both longer-lived species (i.e. longevities > 30 years) (Newman and Dunk 2002, Wise *et al*. 2007, Fisher *et al*. 2011) and shorter-lived species (i.e. longevities <12 years) (Amezuca *et al*. 2006, Grandcourt *et al*. 2006, Fisher *et al.* 2011). This reference point has been suggested to be conservative and in line with a precautionary approach (Robinson *et al*. 2011).

In short-lived pelagic fish species, exploitation rates above natural mortality (*F>M*) over long periods (e.g. 10 years) result in stock biomass declines and are considered unsustainable (Patterson 1992). However, exploitation rates of 2/3 M have also been linked to stock declines in these species, suggesting that the exploitation rate of small-sized, short-lived fish stocks should not exceed 2/3 *M* (Patterson 1992). An alternative 'target' reference point for fishing mortality of 0.75 or 0.80 *M* has been suggested in data poor fisheries (Thompson 1993, NMFS 1996 in Gabriel and Mace 1999).

Target, threshold and limit reference points developed by the DoF for species of inshore demersal fish in the WCB (Wise *et al*. 2007) and Gascoyne Coast Bioregion (Marriott *et al*. 2010) were adopted here for this species (Table 5.2).

In this study, the 'target' level (=2/3 x *M*) is the point at which fishing mortality is considered to be sustainable for the species. The 'threshold' level (=*M*) is a precursor for management and research action to avoid the limit from being reached, and the 'limit' level (=1.5 x *M*) signifies the point at which fishing is considered to be unsustainable and the advice would be that effort and/or catches should be reduced significantly.

5.3 Results

5.3.1 Sample collection

From 1974 to June 2009, a total of 24,898 Australian herring were measured and 13,189 otoliths collected from the commercial and recreational sectors by the DoF. The majority of otoliths were collected from the SCB commercial sector (59.8%), with the remainder in the WCB recreational (18.7%), WCB commercial (13.0%) and SCB recreational (8.6%) sectors (Table 5.3).

Samples from the commercial sector in the SCB were mainly obtained from the South Coast trap net fishery, which is the major commercial fishery in WA. In the WCB, commercial samples were mainly obtained from the South-west Beach Seine Fishery operating in Geographe Bay (South-west Zone). Recreational samples from the WCB were predominantly from the Metropolitan and South-west Zones. In the SCB most of the historical recreational samples were from either Albany (South Zone) or Esperance (South-east Zone).

During the 2009–11 sampling period, a total of 4,486 Australian herring were collected from the commercial sector and 4,532 from the recreational sector. An additional 593 Australian herring (mainly juveniles) were also collected by fishery-independent sampling. A total of 8,937 otoliths were examined for age determination, of which 141 (0.02%) were rejected as poor (unreadable).

The majority of samples from the WCB commercial sector during 2009–11 came from the Metropolitan Zone (61%), essentially from Cockburn Sound and the Peel-Harvey estuary. In the SCB, most commercial samples were collected from the South Coast trap net fishery. Other SCB commercial samples were collected from the smaller estuarine and ocean beach seine commercial fisheries.

Samples collected from the recreational sector had a greater spatial distribution, with the Metropolitan Zone providing 45%, the Mid-west Zone 28%, the South-west Zone 19%, the South Zone 7% and the Kalbarri Zone <1% of all samples. In 2009–11, more than 116 recreational fishers donated a total of 4,532 Australian herring samples. The representativeness of these donated frames was verified by comparison with the length composition of herring reported by volunteer logbook fishers and observed during onsite recreational fishing surveys (Appendix 1).

During the Representative Sample Study, samples were collected on 10 separate days over a one month period (28 April to 25 May 2010). In total, 933 Australian herring were collected. These additional age samples were not used in the assessment of fishing mortality so as not to bias estimates of mortality.

5.3.2 Length structure

The largest Australian herring recorded by the DoF was 391 mm (TL), caught in Wilson Inlet (SCB: South Zone) in 2001 (sex unknown). The largest female and male recorded were both caught in Wilson Inlet. The female was 390 mm, caught in 1998 and the male was 325 mm, caught in 2009. The largest ocean caught fish was 356 mm (SCB) in 1995, sex unknown. The largest ocean caught female was 336 mm (SCB) in 2009. The largest ocean caught male was 304 mm (SCB) in 1977. In the WCB, the largest Australian herring reported was a 355 mm female caught in the South-west Zone in 1998. The largest male reported in the WCB was 297 mm in the Mid-west Zone in 2010.

The mean length of Australian herring caught in estuaries was often greater than those caught in ocean waters in both Bioregions. For example, in 2001, the mean length of fish sampled from commercial catches in estuaries on the SCB ranged from 264 to 278 mm, whereas the mean length in the ocean catch of the South Coast trap net fishery was 239 mm. Similarly, in the WCB, the mean length of the commercial catch sampled in the Swan-Canning estuary was 261 mm in 2001, while the mean length from samples collected in the ocean in Cockburn Sound (just outside the mouth of the Swan-Canning estuary) was 230 mm.

During 2009–11, Australian herring ranged in size from 155 to 374 mm in commercial landings and 97 to 357 mm in recreational landings, although for both sectors, landings were predominantly between 180 and 270 mm (Fig. 5.2). Females ranged from 152 to 374 mm, and males ranged from 166 to 297 mm. In fishery-independent sampling, Australian herring ranged from 51 to 275 mm.

In the WCB, the mean length in commercial landings was greatest in the Mid-west zone (250 mm) and lowest in the South-west zone (228 mm), whilst the reverse occurred in recreational landings, with the greatest mean length recorded in the South-west zone (246 mm) and the lowest in the Mid-west zone (227 mm) (Fig. 5.3). The mean length of the WCB recreational Metropolitan Zone catch was 230 mm (Fig. 5.3). This mean length was exactly the same as that observed in recent shore-based surveys (Smallwood *et al*. 2011a) and from recreational angler logbooks (Appendix 1).

The mean length of each sex was larger in the WCB than the SCB. Within each Bioregion, the mean length of females was larger than males. The mean monthly length of females was greater than males in nearly all months. The lowest mean monthly length by Bioregion and sector for both sexes generally coincided with the pre-spawning period for the species (March to May) (Fig. 5.4).

During the Representative Sample Study, the mean length of females was greater than males each day (Fig. 5.5). The lowest mean lengths for females and males were 213 mm and 205 mm, respectively. The largest mean lengths for females and males were 240 mm and 225 mm, respectively.

The proportion of Australian herring >240 mm in the WCB commercial catch declined from 37% in 1996–98 to 13% in 2009–11 (Fig. 5.6). Similarly, the proportion of fish >240 mm in the WCB recreational catch declined from 42% in 1996–98 to 36% in 2004–06, and to 25% in 2009–11 (Fig. 5.7). The SCB commercial and recreational catch also displayed a similar declining trend in the proportion of large fish. In the South Coast trap net fishery, the proportion of fish >240 mm was 56% in 1983–85, 39% in 1994–96 and 37% in 2009–11 (Fig. 5.8). In the SCB recreational catch (South Zone), the proportion of fish > 240 mm was 50% in 1996–98 and 37% in 2009–11 (Fig. 5.9).

5.3.3 Age structure

The oldest Australian herring recorded was a 12.0 year-old female, which was caught in Wilson Inlet (SCB) in 1997 (Table 5.4). This fish was previously reported as 13.0 years (Ayvazian *et al.* 2000), but a re-analysis by this study has confirmed the revised age. The oldest ocean caught female was 10.5 years, caught in Jurien (WCB: Mid-West Zone) in 1980. The oldest male reported was 9.1 years, caught in the ocean at Cockburn Sound (WCB: Metropolitan Zone) in 1997. The oldest estuary caught male was 8.4 years, caught in Wilson Inlet in 2010. In addition, an 11.4 year-old male was reported in Wilson Inlet during 2005–2007 by Potter *et al*. (2011).

The oldest Australian herring collected during 2009–11 was a female at 9.8 years, caught at Hamelin Bay (WCB: South-west Zone). The oldest males (n=2) were 8.4 years caught at Augusta (WCB: South-west Zone) and Wilson Inlet (SCB: South Zone).

The vast majority (96%) of Australian herring sampled from the commercial South Coast trap net fishery in the three year period, 2009–11, were aged 3 years or less. The catch in this fishery was comprised mainly of 2+ fish, which represented 71% of the samples. The majority (86%) of the SCB recreational catch in 2009–11 was also ≤3 years of age. The catch by this sector consisted primarily of 2+ fish (59%), notwithstanding a few older fish (up to 9 years) that were caught in estuaries. The WCB commercial catch in 2009–11 consisted largely of 2+ and 3+ fish (44 and 38%, respectively). Over 86 % of the samples collected were aged ≤3 years of age. The recreational catch in the WCB displayed a similar age structure to that of the commercial catch with the 2+ and 3+ age classes being dominant (41 and 39%, respectively). Although fish were aged up to 9 years in the WCB recreational catch, nearly 82% of the catch was aged ≤3 years (Fig. 5.10).

Within the WCB, there was minimal evidence of variation in age structure between management Zones, with the 2+ and 3+ age classes being most dominant (Fig. 5.7). The recreational catch in the Mid-west Zone consisted mainly of 2+ fish (60%), with fished age ≤3 years comprising 88% of the catch. The recreational catch in the Metropolitan Zone was mostly 2+ (35%) and 3+ (47%) fish, with fish aged ≤3 years making up 85% of the catch. In the South-west Zone, the recreational catch was slightly older, with a greater proportion of 4+ fish (21%). The 2+ and 3+

age classes were also abundant (27 and 35%, respectively). Fish aged ≤3 years comprised 64% of the recreational catch in this Zone.

The commercial catch in the Metropolitan Zone consisted mainly of 2+ and 3+ fish, with fish aged ≤3 years comprising 87% of samples. The sample from the commercial sector in the Mid-west Zone was small, with only 86 fish aged. Sixty two percent of these fish were aged ≤3 years. Commercial samples from the South-west Zone were only obtained for a few months of the year. Fish aged 2+ (42%) and 3+ (41%) dominated these samples.

The greatest difference in age structure between the two sectors was observed in the South-west Zone, where samples from the recreational sector contained a greater proportion of older fish (≥4 years) (Fig. 5.11). This was identified to be the result of samples collected from the Augusta region. The rest of the recreational and all of the commercial samples were collected from the more heavily fished region of Geographe Bay and contained younger fish.

In the WCB, there was evidence of seasonal variation in the age composition of recreational and commercial catches within the Metropolitan Zone in 2009/10 and 2010/11, although trends differed slightly between sectors (Figs. 5.12, 5.13). A stronger year class in 2007 appears evident from winter 2009 (seen as 2+ fish) to winter 2011 (seen as 4+ fish), and a weaker year class in 2008 occurs immediately afterwards. Seasonal variation in the SCB could not be examined due to lack of samples collected in most months.

In the Representative Sample Study, the 2+ age class dominated these pre-spawning catches, comprising 76–93% of the catch (Fig. 5.14). Of the 918 fish aged during this study, the oldest fish was 6+ years. The mean length of each sex differed significantly between sampling dates ($P<0.01$). There was also a significant difference ($P<0.01$) in the mean age of females, mainly due to a higher mean age on the last two sampling dates. For the first eight sampling dates there was no significant difference ($P=0.04$) in the mean age of females. There was no difference in the mean age of males ($P=0.11$) across the 10 sampling dates.

The proportion of older fish in the commercial and recreational catch declined over time. In the WCB commercial catch, the proportion of fish >3+ years declined from 31% in 1996–98 to 15% in 2009–11 (Fig. 5.6). The WCB recreational catch experienced a similar decline with the proportion of fish >3+ years dropping from 24% in 1996–98 to 13% in 2004–06, and remaining low at 15% in 2009–11 (Fig. 5.7). While the age composition of the South Coast trap net fishery catch is largely influenced by the strength of recruitment to the SCB, this fishery also exhibited evidence of age truncation over time (Fig. 5.8). The catch comprised 27% of fish >3+ years in 1983–85, 12% in 2004–06 and 4% in 2009–11. The SCB recreational catch (South Zone) comprised 30% of fish >3+ years in 1996–98 and 13% in 2009–11 (Fig. 5.9).

5.3.4 Growth

The growth of Australian herring is rapid in the first two to three years of life, and then slows when maturity is attained around this age. The von Bertalanffy growth models provided a reasonable fit for the length-at-age of each sex in each Bioregion, except for a few large fish that were above the mean asymptotic length (Fig. 5.15). A small number of juvenile fish in the samples resulted in t_0 values being less than zero in most cases.

The von Bertalanffy growth parameters estimated from 2009–11 data differed significantly between females and males (Bioregions pooled) (t test, $P<0.01$). The mean asymptotic length for females (273 mm) was significantly greater than that for males (237 mm) ($P<0.01$), while the growth coefficient (k) was significantly lower for females (0.57) than males (0.87) ($P<0.01$)

(Table 5.5). The growth of each sex differed significantly between Bioregions (t tests, $P<0.01$). For females and males, the asymptotic length was significantly lower and the growth coefficient was significantly higher in the WCB, compared to the SCB (t tests, $P<0.01$) (Table 5.5).

The von Bertalanffy growth parameters estimated from 2009–11 data were significantly different to those estimated from data collected in 1996–98 (Bioregions pooled). The mean asymptotic length was significantly higher ($P<0.01$) for females in 2009–11 (273 mm) than in 1996–98 (264 mm), whereas males were significant lower ($P<0.01$) (237 mm in 2009–11 versus 239 mm in 1996–98). The growth coefficient (k) was significantly lower ($P<0.01$) in 2009–11 than in 1996–98 for both females and males (Table 5.5).

Within each Bioregion, the mean asymptotic length was significantly higher ($P<0.01$) in 2009–11 than in 1996–98 for females but not significantly different for males. The growth coefficient was significantly lower ($P<0.01$) in 2009–11 than in 1996–98 for females in both Bioregions and for males in the WCB. The growth coefficient also declined for SCB males, although this decline was not significant ($P=0.02$) (Table 5.5).

The mean length-at-age of females was greater than that of males at all ages. For example, the mean length of females in the WCB at 5 years of age was 259 mm TL, whereas the mean length of males at the same age was 234 mm TL. Females also attained a greater maximum length and age than males.

Within the WCB, strong seasonal variation in length-at-age was evident. Specifically, the monthly mean length-at-age of each sex declined during the pre-spawning period (March to May) (Fig. 5.16).

5.3.5 Spawning period

In 2009–11, the mean monthly GSI for both sexes in the WCB remained below 0.6 from July to March, and then increased sharply in April to 4.1 for females and 4.5 for males. In May, female GSI reached a peak of 4.2 while male GSI declined slightly to 3.5. In June, GSI in both sexes declined rapidly to <2. On the SCB, GSI values in both sexes displayed a similar trend to that displayed in the WCB, except the increase in GSI occurred a little earlier, with values in March of 0.9 for females and 1.3 for males. Females reached a peak in April and males in May in the SCB. The GSI peak for the SCB fish were approximately half that reached on the WCB, with 2.3 and 2.4 for females and males, respectively (Fig. 5.17).

In the WCB, all females caught in December to February had macroscopic stage I and II ovaries (Fig. 5.18). Stage III ovaries (developing) first appeared in March but only comprised 3% of all samples, being more abundant in April and May. Stage IV ovaries were most abundant in April and May, comprising approximately 31–34% of all females collected in these months. Stage V ovaries were present only in April, May and June. Stage VI ovaries (spawning) were found mainly in May and June. Stage VII ovaries (spent) were found in May and June and Stage VIII ovaries (recovering spent) were found from May through to November, but were most abundant in July (Fig. 5.18). Male gonad development in the WCB followed similar monthly trends to those observed in females (Fig. 5.19).

In the SCB, all females caught between August and February had stages I and II ovaries. Stage III ovaries (developing) were first observed in March. Stages IV and V were only evident in April and May (Fig. 5.20). There were no stage VI (spawning) ovaries in any of the females examined on the SCB in 2009–11. Four fish displayed stage VII and VIII (recovering spent) ovaries in June (Fig. 5.20). Male gonadal development in the SCB displayed similar monthly trends to those observed in females, with the exception of some stage VI (spawning) to stage VIII (recovering spent) gonads in April. However these were observed in only 12 of the 293 (4.1%) males sampled in that month (Fig. 5.21). The absence of stage VI to VIII ovaries and testes in the SCB strongly suggests that spawning did not occur in this region in 2009–11.

In the representative sample study conducted in Cockburn Sound (and in the months preceding and following), the mean monthly GSIs for both sexes (>L_{50}) remained below 0.5 in March 2010, and then increased in early April to 1.0 for females and 1.3 for males. The GSIs then increased rapidly in late April with females reaching 5.4 and males reaching a peak of 5.8 on 29 April 2010. The GSIs then declined slightly on 4 May to 3.8 for females and 2.1 for males before increasing again the following day to a peak of 5.6 for females and 5.3 for males. The GSIs then declined slightly over the next two weeks before climbing slightly again on 18 May 2010. GSI then declined in early June to 1.5 for females and 1.8 for males and in late June to 0.7 for females and 0.6 for males (Fig. 5.22).

In late April, gonad stages III to V were present in both sexes. Stage VI (spawning) gonads were first observed on 12 May 2010 and were most prevalent from mid May to early June. Stage VII (Spent) and VIII (recovering spent) were observed predominantly in June in females and late May/June for males (Figs. 5.23 – 5.24).

5.3.6 Sex ratio

Over the period 1977 to 2011, the overall sex ratio (using standardised averages for each year) for each Bioregion and sector was significantly different (P<0.01) from parity. The ratio of females to males in the commercial catch was 57:43 (*n* = 9,454) in the SCB and 60:40 (*n* = 5,197) in the WCB. In the recreational catch, the ratio was 75:25 (*n* = 1,550) in the SCB and 68:32 (*n* = 6,685) in the WCB. The sex ratio in the commercial catch varied among years, with the proportion of females ranging from 39 to 75% in the SCB and 35 to 88% in the WCB (Table 5.6). The proportion of females in the recreational catch in both Bioregions ranged between 62 and 84%, with the exception of 2007 when the WCB catch comprised 43% females (Table 5.7). In 2007, nearly all WCB recreational samples came from the Swan-Canning estuary (121 of 132).

In 2009–11, females dominated samples collected from the commercial and recreational catches. The ratio of females to males in commercial catches (primarily caught by netting method) was 58:42 in the WCB (*n* = 3,496) and 56:44 in the SCB (*n* = 1,153) (Fig. 5.25). In recreational catches (angling) the sex ratio was 68:32 for the WCB (*n* = 4,096) and 80:20 in the SCB (*n* = 324) (Fig. 5.25). In all cases, the sex ratio was significantly different (P<0.01) from parity.

In the WCB, nearly the entire commercial sector catch from the Mid-west Zone was female (92%) in 2009–11. However, the sample size was low with only 129 fish examined from four months of collection. In the Metropolitan Zone the ratio of females to males was 58:42 (*n* = 2,731), which was significantly different (P<0.01) from parity, while in the South-west Zone the ratio was not significantly different (P=0.10) at 51:49 (*n* = 636) (Fig. 5.26). In WCB recreational landings, the sex ratio was significantly different (P<0.01) from parity in all zones. The South-west Zone had the largest proportion of females (86%), followed by the Metropolitan Zone (64%) and Mid-west Zone (63%) (Fig. 5.26).

In 2009–11, the sex ratio during the spawning period (April–June) and non-spawning period (July–March) was significantly different (P<0.01) from parity in each Bioregion and sector, with the exception of the SCB commercial sector, where the female to male ratio was 53:47 (*n* = 768) (P=0.10) during the spawning period.

Differences in sex ratio between age classes were assessed in 2009–11 for each Bioregion and sector only where the sample size in each age class was sufficiently large to perform a χ^2 goodness-of-fit test (i.e. n >50). In WCB recreational landings the ratio of females to males differed significantly (P<0.01) from parity in all age classes except 1+ years (P=0.34) where it was 57:43 (n = 53) (Fig. 5.27). In WCB commercial landings the sex ratio differed from parity (P<0.01) in the 2+ and 3+ age classes, but was not in the 1+ (P=1.00), 4+ (P=0.42) and >5+ (P=0.03) age classes (Fig. 5.27).

During the Representative Sample Study, the overall female:male ratio was 65:35 (n = 933). The proportion of females ranged from 35% on 28 April to 90% on 18 May (Fig. 5.28). The sex ratio was significantly different (P<0.01) from parity on all sampling days except for 29 April (P=0.17). There was an increasing trend in the proportion of females over the one month sampling period (r^2 = 0.73) (Fig. 5.29).

5.3.7 Length- and age-at-maturity

Length-at-maturity was examined using aggregated data from the two Bioregions to enable comparison with the earlier work of Fairclough *et al.* (2000a), as well as for each Bioregion separately. During the spawning periods (April to June) in 2010 and 2011, all females <170 mm TL possessed Stage II ovaries. Stages III to VIII were observed in 97% of females ≥250 mm. The L_{50} for females for the pooled Bioregions was 198.9 mm (±2.3) (Table 5.8). All males <170 mm during the spawning periods in 2010 and 2011 were at Stage II. Testes at Stage III to VIII were observed in 54% of samples in the 170–179 mm length class and in 85% of males >180 mm. The L_{50} for males for the pooled Bioregions was 181.0 mm (±3.3) (Table 5.8).

The length-at-maturity was lower in the WCB than the SCB for both sexes, although this difference was statistically significant only for males. The L_{50} for females was 194.1 mm (±11.4) in the WCB and 219.6 mm (±2.2) in the SCB. The L_{50} for males was 174.4 mm (±1.8) in the WCB and 196.4 mm (±4.3) in the SCB (Table 5.8). A large standard error around the WCB female estimate contributed to the non-significant difference. This was due to a low number of smaller (juvenile) female fish in the WCB sample and a high number of larger fish (220–250 mm) with stage II gonads caught in April (beginning of spawning period) at Jurien (Mid-west Zone).

Age-at-maturity was examined across Bioregions (pooled data) as well as for each Bioregion separately. From the pooled data, the age at which 50% of females and males were mature (pooled data) was 2.35 (±0.63) and 1.80 (±0.15) years, respectively (Table 5.9).

When data from Bioregions were examined separately, both sexes exhibited an earlier age of maturity (A_{50}) in the WCB than in the SCB. The female A_{50} was 2.19 (±0.13) years in the WCB, compared to 2.77 (±0.01) years in the SCB, and the male A_{50} was 1.76 (±0.35) years in the WCB compared to 1.90 (±0.05) years in the SCB (Table 5.9). The early attainment of maturity on the WCB was reflected in the proportion of females and males that possessed maturing gonads (Stage 3–8) at the end of their second year of life. In the WCB, 51% of females and 80% of males had maturing gonads at the end of their second year, whereas in the SCB only 13% of females and 44% of males were mature at the end of their second year (Fig. 5.30). No females or males in either Bioregion were mature in their first year of life.

Within each Bioregion, the L_{50} for each sex declined between 1996–98 and 2009–11 (Table 5.8). In the SCB, the female L_{50} declined from 228.3 mm to 219.6 mm, while the male L_{50} declined from 216.7 mm to 196.4 mm. In the WCB, the female L_{50} declined from 202.6 mm to 194.1 mm, while the male L_{50} declined from 185.0 mm to 174.4 mm. The decline in L_{50}

between 1996–98 and 2009–11 was significant for males in both Bioregions and for females in the SCB, but not for females in the WCB.

Pooled data from both Bioregions also indicated decreases in L_{50} for each sex between 1996–98 and 2009–11 (Table 5.8). Given the significant difference in growth rates between Bioregions for both sexes, L_{50} values derived from pooled data are likely to be affected by the proportions of samples from each Bioregion. Values derived from pooled data were still calculated here to enable a comparison with those reported by Fairclough *et al*. (2000b) for fish collected in 1996–99. The 1996–99 L_{50} values of Fairclough *et al*. (2000b) fell within the error margins determined for values in 2009–11, suggesting no significant change in the length-at-maturity over time for either sex (Table 5.8). However they were significantly lower than those determined in this study for the similar period of 1996–98, which included additional samples.

Between 1996–98 and 2009–11, the age-at-maturity (A_{50}) changed significantly ($P<0.01$) for both sexes in the SCB, but not in the WCB (Table 5.9). In the SCB, the female A_{50} increased slightly from 2.6 to 2.8 years, while the male A_{50} declined from 2.4 to 1.9 years. In the WCB, the female A_{50} was similar in both periods (1.9 and 2.2 years), and the male A_{50} remained unchanged at 1.8 years.

Pooled data from both Bioregions suggested that female A_{50} increased from 2.0 to 2.4 years between 1996–98 and 2009–11, but that male A_{50} remained unchanged over this period (1.9 to 1.8 years) (Table 5.9). The A_{50} values for females and males in 1996–98 were higher than those reported by Fairclough *et al*. (2000a) for pooled data in 1996–99 (1.7 and 1.4 years). As with L_{50}, A_{50} values derived from pooled data are likely to be affected by the proportions of samples collected from each Bioregion.

5.3.8 Juvenile retention

The mean length-at-first maturity (L_{50}) for each sex in each Bioregion was used to define maturity. The proportion of fish below this size (hereafter referred to as 'juvenile') was used as a measure of juvenile retention in each sector and Bioregion in 2009–11. A greater proportion of both the commercial and recreational catch was comprised of juveniles in the SCB than in the WCB. In 2009–11 the proportion of juveniles in the SCB commercial catch was 40.4% for females and 15.8% for males (sexes combined 29%), while in the recreational catch it was 32.5% for females and 29.5% for males (combined 32%) (Figs. 5.31, 5.32). In the WCB, a much lower proportion of juveniles occurred in both the commercial catch (3.3% of females, 0.1% of males, 2% of sexes combined), and the recreational catch (1.4% of females, 0.1% of males, 1% of sexes combined). In 2009–11, the proportion of fish that were below the mean age-at-maturity (A_{50}) was similar to the proportion below the length-at-maturity (L_{50}) (not shown).

However, most 1+ and 2+ Australian herring caught in April and May with maturing gonads (Stages 3–8), which qualify as 'mature' by this criterion, would not yet have spawned. Given the high catch of Australian herring during the pre-spawning period, the proportion of 'mature' fish that are captured prior to their first spawning should be included in the estimated catch of juveniles. Hence, juvenile retention was also estimated from the proportion of maturing gonads (Stages 3–8) in each age class during the spawning period (Fig. 5.30). In this alternative, preferred approach, all fish aged less than 24 months of age were considered immature, a proportion of fish aged 24 to 35 months were considered immature (SCB: females 87% and males 56%; WCB: females 49% and males 20%) and all fish greater than 35 months were considered mature. Although a small portion of fish aged ≥3 years were considered to be immature during the spawning period, for ease of calculation the assumption was made that these fish were all fully mature.

Using this approach, the rate of juvenile retention was higher than that estimated by the length-at-maturity method. From the age structure of fishery samples collected in 2009–11, the proportion of immature fish (yet to spawn) retained in the fishery catch was estimated to be 59 and 67% in the SCB commercial and recreational sectors, respectively, and 21 and 17% in the WCB commercial and recreational sectors, respectively.

5.3.9 Mortality

Total mortality (Z)

Samples from the WCB commercial sector yielded median total mortality (*Z*) estimates of 1.07.yr^{-1} in 1996–98 and 1.26.yr^{-1} in 2009–11 (Table 5.10). In the WCB recreational sector, samples from the Metropolitan Zone yielded median *Z* estimates of 0.72.yr^{-1} in 1996–98, 1.04.yr^{-1} in 2004–06 and 1.36.yr^{-1} in 2009–11. Samples from the South-west Zone (Geographe Bay only) yielded median *Z* estimates of 0.45.yr^{-1} in 1996–98 and 1.09.yr^{-1} in 2009–11. Samples from the Mid-west Zone yielded a median estimate of *Z* of 0.94.yr^{-1} for 2009–11.

In the South Coast trap net fishery, median estimates of *Z* increased from 0.84.yr^{-1} in 1983–85 to 1.67.yr^{-1} in 1994–96, then declined to 1.26.yr^{-1} in 2009–11. The SCB recreational sector yielded median estimates of *Z* of 0.70 yr^{-1} for the South Zone and 0.95 yr^{-1} for the South-east Zone in 1996–98. There were insufficient samples from the SCB recreational sector to determine *Z* in 2009–11.

Natural mortality (M)

Natural mortality (*M*) was estimated to be 0.42.yr^{-1}, based on a maximum age of 10.5 years. The oldest age reported for Australian herring is 12.0 years, but this fish was caught in an estuary (Wilson Inlet) where high productivity and low natural mortality levels may arise due to reduced predation and competition, allowing for greater longevities than in the ocean. Furthermore, estuaries are believed to host only a small percentage of the overall Australian herring population. Given that this assessment is of the breeding stock, which primarily occurs in the WCB ocean waters, the maximum age observed from the oceanic WCB was used to estimate natural mortality.

Fishing mortality (F)

The majority of the South Coast trap net fishery catch is comprised of maturing sub-adults engaged in a pre-spawning migration to the lower WCB to spawn. Estimates of fishing mortality (*F*) derived from the age composition of this fishery are likely to be biased by the disproportionately high number of young fish in this fishery and likely to result in an overestimate of *Z*. Therefore, the assessment of the status of Australian herring was based on *F* estimated from the age composition of fishery landings in the WCB, where the breeding stock occurs and all ages classes are likely to be represented. There is no evidence of a post-spawning migration and so *F* estimates from the WCB are unlikely to be biased by ontogenetic movement, unlike the SCB.

In 2009–11, median estimates of fishing mortality derived from the age composition of the commercial and recreational fisheries in the WCB Metropolitan Zone exceeded estimates of natural mortality by two times (i.e. above the F_{limit}) (Table 5.10, Fig. 5.33). For both sectors, the entire confidence interval range extended above the F_{limit}. In the South-west (Geographe Bay only) and Mid-west Zones, the age composition in recreational landings in 2009–11 yielded median estimates of fishing mortality that exceeded natural mortality by 1.59 and 1.24 times, respectively. For the South-west Zone, the confidence interval extended from just below the

$F_{threshold}$ to above the F_{limit}, although the majority of the range was above the F_{limit} (58%). For the Mid-west Zone, the confidence interval range extended from above the $F_{threshold}$ to above F_{limit}, with the majority of the range between the $F_{threshold}$ and F_{limit} (87%) (Table 5.10).

The age composition in the WCB commercial fishery indicates an upward trend in fishing mortality over time, with a median estimate of 0.65.yr^{-1} in 1996–98 (mainly from South-west Zone) and 0.84.yr^{-1} in 2009–11 (Metropolitan Zone). Fishing mortality estimated from the WCB recreational fishery (Metropolitan Zone) has also increased over time, with a median estimate of 0.30.yr^{-1} in 1996–98, 0.62.yr^{-1} in 2004–06 and 0.94.yr^{-1} in 2009–11 (Table 5.10).

5.3.10 Yield per recruit and eggs per recruit

YPR and EPR were compared under two scenarios: 1) all recruitment sourced from SCB nurseries and 2) all recruitment sourced from WCB nurseries. SCB recruits grow more slowly and attained maturity at an older age than WCB recruits. However, SCB recruits become vulnerable to capture after 2 years, compared to only 1 year for WCB recruits, which compensates for the slower growth/later maturity. Due to this apparent trade-off between inherent productivity and fishery selectivity, the relative productivity (YPR) and reproductive potential (EPR) between stocks was demonstrated to be similar (Fig. 5.34). That is, the WCB scenario indicated an only very slightly higher vulnerability to possible growth overfishing and recruitment overfishing than the SCB scenario at high levels of *F*.

