The development of a rigorous sampling methodology for a long-term annual index of recruitment for finfish species from south-western Australia

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OBJECTIVES

1. Develop a robust, low cost, effective sampling method for an ongoing recruitment index for seven key inshore finfish species from south-western Australia.
2. Determine the size and age structure of the commercial catch of these seven species.
3. Determine the effect of spatial and temporal factors (e.g. geographic location, season, time of day, lunar cycle, tidal cycle, temperature, salinity and wind) on the abundance of each species.
4. Determine the local depletion and recovery rate after intensive sampling for each species.

NON-TECHNICAL SUMMARY

OUTCOMES ACHIEVED

This study has determined the optimal strategies to achieve statistically robust indices of recruitment of five key finfish species in south-western Australia. For another two species such indices could not be established. The sampling strategies developed will initially focus on the most appropriate location, month, and lunar phase, after which fine-tuning of the sampling activity will be undertaken with respect to time of day, tide height, weather conditions etc. A significant outcome from the project is that five finfish species have a sampling strategy for recruits that can be utilized as a monitoring program for the recreational and commercial fisheries that target these species. Because it is difficult to attract and retain research funds for these minor fishery species, demonstration of an optimal sampling strategy that can be used to predict fishery performance is an invaluable and relatively cheap stock assessment tool. An ongoing and cost–effective monitoring program that is under-pinned by a detailed investigation of variability in abundance of recruits and that demonstrates a link between recruits and subsequent abundance of catchable age classes will facilitate better long-term management of the key inshore finfish stocks in south-western Australia. This is particularly relevant now that Western Australia has developed, and is currently implementing, an integrated approach to fisheries management, whereby the total exploitation on any one fish stock will be managed through simultaneous consideration of all exploitive sectors.

The inshore marine finfish fishery in south-western Australia is important for both the commercial and recreational sectors. Seven key species (Australian herring, Australian salmon, tailor, King George whiting, yellow-finned whiting, yellow-eye mullet and sea mullet) comprise a significant component of the inshore finfish resource but due to their limited commercial value, and indeterminate recreational value, ongoing formal stock assessments for each of these species has not been possible. Because the 0^+ stage of each of the seven finfish species inhabit nearshore waters, and hence are accessible to the relatively cheap sampling method of beach-seining, this project sought to develop recruitment indices based on (a) a beach seine sampling program and (b) sampling of commercial catches. Sampling of commercial catch and recruits was undertaken from the Western Australian coastline between the Perth metropolitan area and to the east of Esperance. This extensive stretch of coastline encompasses a significant degree of the state's inshore fishery. The primary goal of this study was to determine if statistically reliable relationships could be established between recruit abundance and commercial catch of the respective adults in subsequent years.

Patterns in the abundance of recruits varied between species but some similarities across most of the seven species were evident. For most species, recruits were found in most months of the year but abundance was typically highest in the winter to early-summer period. Abundance also varied markedly between locations; key nursery locations were Poison Creek and Emu Beach on the south coast, with Koombana Bay, Mangles Bay and Pinnaroo Point important locations on the west coast.

This study describes the age and growth characteristic of the seven key finfish species, building on results from previous studies where appropriate. In developing recruitment indices, recruits of each species must be represented by a standardised age, which in this study

was set at less than 1 year old (i.e. 0^+). The knowledge of age and growth was required to ensure that only those fish less than 1 year old were being counted as "recruits". This was achieved by using the age-growth relationship to determine the maximum length of 1-year olds for each species. Using length as a criterion for choosing recruits obviated the need to determine the age of every fish landed, which would have been impossible within the time-frame of this project and is substantially more expensive than the method used here. The age and growth information also dictate the time-lag between recruits and entry into the fishery; this information was used in developing the recruitment indices.

Intensive beach seine sampling determined that abundance of recruits of the various species were influenced by many physical and environmental factors such as time of day, tide, lunar phase, wind direction, quantities of sea-weed etc. However, an additional important result was the finding that the actual process of sampling (i.e. removing fish) can also influence the estimates of recruit abundance at a particular beach.

The final part of this project was developing the recruitment indices. This essentially consisted of finding the best combination of sampling months and locations for recruits that most closely relate to the size of the commercial catch 2 – 4 years later depending on the species, with this 2 – 4 year lag representing the period that fish grow from recruits to a catchable and marketable size. Such relationships were successfully developed during this project for five finfish species, thereby enabling sampling programs that target recruits in only three months of the year and at limited number of locations. A cost-effective sampling program will therefore optimise collection of recruits sufficient for calculating recruitment indices for five of the seven species examined.

KEYWORDS: inshore, recruitment, recruitment indices, small-scale fisheries.

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CHAPTER 1.0

1.1 Background

The fully exploited estuarine and coastal finfish stocks in south-western Australia, support a significant number of small-scale commercial fishers and are increasingly targeted by the continually expanding 500,000 strong recreational sector. Australian herring, Australian salmon, tailor, King George whiting, yellow-finned whiting, yellow-eye mullet and sea mullet are the seven key species concerned (Ayvazian *et al.* 1997 and FRDC 93/97). Keeping exploitation of this socially important, but commercially limited value, sector at sustainable levels presents one of the major future challenges for fisheries management in Western Australia (WA). In common with many small-scale coastal fisheries across Australia, adequate stock monitoring information necessary for management cannot be cost effectively obtained using traditional fisheries research methods applicable to large fisheries.

The commercial fishery for King George whiting, yellow-finned whiting, yellow-eye mullet, sea mullet and tailor is a multispecies fishery which, as of 1999, involves 82 licensed fishers who operate gill nets in estuaries and embayments along the south-western coast of WA. The annual commercial fisheries production of these finfish species in WA during 1996-1997 was: King George whiting, ($0.28 m, 35 t), yellow-finned whiting, ($0.43 m, 172 t), yellow-eye mullet ($0.09 m, 169 t), sea mullet ($1.03 m, 419 t), and tailor ($0.15, 51 t) totalling 846 tonnes valued at approximately $2 million. In 1996-1997, the Australian salmon commercial fishery in Western Australia involved 32 fishing teams operating haul nets along designated beaches on the south-west and south coasts. During this year, a commercial catch of 2,565 tonnes valued at $1.65 m was landed. The WA commercial fishery for Australian herring included 18 licensed fishing teams who operate fish traps along the south coast and an additional 13 teams operating beach seines along the lower west coast. In 1996-1997 the total commercial catch of Australian herring was 1,037 tonnes valued at $1.33m.