At $F = 1.5M$, the EPR was calculated to be less than 20% of the EPR_0 for the WCB and close to 20% of the EPR_0 for the SCB. The value of the EPR calculated for the Target and Threshold levels of *F* did not fall below 20% of the EPR_0 for the WCB or SCB (Table 5.11). At F = 1.5M, YPR was calculated to exceed the $F_{0.1}$ by 7% and 3% for the WCB and SCB scenarios, respectively. The $F_{0.1}$ was not exceeded for the corresponding Target and Threshold reference levels in either scenario. These results therefore suggest that the selection of $1.5M$ as the limit referent point is appropriate for these stocks as the value approximates the point at which the prospect of significant growth overfishing or recruitment overfishing may occur.

5.4 Discussion

5.4.1 Representativeness of samples

While an abundance of length and age data has been collected for Australian herring, much of the data cannot be used for stock assessment purposes and thus the fishery can be considered 'data limited'. For example, some of the historical samples were collected with limited temporal and spatial coverage and were deemed to be unsuitable for providing a representative age structure for determining estimates of total mortality. The first available collection of age data deemed representative of the fishery catch was from the SCB commercial fishery in 1984. The first suitable historical sample from the WCB was in 1996 and followed a period of heavy fishing exploitation on Australian herring. Consequently, the biological data from this period may already reflect the impacts of relatively high fishing mortality.

Spatial differences in population biology and demographics, attributed to the ontogenetic movement of this species, makes attaining a representative sample of this stock difficult. The relatively discrete spawning area, the extensive distribution of juveniles across a diverse range of nursery habitats, and the strongly seasonal (and extensive) spawning migration makes the collection of truly representative samples extremely challenging.

The majority of the historical length and age data collected for Australian herring is from the major commercial fishery – the South Coast trap net fishery. However, this fishery targets the spawning migration and sampling of this fishery results in a biased age structure (disproportionately high representation of young fish). Fishery landings in the WCB are more likely to be representative of the age structure of the breeding stock and were used in this study to estimate mortality.

Fish collected in WCB estuaries were excluded from samples used to estimate fishing mortality. The age structure of Australian herring collected from estuarine waters is likely to be biased towards older fish. In the WCB and SCB, fish collected from estuaries are generally larger and older than those from the ocean. This size difference can be attributed in part to differences in mesh size used by commercial fisheries, with larger gill net mesh often used in estuaries. Additionally, higher growth and lower mortality in estuaries, compared to ocean waters, may occur due to reduced competition and predation and greater primary productivity (Heupel and Simpfendorfer 2011, Potter *et al*. 2011). Also, when trapped in closed estuaries, Australian herring do not spawn and so redirect energy towards somatic growth rather than gonad development (Fairclough *et al.* 2000b, Potter *et al*. 2011). The exclusion of estuarine fish from the WCB sample in this study is unlikely to affect the representativeness of the age structure because estuaries are believed to host a very small proportion of the overall WCB population.

With the exception of gill netting, which only lands a small proportion of the commercial catch (~5%), the sampling of age composition is unlikely to be biased by the main fishing methods. Gear used by both sectors is likely to result in similar selectivity of all available age classes. In addition, fishing methods for herring have changed little over time making comparison of data over time possible.

The Representative Sample Study demonstrated that monthly samples from the commercial sector could result in a biased representation of the sex ratio and mean length of the population. On the 10 sampling dates during the 29-day sampling period, the percentage of females varied from 35 to 90%. The mean length in the catch also varied significantly for both sexes between sampling dates. However, there was no statistical difference in the mean age of males between dates, and no statistical difference between females across the first eight sampling dates, which indicated that monthly sampling still yielded a representative age structure.

In 2009–11, the WCB recreational sector provided 4,532 samples of Australian herring. Samples were donated by 116 different fishers, encompassing a wide spatial and temporal distribution. The mean length of donated fish was very similar to that reported in recent recreational fishing surveys and voluntary recreational logbooks, which suggests that the donated sample is representative of the recreational catch. The WCB commercial sector provided 3,558 Australian herring. The large number of samples provided by both sectors across two consecutive years is believed to have provided a representative sample of the Australian herring stock in the WCB suitable for determining total mortality.

5.4.2 Length and age structure

Despite a reported maximum age of 12 years, the commercial and recreational catch of Australian herring in 2009–11 was comprised primarily of 2- and 3-year-old fish, with fish aged 3 years or less comprising between 82–96% of all catches from both Bioregions and sectors. The SCB catch was composed of smaller, younger fish than catches in the WCB, with 2+ fish comprising 71 and 59% of the SCB commercial and recreational catch respectively, as opposed to 44 and 41% in the WCB, respectively.

The seasonal age frequencies for the two years of data collection in the WCB suggest new recruits dominate the age structure each year, with fish entering the fishery in the pre-spawning period before being replaced as the dominant year class by the following year's recruits. Therefore, the WA Australian herring fisheries are currently largely reliant on the new recruits replenishing the population.

A comparison with historical data suggests that the current population is now truncated in both size and age, due to declines in the proportion of larger and older fish in both Bioregions. Given a reported modal length of 244 mm for the south coast trap net fishery in the 1940/50s, it appears that the truncation in length occurred after the 1980s. Excessive fishing pressure has been shown to cause a decline in the mean length and age of a fished population due to the removal of the larger and older individuals (Jennings *et al*. 2001). The age structure of the less heavily fished region around Augusta (WCB: South-west Zone) showed a greater composition of older fish whereas samples from the Metropolitan Zone were comprised predominantly of younger fish, with around 85–87% of the commercial and recreational catch comprising of fish $\leq$ 3 years of age. This is likely to have had an impact on stock biomass with lower egg production. Based on fecundity estimates determined by Fairclough *et al*. (2000b), a 2-year-old female produces ~50,000 eggs, whereas a 5-year-old produces ~106,000 eggs. Additionally, the quality of the eggs produced by younger fish has been demonstrated to be poorer in at least some species, with lower growth and survival rates (Berkeley *et al*. 2004).

5.4.3 Growth

The estimates of the von Bertalanffy growth parameter (k) derived from data collected in 2009–11 data were lower than those estimated from data collected in 1996–98 for both sexes. Given that k is proportional to reproductive effort and may be used to predict average fecundity (Charnov 2008), the observed decline in k suggests that average fecundity may have also declined. A decrease in growth could be caused by high levels of fishing mortality and the removal of fast growing individuals (Neuheimer and Taggart 2010) or by environmental changes (Enberg *et al*. 2012). Temperature and salinity in shelf waters of the WCB have followed a warming trend over the past 5 decades, although it is unclear whether the magnitude of change (e.g. 0.6–1.0 ºC) is biologically significant (Pearce and Feng 2007). A decline in growth rate in response to increasing temperatures is inconsistent with the observed higher growth of both sexes in the WCB compared to the SCB, suggesting faster growth occurs in more northern (and warmer) waters.

The significant difference in growth rates between Bioregions is probably a source of variation in the size composition of fishery landings in the WCB. For example, the monthly mean length (within each age class) for WCB fish was observed to decline during the pre-spawning period (March to May). This is hypothesised to be the result of smaller, slower growing fish from the SCB migrating to the WCB to spawn. The pronounced decline in mean length-at-age during this period suggests a large number of SCB fish migrating to the WCB, contributing a significant proportion of WCB fishery landings.

5.4.4 Spawning

Based on macroscopic staging of gonads, GSIs and back calculation of juveniles birthdates, spawning by Australian herring occurs over a short period from May to early June. Spawning takes place predominantly in the lower WCB, with some evidence of limited spawning in the SCB. These findings are consistent with previous observations by Fairclough *et al*. (2000b).

5.4.5 Sex ratio

A bias towards females in both commercial and recreational landings indicates that there may be differences between the sexes in their spatial distribution and schooling behaviour. A bias towards females has also been observed in southern garfish (*Hyporhamphus melanochir*) on the south coast of Australia, with females forming large schools in the shallow, inshore waters (<5 m), while males are relatively widely dispersed and more patchy in distribution with a significantly higher proportion in deeper waters (McGarvey *et al*. 2007). Such separation behaviour in Australian herring is supported by the observations of Lenanton (1978), who found that the two sexes aggregated in different parts of the bays at Rottnest Island (WCB: Metropolitan Zone).

The proportion of females landed in the recreational catch is, on average, higher than the commercial sector. We postulate that females feed more aggressively than males, resulting in a higher proportion of females in recreational catches due to the use of burley (fish attractant) and baited hooks. The netting methods used by the commercial sector are expected to be less selective in this instance, although some commercial operators are known to use burley to attract Australian herring before setting the net around them. This may explain the higher ratio of females observed in some commercial catches.

Although the catch rate of females was higher in both sectors, the proportion of females in the older age classes of the catches did not decline, as might be expected if females were being strongly selected. McGarvey *et al.* (2007) noted a similar phenomenon in garfish landings in SA and suggested that this may reflect a greater number of females recruiting each year to the fishable stock. Alternatively, female dominance may be a natural characteristic of Australian herring populations.

5.4.6 Maturity

Data collected in 2009–11 suggested that females mature later and at a larger size than males, with an L_{50} value of 199 mm and A_{50} of 2.35 years for females, compared to 181 mm TL and 1.80 years for males (Bioregions pooled).

Comparisons with values derived from pooled samples collected in 1996–98 suggest a decrease in L_{50} for each sex and an increase in female A_{50} between 1996–98 and 2009–11. In contrast, data collected in 1996–99 by Fairclough *et al.* (2000b) suggest no significant changes in L_{50} or A_{50} over the same period. These conflicting results can be explained by the differing proportions of fish from each Bioregion in the pooled data. The DoF data collected in 1996–98 had a higher contribution of samples from the SCB, probably resulting in a higher L_{50} than that estimated by Fairclough *et al.* (2000b). In all sampling periods, the L_{50} for both sexes was higher in the SCB than in the WCB.

To account for this bias, historical changes within each Bioregion were also examined. A decline in L_{50} for both sexes occurred in each Bioregion between 1996–98 and 2009–11. For example, female L_{50} declined by 9 mm in each Bioregion over this period. This suggests that the observed decline in size-at-maturity was not an artefact of sampling. A decline in size-at-maturity has been attributed to high fishing mortality in some fish stocks (Olsen *et al*. 2005, Reznick and Ghalambor 2005, Neuheimer and Taggart 2010). Alternatively, environmental factors influencing growth (e.g. temperature, food availability) may have caused a change in size-at-maturity.

5.4.7 Juvenile retention

In 2009–11, the proportion of fish below the length-at-maturity (L_{50}) was 29 and 32% in SCB commercial and recreational landings, respectively, and only 1–2% of WCB commercial and recreational landings. However, this underestimates the extent of juvenile retention since many newly 'mature' fish are captured prior their first spawning. The proportion of fish yet to spawn for the first time was 59 and 67% in the SCB commercial and recreational sectors, respectively, and 21 and 17% in the WCB commercial and recreational sectors, respectively.

An estimate of the proportion of juvenile Australian herring in the total WA catch can be determined by applying the above proportions to the estimated Bioregion and sector catches. Commercial and recreational catch shares were last determined in 2000/01, following the only state-wide recreational fishing survey (Henry and Lyle 2003) in WA. In this period, the catch shares were estimated to be 53% SCB commercial, 6% SCB recreational, 8% WCB commercial and 33% WCB recreational. By applying the proportions of immature fish observed in 2009–11 to these catch shares, 43% of the total WA catch (sectors combined) was estimated to be immature in 2009–11.

At a national level, since all Australian herring caught in SA and Victoria are considered to be immature (Fairclough *et al*. 2000a) and these two states take ~25% of the national catch (commercial and recreational), the total Australian catch of immature fish was estimated to be approximately 57% in 2009–11.

For more precise juvenile retention estimates, consideration should be given whether to include fish ≥3 as partially mature, as well as to the proportions of catch landed by month for each sector to weight the age structure samples collected in 2009–11 to reduce potential sampling bias. Also, all fish caught in the SCB can be considered 'immature' since negligible spawning occurs in this Bioregion and no migration from WCB to SCB occurs. These adjustments would increase the total estimate of juvenile fish landed.

The catch share data derived from the 2000/01 National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) is now over ten years old and needs to be updated. It is believed that a lower share is now taken by the SCB commercial sector and higher share by the WCB recreational sector, which would reduce the estimated proportion of juvenile fish in the total catch. Current catch shares cannot be accurately determined until the current shore-based recreational catch level is quantified.

Despite such uncertainties, it is clear that juvenile fish are a substantial component of the national catch of Australian herring. When coupled with the high level of mortality currently being experienced by the stock, the harvest of juveniles increases the risk of recruitment overfishing by reducing spawning biomass and yield, thereby increasing the risk of stock collapse (Enberg 2005). Reducing the proportion of juveniles in the catch should be considered as a future management target. In some fisheries, a reduced harvest of juvenile fish may be more beneficial to the sustainability of the stock than the protection of spawning adults (Pelletier and Magal 1996).

5.4.8 Mortality

Estimates of current and historical rates of fishing mortality in the Australian herring stock were derived from the age composition of WCB fishery landings, which were considered to be representative of the age structure of the breeding stock. Median estimates of fishing mortality were 0.84 – 0.94.yr^{-1} in 2009–11. This represented a substantial increase since 1996–98, when fishing mortality was estimated to be 0.30 – 0.65.yr^{-1}.

The catch curve analysis used here to estimate total mortality is a relatively simple method and is widely applied in data-limited fisheries (Thorson and Prager 2011). However, the limitations of this assessment approach need to be considered. For example, the assumptions of constant natural mortality and recruitment over time are unlikely to be true for Australian herring. Australian herring is known to experience variable annual recruitment (Section 2). It is also possible that natural mortality has varied in recent years for Australian herring due to changes in predator/prey relationships. In 1998/99, an estimated 60–70% of the pilchard (*Sardinops sagax*) stock was lost to a herpes virus (Gaughan *et al*. 2000). Western Australian salmon (*Arripis truttaceus*) is a major predator of pilchards and following the collapse of the pilchard stock, may have fed more on Australian herring. This is supported by anecdotal reports from commercial salmon fishers who observed Australian herring in the stomachs of western Australian salmon after this event rather than their usual prey of pilchards. The pilchard stock has since recovered. However, no quantitative dietary studies of western Australian salmon have been performed and so recent levels of predation by western Australian salmon on Australian herring are unknown. It was previously suggested that an increase in the New Zealand fur seal (*Arctocephalus forsteri*) population in recent years may have led to increased predation of Australian herring (Richard Campbell pers. comm.). However, a recent dietary study in WA found Australian herring was a negligible component of the New Zealand fur seal diet (Hara 2012).

Efforts were made to overcome the limitations of the catch curve method by using a large sample size in 2009–11 and by combining consecutive years of data. Nonetheless, uncertainty still remains over the accuracy of total mortality estimated by this method for Australian herring. Many authors have found that this method tends to underestimate mortality (Murphy 1997, Dunn *et al*. 2002, Fisher *et al*. 2011) which would suggest that the true estimates of total mortality, and therefore fishing mortality, may actually be higher than those determined in this study.

Although natural mortality in Australian herring may vary between years, natural mortality within years is likely to be similar for all size and age classes above full recruitment. Unlike in larger fish species where natural mortality may decline with increasing size due to decreasing predation, Australian herring typically reach a maximum length of only 300 mm and so natural mortality is likely to be similar at all sizes (i.e. all size/age classes equally vulnerable to predation).

5.4.9 Stock assessment

The YPR and EPR model results support the selection of 1.5M as an appropriate limit reference point for this stock. At F = 1.5M, EPR was approximately 20% of virgin egg production and YPR was similar to the calculated level at $F_{0.1}$. YPR at $F_{0.1}$ and EPR at 20% virgin level relate to widely used benchmarks for fisheries management based on historical experience globally.

In 2009–11, median estimates of fishing mortality (F) for herring derived from sampling of the WCB (Metropolitan Zone) commercial and recreational sectors were well above the 'limit' reference level of 1.5M (=F_{limit}). Comparisons with historical estimates of fishing mortality indicate that fishing mortality has increased substantially since the mid 1990's. The level of fishing mortality estimated in 2009–11 is considered to be unsustainable for the Australian herring stock.

In 2009–11, the commercial and recreational catches of Australian herring were comprised primarily of one or two age classes, typically 2+ and 3+ fish, with the contribution of fish older than 3 years quite low (between 4–18%). The monthly age frequencies during the two full years of sampling by this project suggest that a single year class dominates the age structure each year. Each year class enters the fishable stock during the pre-spawning period (March–May), forming the dominant year class and the basis of the fishery until it is replaced by the following year class during the next pre-spawning period. Currently, annual landings in the Australian herring fishery are largely dependent on the strength of new recruits entering the fishery each year. Therefore, years of low recruitment represent a large risk to the stock sustainability, as may have been experienced in 2011 with the 'marine heat wave' event (Pearce *et al*. 2011) coinciding with the spawning migration for Australian herring.

There is strong evidence that the current population of Australian herring is truncated relative to the past. With the reduction in the number of larger and older fish in the population, egg quantity and quality is likely to decline (Trippel 1998, Jenning *et al*. 2001, Berkeley *et al*. 2004). It is of considerable concern then, that the commercial and recreational catch is now composed predominantly of 2+ and 3+ year old fish. The majority of these fish are female and a significant proportion are immature. From samples collected in this project it is estimated that 43% (by number) of the current WA catch, including both Bioregions and sectors, is immature. Given that the entire South Australian catch is comprised of immature fish, it is estimated that 57% of the total national catch is immature.

Australian herring has a low to moderate risk of vulnerability to exploitation due to life history parameters of intermediate life span, rapid growth, early maturity and high fecundity (see Section 6). Nonetheless, it is of concern that a significant proportion of commercial and recreational landings are taken during the pre-spawning period, and a large proportion of the total catch is comprised of immature fish. Given this, and the high total mortality estimated in this study, there is a high risk to the sustainability of the stock.

5.4.10 Future monitoring

Given the high estimates of F determined here for Australian herring, continued monitoring of the age structure is recommended. It is proposed that annual sampling with three yearly assessments of the WCB recreational and SCB commercial sectors be conducted. These two sectors take the majority of the WA catch (~86%). The WCB contains the breeding stock of this species and thus provides the best representative sample for determining a robust estimate of F. By collecting additional consecutive years of age data, the confounding influence of recruitment variability on F estimates will be reduced. Age structure sampling of the South Coast trap net fishery will allow year class strength in the catch to be estimated and compared with fishery-independent indices of 0+ recruitment. While samples from the WCB commercial sector are currently easier to obtain, continued sampling of the recreational sector (via frame donations) is critical because 1) the recreational catch more likely to be representative of the population due to better spatial and temporal coverage, and 2) the future availability of commercial landings is uncertain due to potential declines in commercial fishing for economic or legislative reasons. However, maintaining the interest of the recreational fishing sector to continue to donate samples will be challenging.

Ongoing age-based sampling of Australian herring is relatively inexpensive due to assistance from the commercial and recreational sectors and the fact that Australian herring can be aged by whole otoliths, thus eliminating costs associated with sectioning otoliths. Preliminary results from this project indicate that sampling may be optimised, i.e. restricted to a subset of key times/locations without compromising the representativeness of the age structure sample, which will further reduce costs.

In future, the implementation of a tagging study may help provide more certainty about mortality levels, by providing an estimate of F that is independent of age structure data[10].

10 A herring tagging study commenced in 2012, with only ~4000 fish tagged in the WCB despite a target of ~10,000 fish. The study was suspended due to the scarcity of herring, which made it difficult to meet the required target.

This study has successfully determined the key biological parameters for Australian herring and substantially advanced our understanding of population structure. However, there still remain significant gaps in knowledge about recreational catch levels and the extent of connectivity between regions and the absence of a long-term index of spawning stock abundance that would enable the development of an age-structured population dynamics model. Future research should be focused on addressing these issues.

Table 5.1. Parameters used in Egg Per Recruit and Yield Per Recruit models for Australian herring.

Bioregion	Parameter	Female	Male
West Coast	L_∞ (in mm)	272	232
	k	0.57	0.86
	t_0	-0.30	-0.08
	$A_{50\%}$ (in years)	2.19	-
	$A_{95\%}$ (in years)	3.97	-
	Full selectivity (age, in years)	1	1
South Coast	L_∞ (in mm)	296	246
	k	0.48	0.79
	t_0	-0.20	0.02
	$A_{50\%}$ (in years)	2.77	-
	$A_{95\%}$ (in years)	3.81	-
	Full selectivity (age, in years)	2	2
Both	Alpha Weight	0.0000164	0.0000164
	Beta Weight	2.9013	2.9013
	Natural mortality (M)	0.423	0.423
	Maximum age (in years)	10.4	10.4
	Alpha Fecundity	-9.9703	-9.9703
	Beta Fecundity	21.429	21.429

Table 5.2. Biological reference points for fishing mortality for Australian herring (adapted from Wise *et al*. 2007).

Reference Point	Fishing Mortality	Likely management response
Target	2/3 * M	Sustainable
Threshold	M	Monitor closely
Limit	1.5 * M	Restrict fishing

Table 5.3. Total annual number of length and otolith samples of Australian herring collected from commercial and recreational fishing sectors in the South Coast and West Coast Bioregions, 1974 – 2011.

Year	SOUTH COAST BIOREGION				WEST COAST BIOREGION			
	Commercial		Recreational		Commercial		Recreational	
	Lengths	Otoliths	Lengths	Otoliths	Lengths	Otoliths	Lengths	Otoliths
1974								21
1975					50	123		
1976					47	34	27	
1977	550				628	50	20	
1978	657	75				34	14	
1979	39				20		68	65
1980								
1981	1,095	550*						
1982								
1983								
1984	640	640						
1985	810	810						
1986								
1987								
1988								
1989								
1990								
1991								
1992								
1993								
1994								
1995	4,088	1,667						
1996	6,339	1,725	39	45	120	111	172	156
1997	1,111	1,021	606	398	451	398	482	388
1998	1,273	1,267	605	541	492	435	1,148	943
1999	210	134	69	69	313	232	24	35
2000	379	189			551	152		
2001	212	144			327	142		
2002								
2003								
2004							59	58
2005			13	13			392	328
2006			55	55			323	321
2007							135	125
2008							27	26
2009	266	266	60	60	1,084	1,084	784	770
2010	598	598	69	69	2,169	2,117	2,345	2,343
2011	273	272	200	189	305	305	1,082	1,082
Total	**18,540**	**8,808**	**1,716**	**1,439**	**6,557**	**5,217**	**7,102**	**6,661**

* Sample currently missing or disposed of.

Note: There is also an additional 18,750 length data from the tagging of commercially caught fish in 1997 and 1998 and 7,123 lengths from monitoring at the Canning Vale markets in 1999–2002. No sex or age data were collected from these fish so they have not been included in this table.

Table 5.4. Maximum ages of Australian herring reported by sex and Bioregion in Western Australia in this and other studies.

Sex	Bioregion	Age (yrs)	Year	Location	Sector	Method	TL (mm)
Female	South	12.0	1997	Wilson Inlet	Commercial	Haul or Gill net	368
		10.3	1998	Wilson Inlet	Commercial	Haul or Gill net	390
	West	10.5	1980	Jurien	Research	Gill net	315
		10.1	1998	Cervantes	Recreational	Line	295
Male	South	11.4 *	2005–2007	Wilson Inlet	Commercial or Research	NA	NA
		8.4	2009	Augusta	Recreational	Line	255
		8.4	2010	Wilson Inlet	Recreational	Line	297
	West	9.1	1997	Cockburn Sound	Research	NA	251
		8.5	1980	Jurien	Research	Gill net	280

* reported by Potter *et al.* 2011.

Table 5.5. Comparisons of von Bertalanffy growth parameters (+/- standard error) between years, Bioregions and sex. L_∞ hypothetical mean asymptotic length at an infinite age; TL, total length; *k*, growth coefficient; t_0, hypothetical age at zero; *n*, sample size.

Year	Bioregion	Sex	L_∞ (mm, TL)	K (year^{-1})	t_0 (year)	n
1996–99*	Pooled	F	261.8	0.81	-0.04	2,777
		M	238.7	0.99	0.01	1,985
1996–98	Pooled	F	263.6 (±0.7)	0.81 (±0.01)	-0.04 (±0.01)	2,412
		M	239.4 (±0.6)	1.02 (±0.01)	0.02 (±0.01)	1,708
	WCB	F	262.8 (±0.8)	0.82 (±0.01)	-0.04 (±0.01)	1,954
		M	238.0 (±0.6)	1.04 (±0.02)	0.02 (±0.01)	1,479
	SCB	F	266.2 (±1.5)	0.78 (±0.02)	-0.03 (±0.02)	458
		M	249.8 (±2.2)	0.89 (±0.04)	-0.01 (±0.02)	229
2009–11	Pooled	F	272.8 (±1.1)	0.57 (±0.01)	-0.26 (±0.03)	5,157
		M	237.3 (±0.7)	0.87 (±0.02)	-0.06 (±0.02)	3,210
	WCB	F	271.5 (±1.1)	0.57 (±0.01)	-0.30 (±0.03)	4,565
		M	236.7 (±0.8)	0.86 (±0.02)	-0.08 (±0.02)	2,731
	SCB	F	295.8 (±6.2)	0.48 (±0.03)	-0.20 (±0.08)	592
		M	246.0 (±3.2)	0.79 (±0.05)	0.02 (±0.05)	479

* reported by Fairclough *et al.* (2000b).

Table 5.6. Annual sex ratio of Australian herring sampled from commercial fishery landings, 1977–2011 (years in which ≤ 50 fish were sexed are not shown).

Year	South Coast Bioregion			West Coast Bioregion		
	Female	Male	Number	Female	Male	Number
1977				68.0	32.0	50
1978	54.0	46.0	139			
1981	38.6	61.4	526			
1984	65.2	34.8	250			
1985	66.4	33.6	259			
1995	52.4	47.6	1,724			
1996	44.3	55.7	2,536	35.0	65.0	120
1997	51.2	48.8	1,085	52.9	47.1	450
1998	43.0	57.0	1,215	51.0	49.0	492
1999	60.1	39.9	163	63.1	36.9	222
2000	75.0	25.0	232	87.9	12.1	232
2001	73.8	26.2	172	78.5	21.5	135
2009	68.3	31.7	265	53.1	46.9	1,075
2010	52.1	47.9	597	61.4	38.6	2,117
2011	52.2	47.8	291	46.7	53.3	304
Average	**56.9**	**43.1**	**9,454**	**59.8**	**40.2**	**5,197**

Table 5.7. Annual sex ratio of Australian herring sampled from recreational fishery landings, 1979–2011 (years in which ≤ 50 fish were sexed are not shown).

Year	South Coast Bioregion			West Coast Bioregion		
	Female	Male	Number	Female	Male	Number
1979				73.5	26.5	68
1996				82.5	17.5	166
1997	71.8	28.2	586	74.0	26.0	481
1998	75.1	24.9	602	61.9	38.1	1,146
1999	68.1	31.9	69			
2005				72.8	27.2	316
2006				70.3	29.7	249
2007				43.2	56.8	132
2009	74.1	25.9	58	71.1	28.9	774
2010	78.3	21.7	69	67.2	32.8	2,213
2011	84.3	15.7	159	67.9	32.1	1,140
Average	**75.0**	**25.0**	**1,550**	**68.4**	**31.6**	**6,685**

Table 5.8. Length-at-maturity (± s.e.) for Australian herring by year, Bioregion and sex.

Year	Bioregion	Sex	L_{50} (mm)	L_{95} (mm)	Number
1996–99 *	Pooled	F	196.9	241	
		M	179.0	204	
1996–98	Pooled	F	207.2 (±0.6)	243.1 (±1.7)	723
		M	188.1 (±2.1)	213.6 (±5.9)	387
	WCB	F	202.6 (±0.6)	233.2 (±1.6)	650
		M	185.0 (±1.2)	201.0 (±3.3)	282
	SCB	F	228.3 (±1.8)	255.7 (±4.9)	164
		M	216.7 (±5.5)	265.4 (±15.9)	105
2009–11	Pooled	F	198.9 (±2.3)	254.2 (±6.6)	2,099
		M	181.0 (±3.3)	217.8 (±9.6)	1,279
	WCB	F	194.1 (±11.4)	250.8 (±31.5)	1,781
		M	174.4 (±1.8)	188.8 (±5.2)	971
	SCB	F	219.6 (±2.1)	265.3 (±6.0)	318
		M	196.4 (±4.3)	231.1 (±12.5)	308

* Published results from Fairclough *et al*. 2000b

Table 5.9. Age-at-maturity (± s.e.) for Australian herring by year, Bioregion and sex.

Year	Bioregion	Sex	A_{50} (yr)	A_{95} (yr)	Number
1996–99 *	Pooled	F	1.7		
		M	1.4		
1996–98	Pooled	F	1.99 (±0.1)	2.86 (±0.2)	587
		M	1.85 (±0.1)	2.40 (±0.2)	279
	WCB	F	1.88 (±0.1)	2.51 (±0.2)	491
		M	1.81 (±0.2)	2.25 (±0.3)	241
	SCB	F	2.58 (±0.1)	3.45 (±0.1)	96
		M	2.37 (±0.1)	2.99 (±0.1)	38
2009–11	Pooled	F	2.35 (±0.6)	4.07 (±1.7)	1,939
		M	1.80 (±0.2)	2.44 (±0.3)	1,241
	WCB	F	2.19 (±0.1)	3.97 (±0.4)	1,635
		M	1.76 (±0.4)	2.27 (±0.4)	936
	SCB	F	2.77 (±0.1)	3.81 (±0.1)	304
		M	1.90 (±0.1)	3.47 (±0.2)	305

* Published results from Fairclough *et al*. 2000b

Table 5.10. Samples size (*n*), total mortality rate (*Z*) with 95% confidence intervals (CI), natural mortality rate (*M*) and fishing mortality rate (*F*) for Australian herring by Bioregion, Zone, sector and sampling period. Mortality rates are year^{-1}.

Group	Year	n	Z (95% CI)	M	F
WCB Commercial fishery					
- South-west Zone (Geographe Bay)					
	1996–98	619	1.07 (1.27 – 0.67)	0.42	0.65
- Metropolitan Zone					
	2009–11	1,280	1.26 (1.52 – 1.10)	0.42	0.84
WCB Recreational fishery					
- Metropolitan Zone					
	1996–98	606	0.72 (0.89 – 0.62)	0.42	0.30
	2004–06	463	1.04 (1.24 – 0.87)	0.42	0.62
	2009–11	1,947	1.36 (1.62 – 1.18)	0.42	0.94
- South-west Zone (Geographe Bay)					
	1996–98	346	0.45 (0.56 – 0.36)	0.42	0.03
	2009–11	229*	1.09 (1.38 – 0.81)	0.42	0.67
- Mid-west Zone					
	2009–11	1,231	0.94 (1.08 – 0.85)	0.42	0.52
SCB Commercial fishery (Trap Net)					
	1983–85	499	0.84 (1.01 – 0.68)	0.42	0.42
	1994–96	504	1.67 (2.03 – 1.37)	0.42	1.25
	2009–11	733	1.26 (1.58 – 1.06)	0.42	0.84
SCB Recreational fishery					
- South Zone					
	1996–98	332	0.70 (0.84 – 0.56)	0.42	0.28
- South-east Zone					
	1996–98	438	0.95 (1.30 – 0.75)	0.42	0.53

* Note: Number of samples is below the minimum recommended amount of 300 and is shown only for preliminary assessment purposes.