In comparison with the ongoing commercial data series, there are few data on the recreational catch of this suite of species. However, the results from an Australian salmon and Australian herring anglers creel survey (FRDC Project 93/79) demonstrated that Australian herring, Australian salmon, western sand whiting, and tailor were among the top ten species caught by beach anglers fishing along the south-west coastline (Ayvazian *et al*. 1997). The 1994 and 1995 total recreational catches of Australian salmon were 158 tonnes and 189 tonnes, respectively; which was 5.5 and 9.1%, respectively, of the total state catch (commercial and recreational). Similarly, the recreational catches for Australian herring during 1994 and 1995 were 247 tonnes and 177 tonnes respectively; being 25.6 and 15.3%, respectively, of the total state catch. Additionally, an investigation into recreational netting in estuaries on the west and south coasts by Lenanton *et al*. (1996) discovered that both mullet species were also targeted by this sector.

Historically, the status of these stocks has been evaluated by using commercial catch and effort data recorded monthly in compulsory returns. Relying on these data for stock assessment modelling has, however, posed several problems including interpreting whether variations in catch levels have resulted from changes in the abundance of the species or changes in fisher behaviour (e.g. targeting) due to, for example, market prices.

An alternative to relying primarily on commercial catch and effort records and intermittent recreational creel surveys to provide data for stock assessment is to utilise an independent index of recruitment. For an index to be useful it requires: 1) an understanding of the biology of the species (temporal and spatial distribution and abundance) and 2) a long time series of data (Caputi 1993). Such an index provides a relative measure of the annual abundance of recruits, and in conjunction with biological information from the fishery and the appropriate time lag, can allow the prediction of future catches and anticipate the need for management action.

The development of a survey-based recruitment index for Australian herring (FRDC Project 96/105) indicated that this method has the potential to be extended to other stocks in question to provide an ongoing stock monitoring system. For example, data from FRDC Project 96/105 indicate the highest abundances of Australian herring occur on one site on the west coast and one site on the south east coast for a few months during the late winter-early spring. Australian herring also appear to be more abundant in the seine hauls during the day and the full moon phase. A sampling program which accounts for these variables can be designed to minimise the cost of sampling while maximizing the quality of the information collected. By refining the sampling program, the Australian herring index of recruitment can also be made more accurate. During the sampling program for Australian herring, Australian salmon, King George whiting, yellow-finned whiting, yellow-eye, sea mullet and tailor recruits consistently contributed a large proportion of the catch at each site, suggesting that similar recruitment indices from a common survey could be developed.

This project aimed to develop an index of recruitment for each of the seven species listed above, noting that the biology and life history of all of these species is known in WA waters. While each species has a unique life history, the juvenile stages of each species are abundant in the shallow nearshore zone. The project samples fish from coastal sites along south-western WA and incorporates statistically designed experiments to determine for 0^+ and 1^+ fish the optimum sampling locations, months, time of day, and stage in the lunar cycle. All of these variables will affect, to some degree, the abundance of each species in the sample. The lunar cycle has been found to affect both the settlement of larval coral reef fishes (Thorrold *et al*. 1994, Rooker and Dennis 1991) and the catches of adult fishes from the family Mugilidae (mullets) (Ahmed and Sheshappa 1992).

Additionally, the commercial catch will be monitored for length, weight, age and sex at the same spatial and temporal scales in order to link the abundance of the recruits to the commercial catches on a regional scale. To extend the time-series of data, this project also utilises the three years of fishery-independent data for each species collected in FRDC Project 96/105. In order to provide a means of robustly linking the data for recruits to the older fish that constitute the commercial catch when developing a recruitment index for each species, this project also determines the age structure of each of the seven species from the commercial catch, utilizing as required the length-age relationships established here or in previous studies.

1.2 Need

There is a critical need for a reliable stock monitoring system for future management of the important multispecies commercial and recreational finfish fishery in the south-west of WA.

Specifically, a robust annual recruitment index for monitoring long term trends in abundance for the key finfish species is needed. The proposed recruitment index survey system is also required to complement and improve the usefulness of existing long-term commercial catch and effort records.

In order to develop a cost effective index system, there is a need to collect sufficient data on the spatial and temporal abundance of each species, within a rigorously planned experimental framework, to allow maximum use of current statistical techniques.

The comprehensive statistical approach to the survey design proposed for this project, although not previously applied to the development of finfish recruitment indices, will enable the dimensions, and hence cost, of the long term field sampling to be minimised.

1.3 Objectives

1. Develop a robust, low cost, effective sampling method for an ongoing recruitment index for seven key inshore finfish species from south-western Australia
2. Determine the size and age structure of the commercial catch of these seven species.
3. Determine the effect of spatial and temporal factors (e.g. geographic location, season, day time, lunar cycle, tidal cycle, temperature, salinity and wind) on the abundance of each species.
4. Determine the local depletion and recovery rate after intensive sampling for each species.

1.4 Rationale and approach

The project objectives will be addressed in the following chapter format. These chapters are structured so that the data collected and analyses undertaken follow a logical sequence that leads to the development of cost-effective sampling strategies and recruitment indices.

Chapter 2. The age- and size-structure and growth rates of the commercial catch of seven inshore fish species from south-western Australia (**Objective 2**).

- Development of length-age relationships (i.e. growth curves) is required so that size and age at which young fish enter the fishery can be determined. This, in turn, will indicate what size and age will need to be examined when assessing whether or not a recruitment index can be developed.
- While size and age structure information for the seven species is utilised for the determination of length-age relationships, these data are presented elsewhere because they are not used directly in the investigation of recruitment indices.

Chapter 3. Factors affecting the abundance and distribution of recruits (0^+) of seven inshore fish species from south-western Australia (**Objectives 3 and 4**).

- Research sampling of 0^+ fish will provide the background against which to assess whether a cost effective sampling strategy (temporal and spatial choices) can adequately and robustly represent the abundance of recruits of the seven fish species.

- Interpretation and understanding of the effects of spatial and temporal factors (e.g. geographic location, season, day, time, lunar cycle, tidal cycle, temperature, salinity and wind) on the abundance of each species is a pre-requisite to developing an optimal sampling strategy and recruitment index.
- The potential for the removal of 0^+ fish during sampling, i.e. localised depletion, to bias data from subsequent samples needs to examined, and if necessary, accounted for in the development of an optimal sampling strategy and recruitment indices.

Chapter 4. The length-weight relationships and length frequency distributions of seven inshore fish species from south-western Australia.

- Length-based information will be used in developing the recruitment indices so has been extensively analysed. Because of the volume of these analyses, which are distinct from the analyses of distribution and abundance they are presented in this stand-alone chapter.

Chapter 5. The development of a rigorous sampling method for determining an index of recruitment for seven inshore fish species from south-western Australia (**Objective 1**).

- The relationships between patterns in abundance and distribution of recruits will be assessed against lagged catch rates of the appropriate sized/aged fish from the commercial catches. Exploration of the possible relationships is the basis for determining whether a cost-effective sampling strategy can be developed for predicting the level of input of recruits, and hence, for predicting trends in catch rates for the key species of the inshore finfish fishery in south-western Australia.

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CHAPTER 2.0 The age- and size-structure and growth rates of seven inshore fish species from the commercial catch from south-western Australia

Suzanne Ayvazian, Gabrielle Nowara and Montgomery Craine

Objective 2. Determine the size and age structure of the commercial catch of these seven species.

2.1 Introduction

Along the lower south-west coast of Western Australia (WA) there are a number of inshore habitats, including permanently open estuaries, seasonally open through to permanently closed estuaries, sheltered embayments and exposed beaches. These habitats support a diverse fish fauna that is targeted by a considerable amount of small-scale commercial and expanding recreational fishing activity. The total commercial landings of finfish species from the west and south coast estuaries, Cockburn Sound, west coast beach bait, Australian herring and Australian salmon fisheries was 3800 tonnes during 2001 (Ayvazian and Nowara 2002, Mitchell *et al*. 2002). While these commercial fisheries catch a wide range of species, the key species of concern are Australian herring, Australian salmon, tailor, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet (Ayvazian *et al*. 1997).

Clearly, managing the sustainability of these limited value finfish fisheries presents one of the major challenges for the Department of Fisheries in WA. In common with many small-scale coastal fisheries across Australia, adequate information on life history, ecology and population parameters of these important inshore species is lacking. This information is essential to understand the dynamics of the population and develop predictive assessment models. However, due to the small-scale nature of the commercial activities and the limited economic value, adequate stock monitoring information for these species necessary for management cannot be cost effectively obtained using traditional fisheries research methods applicable to large fisheries. Historically, the status of these stocks has been evaluated using commercial catch and effort data recorded monthly in compulsory logbooks. More recently these data appear problematic including interpreting whether variations on the catch levels have resulted from changes in the abundance of the stock or market value. Further, in an effort to encourage a resource shift towards the expanding recreational fishing sector, the WA Government has initiated a Voluntary Fisheries Adjustment Scheme to buy back commercial fishing licenses. This scheme has reduced the number of commercial estuarine fishers significantly, including the total removal of all commercial fishing units in the Leschenault Estuarine Fishery.

An alternative approach to the use of commercial catch and effort records and periodic angler creel surveys to provide the information for stock assessment is the development of an index of recruitment. This index would provide a relative measure of annual abundance of recruits across a broad geographic scale, and with information from the fishery and the appropriate time lag, can allow the prediction of future commercial catches and anticipate the need for management action. The requirements to construct a robust index include; 1) an understanding of the biology of the species, (including temporal and spatial distribution and abundance) and 2) a long time series of data (Caputi 1993). Predictions of future commercial catches rely on knowledge of the biology of the species and the appropriate time lag (age)

when the recruits will enter the fishery. Using age-based indices for each of the seven inshore species of concern in WA coastal waters, it would be possible to link the 0^+ age group abundance and its subsequent presence as a recruiting year class to the fishery.
The main aims of this chapter are to:

1). Establish an ageing protocol and determine the growth characteristics of each of the seven species of concern from the commercial fishery.

2). Use this information as a foundation for subsequent analyses of the connections between the 0^+ age group indices and the adult abundance indices, (as measured by the WA Department of Fisheries' commercial fishing catch and effort system), in order to prepare catch forecasts for each species (Chapter 5).

2.2 Material and Methods

Sampling

Samples of the commercial catch of the seven species were collected between August 1999 and June 2002 from locations on the lower west and south coasts of WA (Figure 2.1). Routinely five commercial fishers, four along the west coast and one from the south coast, saved a mixed size range of fish from the seven key species from their catch each month. In addition, samples of catches were collected directly on board the commercial vessels whenever possible or purchased from the Canningvale metropolitan fish markets, fish processors in Albany or directly from other fishers. While we attempted to obtain 20 fish from each of the seven species from the south and west coasts each month (Table 2.3) there were months where this was not achieved. This was due to a lack of availability of some species (i.e. tailor on the south coast), low abundances at certain times of the year (i.e. Australian salmon) and fishers targeting other species that might be more financially beneficial (i.e. blue manna crabs at certain times of the year). In those instances where no commercial fishing occurred for particular species in certain months, Department of Fisheries Research staff set the equivalent of commercial nets to obtain samples. These methods have produced consistent samples of yellow-eye and sea mullet, Australian herring and King George whiting.