Table 5.11. Outputs of Yield Per Recruit (YPR) and Egg Per Recruit (EPR) models for Australian herring using biological parameters from the West Coast and South Coast Bioregions, compared at various *F*-based reference points.

Model	Recruitment Source	Reference point	F value	Value	% of $F_{0.1}$	% of EPR_{Virgin}
YPR	West Coast	F_{Target}	2/3 M	23.6	85.4	
		$F_{Threshold}$	M	27.3	98.8	
		F_{Limit}	1.5 x M	29.7	107.5	
		$F_{0.1}$	0.288	27.7	100.0	
		F_{Max}	0.466	30.6	110.5	
	South Coast	F_{Target}	2/3 M	22.7	76.1	
		$F_{Threshold}$	M	27.1	90.9	
		F_{Limit}	1.5 x M	30.8	103.1	
		$F_{0.1}$	0.559	29.9	100.0	
		F_{Max}	0.839	35.4	118.5	
EPR	West Coast	Virgin	0	45313		100.0
		F_{Target}	2/3 M	17740		39.2
		$F_{Threshold}$	M	12537		27.7
		F_{Limit}	1.5 x M	8232		18.2
	South Coast	Virgin	0	39275		100.0
		F_{Target}	2/3 M	17171		43.7
		$F_{Threshold}$	M	12585		32.0
		F_{Limit}	1.5 x M	8571		21.8

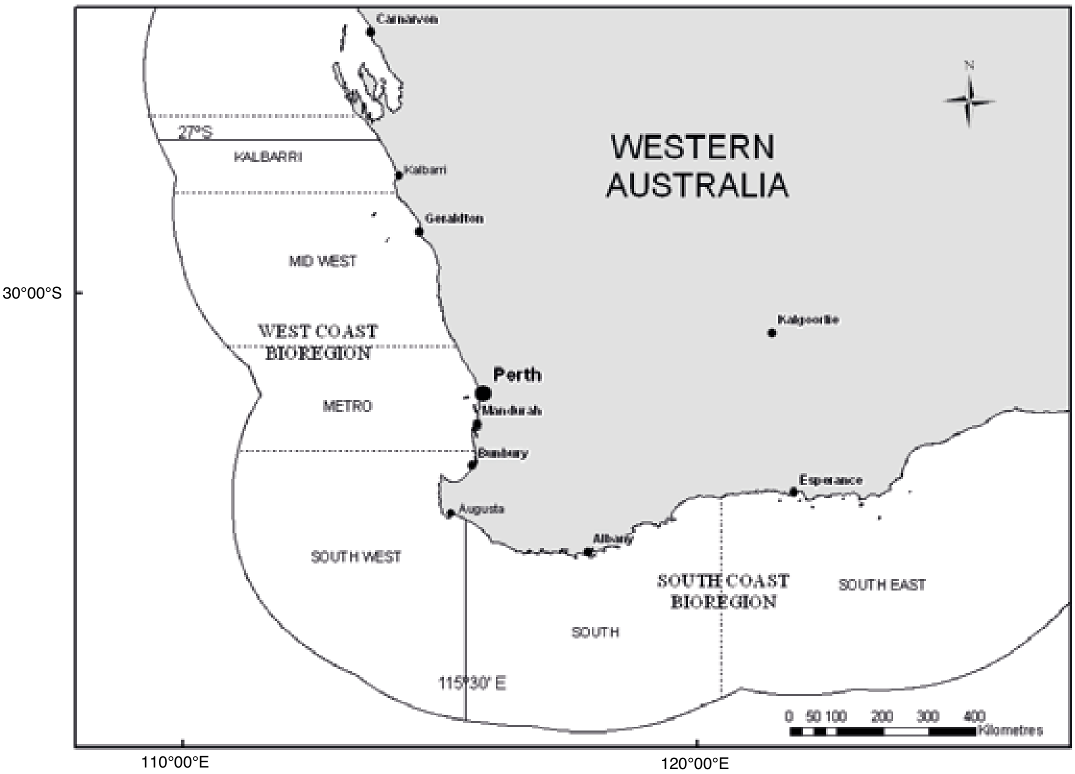


Figure 5.1. Sampling locations of Australian herring in southern Western Australia. Bioregions and management Zones are shown.

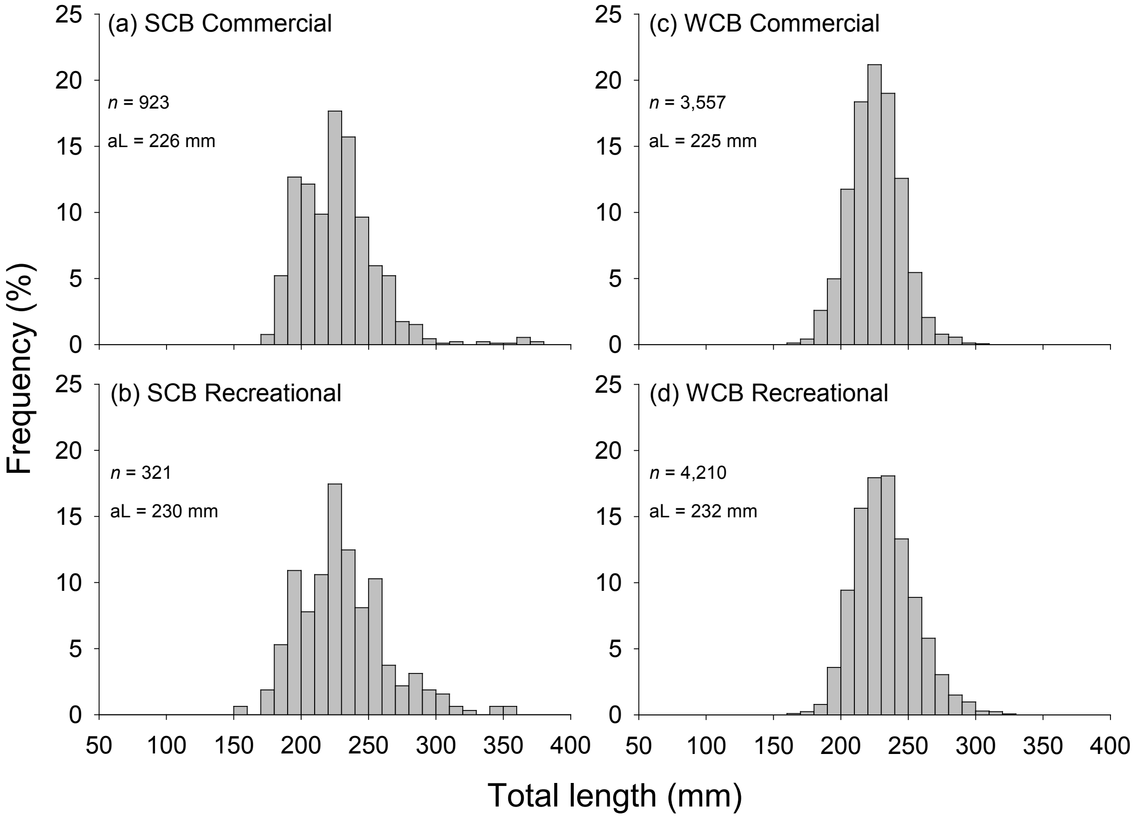


Figure 5.2. Length composition of commercial and recreational caught Australian herring by Bioregion for 2009–11. **(a)** South Coast Bioregion commercial, **(b)** South Coast Bioregion recreational, **(c)** West Coast Bioregion commercial and **(d)** West Coast Bioregion recreational. n, number of fish measured; aL, average total length of fish in sample.

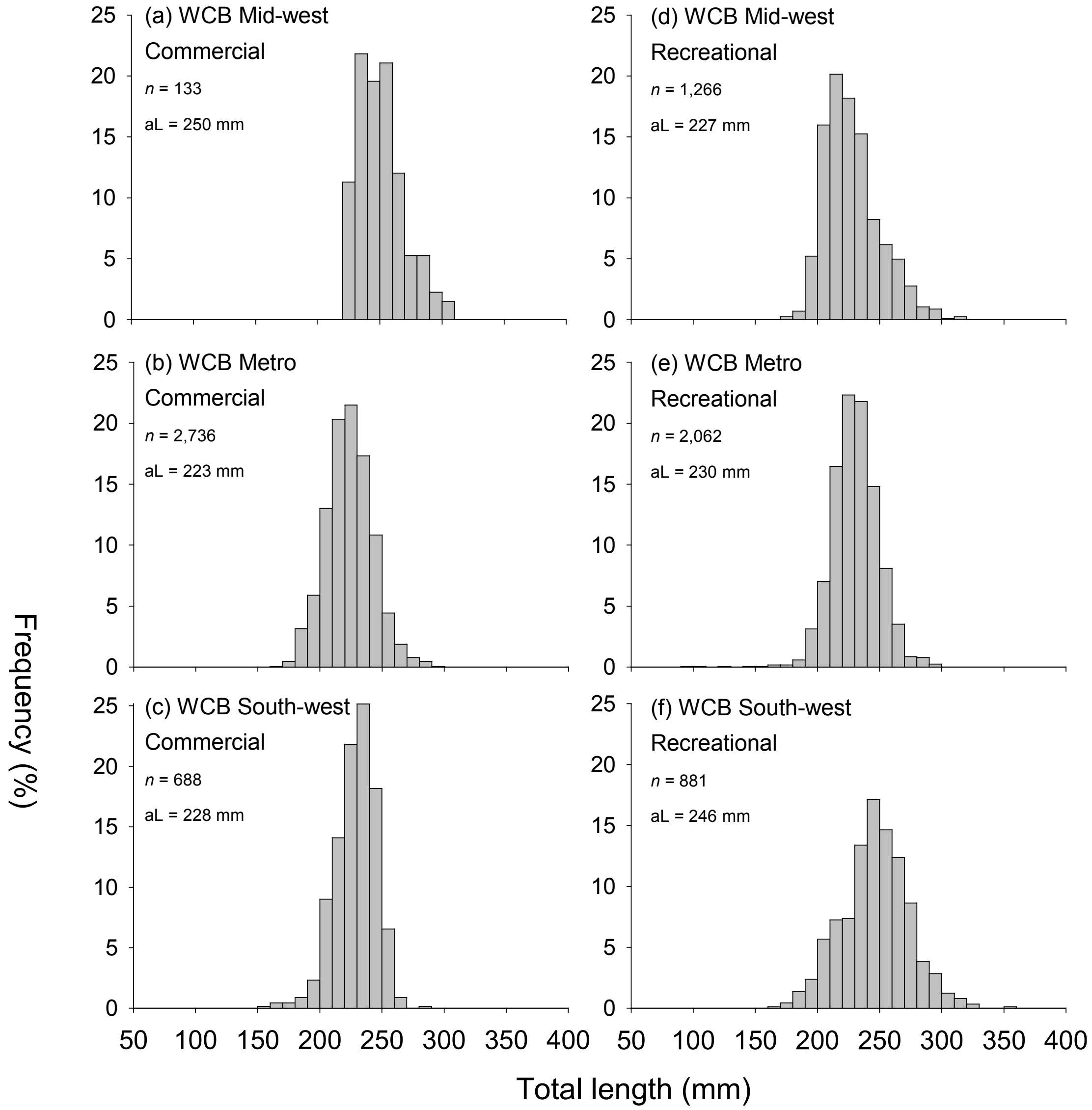


Figure 5.3. Length composition of commercial and recreational caught Australian herring by Zone in the West Coast Bioregion for 2009–11. **(a)** – **(c)** commercial, and **(d)** – **(f)** recreational. n, number of fish measured; aL, average length of fish in sample.

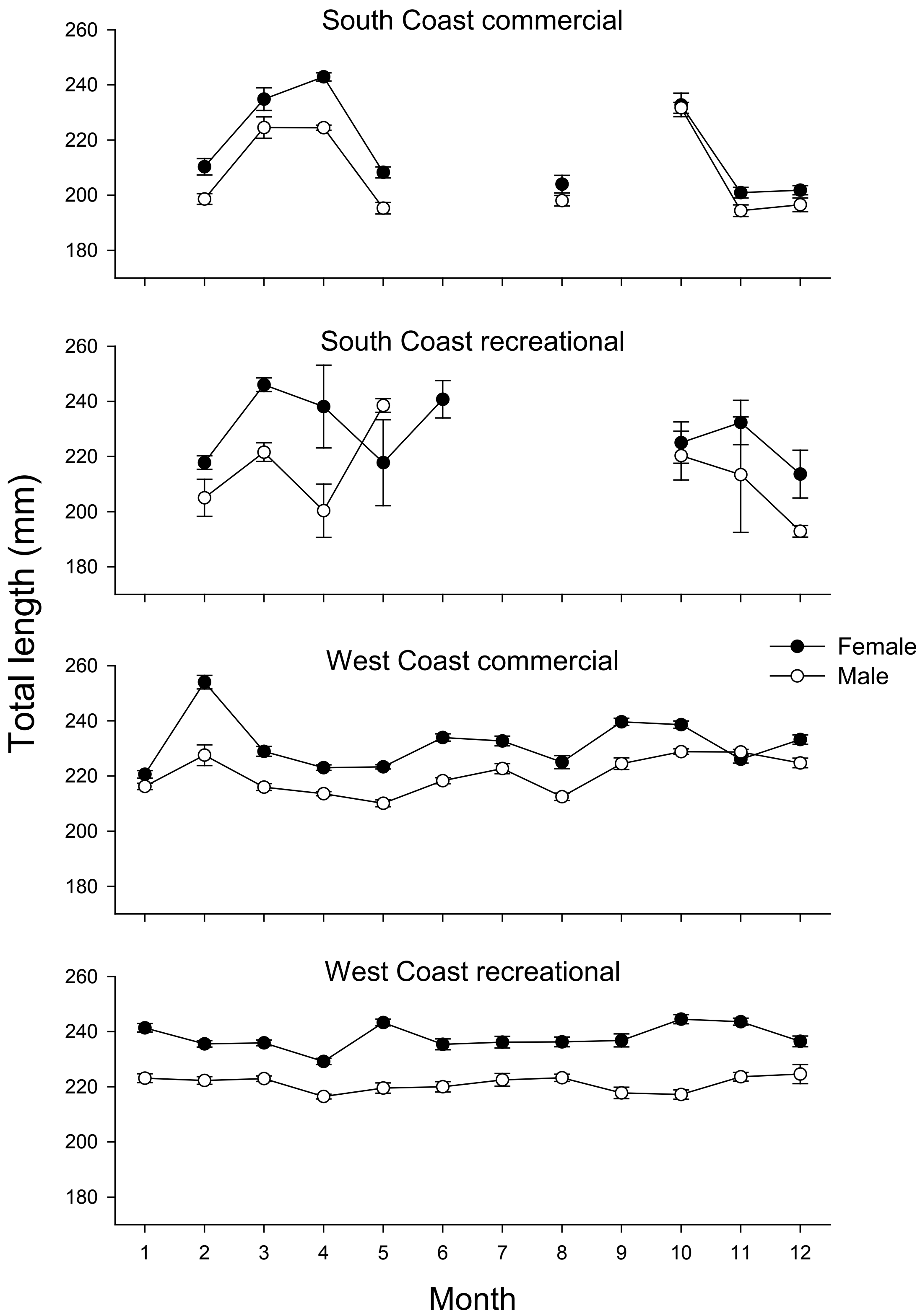


Figure 5.4. Monthly mean length (mm) ± 1 s.e of Australian herring sampled during 2009–11, by Bioregion and sector. Note: y-axes do not start at zero.

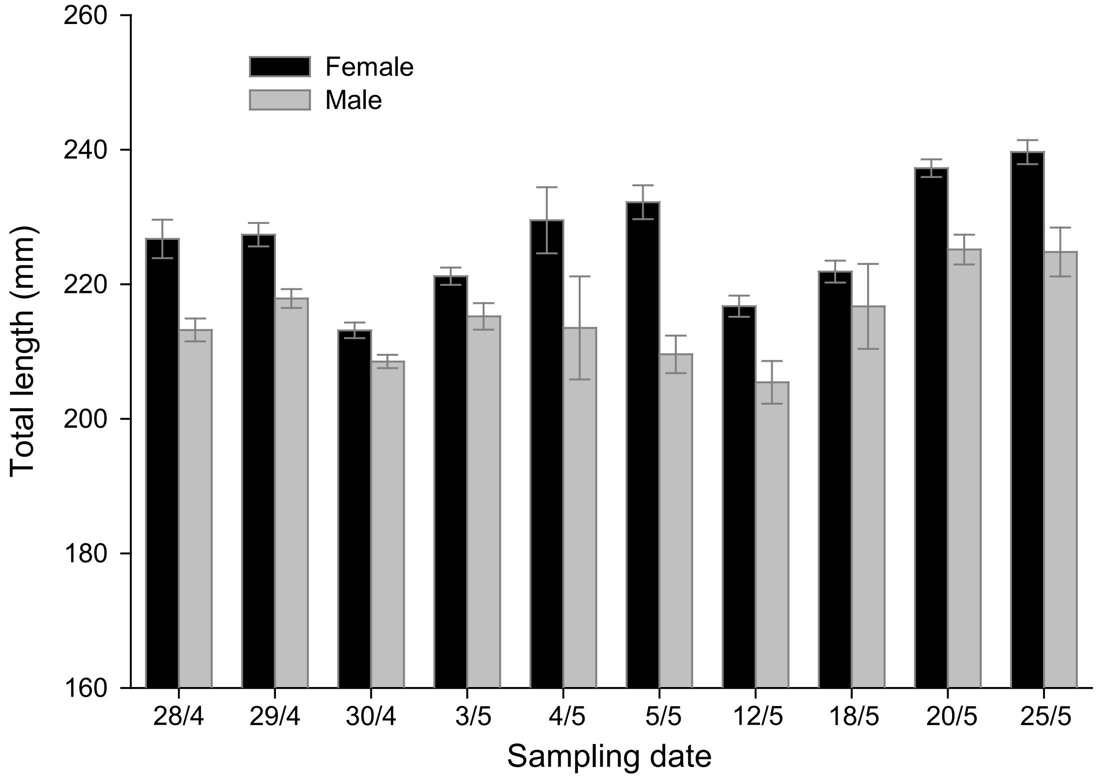


Figure 5.5. Mean total lengths (mm) ± 1 s.e. of female (dark grey bars) and male (light grey bars) Australian herring for the representative sampling study (Cockburn Sound - 28 April to 25 May 2010). Note: y-axes do not start at zero.

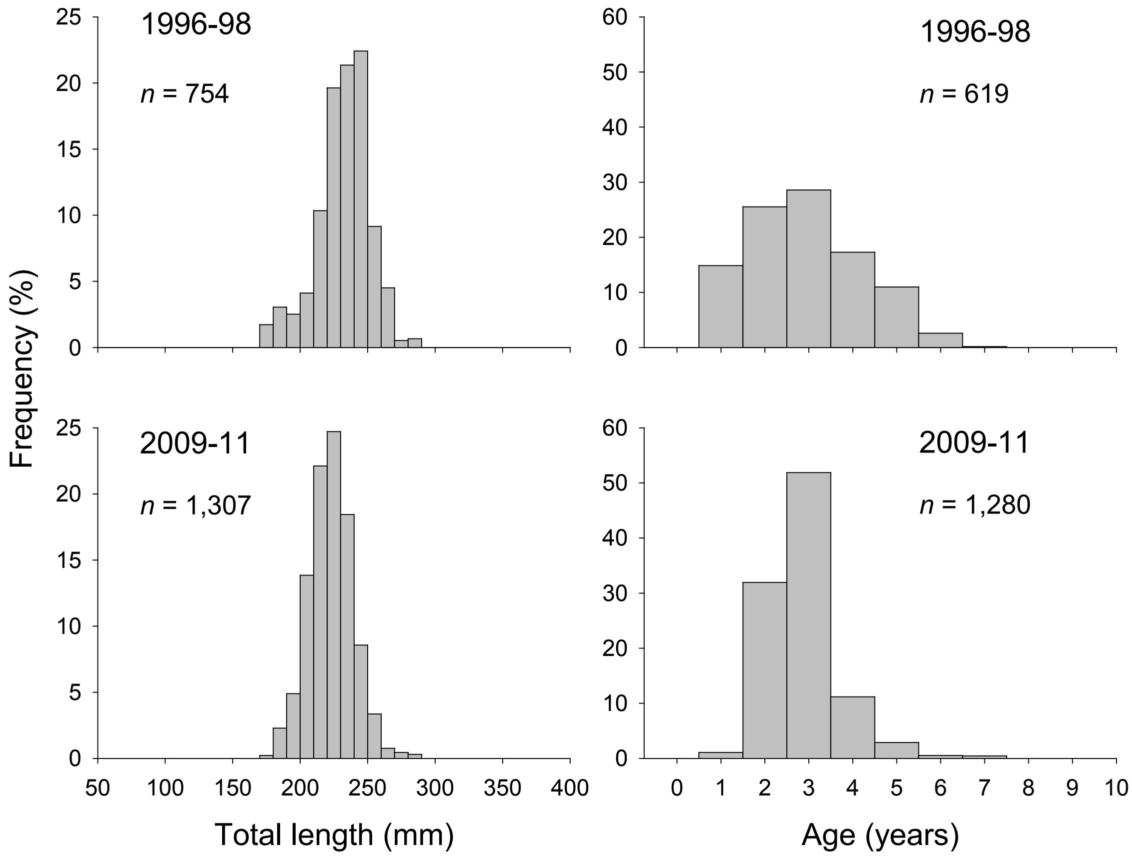


Figure 5.6. Length and age composition of Australian herring caught in the West Coast Bioregion commercial fishery (ocean catch only) during 1996–98 (South-west Zone) and 2009–11 (Metropolitan Zone). n, number of fish. Note: 2009–11 data does not include samples collected during Represenative Sampling Study in Cockburn Sound.

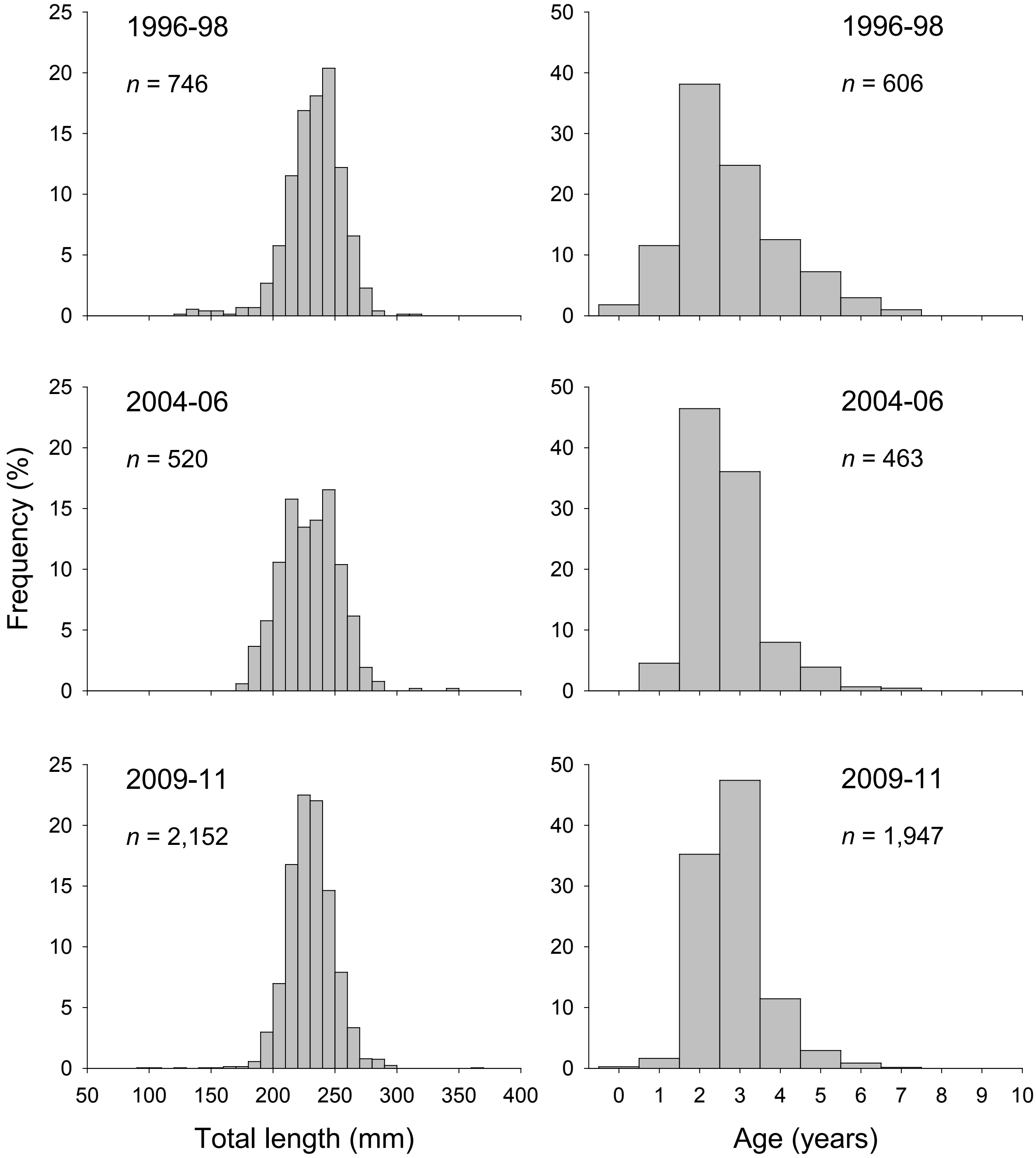


Figure 5.7. Length and age composition of Australian herring caught in the West Coast Bioregion recreational fishery (Metropolitan Zone only) during 1996–98, 2004–06 and 2009–11. n - number of fish.

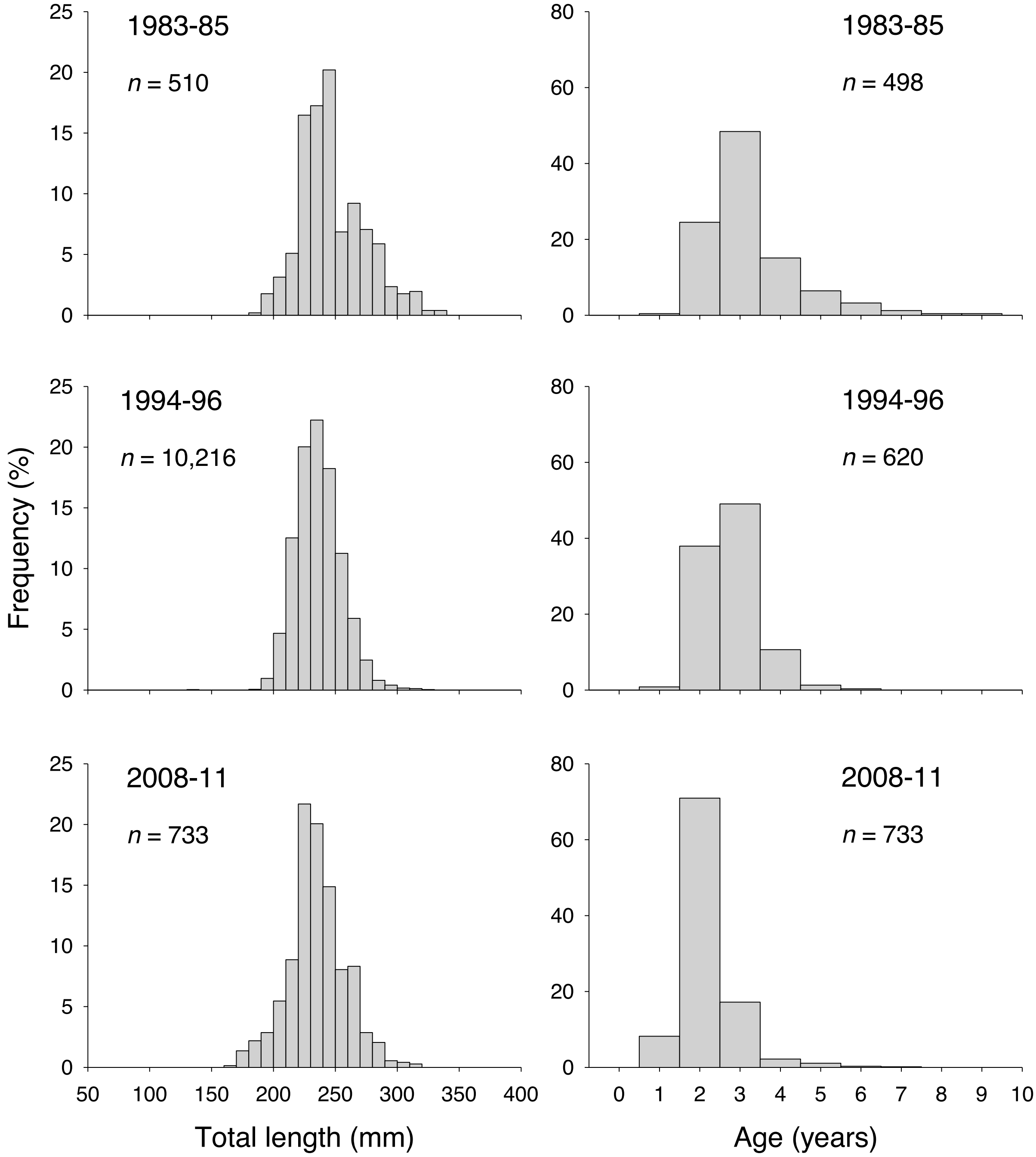


Figure 5.8. Length and age composition of Australian herring caught in the South Coast Bioregion commercial fishery (Trap Net only) during 1983–85, 1994–96 and 2009–11. n, number of fish.