All samples were returned to the laboratory for processing. Biological measurements recorded for each fish were the total length (TL) and fork length (FL) to the nearest mm, sex, total weight and gonad weight to the nearest 0.01 g, and the gonad stage (Laevastu 1965). The sagittal otoliths were removed from all fish, then cleaned, dried and stored in paper envelopes. In addition, length measurements (TL, to the nearest mm) of a minimum sample of 50 fish of each species per month from the commercial catch for both of the west and south coasts were taken in order to obtain data on the size structure of the commercial catch. These were recorded with the method of capture and mesh sizes of nets used.

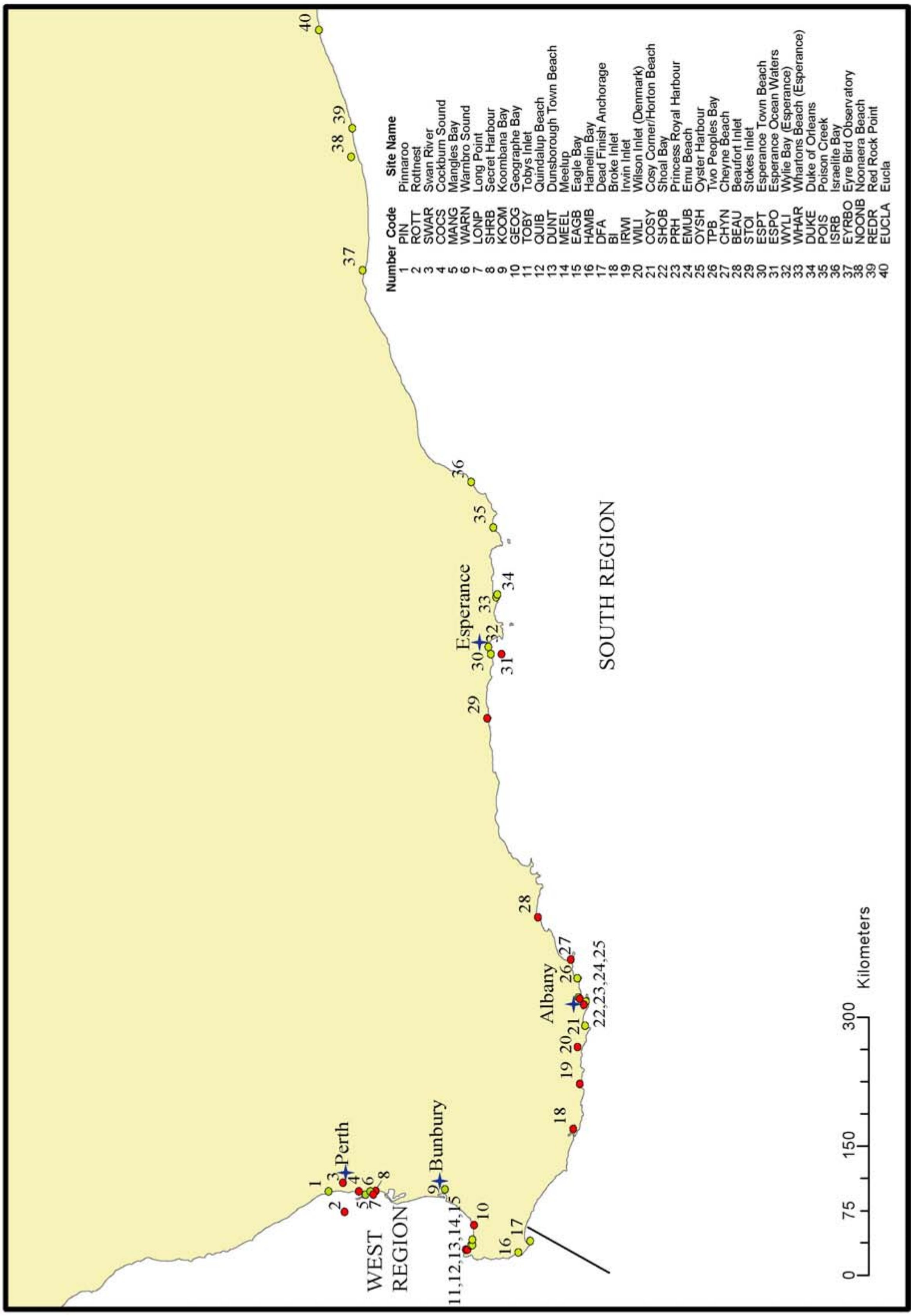

Figure 2.1. Sampling locations on the west and south coasts of Western Australia of recruits and adult fish of the seven species collected between July 1996 and June 2002. Green circles denote recruit sampling sites and red circles denote adult sampling sites.

Age and growth

Preparation of otoliths

The method of preparation of the otoliths for reading depended on the species.

Australian herring otoliths were read whole, immersed in glycerol to provide greater clarity for reading of the rings, under a dissecting microscope using reflected light. Previous work showed that reading whole otoliths of Australian herring gave the same results as sectioned otoliths (Fairclough *et al*. 2000a).

All yellow-finned whiting otoliths were read whole because opaque zones could easily be identified.

From an initial sample of 100 yellow-eye mullet covering a range of sizes, one otolith was read whole and the other was sectioned. A comparison of the results between whole and sectioned otoliths showed that both techniques gave similar readings when 0, 1, 2 or 3 rings were present, but the whole otoliths underestimated age when 4 rings or more were present. Consequently, for otoliths with 3 rings or less, ageing was conducted on whole otoliths, but otoliths with >3 rings were sectioned.

All otoliths of King George whiting were initially read whole, immersed in glycerol, as for Australian herring. Preliminary examination of the otoliths of King George whiting >400 mm TL (approximately 4 years of age) showed that it was difficult to distinguish the outer rings, so these otoliths were sectioned.

Otoliths for all ages of Australian salmon, tailor and sea mullet were sectioned.

Otoliths of all species requiring sectioning were first embedded in resin prior to sectioning with a Buehler Isomet low speed diamond saw. Trial sections were examined to determine the most appropriate section-thickness for each species. The sections for King George whiting were clearest to read when 0.37 to 0.4 mm thick. For the other species sections were 0.57 mm thick. After cutting, each section was cleaned by dipping in 2% hydrochloric acid solution for 5-10 seconds and then rinsed in water for another 5-10 seconds, before being mounted on a slide under a cover slip. Three otolith sections were taken from each otolith.