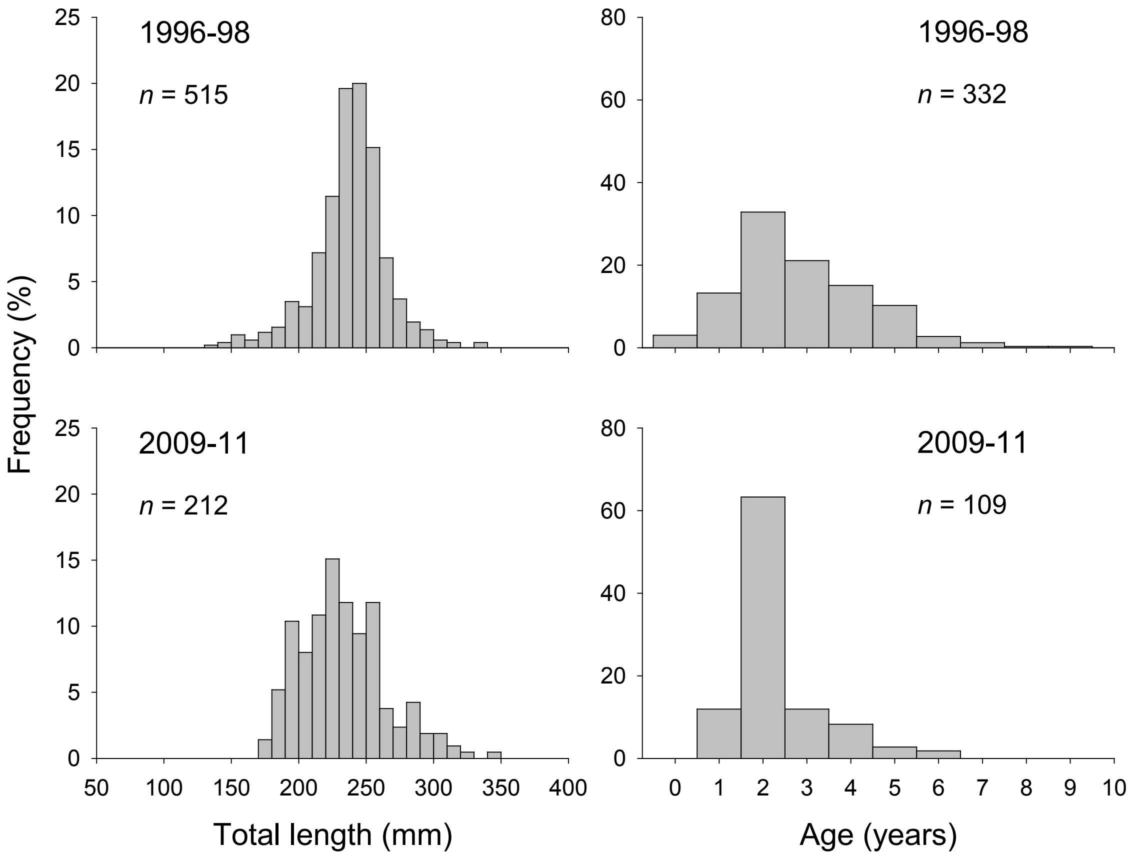


Figure 5.9. Length and age composition of Australian herring caught in the South Coast Bioregion recreational fishery (South Zone only) during 1996–98 and 2009–11. n, number of fish.

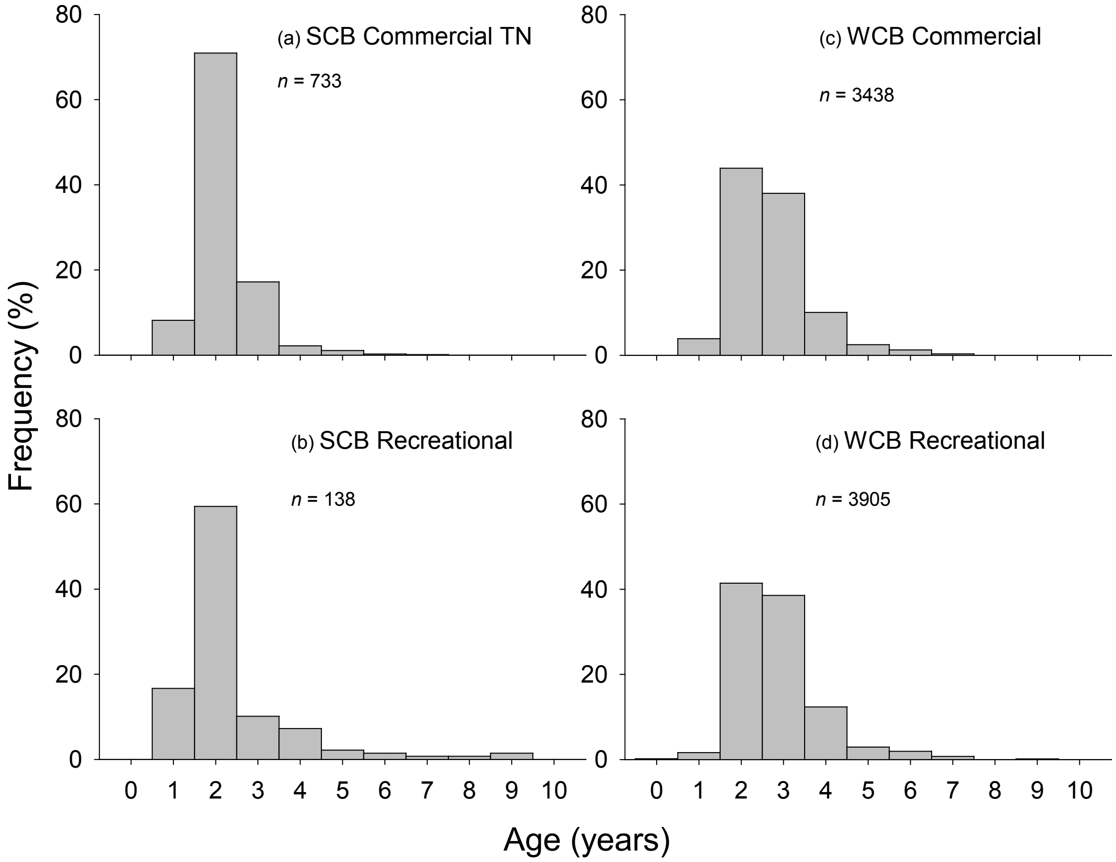


Figure 5.10. Age composition of commercially and recreationally caught Australian herring by Bioregion for 2009–11. (a) South Coast Bioregion commercial (Trap Net fishery only), (b) South Coast Bioregion recreational, (c) West Coast Bioregion commercial and (d) West Coast Bioregion recreational. n, number of fish aged.

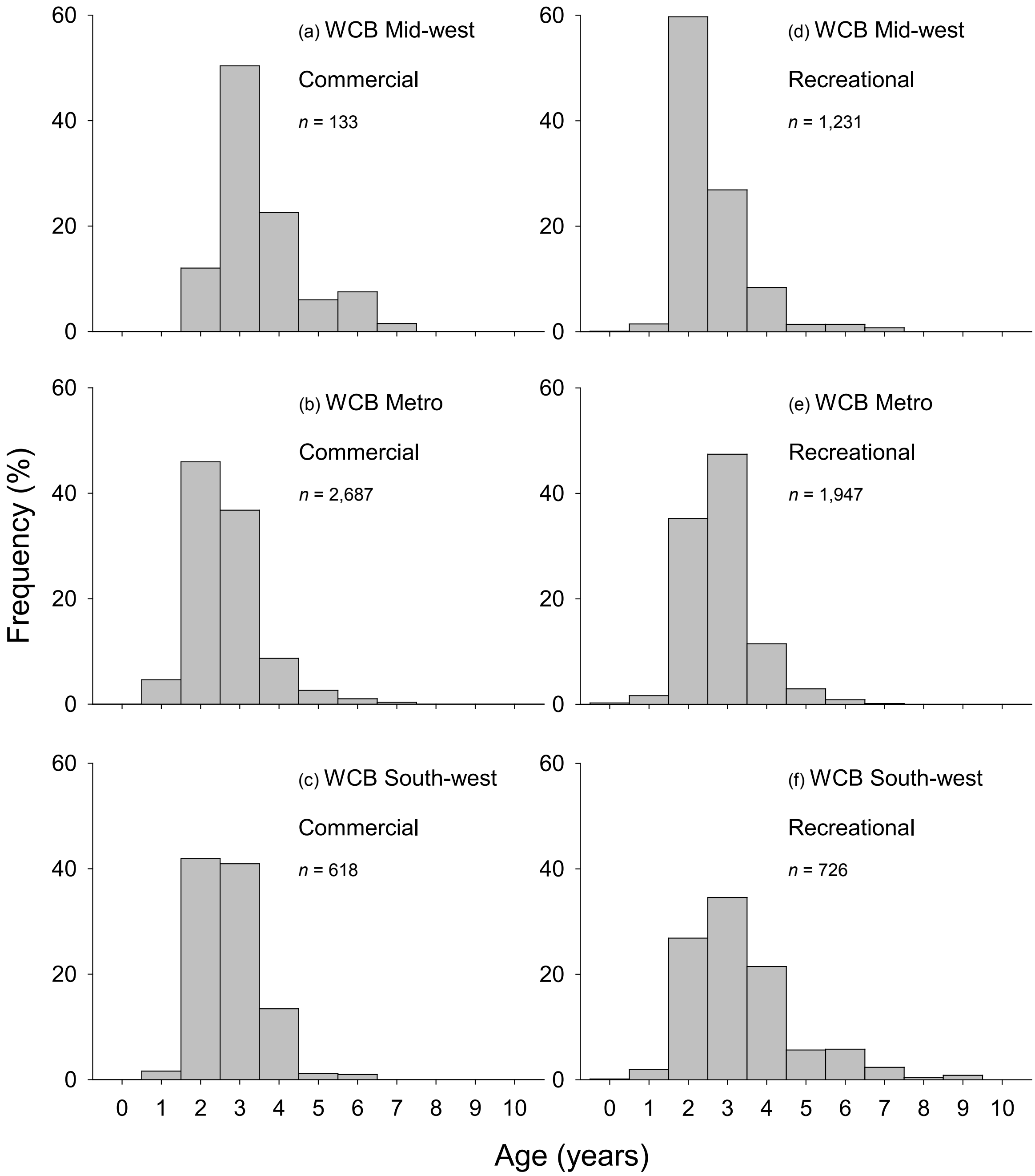


Figure 5.11. Age composition of commercially and recreationally caught Australian herring by Zone in the West Coast Bioregion for 2009–11. **(a)** – **(c)** commercial, and **(d)** – **(f)** recreational. n, number of fish aged.

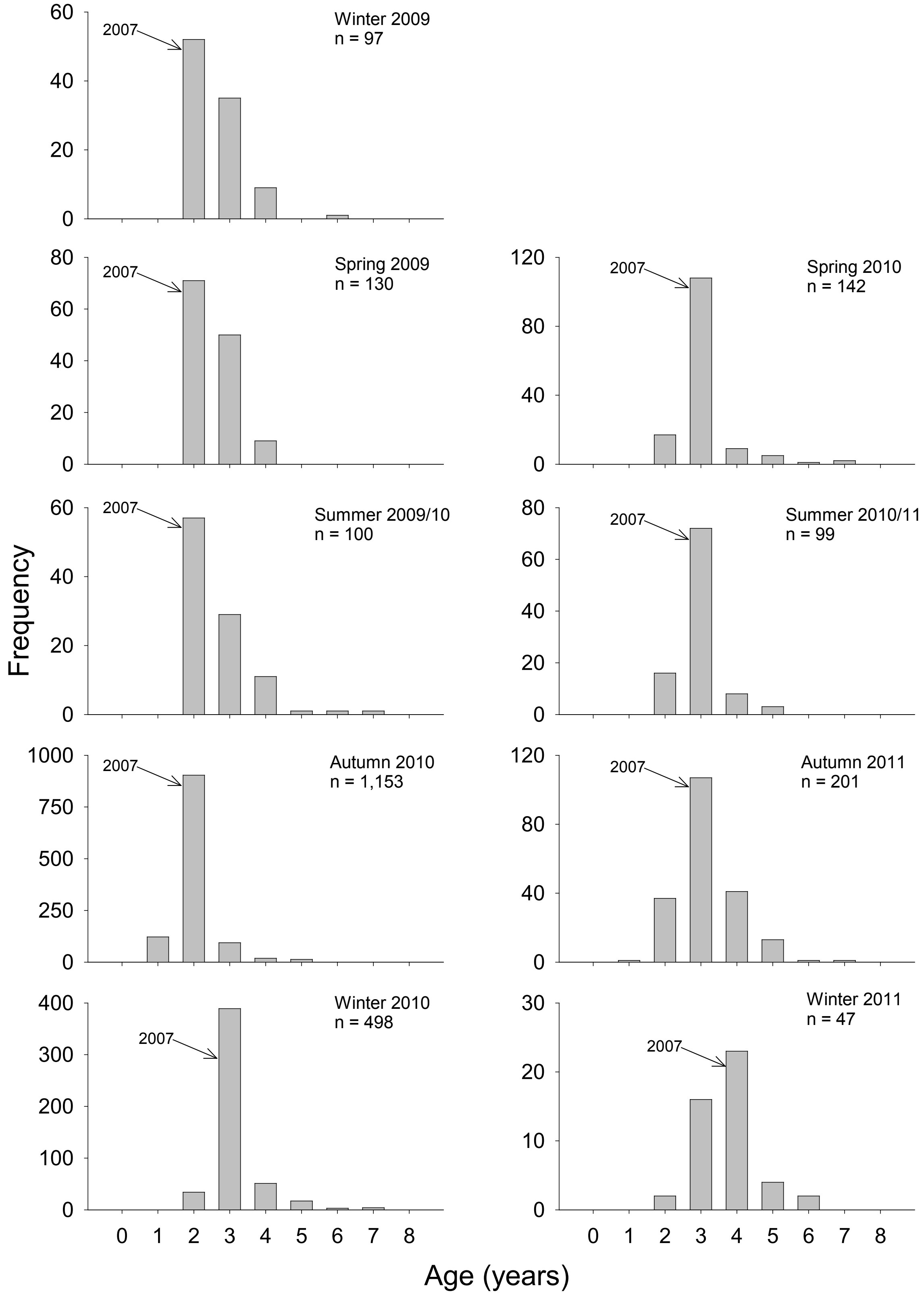


Figure 5.12. Seasonal age composition of the West Coast Bioregion (Metropolitan Zone) commercial fishery in 2009–11. n, number of fish aged.

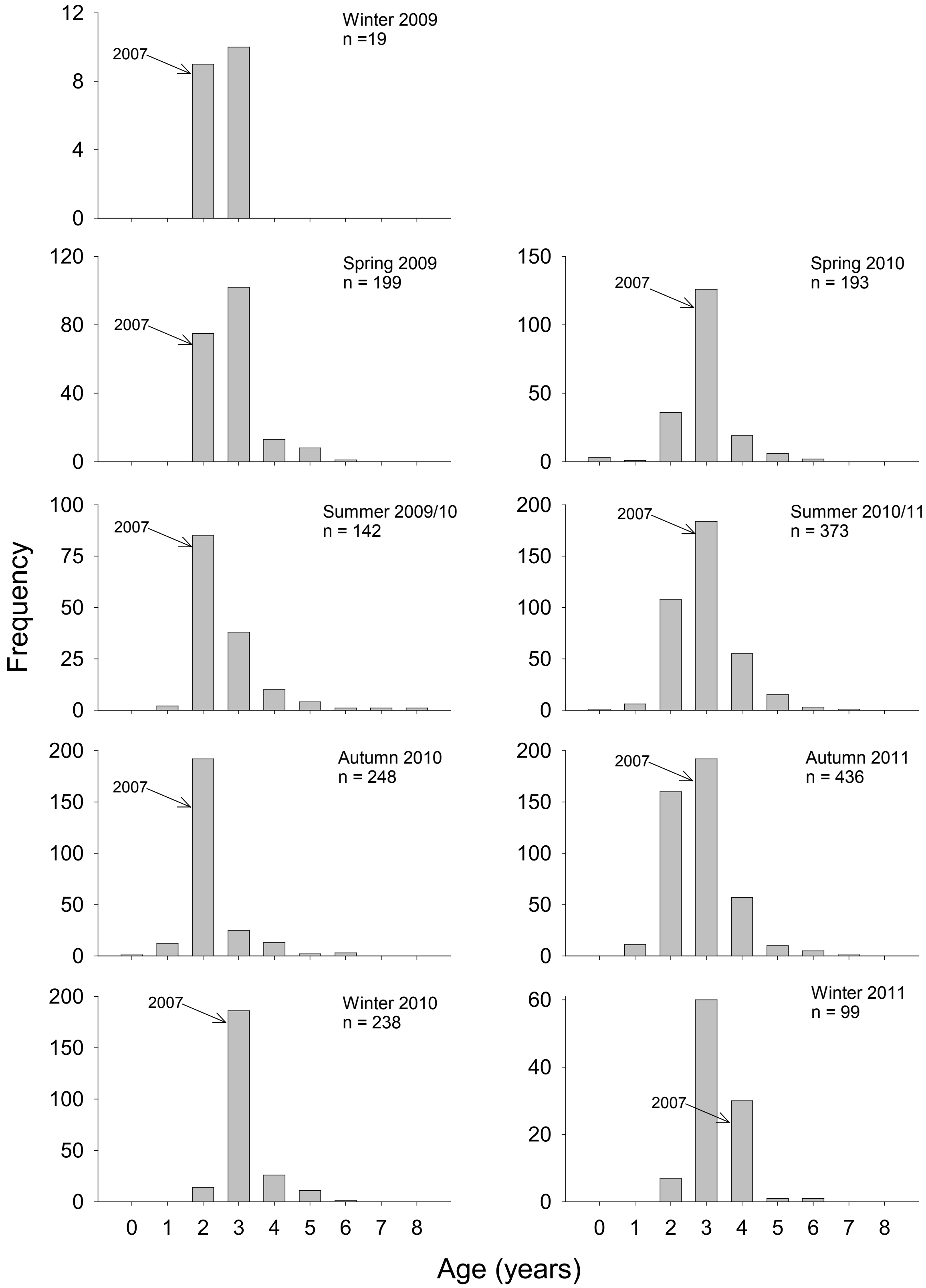


Figure 5.13. Seasonal age composition of the West Coast Bioregion (Metropolitan Zone) recreational fishery in 2009–11. n, number of fish aged.

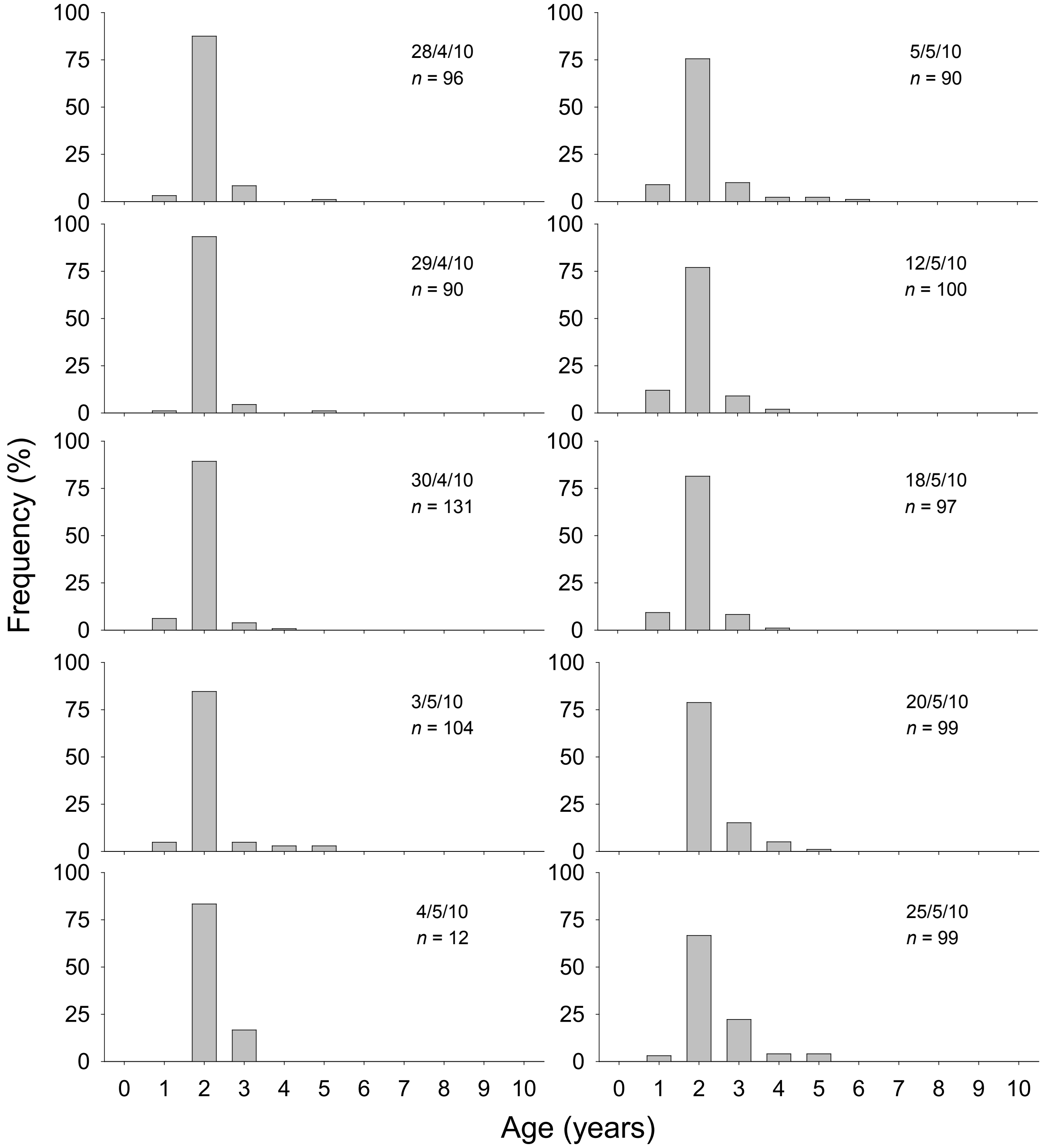


Figure 5.14. Daily age frequencies during the representative sampling study (Cockburn Sound – 28 April to 25 May 2010). n, number of fish aged.

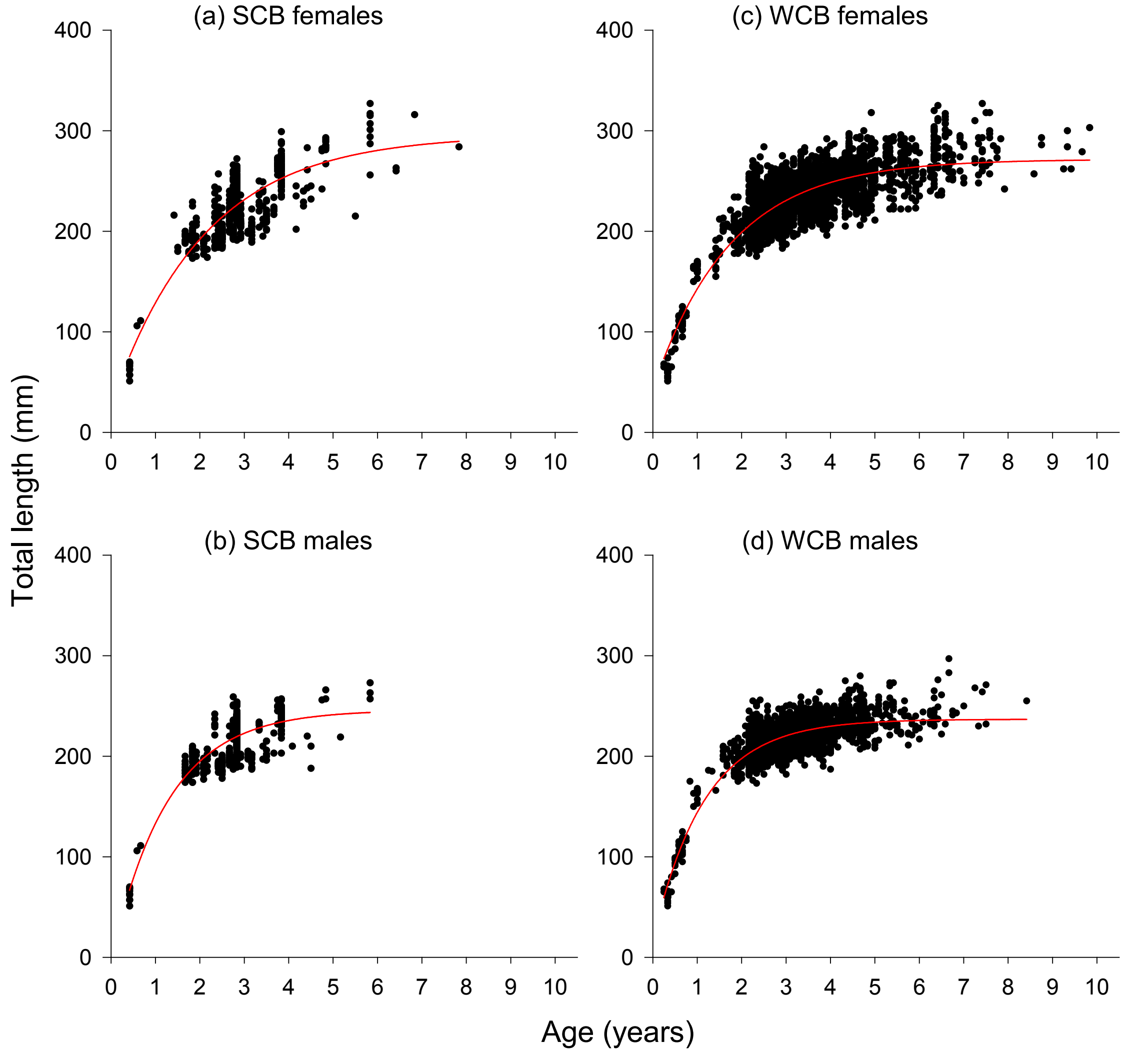


Figure 5.15. von Bertalanffy growth curves fitted to length-at-age data collected in 2009–11 for female and male Australian herring by Bioregion.

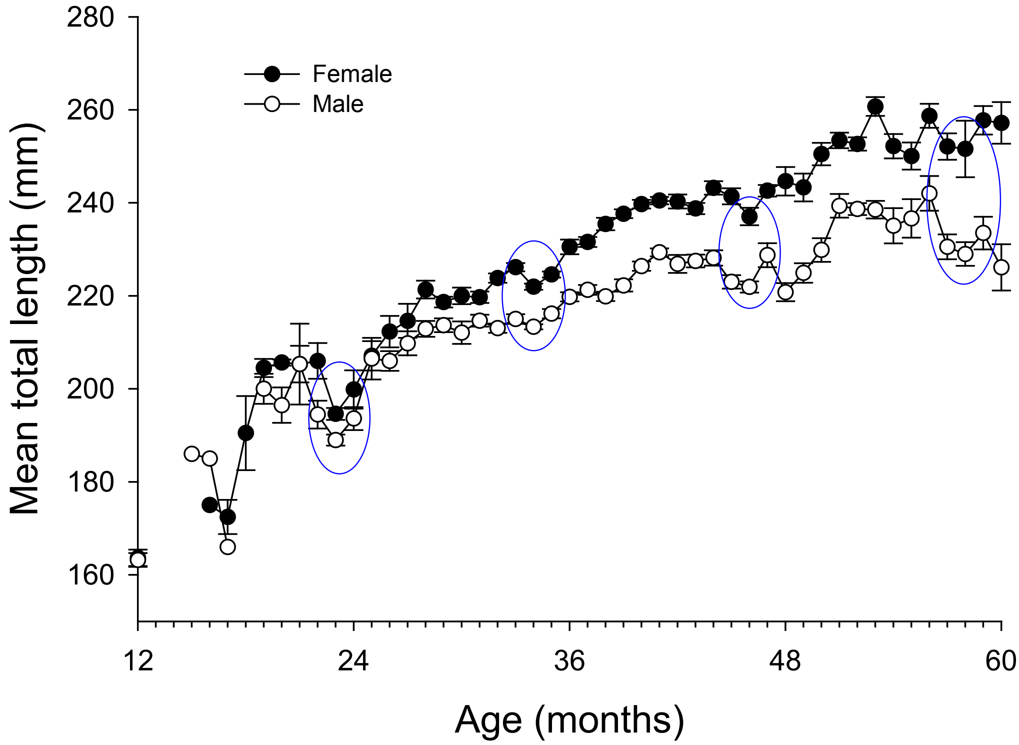


Figure 5.16. Mean monthly length at age by sex for Australian herring from samples collected in the West Coast Bioregion (sectors pooled) in 2009–11. Circles highlight the decline in the mean length in the West Coast Bioregion for both sexes during the annual spawning periods. Note: axes do not start from 0.

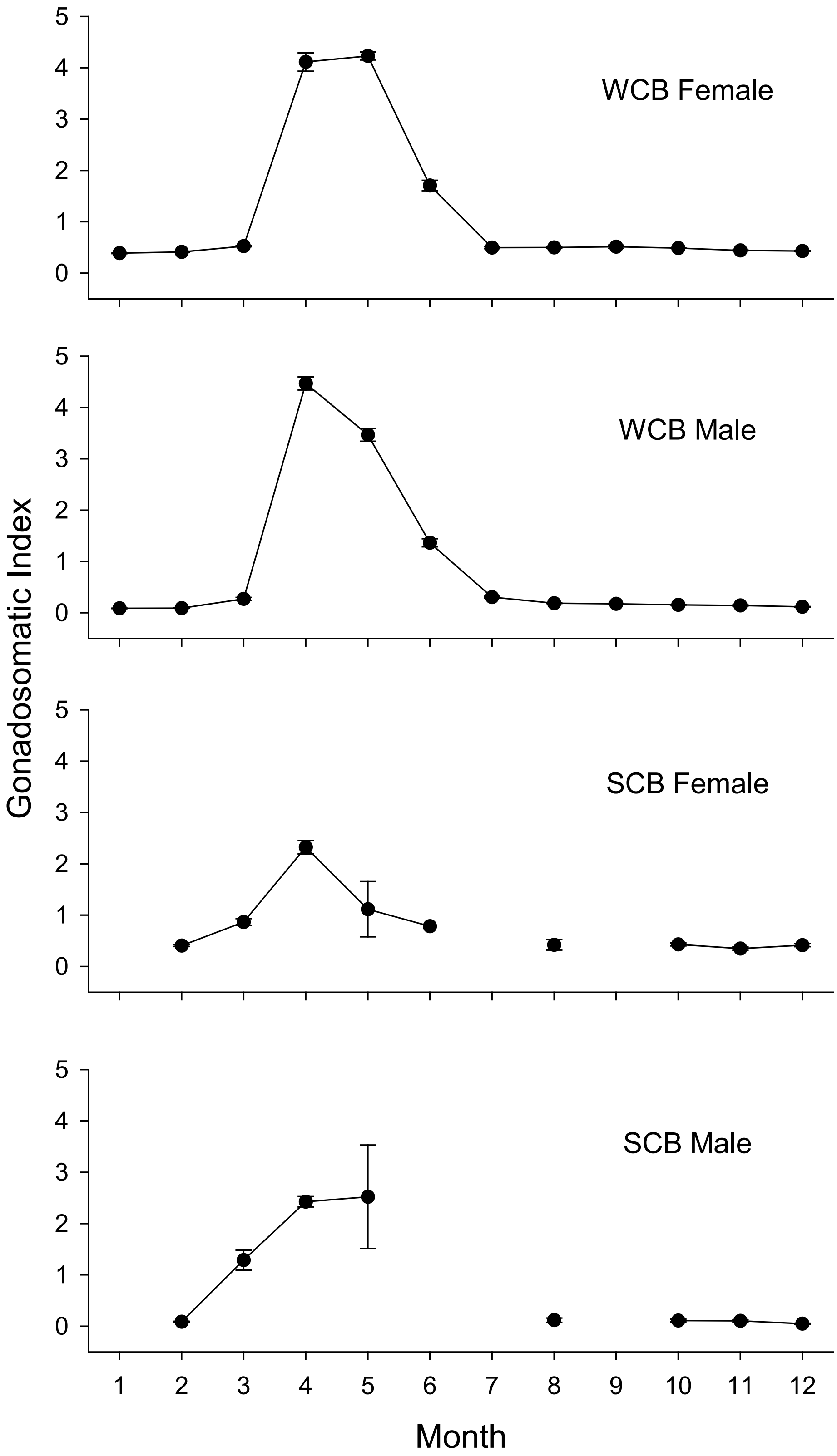


Figure 5.17. Monthly gonadosomatic indices (mean ± 1 s.e.) for female and male Australian herring (total length >L_{50}) caught in the West Coast (upper two) and South Coast Bioregions (lower two) in 2009–11. Note, error bars are too small to be visible on this scale for most points.