Reading otoliths

For each species, two examiners read the rings on the otoliths independently of one another. The number of rings (opaque zones) was counted along the same axis for each otolith of the same species. In addition to recording the number of rings, a marginal increment category (Table 2.1) and a readability index were recorded. The readability index was chosen from 1 (Unreadable), 2 (Poor), 3 (Fair), 4 (Good) and 5 (Very good).

Sectioned otoliths where viewed under transmitted light on a compound microscope at 10x magnification.

For each species, approximately 200 otoliths (whole or sectioned) were viewed in a first-pass to familiarise the reader with structures of the otolith. Subsequently, all slides were read twice by the same or different reader with the number of rings, marginal increment category and readability index recorded. All slides where read “blind”, i.e. with no indication as to the size of the fish or the time of capture. For slides where the ring count and or marginal increment varied between the two reads they were read “blind” a third time. A final ring count, marginal increment, and readability were then assigned for each otolith based on the previous two or three readings.

The opaque zones in Australian salmon were most obvious on the ventral part of the otolith. There was a large degree of sub-annual banding that occurred in the first year, making identification of the first opaque zone difficult. This was also the case in the congeneric *A. trutta* (Stevens and Kalish 1998) from New Zealand. The first opaque zone could be more clearly defined for individuals of 2 or more years in age. This allowed the comparison of the second opaque zone to the first thus eliminating other opaque zones being counted as annuli, and thereby permitting reliable identification of the first annulus.

In general tailor otoliths are difficult to age. There are many spurious marks on the otoliths making interpretation problematic. During December 2001 Adam Butcher and Mark McLennan from Queensland DPI joined scientists at the WA Department of Fisheries to convene a four day ageing workshop. The outcome of this workshop was a preliminary protocol for ageing tailor in Australia waters. This procedure has been fully documented in FRDC Final Report 1999/123 entitled “Age validation in tailor (*Pomatomus saltatrix*)” by Brown *et al.* 2003 and used in this current study.

The salient point from the protocol is to maximise understanding of all internal otolith structures. Therefore the three sections from the otolith need to be examined with transmitted, when necessary reflected, light and the focus moved through the planes of vision to visualise all structures so as to determine the least ambiguous section on which to complete the ageing protocol.

The following structures need to be **identified prior to assessing ring counts** for tailor.

- Firstly, the dense and opaque primordium that includes the nucleus.
- Secondly, surrounding this zone is a somewhat less opaque zone.
- Outside of these opaque regions is the settlement check, which may not be well defined.
- A translucent zone follows these opaque zones and the settlement check.
- Exterior to these three zones is a highly distinct band, visible through the sulcus and the dorsal margin. We believe that this is the first annual growth check.
- Locate the sulcus and follow the margin towards the proximal surface. This is the surface used to count the opaque bands representing annual growth checks.

The procedure requires that the otoliths be read twice by each reader and scored. An Average Percentage Error (APE) can then be calculated to examine within and between reader variability. Discrepancies should be discussed and supporting information used to develop the most accurate estimate of age. However, it is realised that there will be some otoliths with a low readability score.

Marginal increments

In order to ascertain the periodicity of ring formation, distances were measured between successive opaque zones and from the final opaque zone to the outside margin of the otolith along an axis from the primordium to the proximal surface next to the crista inferior. An image-analysis system comprised of a dissecting microscope, a video camera, and a computer installed with image analysis software was used to conduct these measurements. For an otolith with one opaque zone, the marginal increment was expressed as a proportion of the distance between the core and the first opaque zone and between the first opaque zone and the edge of the otolith. For an otolith with more than one opaque zone, the marginal increment was expressed as a proportion of the immediately preceding translucent zone and plotted as a function of month of the year. The otolith edge was recorded as either opaque or translucent. If the otolith edge was opaque a ring was counted. The average monthly marginal increments were plotted as a function of the month of the year.

At the same time that the number of rings was counted for each of the species, a marginal increment category was recorded to indicate the definition of the edge of the otolith (Table 2.1).

Table 2.1. Marginal increment (MI) categories used in recording the status of the edge of the otoliths of the seven species.

MI category	Appearance of otolith margin
0	Opaque material visible on the outer edge
1	Translucent zone < 50% of previous translucent zone
2	Translucent zone > 50% of previous translucent zone

Conversion of annuli counts to ages

The age of each fish (in months) was determined from the count of the number of rings, birth date and capture date. For each species a birth date was assigned using preliminary information on the gonadosomatic index (GSI) and information from the literature. The months during which rings are laid down, and the main ring-laying month were determined for each species (Table 2.2). During the ring-laying months, the status of the otolith edge was taken into account in the calculation of the age from the number of rings.

Table 2.2. The birth date, ring laying months, main ring laying month and the marginal increment (MI) category when the ring count is recorded for each of the 7 species.

Species	Birth date	Ring laying months	Main ring laying month	MI category when ring count recorded
Australian herring	May 1	Aug to Dec	September	0
Australian salmon	May 1	Aug to Dec	October	1
Tailor	January 1	Aug to Dec	October	1
King George whiting	August 1	Aug to Dec	September	1
Yellow-finned whiting	January 1	Sept to Jan	December	1
Sea mullet	June 1	Aug to Dec	October	1
Yellow-eye mullet	August 1	Sept to Dec	November	1

Tailor in the south-west of WA have been assigned a January 1 birth date. However it appears that in some years there is also a strong recruitment-pulse during winter, signifying a second spawning. Tailor rings appear to be laid down between August and December with October assigned as the main month. A ring was counted only if the transparent zone was visible after the formation of the opaque zone.

For sea mullet, ring deposition occurred in the months between August and December, with the main ring deposition month being October. A ring was counted only if the transparent zone was visible after the formation of the opaque zone (MI category = 1). A birth date of June 1st was assigned to sea mullet, based on the peak in the GSI. For sea mullet captured in the non-ring laying months between January and July:

age (in months) = (No. of rings x 12) + no. months between the birth date and the ring laying month (October) + capture month + (12 – ring laying month).

For sea mullet captured in the months between August and December (the ring laying months), the marginal increment category was used in the calculation to take into account that the fish that had already completed or nearly completed another year:
If MI category = 1,

age (in months) = (No. rings x 12) + no. months between the birth date and the ring laying month (October) + (if the capture month is greater than the ring month, add (capture month – ring laying month) otherwise subtract (ring laying month – capture month)).

If the MI category = 0 or 2,

age (in months) = (No. rings + 1 x 12) + no. months between the birth date and the ring laying month (October) + (if the capture month is greater than the ring month, add (capture month – ring laying month) otherwise subtract (ring laying month – capture month)).

The formula for calculation of the fractional age for the other six species is essentially the same, except that adjustment has been made for the appropriate birth date, ring laying months, main ring laying month, and when the ring was counted.

Growth curves

A von Bertalanffy growth curve was used to model the growth of each species. The model is,

$$L = L_\infty(1 - \exp(-Kt)) + \varepsilon_1,$$

where ε_1 is a normally distributed error term with a mean of 0 and a homogenous variance , L is the total length of the fish at age t, L_∞ is the asymptotic size and K is the growth constant. This growth equation was used to model the growth of each of the seven species for both sexes.

Because analysis of regression performed with dummy variables has the same power to detect a difference between two levels within a factor as does analysis of variance, nonlinear regression with dummy variables was undertaken to test the difference in expected asymptotic size (L_∞) and expected growth constant (K) of male and female of each species. The model is,

$$L = (L_\infty + \alpha z)(1 - \exp(-(K + \gamma z)t)) + \varepsilon_2,$$

where, $\varepsilon_2 \sim N(0, \sigma_2^2)$, z is a dummy variable with the value of 1 equal to the control group and 0 for all other conditions, and α and γ are to be determined. The hypothesis of $\alpha = 0$ can be used to test the significance of sex and regional differences in L_∞. Similarly, the hypothesis of $\gamma = 0$ can be used to test the significance in sex and regional differences in K. Historically the vb model had been fit as a log-linear model; the non-linear modelling approach used here obviates the need to specify a t_0 parameter. Note that variance associated with the additive error term allows for scatter about the origin, but the expectation is for a length of zero at age zero.

Size at maturity

The size at maturity for each of the seven species was calculated using a logistic generalised linear model with the 95% confidence intervals calculated by 500 bootstrap samples.

2.3 Results

Age and growth

The number of length measurements taken from commercially caught fish of the seven species over the 3 years of the project ranged from 1,343 Australian salmon to 7,207 sea mullet (Table 2.3). Additional samples of each species were used for the ageing study, with an average of 970 fish examined for each species (Table 2.4).

Table 2.3. Number of fish sampled for length from commercial catches for each of the 7 species.

Species	South	West	Total
Australian herring	3138	2877	6015
Australian salmon	1246	97	1343
Tailor	395	2975	3370
King George whiting	4162	1250	5412
Yellow-finned whiting	467	1675	2142
Sea mullet	3604	3603	7207
Yellow-eye mullet	2377	3482	5859

Table 2.4. Number of fish used in the ageing study for the 7 species (F – female, M – male, J –juvenile, U- unknown).

Species	South					West				
	F	M	J	U	Total	F	M	J	U	Total
Australian herring	337	105	5	29	**476**	352	81	30	16	**479**
Australian salmon	193	182	25	7	**407**	21	21	0	1	**43**
Tailor	81	40	1	8	**130**	227	152	7	45	**431**
King George whiting	291	282	106	15	**694**	194	127	283	84	**688**
Yellow-finned whiting	89	71	0	0	**160**	272	147	149	0	**568**
Sea mullet	230	245	158	37	**670**	170	177	115	83	**545**
Yellow-eye mullet	351	82	219	28	**680**	415	122	252	27	**816**

For Australian herring there was an agreement of 70% on 434 fish between two readers. A second examination of 680 otoliths produced an 80% agreement between two readers.

An initial examination of intra-reader variability for all Australian salmon otoliths produced a percentage agreement between the ring counts of the two reads of 78%. When this was examined with only those otoliths with a readability of greater than 2 (i.e. those that were scored with some certainty) the percentage agreement rose to almost 86%.

The agreement between readers for tailor with a sample of 54 otoliths was 46%. The first reader got a higher reading than the second reader 50% of the time, and the second reader got a higher reading 3.6% of the time.

For King George whiting the overall agreement between the two readers was 85% for 663 fish. For yellow-finned whiting there was a 90% agreement between two readers for 517 otoliths.

Comparison between readers of the sea mullet otoliths showed an 86% agreement from 729 otoliths. Yellow-eye mullet results between the two readers produced over 80% agreement.

Marginal increments

A previous marginal increment analysis for Australian herring demonstrated that opaque zones had an annual periodicity (Fairclough *et al.* 2000a). For Australian salmon it was difficult to determine a pattern from the marginal increment data for particular age classes, due to the paucity of data in many months. However, pooled data indicates an increasing marginal increment from August to November and possibly a decrease in December to January for each of the years examined (Figure 2.2a).

Tailor marginal increment data were likewise pooled across regions (Figure 2.2b). The data for samples with two opaque zones is incomplete, but shows a decline from September to November of 2000; in other years the picture is unclear. For the pooled data, there are declines in the peak of the marginal increments from September to October 1999, October to December 2000 and January to February 2002. The limited data shows an approximate annual pattern, although there is an additional decline in the MI between June and July of 2000 that may be explained, in part, by the reliance on the marginal increment measurements reported from the youngest fish (one opaque zone) most notably until early 2000.

The marginal increments of the otoliths of King George whiting were examined only on the south coast as the rings have been shown to have an annual periodicity for this species on the west coast (Hyndes *et al.* 1998) (Figure 2.2c). On the south coast, the data for one and two opaque rings were limited, so the pooled data were examined. The pooled data shows a decline in the marginal increment from September 1999 to January 2000, and between July and August 2000. A decline began appearing in October 2001, continuing until data collection was completed in December 2001, though this had not fallen to the lowest level recorded in previous years. However, the data indicate that the general pattern of ring deposition is an annual event, although the decline in MI during August of 2000 for both the two and three opaque zone fish samples needs to be investigated further.