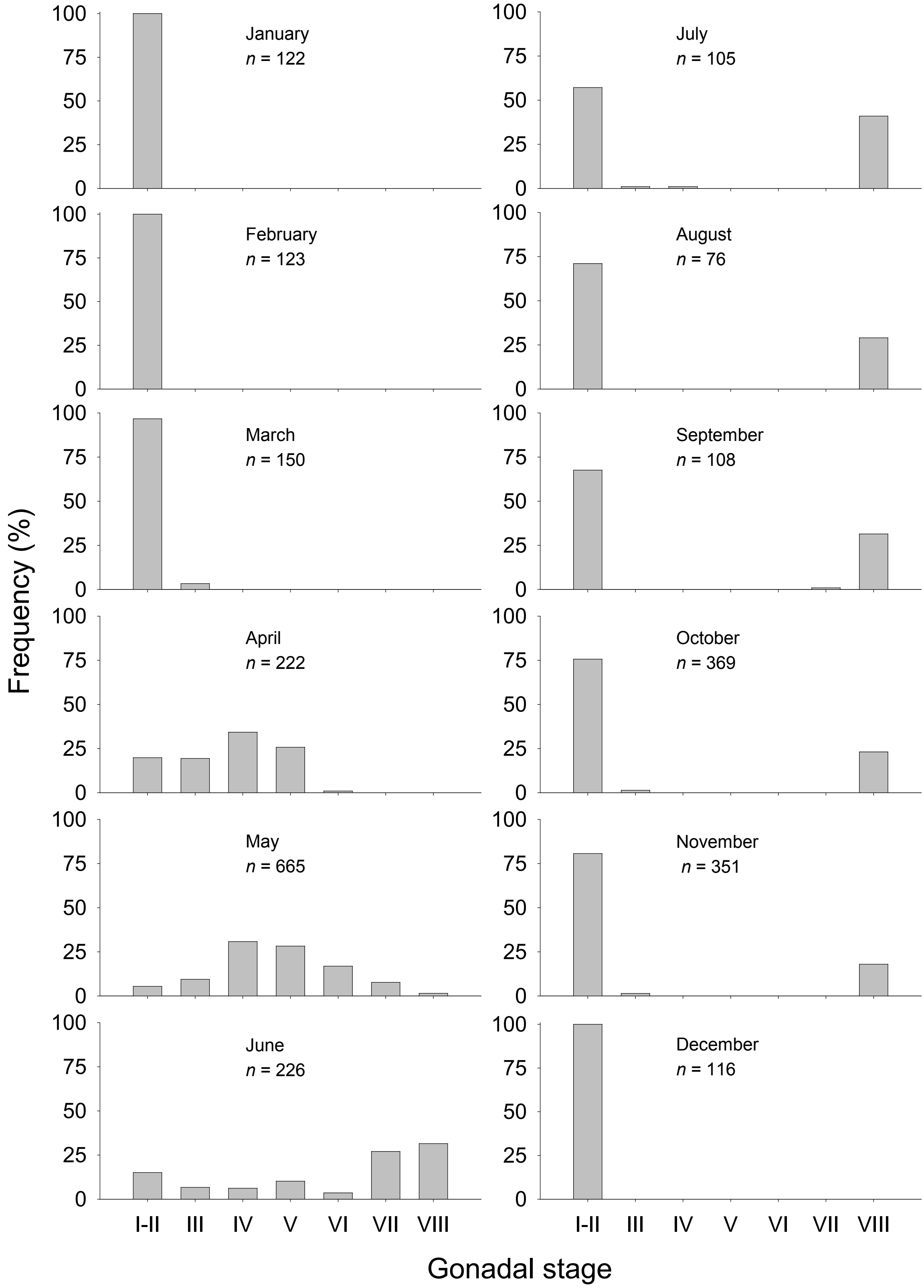


Figure 5.18. Monthly percentage frequencies of macroscopic gonad developmental stages in female Australian herring caught in the West Coast Bioregion in 2009–11. n, number of fish staged.

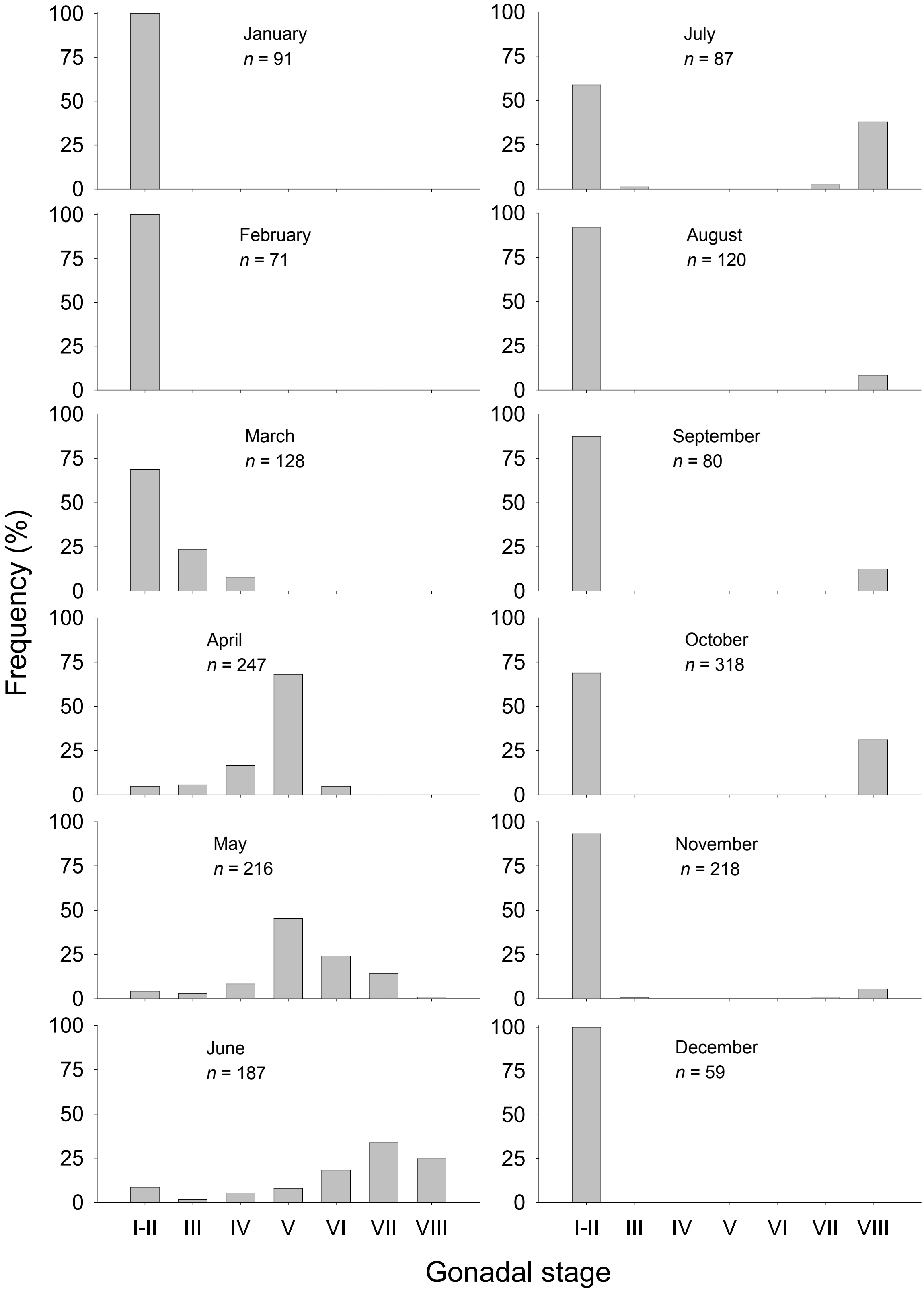


Figure 5.19. Monthly percentage frequencies of macroscopic gonad developmental stages in male Australian herring caught in the West Coast Bioregion in 2009–11. n, number of fish staged.

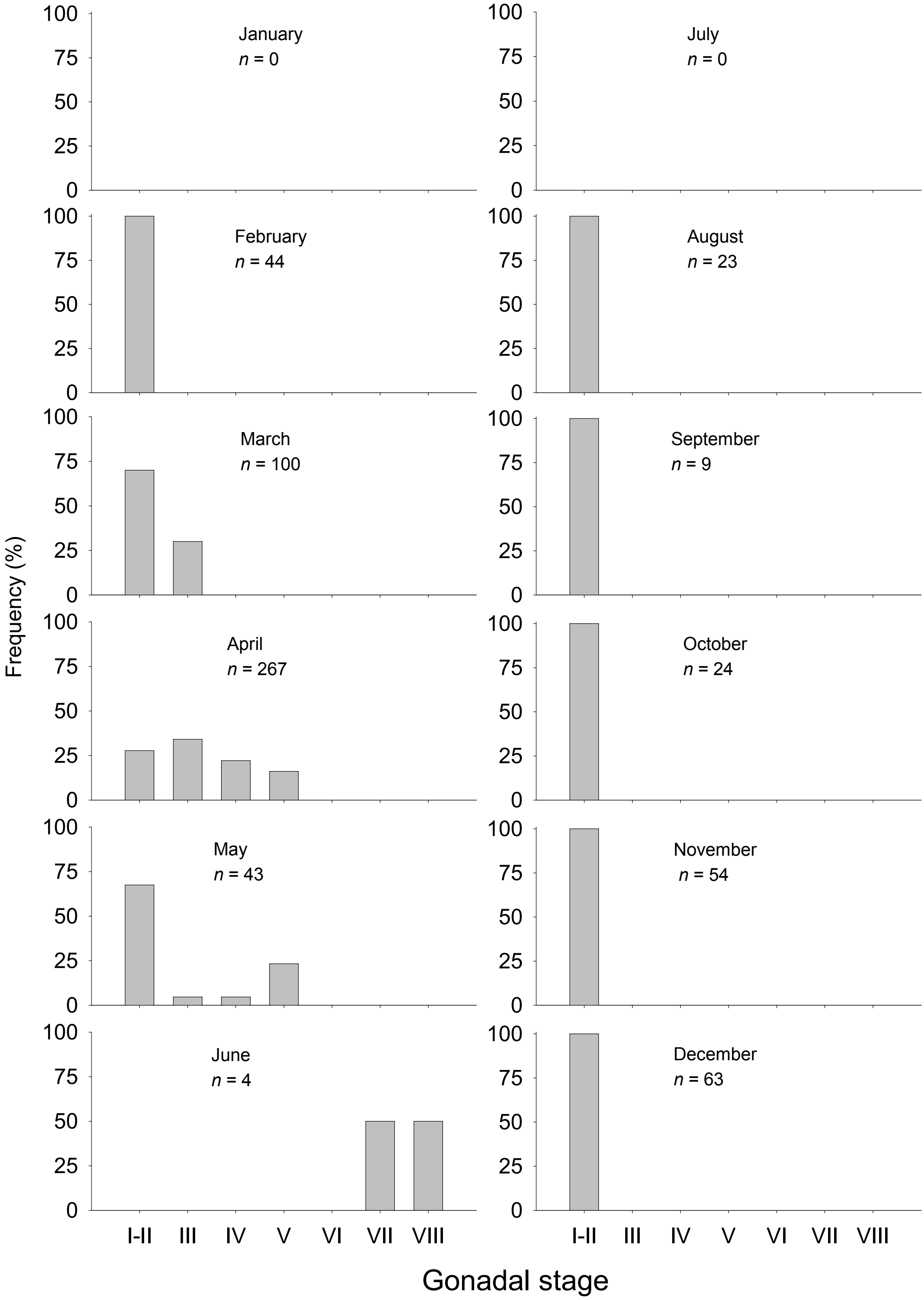


Figure 5.20. Monthly percentage frequencies of macroscopic gonad developmental stages in female Australian herring caught in the South Coast Bioregion in 2009–11. n, number of fish staged.

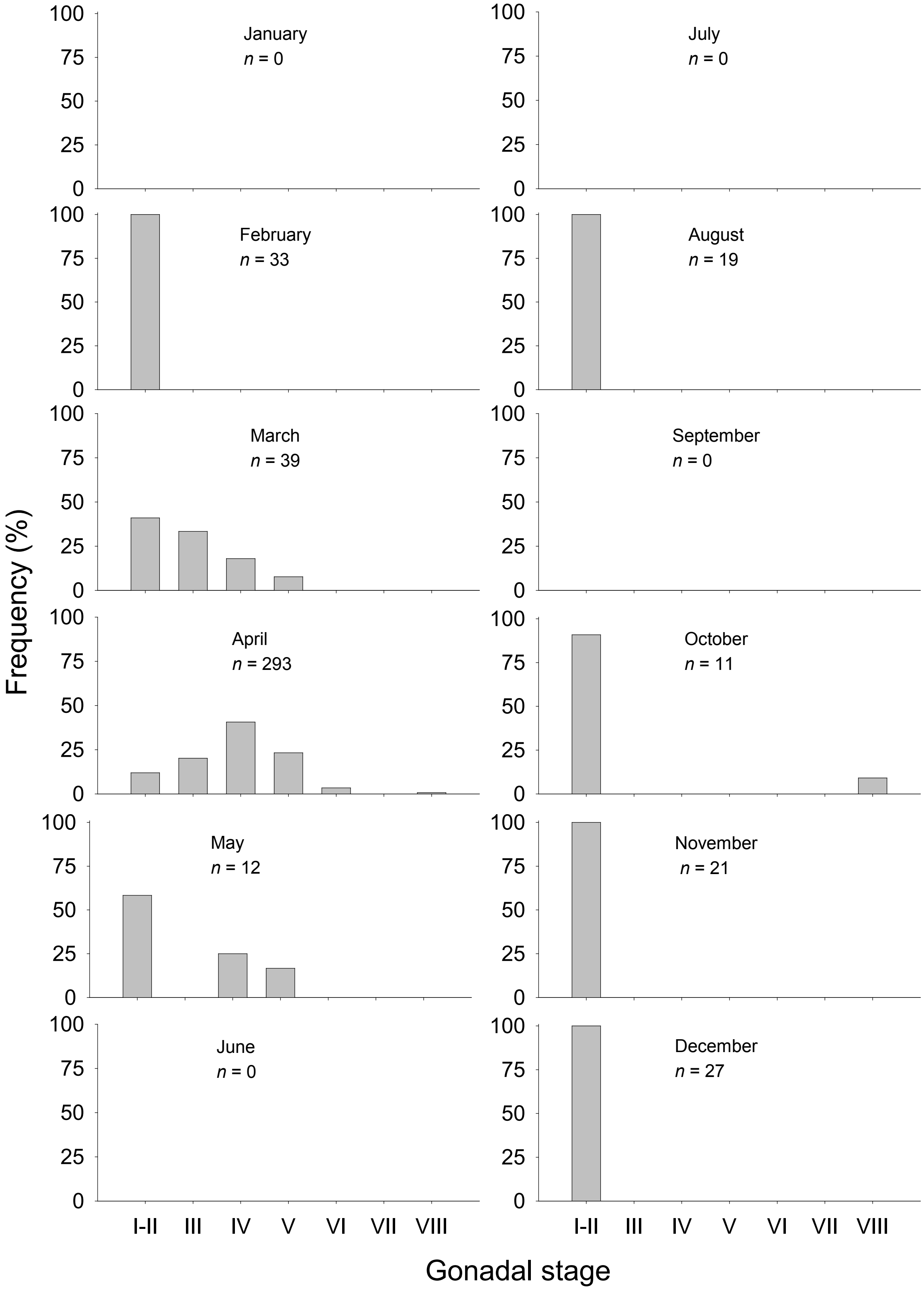


Figure 5.21. Monthly percentage frequencies of macroscopic gonad developmental stages in male Australian herring caught in the South Coast Bioregion in 2009–11. n, number of fish staged.

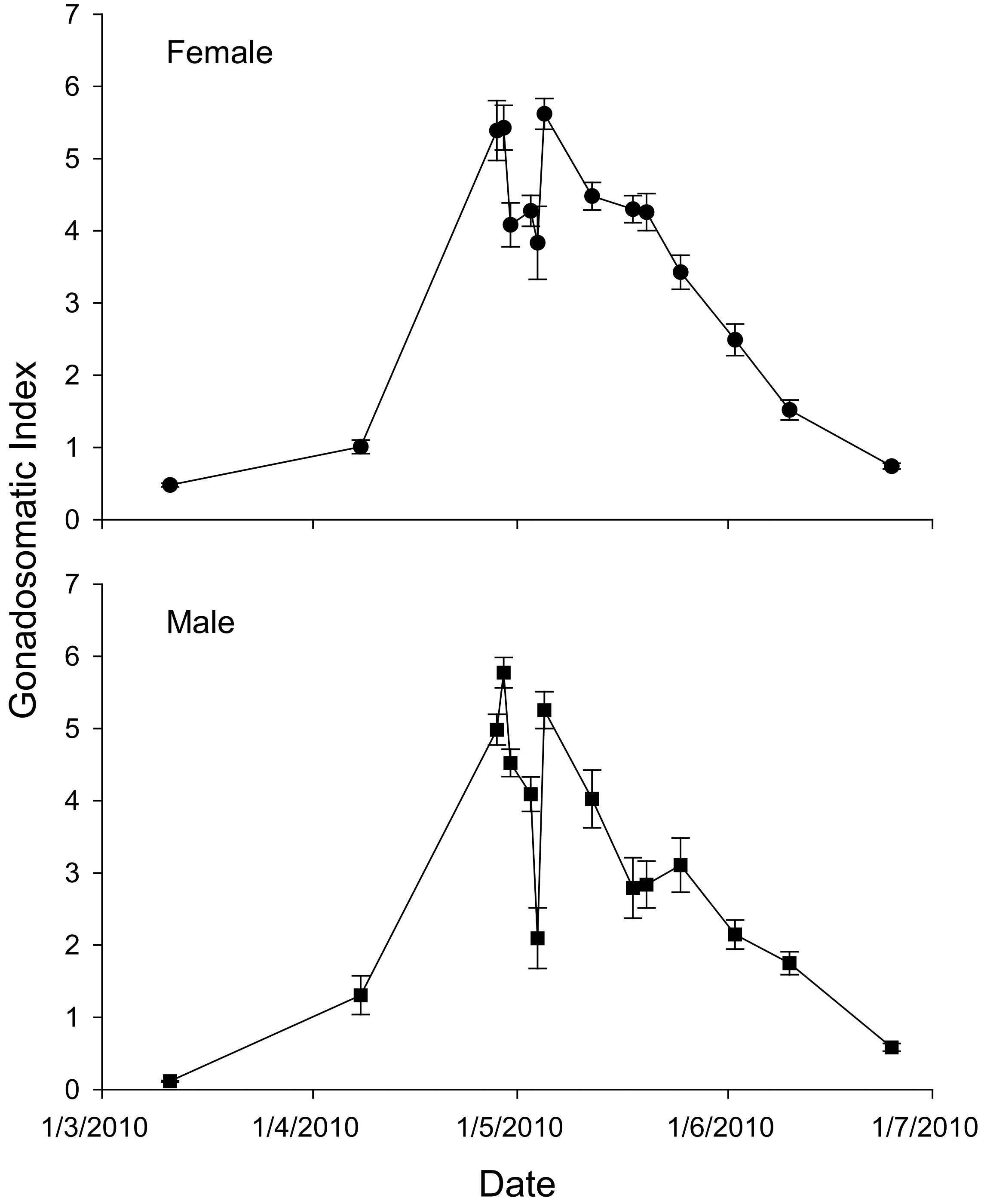


Figure 5.22. Gonadosomatic index for Australian herring female (top) and male (bottom) for the Cockburn Sound between March to July 2010, and includes the representative sampling study.

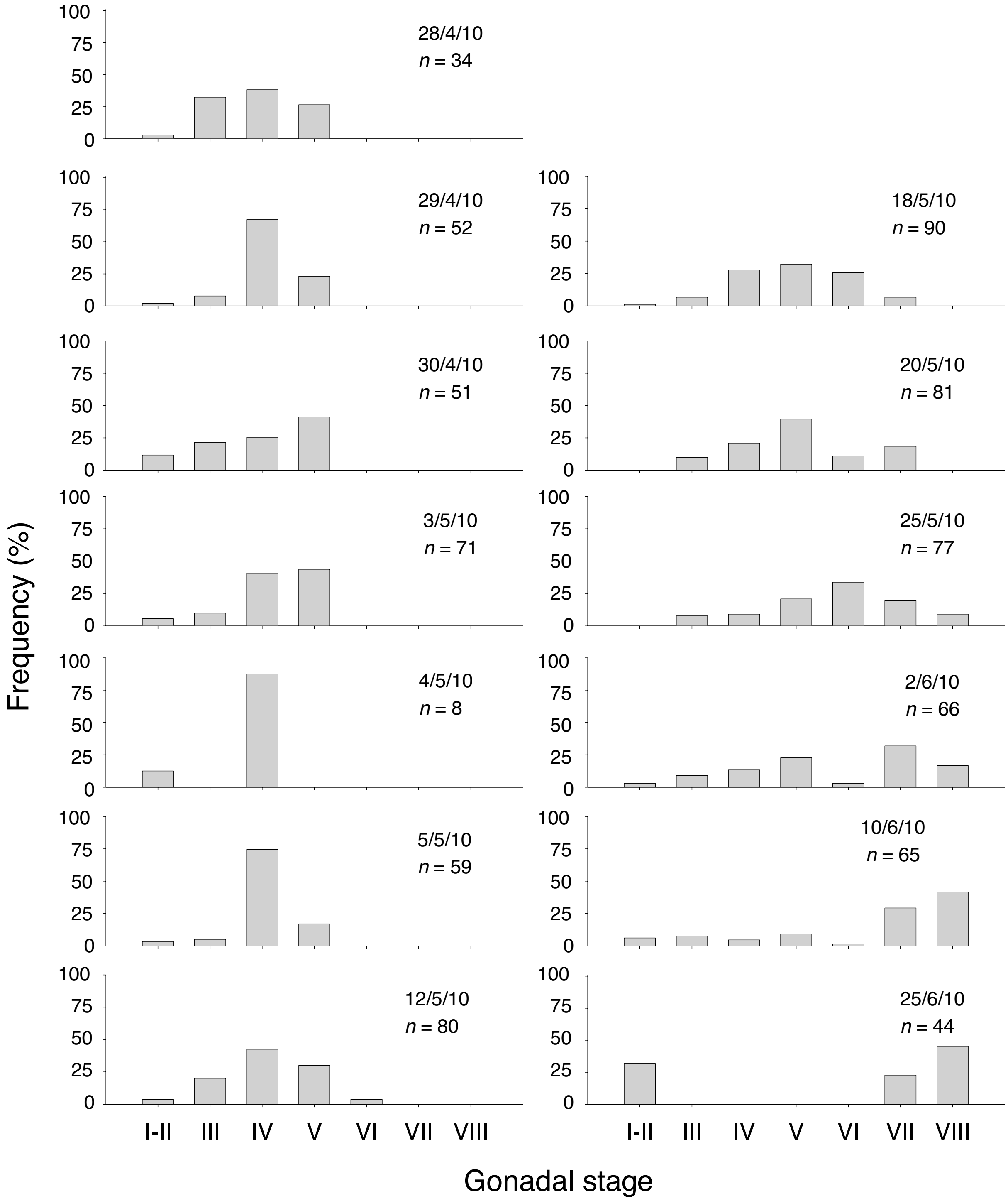


Figure 5.23. Percentage frequencies of macroscopic gonad developmental stages in female Australian herring caught in the Cockburn Sound (WCB – Metropolitan Zone) between 28/4/10 to 25/6/10. n, number of fish staged. Note, includes the representative sampling study and an additional three sampling events in June to capture the end of the spawning period.

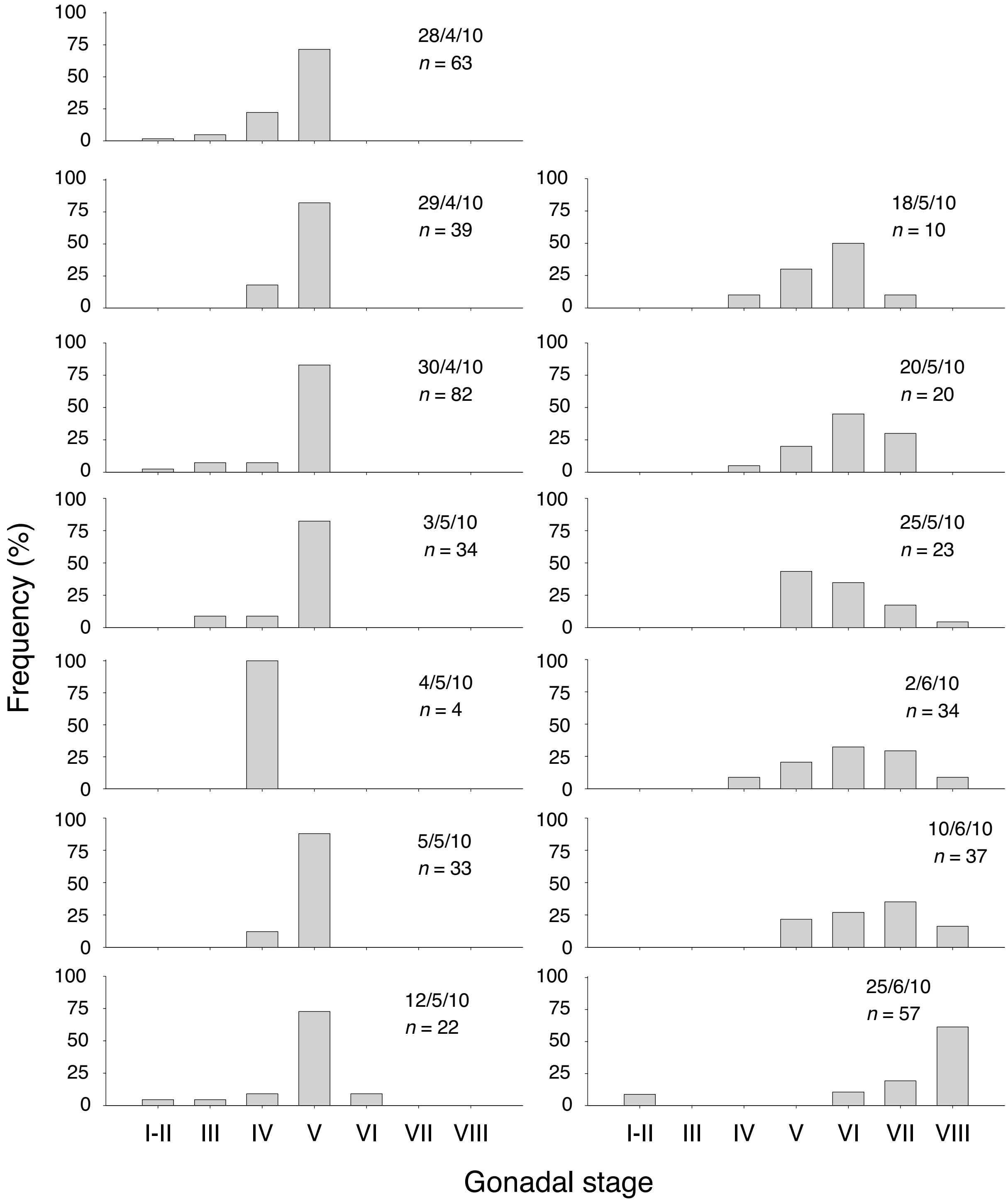


Figure 5.24. Percentage frequencies of macroscopic gonad developmental stages in male Australian herring caught in the Cockburn Sound (WCB – Metropolitan Zone) between 28/4/10 to 25/6/10. n, number of fish staged. Note, includes the representative sampling study and an additional three sampling events in June to capture the end of the spawning period.

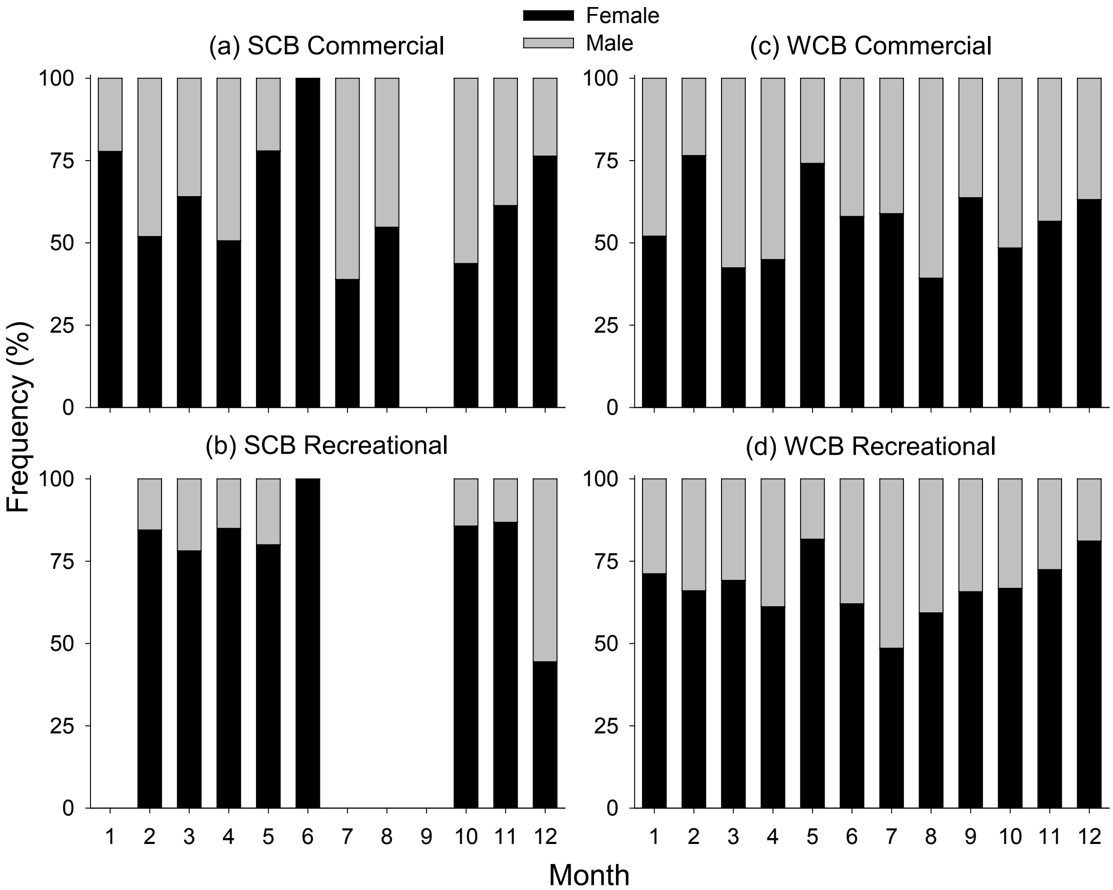


Figure 5.25. Sex ratio of commercial and recreational caught Australian herring by Bioregion for 2009–11. **(a)** South Coast Bioregion commercial, **(b)** South Coast Bioregion recreational, **(c)** West Coast Bioregion commercial and **(d)** West Coast Bioregion recreational.

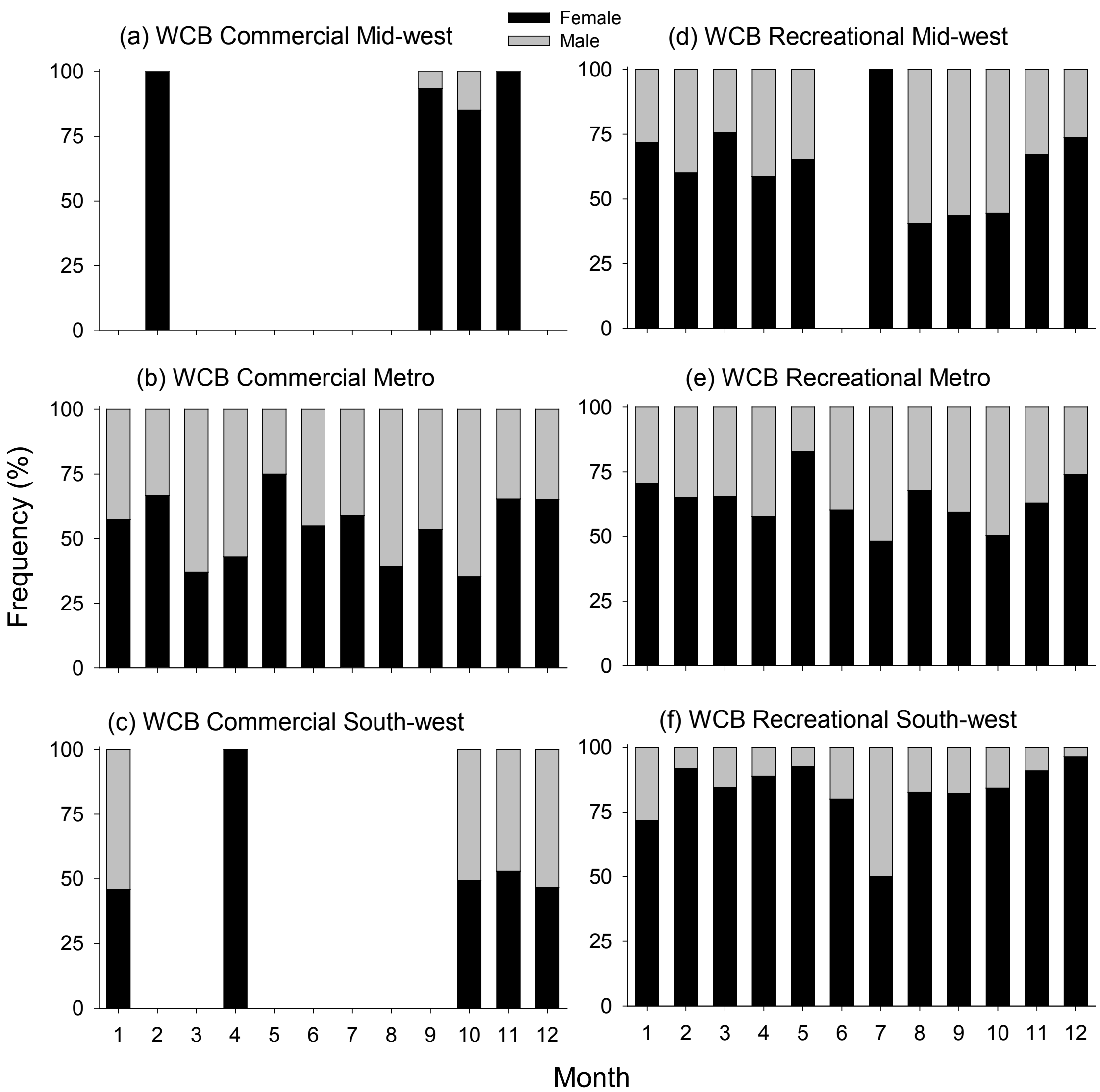


Figure 5.26. Sex ratio of commercially and recreationally caught Australian herring by Zone in the West Coast Bioregion for 2009–11. **(a) – (c)** commercial, and **(d) – (f)** recreational.

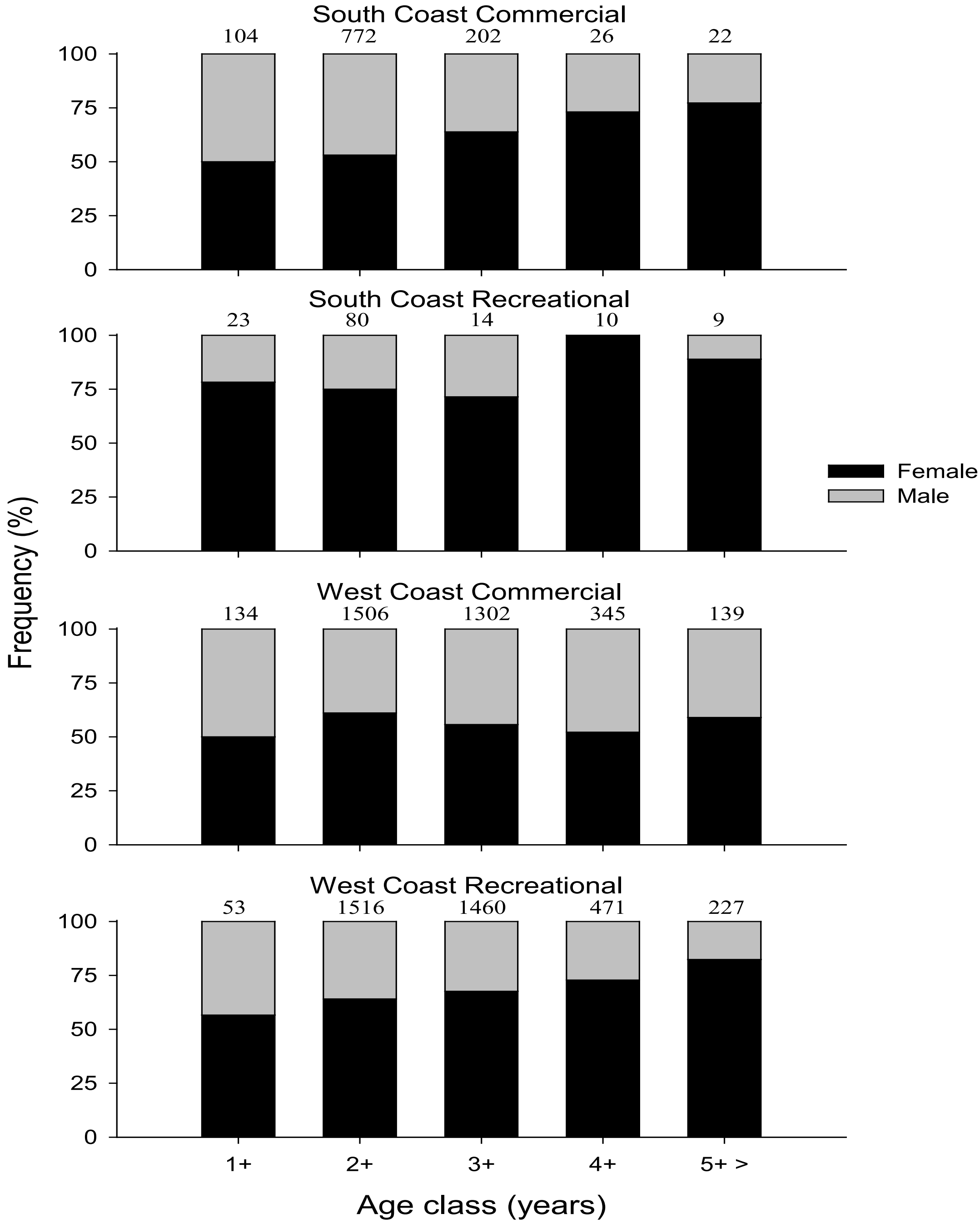


Figure 5.27. Proportion of female and male Australian herring in each age class sampled in 2009–11 by Bioregion and sector. Total number of fish sexed is shown above each age class.

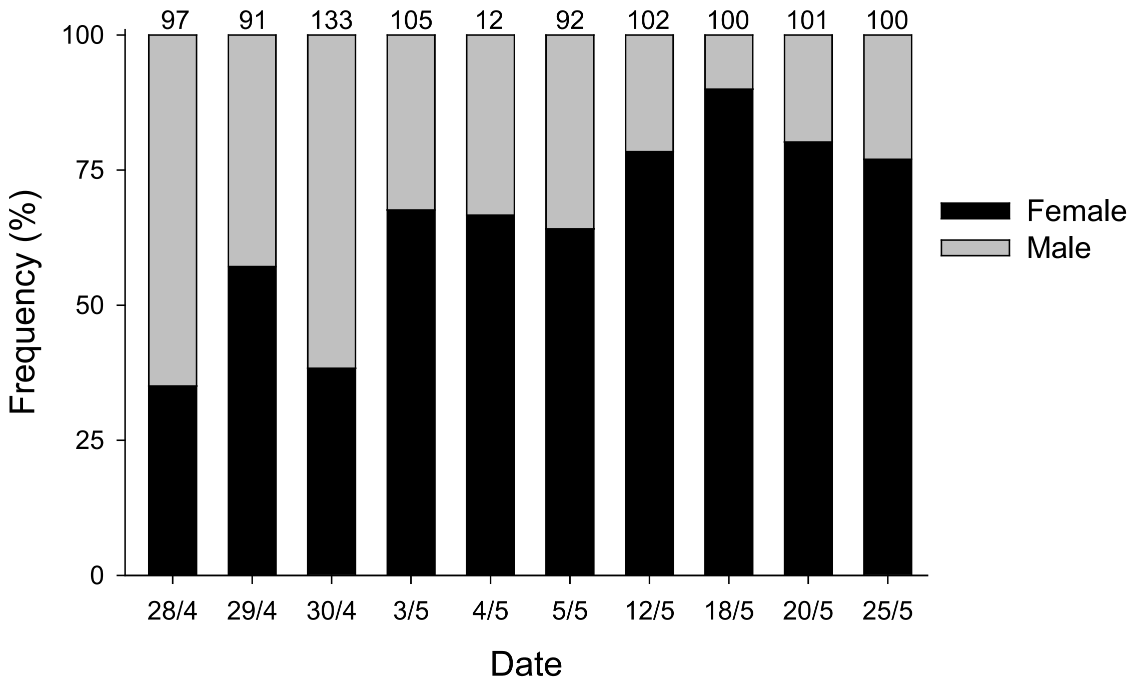


Figure 5.28. Proportion of female and male Australian herring in daily samples from Cockburn Sound commercial landings – 28 April to 25 May 2010. Total number of fish sexed is shown above each sampling date.

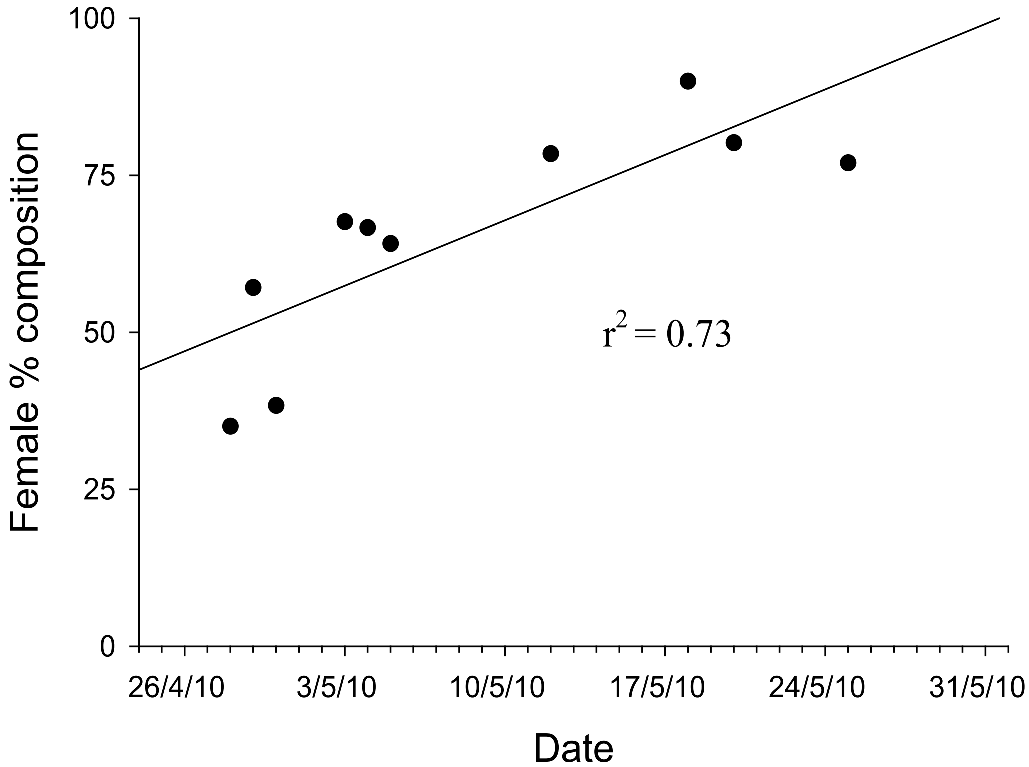


Figure 5.29. Ratio of female Australian herring versus date for the representative sampling study (Cockburn Sound – 28 April to 25 May 2010).

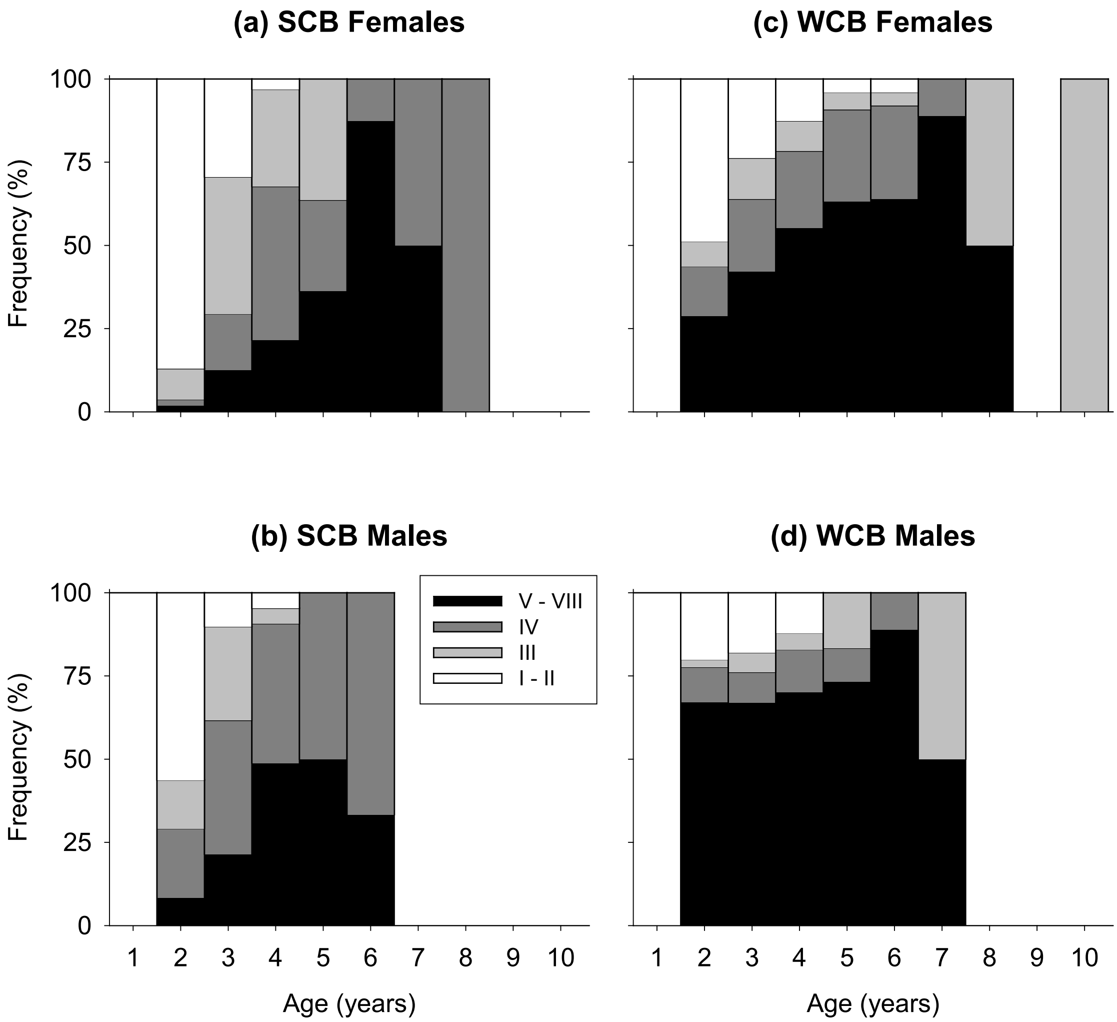


Figure 5.30. Frequency of occurrence (%) of macroscopic gonad developmental stages in age classes of female and male Australian herring in both Bioregions using data collected during the spawning periods (April – June) in 2010–11.

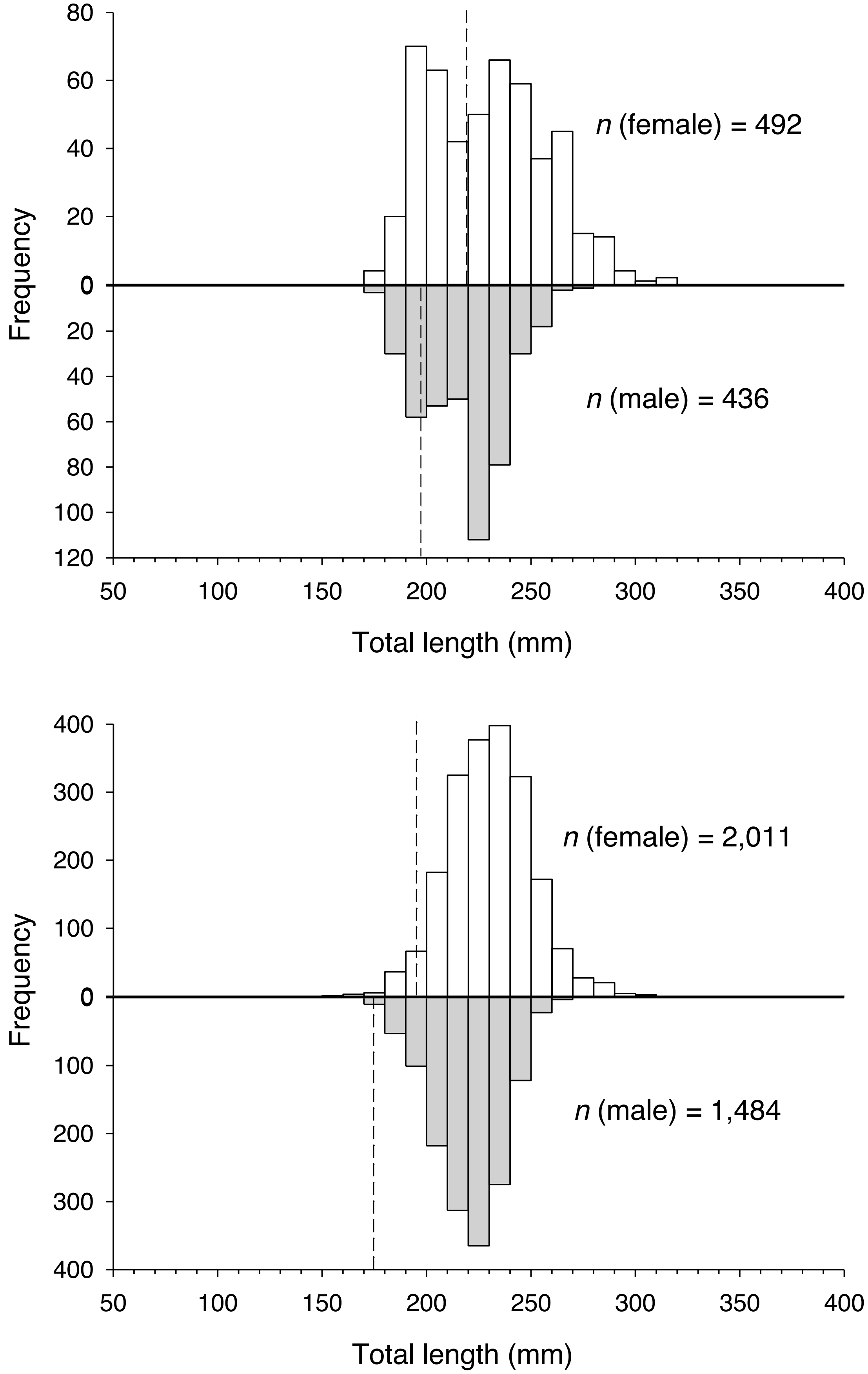
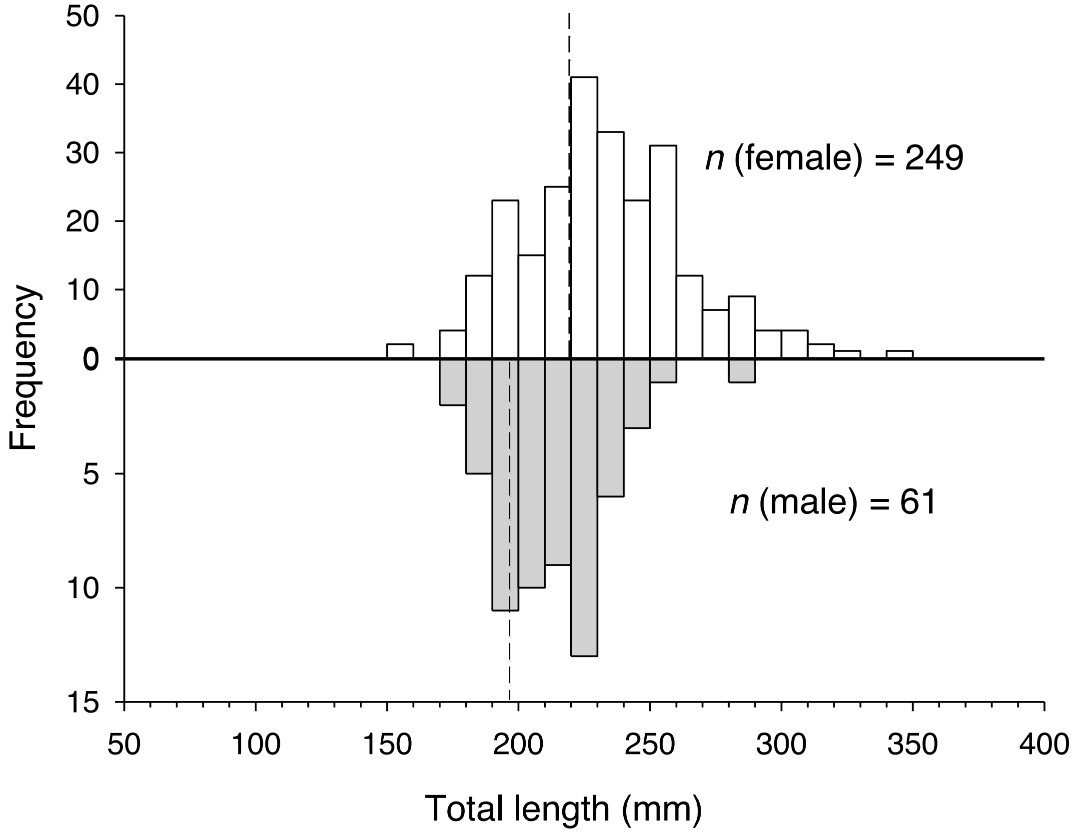


Figure 5.31. Length frequencies of Australian herring (commercial sector) in South Coast (top) and West Coast (bottom) Bioregions with corresponding length at maturity (L_{50}) (dotted line) for 2009–11.



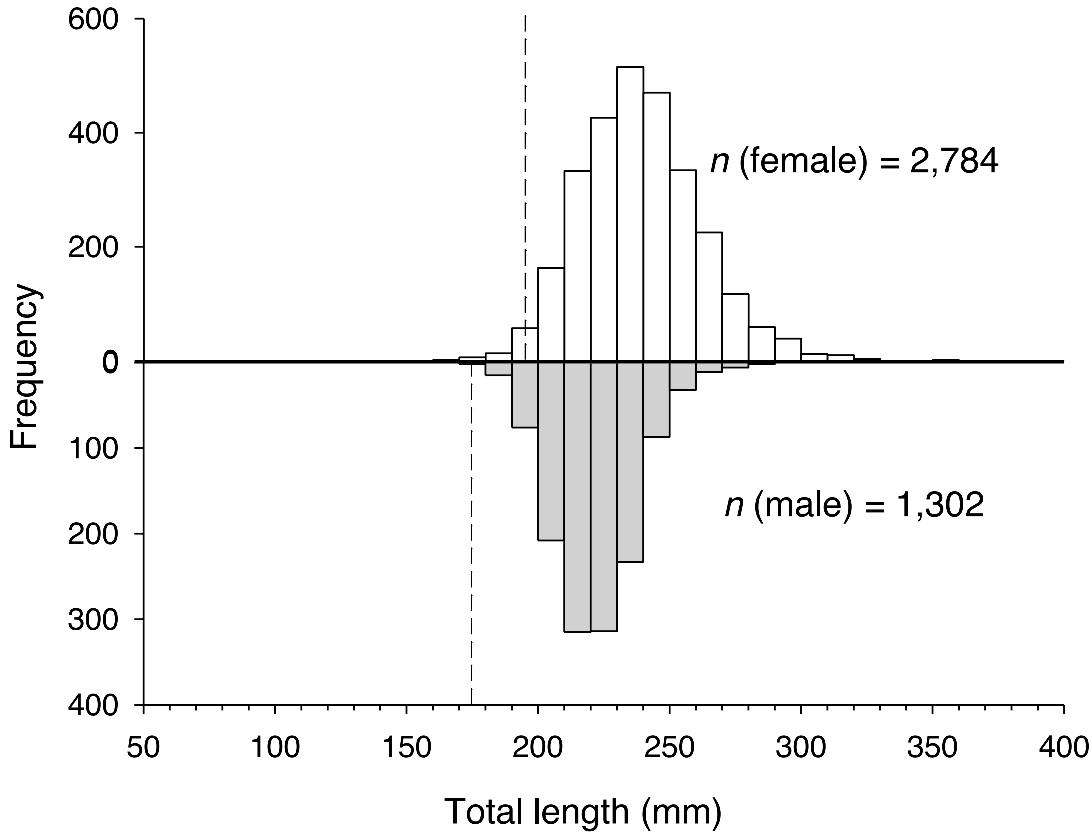


Figure 5.32. Length frequencies of Australian herring (recreational sector) in South Coast (top) and West Coast (bottom) Bioregions with corresponding length at maturity (L_{50}) (dotted line) for 2009–11.

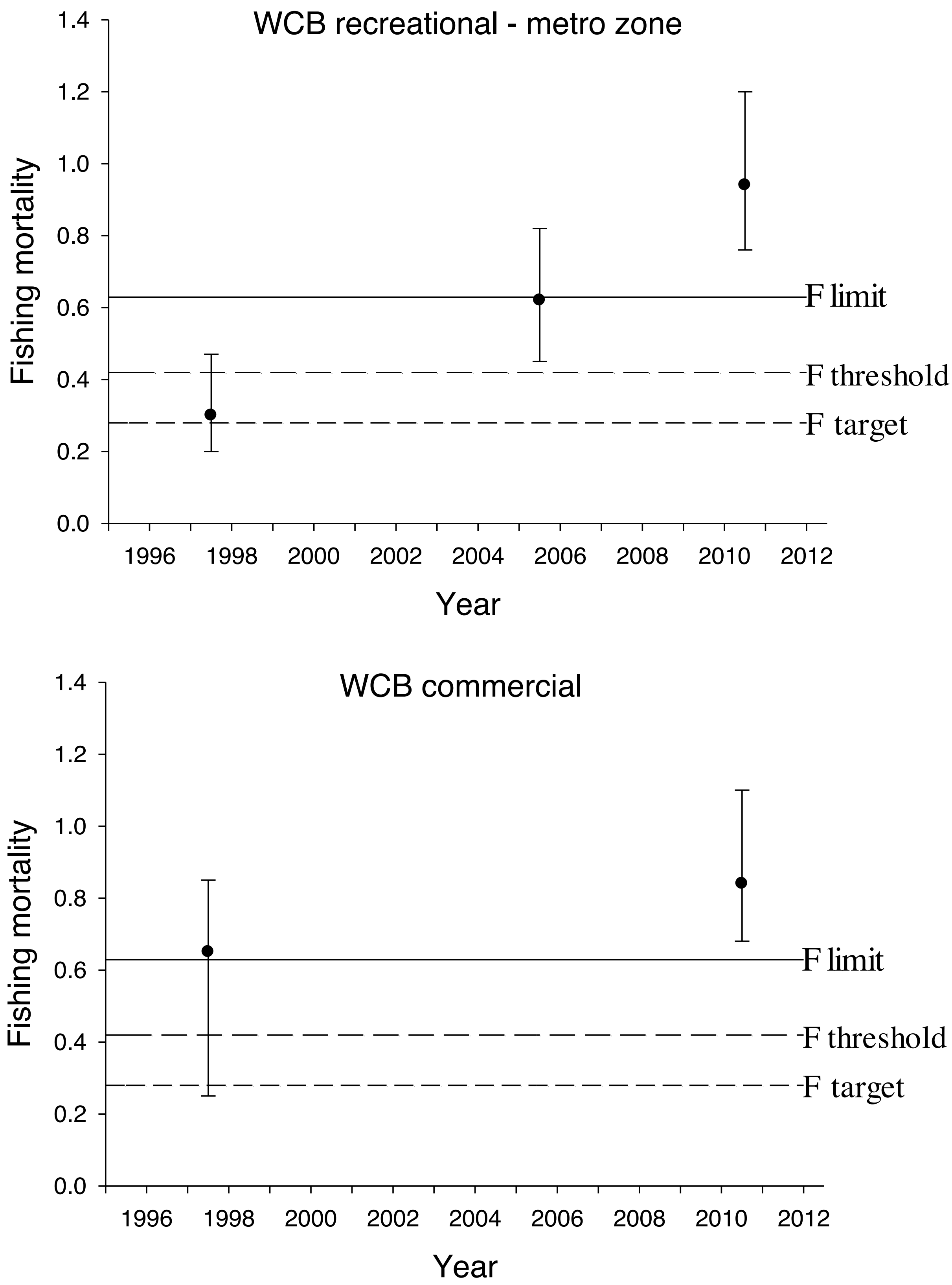


Figure 5.33. Australian herring fishing mortality estimates (±95% CI) derived from the age structure of recreational landings in the Metropolitan Zone (top) and commercial landings (bottom) in the West Coast Bioregion. Biological reference points (F limit, F threshold and F target) are shown.