The marginal increments of the otoliths of yellow-finned whiting were examined only on the south coast as the annuli have been validated for this species on the west coast by Hyndes and Potter (1997). However, there were insufficient data to adequately assess the marginal increments of south coast yellow-finned whiting, so it was assumed from the study by Hyndes and Potter (1997) on the west coast that opaque bands also formed annually on the south coast.

For sea mullet the data were examined separately for the south (Figure 2.2d) and west (Figure 2.2e) coasts. In the south coast region, a decline in the MI for otoliths with one opaque zone was recorded from November 1999 to January 2000 and between October 2000 and February 2001. For otoliths with two opaque zones there was a low MI in December 1999 although there were no data in the preceding months, and there were declines in the MI from November 2000 to January 2001 and October to December 2001. For otoliths with 3 or more opaque zones an annual pattern of decline was shown in November 1999 to January 2000, December 2000 to January 2001 and September to November 2001. The pooled data also showed an annual pattern in decline of the MI from November to the following February in 1999/2000 and 2000/2001 and the beginning of a decline from October to November 2001. The variability in the MI measurements during early to mid 2001 most probably reflects the reliance on the lower values for the MI measurements of the one opaque zone samples in the pooled data. Thus the laying down of the rings (opaque zones) is considered to be an annual event for sea mullet from the south coast region.

In the west coast (Figure 2.2e) region, fish with one opaque zone showed a decline in the MI to the lowest level between December and January, in both 1999/2000 and 2000/2001. Whilst there are some missing data in late 2001, there is a similar low point in December 2001. For fish with one opaque zone, there is a decline from November to December 2000. There is insufficient data to discern a pattern for other years. Similarly, there is insufficient continuous data to discern a pattern for otoliths with 3 or more opaque zones. When the data are pooled, a decline in the MI occurs from October 1999 to February 2000, November 2000 to January 2001 and September to December 2001. The laying down of the opaque region for sea mullet on the west coast can be said to occur annually at least for one and two zones.

Yellow-eye mullet were also examined separately for the south (Figure 2.2f) and west (Figure 2.2g) coasts. On the south coast, otoliths of fish with two and three or more opaque zones showed a similar pattern to the pooled data. There was a decline in the marginal increment between October and November 1999, October 2000 and January 2001, and August to November 2001, when the sampling finished. The marginal increments for yellow-eye mullet on the west coast showed a similar pattern for one, two and three or more opaque rings, where data were available, to the pooled data for the region. The marginal increment for the pooled data showed a decline from August to December 1999, from August 2000 to February 2001 and from August to November 2001 when sampling finished. The deposition of opaque bands for yellow-eye mullet are therefore considered to occur annually, although it may be occurring slightly later on the south coast than on the west coast.

Growth

The von Bertalanffy growth curves and age-length data for each region for each of the seven species have been plotted (Figures 2.3a-g). The growth curves and age-length data for Australian herring indicate that ages 2^+ to 5 predominate in commercial catches for both regions. Australian salmon age-length information spans a wide range of ages from 0^+ to 9 years on the south coast. There were not enough fish examined on the west coast to make conclusive statements. Similarly, commercially caught tailor on the south coast were sparse, but on the west coast the ages ranged from 1^+ to 5 years with most fish between 2^+ and 4. King George whiting from both coasts had ages between 2^+ and 7^+ with the predominant group 2^+ to 4^+ on the south coast and evenly distributed between 1^+ and 4^+ on the west coast. Yellow-finned whiting were sparse from the south coast. The commercially caught west coast samples were predominantly 2^+ to 4^+ years with fish ranging from 0^+ to greater than 10 years. Sea mullet caught from both coasts were generally 2^+ to 6 years. Yellow-eye mullet caught from both coasts were predominantly 2^+ to 5^+ years. Females attained a greater maximum length for Australian herring, yellow-finned whiting, sea mullet and yellow-eye mullet.