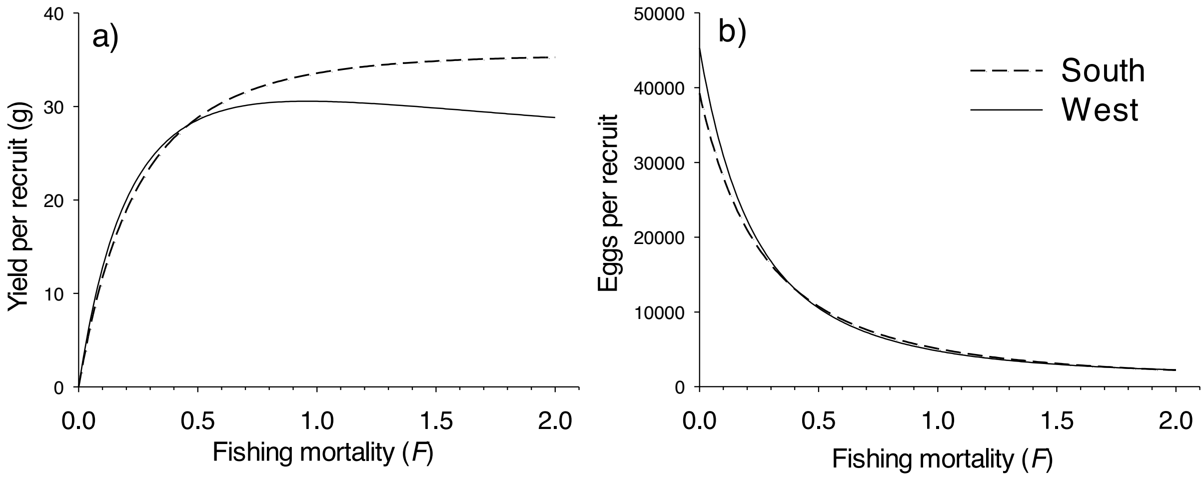


Figure 5.34. Australian herring YPR and EPR model outputs, comparing scenarios of 100% of recruits derived from SCB nurseries (South) versus 100% of recruits derived from WCB nurseries (West).

6.0 'Weight-of-evidence' assessment and implications

6.1 Introduction

The sustainable management of fish stocks requires sufficient information to be available to enable suitably robust stock assessments to be completed so that their current risk profile can be reliably estimated. While the most sophisticated assessments require a substantial amount of high quality data, the majority of the world's fisheries are relatively 'data-poor' or 'data-limited', which restricts the assessment methods that can be applied (Cochrane *et al.* 2010).

WA's nearshore finfish species, including Australian herring (*Arripis georgianus*) and other West Coast Bioregion (WCB) indicator species, were classified as data-poor or data-limited. The status of WCB nearshore indictors was previously monitored through examination of trends in recruitment indices, trends in catch rates of small-scale commercial fisheries and/or from limited recreational catch and effort data. Due to the levels of uncertainty in each of these data sources, the stock status of Australian herring could not be reliably determined through the simple application of Level 1 or 2 assessments (Table 6.1). Consequently, this project collected additional age structure data and conducted catch curve analyses to estimate the level of mortality in the stock, which permitted a higher level of assessment (Level 3 Assessment in Table 6.1). The estimated fishing mortalities (*F)* were assessed against various reference levels (F_{Target}, $F_{\text{Threshold}}$, F_{Limit}) to assist in determining the sustainability risk. These additional data were then used in conjunction with the other available information to complete a 'weight of evidence' (*sensu* Wise *et al.* 2007) assessment for this indicator species.

A 'weight of evidence' approach was initially applied in WA to successfully determine the status of inshore demersal finfish stocks in the WCB (Wise *et al*. 2007, Haddon 2007, O'Neill 2009). The outcomes of this approach led to the implementation of significant management reforms for the associated commercial and recreational fisheries, which have reduced the sustainability risks for this suite of species (Fairclough *et al.* in prep.). The approach has also recently been successfully used to determine the status of inshore demersal finfish stocks in the Gascoyne Coast Bioregion (GCB) (Marriott *et al.* 2012, Morison 2011).

In a 'weight of evidence' assessment, the information from all suitable data sources is used, with or without the results of a catch curve analysis, to assess the status of a stock. Where available, F-based reference levels can be used by fishery managers as performance measures (Table 6.2) but with the overall level of risk, and level of management response, being refined according to other evidence such as their relative vulnerability (Table 6.3). Where F cannot be reliably estimated, a range of other performance measures can be developed, such as target catch rates or recruitment indices.

Within a 'weight of evidence' approach, the appropriate level of management response can be refined based on the productivity (i.e. biological characteristics such as rates of growth and reproduction) of the species which reflects their intrinsic resilience to the effects of fishing (Table 6.3). Similarly, the appropriate types of management arrangements can be selected based on an assessment of their relative susceptibility (i.e. attributes related to catchability), which can be managed.

Where adequate information exists for a high level assessment (e.g. Level 5), the management responses to ensure sustainability of the stock, given the current risk level and projected future harvest scenarios, can be relatively specific. In more data limited situations there is typically greater uncertainty in assessment results and therefore coarser (and more precautionary) management responses are often more appropriate.

6.2 Summary of stock status

While the distribution and capture of Australian herring extends southwards from the northern boundary of the WCB and then extends eastwards across to South Australia, the spawning stock is predominantly located in the WCB. The fishery-dependent indicators of the status of the spawning stock were therefore mainly developed using data from the WCB while other indicators of overall stock status (fishery-independent recruitment indices, proportion of immature fish in the catch) were based on data collected in both the WCB and SCB (Table 6.4).

Fishing mortality : Age-based assessments were undertaken, using representative age samples of the stock obtained from both the commercial and recreational sectors in the WCB and SCB. All biases in the samples obtained from the various sectors and locations that could affect estimates of *F* were considered. In particular, the estimates of *F* derived from samples from the SCB were considered unreliable indicators of spawning stock status due the relatively high proportion of pre-spawning or non-spawning individuals that are captured in this region. These values were therefore not used in the assessment process. In addition to the regional biases, the relatively short life span and highly variable recruitment of Australian herring will generate additional uncertainty in interpreting estimates of *F* from single annual samples. This was addressed by including multiple years of data in the analysis.

Estimated median *F* values in 2009–2011 derived from samples collected from the WCB commercial fishery and the WCB Metropolitan Zone recreational fishery were 0.84 and 0.94, respectively, which are at or above the limit reference point F_{Limit}. Estimates of *F* in 1996–1998 derived from these fisheries were lower, indicating an increasing trend in *F*.

Egg- and yield-per-recruit : Alternative scenarios using parameters for the WCB and SCB produced similar results in the EPR and YPR analyses. This indicated that detected differences in biological parameters between regions are not likely to influence the inherent vulnerability of the stock to growth or recruitment overfishing, given the assumptions of these analyses. Results also supported the selection of 1.5M as an appropriate limit reference point (F_{limit}) for this stock.

Fishery catch rates : It was not possible to develop a reliable time series of standardised catch rates that could have facilitated the development of a stock production model. There were uncertainties associated with both commercial and recreational catch rates which limited their reliability as annual indicators of breeding stock abundance. In the recreational sector, long-term catch rate trends were available only from a few individual anglers and a fishing club. Low levels of effort and other data limitations reduced the reliability of these catch rates as an indicator of stock abundance. Long-term recreational catch trends could not be verified due to the lack of recent shore-based fishing surveys. In the commercial sector, variable effort levels associated with external drivers (e.g. market requirements, licence buy-backs) reduced the reliability of catch rates as indicators of stock abundance.

For the above reasons, catch rates were not considered reliable indicators of short-term (1–5 year) fluctuations in stock abundance. However, the widespread agreement between trends in commercial and recreational catch rates over long-term (decadal) scales generated a moderate level of confidence in these catch rates as indicators of long-term changes in abundance. Trends in most catch rates suggested a high abundance of Australian herring in the 1980s, a moderate abundance in the 1990s and a low abundance since 2000. The current abundance appears to be at the lowest level reported in each Bioregion since the mid 1970s.

A strong lagged correlation between fishery catch rates and fishery-independent recruitment indices suggested that annual catch rate trends in southern areas (i.e. southern WCB, SCB and South Australia) are essentially recruitment-driven. This correlation also raised the confidence in these southern catch rates as indicators of Australian herring abundance.

The catch and catch rate trends in southern areas, where all of the major commercial fisheries are located, suggested low and/or declining abundance since 2000, due to low recruitment. In contrast, catch rate trends in the smaller commercial Australian herring fisheries in the northern part of the species range (i.e. Metropolitan and Mid-west Zones of the WCB) suggested stable or increasing abundance after 2000. An increasing trend after 2000 was also evident in recreational catch rates of Australian herring in northern areas. This agreement between sectors generated a moderate level of confidence in their catch rates as broad indicators of abundance. These trends suggested that the annual abundance of Australian herring in northern areas is not directly related to annual recruitment indices, unlike abundance in southern areas.

Fishery catch composition : The declining trend in the proportions of larger and older fish in commercial and recreational catches and the high rate of juvenile fish retention are a cause for concern about the current level of recruitment and exploitation. Overall juvenile retention rates are even higher when catches by South Australian fisheries are included. The significance of an apparent decline in the length-at-maturity is unclear but could represent impacts of high exploitation and/or shifts in growth and maturity in response to environmental factors.

Recruitment : Fishery-independent recruitment indices have been consistently low in the WCB since 1999. There has been an increase in recruitment since 2005 in the South-east Zone of the SCB, which is believed to be a significant source of recruits to the spawning stock, along with local recruits from the WCB. Nonetheless, the recent low recruitment levels at three of the four monitored sites suggest that the overall current level of recruitment to the stock remains relatively low.

Overall vulnerability : The productivity level of this species is relatively high, implying 'low' vulnerability (Table 6.5). However, the relatively high catchability of the species raises the overall vulnerability level to 'low/medium'.

Summary : There is a high risk to the sustainability of the Australian herring stock as indicated by the high *F,* the high percentage of immature fish in the catch and the declining mean length and age of the catch observed over the past 15 years. The current truncated age structure (i.e. low proportion of older fish) and apparently low overall recruitment reduces the resilience of the stock. Uncertainties in the total recreational catch level further contribute to the high risk status of the stock.

6.3 Implications for management – Decision rules

Performance measures related to *F* reference points have been developed for Australian herring. If a reduction in catch is required, general Decision Rules in Table 6.3 provide an indication of the extent of reduction required to meet the management objective. The productivity of the stock provides a basis for fisheries managers to refine these Decision Rules.

The current F for Australian herring is estimated to be above F_{Limit}. EPR modelling suggests recruitment overfishing is occurring. This suggests that a substantial reduction (e.g. 50–100%) in fishing effort and/or catch is required. Given the relatively high productivity of the stock, a reduction in the lower part of this range may be acceptable.

6.4 Future monitoring and assessment

Given the current stock status of Australian herring, and the relatively short life span and variable recruitment of the species, continued annual monitoring of the age structure with three yearly assessments of the WCB recreational sector and the SCB commercial sector is recommended. These two sectors take the majority of the WA catch (~86%). In particular, the WCB hosts the breeding stock of this species and thus is most likely to provide a representative age sample for determining a robust estimate of F. By collecting additional consecutive years of age data, the confounding influence of recruitment variability on F estimates will be reduced. Ongoing age-based sampling of Australian herring is relatively inexpensive due to assistance from the commercial and recreational sectors and the fact that Australian herring can be aged by whole otoliths, thus eliminating costs associated with sectioning otoliths. Also, results of this project indicate that sampling can be optimised, i.e. restricted to a subset of key times/locations without compromising the representativeness of the age structure sample, which will further reduce costs. An optimised program could sample fish in the Metropolitan Zone of the WCB during April/May and October/November, from either the recreational and/or commercial sectors.

The implementation of a tagging study may provide more certainty about mortality levels, by providing an estimate of F that is independent of age structure data.

Recruitment indices, particularly at the Poison Creek site (South-east Zone of SCB), provide a relative index of stock abundance. Recruitment at Poison Creek is correlated with the SCB commercial catch rate 3 years later. The longevity of this monitoring program is extremely important in assessing the relative biomass of the Australian herring stock. More research (e.g. larval surveys, modelling of larval dispersal) is needed to determine the influence of the Leeuwin Current and other environmental factors on recruitment success.

Shore-based fishers take the majority of the recreational catch in WA. The implementation of regular surveys of recreational fishing that provided robust estimates of the shore-based catch of Australian herring would provide valuable information for the effective management of this sector. Catch rates from shore-based surveys would also provide an index of spawning stock biomass. However, a suitable sampling frame will need to be developed to enable cost-effective shore-based surveys.

The WCB hosts the Australian herring spawning stock and so catch rates in this Bioregion are likely to provide a better index of adult stock abundance than those in the SCB or SA. The Research Angler Program (RAP) voluntary recreational fisher logbook appears to provide the most reliable index of abundance currently available in the WCB. Continuation and improvement of this program will provide an ongoing indicator of catch rate and catch composition in the WCB recreational fishery, particularly in the absence of shore-based fishing surveys. Further analysis is required to identify any biases and ensure the representativeness of the data, including comparisons with data from recent surveys as these become available. A review of the RAP is scheduled for 2012.

Table 6.1 Application of the 'weight of evidence' rationale for the assessment of the status of stocks of exploited finfish. (F = fishing mortality, I = fishery-independent index, B = biomass).

DATA SOURCE

Monitoring	Level 1 & 2	Level 3 & 4	Level 5
	Catch, effort and catch rate data	+ fishery-dependent &/or independent data	+ data integration in model framework

ASSESSMENT METHOD

Model development	*WEIGHT OF EVIDENCE approach Examine all available data*		
	Catch/catch rate	F &/or fishery-independent indices Catch/Catch rate Other biological data	Integrated model

HARVEST STRATEGY

Stock status	*Define threshold reference point Compare current level to threshold level*		
	Catch range	$F_{threshold}$, $I_{threshold}$	$B_{threshold}$, $F_{threshold}$

Performance indicators	*Define limit and target reference points Compare current level to limit/target levels*		
	Catch level	F_{limit}, F_{target} I_{limit}, I_{target}	B_{limit}, B_{target} F_{limit}, F_{target}

Scientific Advice	*Decision tables*		
	Risk status	Risk status	Probability of achieving objective
	General category level advice on options	Advice on the range of options	Specific advice on impact of options

MANAGEMENT STRATEGY

Management response	*Management action (harvest tactics – input/output controls)*		
	Highly precautionary settings	Precautionary settings	Precise settings
	Basic research	Further research	Specific research

Table 6.2. General decision rules based on a target, threshold and limit reference points for F (adapted from Wise *et al.* 2007).

Fishing mortality (F) estimates are available but no biomass estimates	Provides for a decision rule related to fishing pressure
$F<F_{target}$	Fishing effort (and/or catches) may increase
$F_{target}<F<F_{threshold}$	Fishing effort (and/or catches) to remain constant
$F_{threshold}<F<F_{limit}$	Fishing effort (and/or catches) reduced, e.g. 10–50%
$F>F_{limit}$	Fishing effort (and/or catches) reduced, e.g. 50–100%

Table 6.3. Attributes indicating vulnerability of stock(s) of indicator species (adapted from Wise *et al*. 2007).

Attribute	Type	Low Vulnerability	Medium Vulnerability	High Vulnerability	Reference*
Growth (von Bertalanffy K)	Productivity	Rapid growth: Steep growth trajectory e.g., $K > 0.25$	Intermediate growth trajectory e.g., $0.25 \geq K \geq 0.15$	Slow growth: gradual growth trajectory. e.g., $K < 0.15$	2, 4.
Trophic level**	Productivity	Low e.g. < 3	Intermediate e.g. 3 to 4	High order predator e.g. > 4	2, 3***
Longevity (maximum age = t_{max})	Productivity	Short lifespan e.g., $t_{max} < 10$ yr	Intermediate lifespan e.g. $10 \geq t_{max} \geq 30$ yr	Long lifespan e.g. $t_{max} > 30$ yr	1, 4
Age at maturity (t_{mat})	Productivity	Early maturing e.g. < 2 yr	Intermediate maturing e.g. $2 \geq t_{mat} \geq 8$ yr	Late maturing e.g. > 8 yr	4
Selectivity and availability	Susceptibility	Low overlap (by depth and/or area) and/or selectivity to fishing gear e.g. < 25% of stock is available to fishery. ≤ 50% of age classes selected by fishing gear	Moderate overlap (by depth and/ or area) with fishery and/or fishing gear selects a low proportion of immature fish e.g. 25–50% of stock is available to fishery. $t_c \geq t_{mat}$	High overlap (by depth and/or area) with fishery and/or fishing gear selects a high proportion of immature fish e.g. > 50% of stock is available to fishery. $t_c < t_{mat}$	2****
Schooling/ aggregation behaviour	Susceptibility	Extended spawning period and/or do not form dense schools at any time. e.g. spawning > 4 months	Limited spawning period and/or forms aggregations that are not predictable in time and space, but are highly catchable e.g. spawning 3 – 4 months; not associated with lunar phase and/or spawning aggregation sites unknown/not well defined.	Forms predictable aggregations in time and space that are highly catchable e.g. spawning 1 – 2 months; and/or associated with particular lunar phase(s) - e.g. full and/or new moons; known spawning aggregation sites.	1, 4
Mode of reproduction	Susceptibility	Straightforward gonochoristic mode of reproduction (i.e. not sex-changing)	Mode of somewhat complex reproductive development, e.g. pre-maturational sex change or diandric sex change, with males and females found over a broad overlapping range of sizes and ages	Complex mode of reproduction, e.g., functional monandric sex change, with most of the larger older individuals comprised only of one sex.	1
Fecundity (per spawning event) at age of first maturity	Productivity	High e.g. > 10^4	Intermediate e.g. $10^2 – 10^3$	Low e.g. < 10^2	2

Attribute	Type	Low Vulnerability	Medium Vulnerability	High Vulnerability	Reference*
Recruitment variability and breeding strategy	Productivity	Regular, or consistent recruitment that is predictable on an annual basis, and/or propagules widely dispersed (e.g. 100s of kms) during pelagic phase or juvenile stage e.g. broadcast spawner with lower (~ 20% annual range) recruitment variability	Average recruitment is consistent but variable among years over short time periods and/or propagules have limited dispersed capacity (e.g. 10s of kms) during pelagic phase or juvenile stage e.g. broadcast spawner with recruitment varying over a range of ~50% within an average 3 year period	Infrequent, highly variable recruitment over time that cannot be predicted (e.g. annual range 0–100%), and/or restricted dispersal of eggs, larvae, juveniles e.g. demersal egg layer or live bearer	1, 3
Distribution and movement of adults	Susceptibility	Widespread distribution, and/or highly mobile e.g. capacity to move 100s of kms along coastline	Limited distribution, and/or limited mobility e.g. adults move 10s of kms along coastline	Restricted/endemic and/or sedentary (longshore movement restricted), possibly inshore-offshore movements only e.g. adult home range < 10km	1
Post-release mortality	Susceptibility	Generally high survivorship post-release. Large amount of evidence of post-release and survival. e.g. probability of survival > 67%	Survivorship largely dependent on capture method and depth of capture. Intermediate levels of post-release survival. e.g. probability of survival 33 – 67%	Majority dead or in poor health/ showing signs of barotrauma when released, regardless of depth of capture or capture method e.g. probability of survival < 33%	2
Resilience to other sources of mortality	Productivity	Highly adaptable to variable environments and/or environments/ habitats are healthy and in an optimum condition	Moderate levels of resilience, and/ or environments/habitats are not in an optimum condition but are recovering	Limited adaptability to change and/or environments/habitats are degraded and/or under threat	1
Level of Uncertainty	All	Most attributes known e.g. 0 – 3 unknown	Some attributes known e.g. 4 – 8 unknown.	Few attributes knowne.g. 9 – 12 unknown	
Overall Productivity		Most productivity attributes are low	Most productivity attributes are medium	Most productivity attributes are high	
Overall Susceptibility		Most susceptibility attributes are low	Most susceptibility attributes are medium	Most susceptibility attributes are high	

* Reference: Examples for vulnerability criteria consistent with reference levels developed in the following publications: 1 = Wise *et al.* (2007); 2 = Patrick *et al.* (2010); 3 = Hobday *et al.* (2011); 4 = Department of Fisheries (2011b).

** Trophic level scores can be obtained from FishBase (Froese and Pauly 2011)

*** Example cut-off scores derived by rounding up the cut-off scores from Patrick *et al.* (2010) and Hobday *et al.* (2011) to the nearest whole integer. This seems to be appropriate for scalefish indicator species, because most targeted species are likely to have higher trophic status than the broader range of species categorised for Ecological Risk Assessments.

**** Example levels of availability consistent with those in Patrick *et al.* (2010). Example selectivity levels for medium and high vulnerability categories consistent with convention that the MLL should be set at approximately the length at mean maturity (Ricker 1969). t_c = mean age at first capture; t_{mat} = mean age at first maturity.

Table 6.4. Summary of quantitative assessments for Australian herring. (WCB = West Coast Bioregion; SCB = South Coast Bioregion; comm. = commercial fishery; rec = recreational fishery).

Method	Result	Confidence	Implication for stock status
F (fishing mortality)	F > F Limit	Medium	Above Limit reference point
0+ recruitment trend	SCB – previously low, now increasing. WCB – low during last 5 years.	High	Low stock abundance likely in next few years. Recent recruitment trends may reflect lower recruitment potential and/or unfavourable environmental conditions
Fishery catch rate trend (WCB)	Current level below or near long-term average. Variable trend, depending on location, increasing in northern areas, decreasing in southern areas.	Medium/Low	Decline in southern areas reflects declining recruitment, significance of northern increase unclear
Fishery catch trend (WCB)	Variable, depending on location (from well below to near the long-term average).	High (comm.) Low (rec.)	Suggesting low stock abundance and recruitment in some areas
% immature fish in catch	WA catch: ≥ 43%. Australian catch (includes SA): ≥ 57%	High	Relatively high proportion
Length and age truncation	WCB comm. & rec – increasing truncation since mid-1990's. SCB comm. – increasing truncation since mid-1980s.	High	Trends are consistent with high exploitation rates
Change in length and/ or age at maturity	Decline in $L_{50\%}$ since mid-1990s.	High	Possibly an outcome of high exploitation or an environment-driven growth variation

Unacceptable	Uncertain	Acceptable

Table 6.5. Summary of the productivity and susceptibility attributes and implications for vulnerability of Australian herring (as defined in Table 6.3). The vulnerability scores for Productivity were low to medium, which indicates that this stock has relatively high productivity. The vulnerability scores for Susceptibility ranged from low to high, which indicates that this stock is moderately susceptible to fishing. Overall vulnerability level is LOW to MODERATE.

All Regions	**Type**	**Vulnerability Assessment**		
		Low	**Medium**	**High**
Growth (von Bertalanffy K)	Prod.	✓		
Trophic level	Prod.		✓	
Longevity (maximum age = t_{max})	Prod.		✓	
Mode of reproduction	Susc.	✓		
Fecundity (per spawning event) at age of first maturity	Prod.	✓		
Recruitment variability and breeding strategy	Prod.		✓	
Distribution and movement of adults	Susc.	✓		
Post-release mortality	Susc.	✓		
Resilience to other sources of mortality	Prod.	✓		
West Coast				
Age at maturity (t_{mat})	Prod.	✓		
Selectivity and availability	Susc.		✓	
Schooling/aggregation behaviour	Susc.		✓	
South Coast				
Age at maturity (t_{mat})	Prod.		✓	
Selectivity and availability	Susc.			✓
Schooling/aggregation behaviour	Susc.			✓
Overall level of uncertainty	**Low**			

7.0 Acknowledgements

The authors would like to acknowledge the Western Australian Government's State Natural Resource Management Program for their funding and support of this project. The project would not have been possible without the generous support of the recreational and commercial fishing community. We would like to thank the many recreational fishers who provided samples through the 'Send Us Your Skeletons' program. We would particularly like to thank Frank Ianni for his assistance throughout this project. Thank you also to all the staff at the Department of Fisheries' Research Division who provided invaluable field and office support over the period of the study. Finally, we thank Keith Jones for his very thorough review and constructive comments, which greatly improved the quality of this report.

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Appendix 1.

Evaluation of voluntary logbooks for monitoring annual trends in the WCB recreational Australian herring fishery.

Introduction

In Western Australia (WA), Australian herring (*Arripis georgianus*) is the most common finfish species retained by recreational fishers (Section 3). Shore-based fishers in the West Coast Bioregion (WCB) are believed to take the largest single share (about 50%) of the total WA recreational catch of Australian herring. Despite high levels of shore-based catch and effort and the very high social value of this fishery, relatively little quantitative information about this sector exists (but see Lenanton and Hall 1976, Ayvazian *et al.* 1997, Smallwood *et al.* 2011a). Therefore, trends in the annual catch rate and catch composition of Australian herring taken by shore-based fishers and the characteristics of these fishers are largely unknown. A lack of information about the shore-based recreational fishery makes it difficult to develop appropriate monitoring and effective management programs for Australian herring.

The need for more information on shore-based fishing prompted a recent pilot study to investigate methods of estimating shore-based catch and effort in the WCB (Smallwood *et al.* 2011a). Since phone/diary surveys of shore-based fishing in the WCB are currently not cost-effective due to the lack of a known sampling frame (e.g. licence holder database), the pilot study focused on field-based techniques (angler interviews, aerial surveys, remote cameras) to estimate catch and/or effort. The 3-month study, which was restricted to the Perth area, highlighted the challenges of surveying shore-based fishers in the WCB, including surveying large numbers of fishers at a large number of locations, often with limited access. This study concluded that obtaining annual estimates of shore-based catch and effort at a bioregion-wide level with acceptable levels of confidence would be costly.

Given the relatively high recreational catch of Australian herring and its potential impact on the sustainability of the stock, there is an urgent need for a better understanding of catch and effort levels in this fishery. Due to the high cost, future surveys of shore-based recreational fishing in the WCB are likely to be conducted infrequently. In the interim, a range of other data sources, such as voluntary recreational logbooks, have the potential to supplement the infrequent data from shore-based surveys.

A voluntary recreational fisher logbook program, as part of the Department of Fisheries' (DoF) Research Angler Program (RAP), commenced in 2005/06 and is ongoing. To use logbook data appropriately it is important to determine whether the catch and effort characteristics of logbook fishers are representative of other recreational fishers. This requires comparisons of logbook data with equivalent types of survey data. The aims of this section are to:

Describe the catch and effort characteristics of logbook fishers who capture Australian herring, with a focus on shore-based fishers in the WCB (who take the largest recreational catch share of Australian herring in WA).

Determine whether the characteristics of voluntary logbook fishers who capture Australian herring are typical of recreational fishers in the WCB, by comparison with other surveys.

Methods

Voluntary recreational logbooks

Recreational fishers participating in the logbook program were asked to record fishing date, location, start and finish times of each fishing session, captured species, whether fish were retained or released and the total length of each fish to the nearest millimetre. Australian herring are easily identified by recreational fishers. Therefore, mis-identification of Australian herring by logbook fishers was assumed to be negligible.

To examine discarding behaviour by logbook fishers in response to fish size, the length distribution of all Australian herring retained and released by logbook fishers in the WCB was calculated. Catches from all years (2005/06 to 2010/11) were pooled. Lengths were grouped to the nearest centimetre. Release rate was determined for each size class.

Catch and effort data reported by voluntary logbook fishers in the WCB were examined to characterise fishing behaviour associated with recreational targeting and capture of Australian herring. To avoid including fishing sessions that were not targeting Australian herring, fishing sessions that did not catch Australian herring (i.e. resulted in non-Australian herring or nil catch) were excluded in some analyses of fishing behaviour. Between 2005/06 and 2010/11, 66% of shore-based logbook fishing sessions captured Australian herring (retained or released). Therefore, 36% of sessions were excluded.

The duration of an individual logbook fishing session was calculated as the difference between start and finish times reported by the fisher. A 'session' was defined as a continuous period of fishing conducted at a particular location. Logbook fishers very rarely reported >1 session per day and so the number of sessions was effectively equal to the number of days fished.

Session durations were calculated for all shore- and boat-based logbook sessions conducted in the WCB from 2005/06 to 2010/11. Session durations were grouped to the nearest hour. Frequency distributions of durations were plotted separately for shore- and boat-based fishing. Years and months were pooled after inspection of data suggested no significant annual or seasonal differences.

Commencement times for all shore- and boat-based logbook sessions conducted in the WCB from 2005/06 to 2010/11 were grouped to the nearest hour (time of day). The distribution of commencement times were examined separately for each quarterly (3-month) period. Years were pooled after inspection of data suggested no significant annual differences.

Average catch rates of Australian herring were determined for each i) session duration and ii) commencement time. Catch rates were calculated from the average of individual catch rates reported by all fishers who captured Australian herring during that particular session/time.

The 'Perth area' was defined as logbook reporting blocks BN56-BN64, BO56-B064, BP56-BP64, BQ56-BQ64 and BR56-BR64 (see Fig. 3.1 in Section 3). Shore-base catch and effort at Rottnest Island was excluded.

Perth shore-based recreational fishing surveys

A pilot study was conducted during two periods, April–June 2010 and December 2010 to February 2011, to examine the relative benefits of different survey techniques for measuring shore-based recreational fishing catch and effort in the Perth area. Data from these surveys were compared with data provided by shore-based logbook fishers.

Full details of these shore-based surveys are given by Smallwood et al. (2011b). Briefly, catch information was obtained in April–June 2010 (but not Dec. 2010 – Feb. 2011) by roving creel surveys and interviews of incomplete trips. Shore-based fishers were interviewed in the Perth area (Ocean Reef to Woodmans Point Groyne). There were 1,194 incomplete trip interviews with fishing parties during the 3-month study. An individual was randomly selected from each fishing party to answer questions on behalf of all people in the group. Effort information was obtained during both survey periods from counts of shore-based fishers during daytime aerial surveys of the entire survey area. In April–June 2010, counts of shore-based fishers were also estimated from 24-hour video footage obtained from remote cameras installed at four popular fishing locations. Australian herring was the most common species retained during the survey (65% of total finfish catch).

West Coast Bioregion boat-based recreational fishing surveys

Surveys of boat-based recreational fishers in the WCB were conducted by the WA Department of Fisheries (DoF) in 1996/97, 2005/06, 2008/09 and 2009/10. For details of the methods of these surveys see Sumner *et al.* (2008). Briefly, boat-based fishers were interviewed at various boat ramps between Kalbarri and Augusta. Catch information was obtained using the bus route method between ramps within districts, with complete trip information obtained at the time of the interview. Estimates of total catch and effort in the Bioregion were calculated using weightings derived from the distribution of effort observed in the survey.

Results

Catch

From 2005/06 to 2010/11, Australian herring was the most common finfish species captured by shore- and boat-based volunteer logbook fishers in ocean waters of the WCB. In this period, Australian herring comprised 66% (by number) of all finfish retained by shore-based logbook fishers and 22% by boat-based logbook fishers. Within the Perth area, Australian herring comprised 73% of all finfish retained by shore-based logbook fishers.

From 2005/06 to 2010/11, the length range of all Australian herring captured (retained or released) by volunteer logbook fishers in the WCB was 7–44 cm TL. However, the majority (84%) of fish were within the relatively narrow range of 20–27 cm (Fig. 1). The length distribution of Australian herring caught by shore- and boat-based fishers was similar and closely approximated a normal distribution. Shore- and boat-caught Australian herring both averaged 23 cm. Within the Perth area, where the majority of Australian herring were caught, the length distributions of total annual shore-based catches were very similar each year, with modal lengths of 23 or 24 cm in all years.

The rate of release by shore-based fishers in the Perth area progressively declined with increasing length over the length range 11 to 19 cm (Fig. 1a, b). These fishers released 50% of all Australian herring <19 cm. However, fish of this size comprised only 2% of the total shore-based catch. Only 1% of all larger fish (19 cm or greater) caught by shore-based logbook fishers in the Perth area were released.

Boat-based logbook fishers in the WCB displayed a similar pattern of length-related releases to shore-based fishers. The rate of release by boat-based fishers progressively declined with increasing length over the length range 13 to 21 cm (Fig. 1e, f). Less than 4% of all larger fish (21 cm or greater) caught by boat-based logbook fishers were released. Boat-based logbook fishers released 21% of all smaller Australian herring <21 cm. However, these small fish comprised only 5% of the total boat-based catch.

Effort

From 2005/06 to 2010/11, logbook fishers in the WCB reported that the duration of a fishing session in which at least one Australian herring was caught (including fish subsequently released) ranged in duration from <1 to 16 hours. However, 89% of shore-based sessions and 83% of boat-based sessions that captured Australian herring were <4 hours duration.

The average duration of shore-based logbook sessions that captured Australian herring was very similar to the average duration of other shore-based logbook sessions that did not capture Australian herring (Fig. 2). In contrast, the average duration of boat-based sessions that captured Australian herring was slightly shorter than those that did not captured Australian herring. About a quarter of all boat trips reported by logbook fishers were >4 hours but these sessions rarely captured Australian herring (Fig. 2).

In the WCB, 66% of shore-based and 63% of boat-based logbook sessions that captured Australian herring were between 1 and 3 hours in duration (Fig. 2). Shore-based sessions tended to be slightly shorter (most commonly 1–2 hours) than boat-based sessions (most commonly 2–3 hours). The typical durations of shore- and boat-based sessions were similar in all seasons.

The commencement times of fishing sessions that captured Australian herring varied depending on the season and type of fishing. Shore-based fishers typically commenced fishing earlier in the day than boat-based fishers. Both types of fishers commenced slightly later in the day during winter months. The vast majority (82%) of shore-based fishing sessions commenced in the morning, usually just after sunrise. Shore-based sessions typically commenced between 5 and 7am during October–March, between 6 and 8am during April–June and between 7 and 8am during July–September (Fig. 3a). There was a small peak in shore-based effort in the late afternoon around 5 or 6pm, depending on the time of year.

The majority (67%) of boat-based sessions also started in the morning, but several hours later than shore-based sessions. Morning boat-based sessions typically commenced between 7 and 10am during October–March, between 8 and 10am during April–June and between 9 and 12am during July–September (Fig. 3b). At all times of year, there was a lull in boating activity between about 11am to 1pm when few sessions commenced, followed by a secondary peak in activity in the afternoon.

Catch rate

Among logbook sessions that captured Australian herring, sessions of 1–2 hours had an average catch rate of 5.4 fish/hour for shore-based fishers and 5.6 for boat-based fishers (Fig. 4). Sessions of 2–3 hours had an average catch rate of 3.2 and 2.3 fish/hour, respectively. All longer sessions (shore and boat) resulted in an average catch rate of about 1.4 fish/hour.

Despite a strong preference by the majority of shore-based logbook fishers for fishing during the early morning, there was no evidence of higher catch rates of Australian herring at this time of day. Shore-based catch rates of Australian herring reported in the late afternoon by logbook fishers were similar to those reported during the early morning (Fig. 5a). Lower catch rates were reported by shore-based fishers in the middle of the day.

Catch rates of Australian herring by boat-based logbook fishers were reported to be highest in the afternoon (Fig. 5b). However, this trend was likely to be an artifact of an increase in the level of targeting of Australian herring as a proportion of total session time by boat fishers in the afternoon. Boat-based logbook fishers embarked on longer duration sessions in the morning compared to those commenced in the afternoon. Early morning boat trips averaged 4 hours in duration, whereas late afternoon trips averaged approximately 1 hour (Fig. 5c). Longer trips were likely to include a higher proportion of time engaged in activities other than targeting Australian herring, including traveling and targeting of other species.

Discussion

Comparison of data: logbooks versus shore-based fishing surveys

Australian herring comprised 66% of the finfish retained by WCB shore-based logbook fishers. This was in close agreement with survey data, which indicated that Australian herring was the most popular finfish species caught by shore-based fishers in the WCB and comprised approximately 65% (by number) of the retained catch (Smallwood et al. 2011a, Section 3 this report).

The length composition of the Australian herring retained by WCB shore-based logbook fishers was almost identical to that of herring measured during recreational fishing surveys and of donated frames (Section 5). Samples of herring donated by recreational fishers in the Perth region from 2009 to 2011 indicated a normal distribution, with an average length of 23 cm and a range of approximately 19 to 27 cm (Fig. 5.3e in Section 5). A recent on-site survey in the Perth region also indicated that the lengths of shore-caught Australian herring are approximately normally distributed with a median length of 23 cm TL (Smallwood et al. 2011a).

The average catch rate of shore-based logbook fishers may be higher than that of other shore-based recreational fishers in the WCB. In April–June 2010, the average shore-based catch rate of Australian herring in the Perth area was estimated to be 1.21 fish/hour (retained and released fish) (Smallwood et al. 2011a). In comparison, the average (± s.d.) monthly catch rate by shore-based logbook fishers in the Perth area between 2005/06 and 2010/11 was 2.7 ± 1.2 fish/hour. The mean catch rate by logbook fishers in April–June 2010 was 3.4 fish/hour (although only 9 logbook fishers caught Australian herring in this period). However, methodological differences between this survey and logbooks (i.e. interviews of fishing parties during incomplete trips versus logbook records of completed trips by individual fishers) make it difficult to compare estimates of catch rates. If logbook catch rates are found to be higher than the average recreational catch rate, they may still provide a useful relative index of availability.

During April–June 2010, the mean duration of a shore-based fishing trip in the Perth area was estimated to be 2.4–3 hours, with some variation depending on day type (weekday/weekend), time of day and fishing platform (beach/groyne/jetty) (Smallwood et al. 2011a). From 2005/06 to 2010/11, the mean duration of a shore-based logbook session in the WCB ranged from 1.6 to 2.9 hours during April–June each year. In 2010, the mean logbook session duration was 2.4 hours – similar to that estimated during interviews. Therefore, the typical duration of fishing sessions by shore-based logbook fishers (including sessions with Australian herring and non-Australian herring catches) is similar to that of other shore-based recreational fishers.

Although the fishing sessions of logbook fishers are similar in duration to those of other shore-based recreational fishers, the time of day when fishing occurs appears to differ markedly. Recent aerial surveys of the Perth coastline and 24-hour camera footage of popular jetties/groynes suggest that shore-based fishing activity primarily occurred during daylight hours, with a very small proportion of effort occurring prior to 4am or after 8pm (Smallwood et al. 2011a, Smallwood et al. 2011b). These surveys suggest that effort levels are similar during morning and afternoon periods, with peaks in activity during the early morning (8–10am) and late afternoon (4–6pm) and a lull in activity around mid-day (Smallwood et al. 2011a, Smallwood et al. 2011b). Shore-based logbook fishers also recorded negligible levels of night-time fishing. However, during daylight hours, shore-based logbook fishing occurred almost exclusively in the early morning, coinciding with the early peak in activity observed in surveys. Thus, it appears that logbook fishers are far less likely to fish during the afternoon than other (non-logbook) shore-based fishers.

Interestingly, shore-based logbook catch rates and the average duration of fishing sessions were similar in the early morning and late afternoon. Assuming an approximately equal distribution of fishing effort between morning and afternoon periods (as seen in surveys), this implies that similar shore-based recreational catch levels of Australian herring occur in the morning and afternoon in the Perth area.

Comparison of data: logbooks versus boat-based surveys

Australian herring comprised 22% of the finfish retained by WCB boat-based logbook fishers. This proportion was similar to that observed in surveys of WCB boat-based fishing (25–27%) (Sumner *et al.* 2008). The average length of Australian herring retained by boat-based logbook fishers (23 cm TL) was the same as that observed during surveys (DoF unpubl. data).

In contrast to shore-based fishing trends, the overall effort distribution of boat-based logbook fishers appears to be similar to other boat-based fishers. Surveys of boat-based fishing in the WCB indicated that boat-based fishing effort peaks in the morning (Sumner *et al.* 2008, DoF unpubl. data) and declines from about 1 pm onwards. Boat-based logbook effort followed a similar distribution through the day.

Logbook data suggested that some aspects of boat-based fishing effort, such as commencement time and trip duration, are indicators of the level of targeting of Australian herring and should be considered when interpreting trends in boat-based catch rates of Australian herring obtained during surveys.

Catch rates of Australian herring by boat-based logbook fishers were reported to be highest in the afternoon. However, this trend was probably an artifact of an increase in the time spent targeting Australian herring as a proportion of total session time. Boat-based logbook fishers embarked on longer duration sessions in the morning compared to those commenced in the afternoon. Early morning boat trips averaged 4 hours in duration, whereas late afternoon trips averaged approximately 1 hour. It is likely that longer trips included a higher proportion of time engaged in activities other than targeting Australian herring, including travel and targeting of other species. For example, trips to offshore waters, which required lengthy travel time, would probably commence in the morning. Shorter fishing trips, which often occurred in the afternoon, would probably be spent in nearshore waters. On longer boat trips to offshore waters, when demersal or offshore pelagic species were the main targets, Australian herring could still be caught on the return journey through nearshore waters. However, the time spent targeting Australian herring would be a low proportion of the total trip time, resulting in a low reported catch rate. On shorter trips that remained within nearshore waters, a high proportion of the total trip time could be spent targeting Australian herring and other nearshore species, resulting in a high reported catch rate.

Boat-based surveys could be a cost-effective data source for monitoring Australian herring. However, the effects of trip duration and fishing location on boat-based catch rates, which are indicative of the level of targeting of Australian herring, would need to be quantified before data from boat-based surveys could be confidently used to monitor Australian herring availability. Such factors are less relevant to the interpretation of shore-based catch rates.

Conclusions

Comparisons with data from recent recreational fishing surveys suggest that many catch and effort characteristics of logbook fishers are representative of the WCB recreational Australian herring fishery, including catch composition (species and length), seasonal trends in catch rates, average duration of daily fishing sessions and timing of daily fishing sessions (boat-based fishing only).

However, some characteristics of logbook fishers may not be representative of other recreational fishers. For example, the timing of fishing (commencement times) by shore-based logbook fishers appears to differ to other shore-based fishers and their catch rates of Australian herring may be higher.

Despite some differences between logbook fishers and others, the data provided by logbook fishers are still likely to be useful for monitoring trends in the WCB recreational Australian herring fishery. Monthly trends in logbook catch rates, especially those of shore-based fishers in the Perth area, suggest a peak in availability in WCB ocean waters during autumn, which is in agreement with trends in the WCB boat-based catch rate during recent surveys, with anecdotal information about the seasonal abundance of Australian herring and with monthly trends in various WCB commercial fisheries (Section 3). Such widespread agreement suggests that these seasonal trends are real and that catch rates reported by voluntary logbook fishers are a valid index of Australian herring availability.

Since the commencement of the logbook program, shore-based fishers in the Perth area have contributed the largest share of logbook catch and effort data. Since shore-based fishers in this region are the dominant sector within the WCB recreational Australian herring fishery (in terms of % catch and effort), logbook data is well suited to monitoring trends in the fishery.

When monitoring Australian herring availability, the annual frequency of logbook data represents an advantage over less frequent data from surveys. Australian herring is a relatively short-lived species, with highly variable annual recruitment. Limited historical records of recreational and commercial catch rates in the WCB indicate high annual variation in response to recruitment events. An annual index of Australian herring availability, which is currently available only from logbook data, would be desirable to ensure any recruitment-driven spikes in catch rate are distinguished from longer term trends in stock abundance.

Voluntary recreational logbook catch rates can potentially provide a cost-effective, relative index of annual abundance for Australian herring and other species. In addition, logbooks can provide information about aspects of recreational fishing behaviour, such as the temporal distribution of effort (commencement time, length of trip) and information about released catches that are difficult to obtain by other survey methods. Hence, logbooks may assist in the design of other surveys and compliment other survey data. For example, logbook data suggests that factors such as trip duration are indicators of the level of targeting of Australian herring by boat-based fishers and could be used to interpret catch rate trends in future boat-based surveys.

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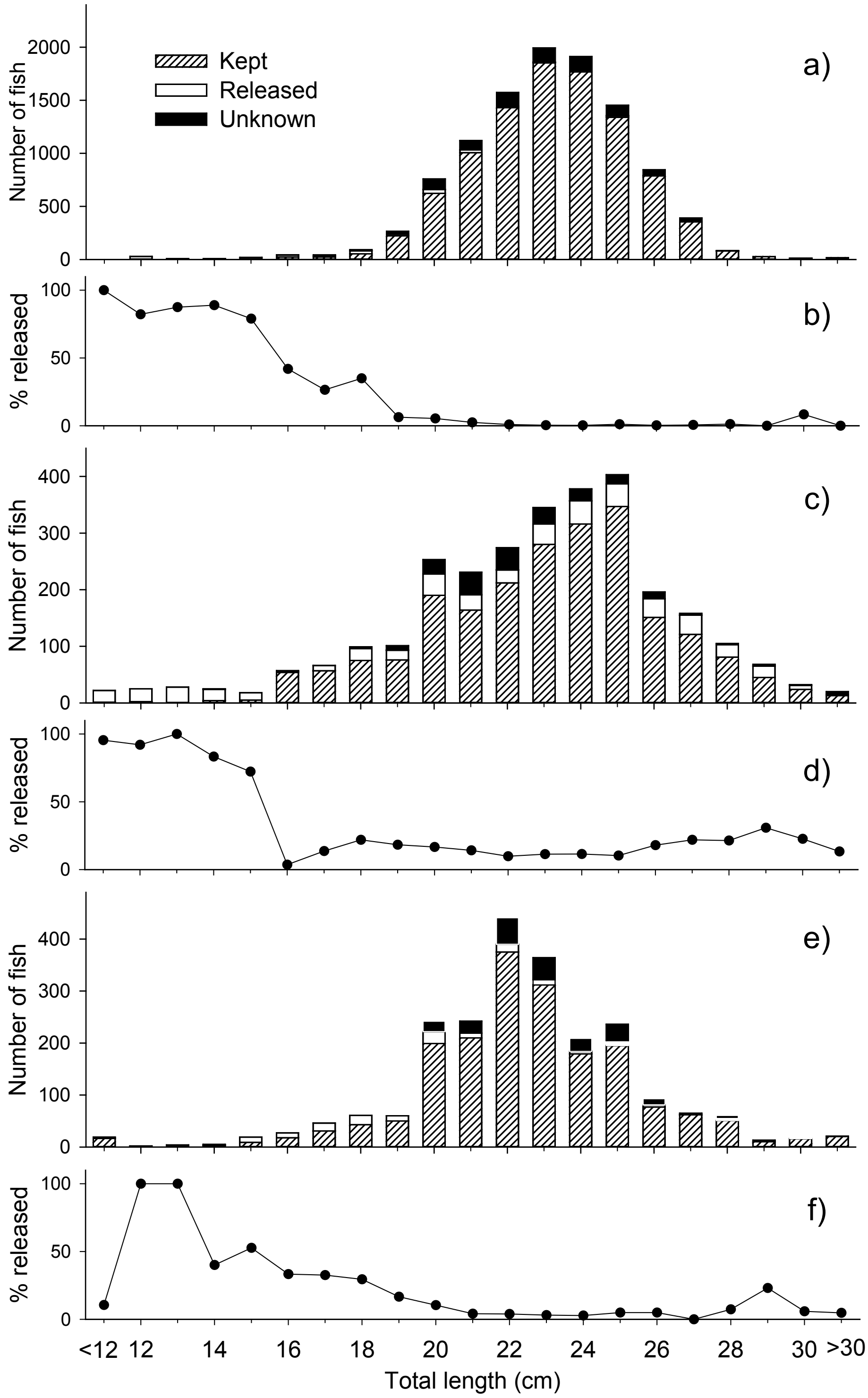

Figure 1. Length frequency distribution of total Australian herring catch and percentage of released fish in each length class (total length) reported by logbook fishers in the West Coast Bioregion (WCB), 2005/06–2010/11. **a, b)** shore-based fishers in the Perth area, **c, d)** shore-based fishers elsewhere, **e, f)** boat-based fishers in all areas of WCB.

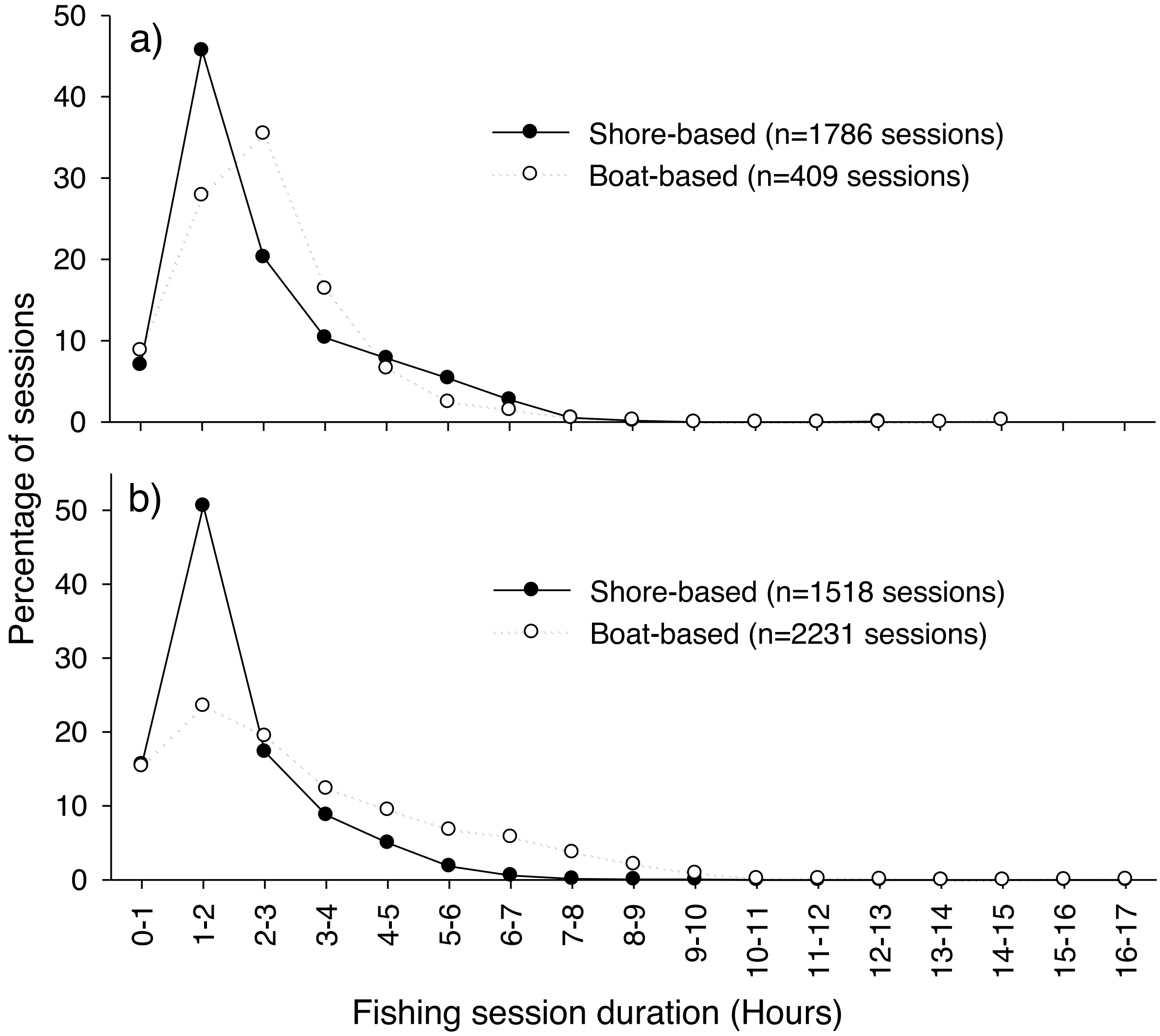

Figure 2. Duration of fishing sessions reported by shore- and boat-based logbook fishers in West Coast Bioregion, 2005/06–2010/11. **a)** Sessions in which Australian herring was caught (either retained or released) (i.e. excludes sessions resulting in non-Australian herring and nil catches), **b)** All other sessions (i.e. sessions resulting in non-Australian herring and nil catches).

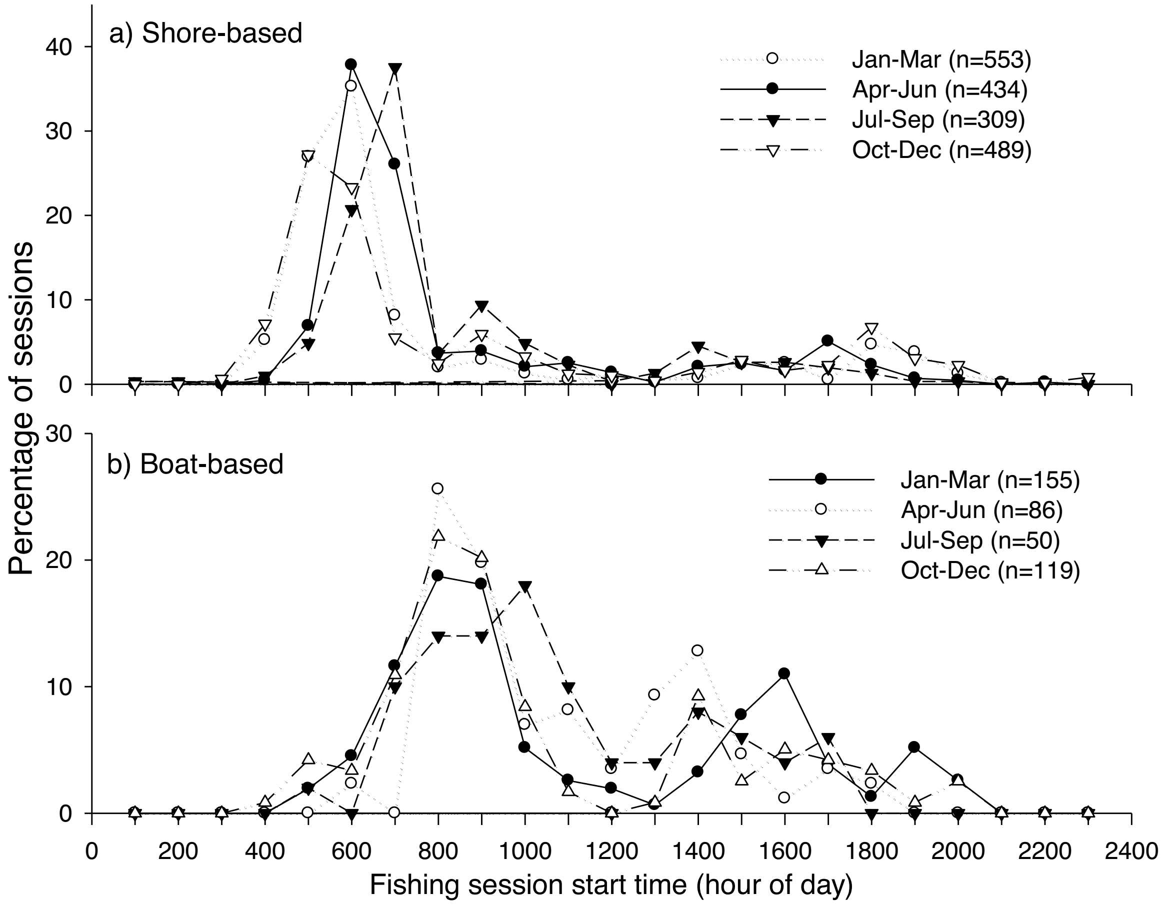

Figure 3. Timing of fishing sessions (start time, grouped by hour of day) by **a)** shore-based and **b)** boat-based logbook fishers in the West Coast Bioregion, 2005/06–2010/11. Data includes only those sessions where Australian herring was caught (either retained or released), does not include sessions where non-Australian herring or nil catch was reported.

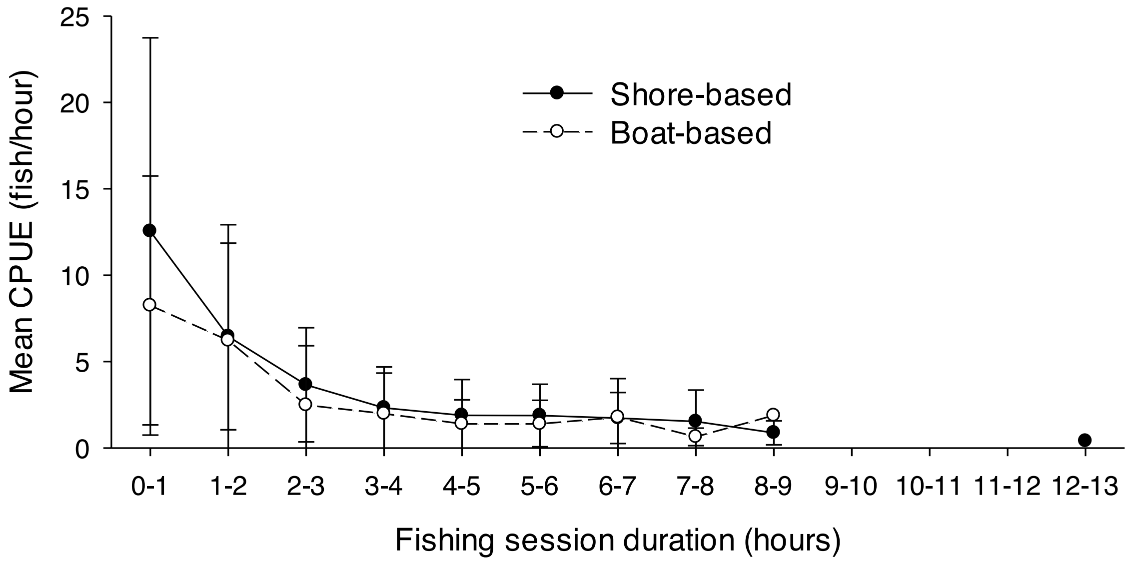

Figure 4. Mean (± s.d.) catch rate (fish/hour) of Australian herring caught by shore- and boat-based logbook fishers in the West Coast Bioregion versus the session duration, 2005/06–2010/11. Data includes only those sessions where Australian herring was caught (either retained or released), does not include sessions where 'nil catch' was reported.

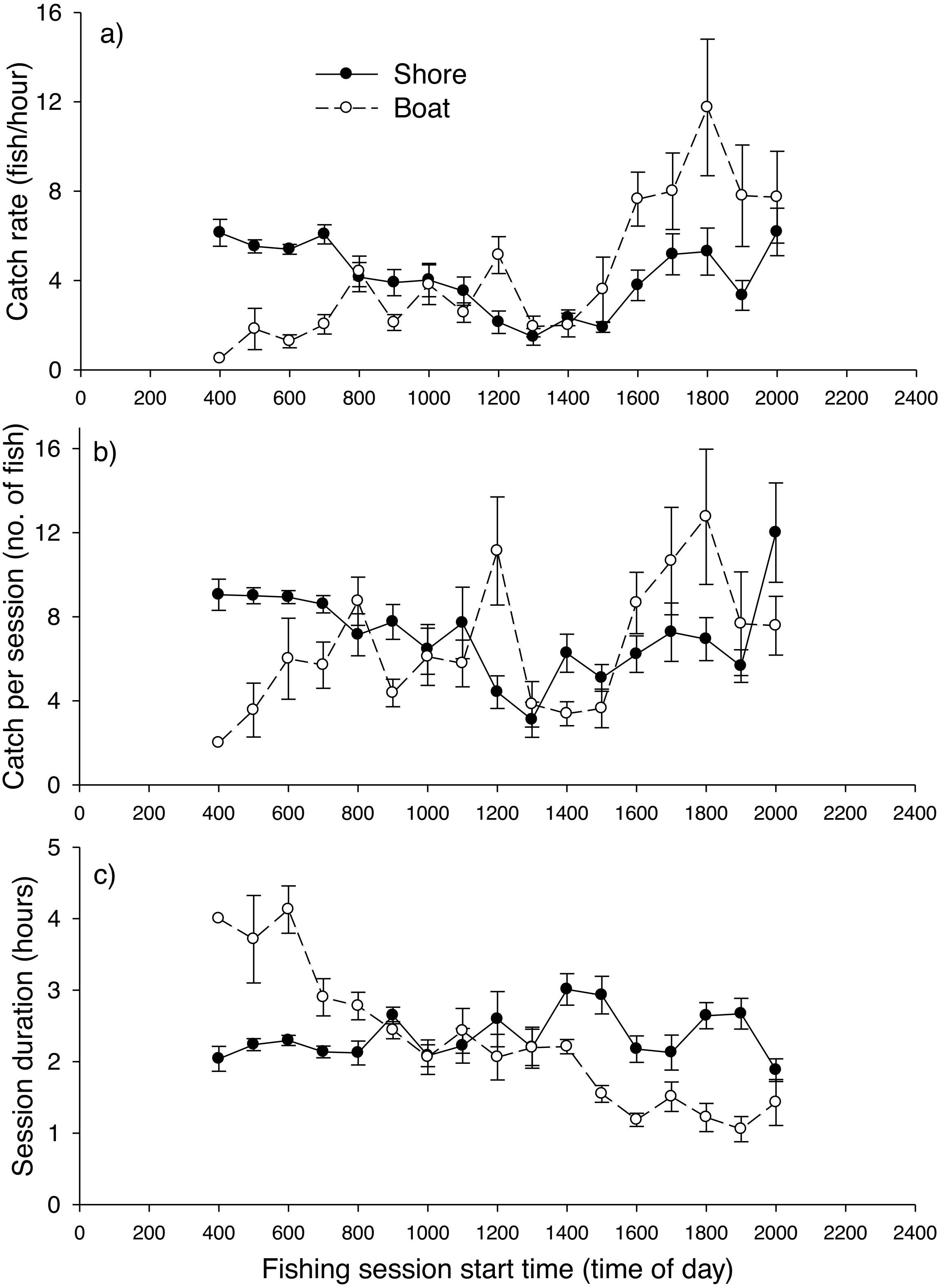

Figure 5. **a)** Average catch rate of Australian herring (fish/hour) (± s.e.), **b)** average catch of Australian herring per session and **c)** average duration (hours) of fishing sessions by shore- and boat-based logbook fishers in the West Coast Bioregion versus commencement time of fishing session, 2005/06 to 2010/11. (Includes only those sessions when Australian herring was caught (either retained or released), does not include sessions where non-Australian herring or nil catch was reported; sessions commencing before 4am and after 9pm were excluded due to lack of data).