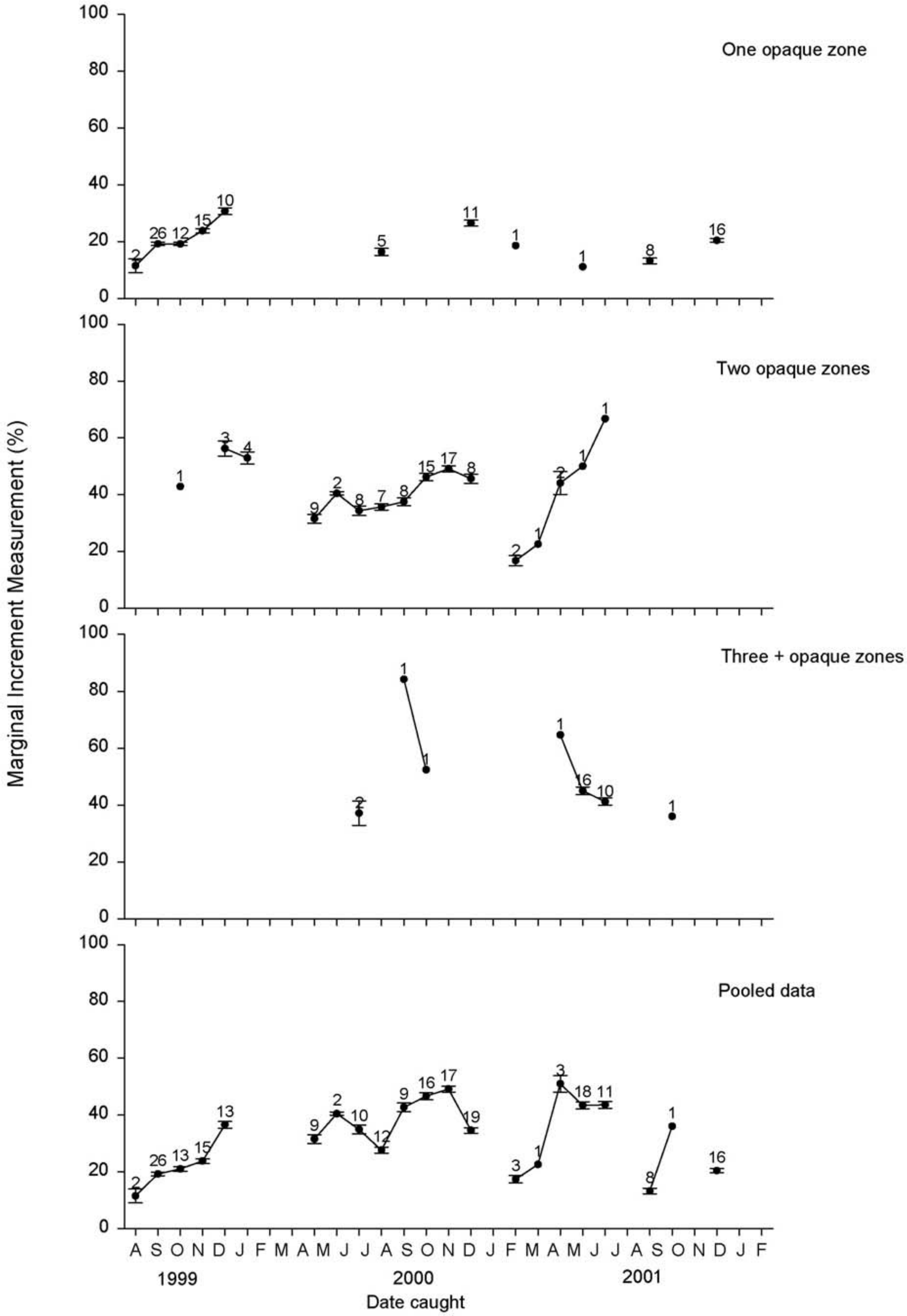

Figure 2.2a Mean monthly marginal increment measurement (%) ±1 se for otoliths of WA salmon caught in both regions between August 1999 and December 2001.

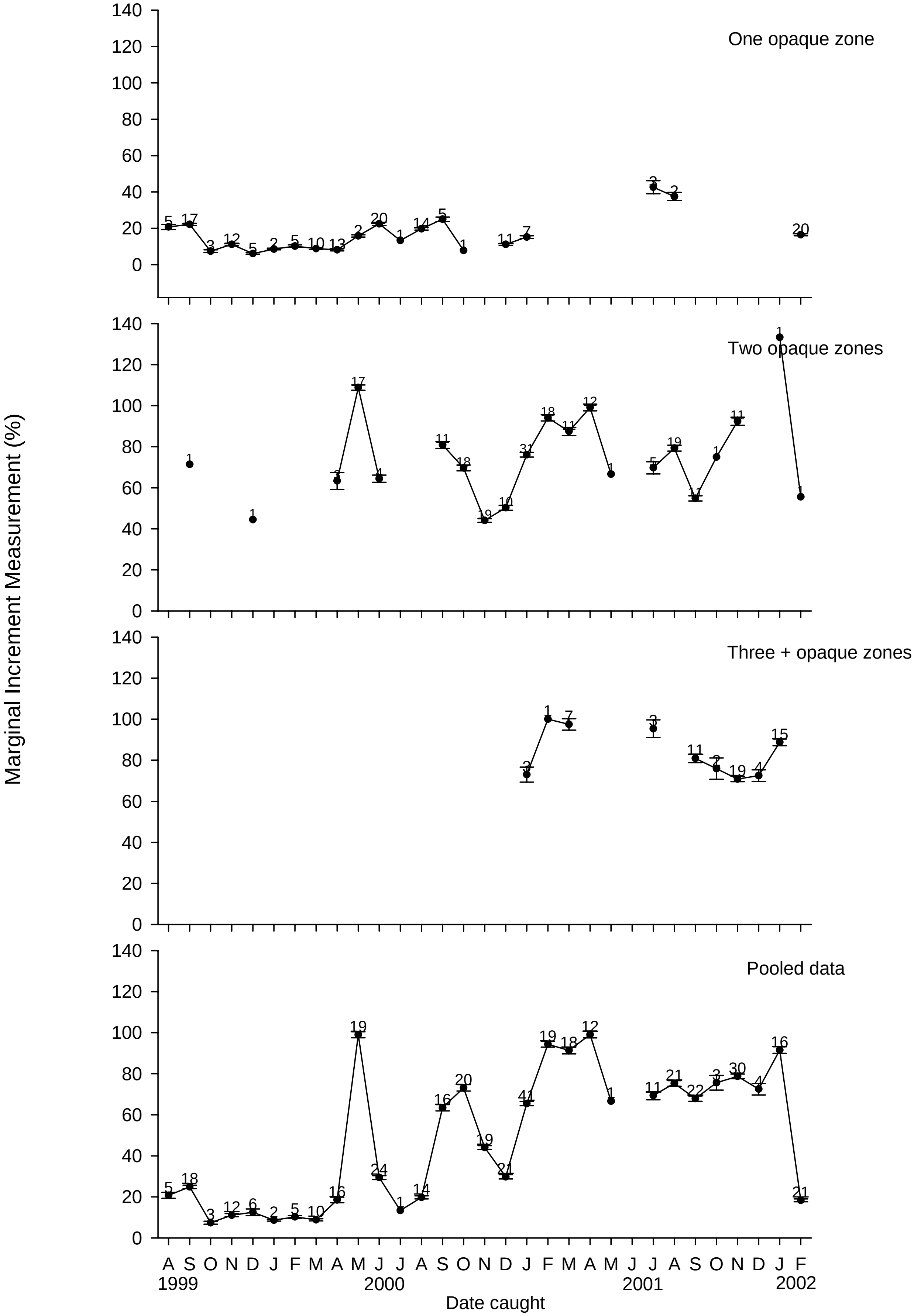

Figure 2.2b. Mean monthly marginal increment measurement (%) ±1 se for otoliths of tailor caught in both regions between August 1999 and February 2002.

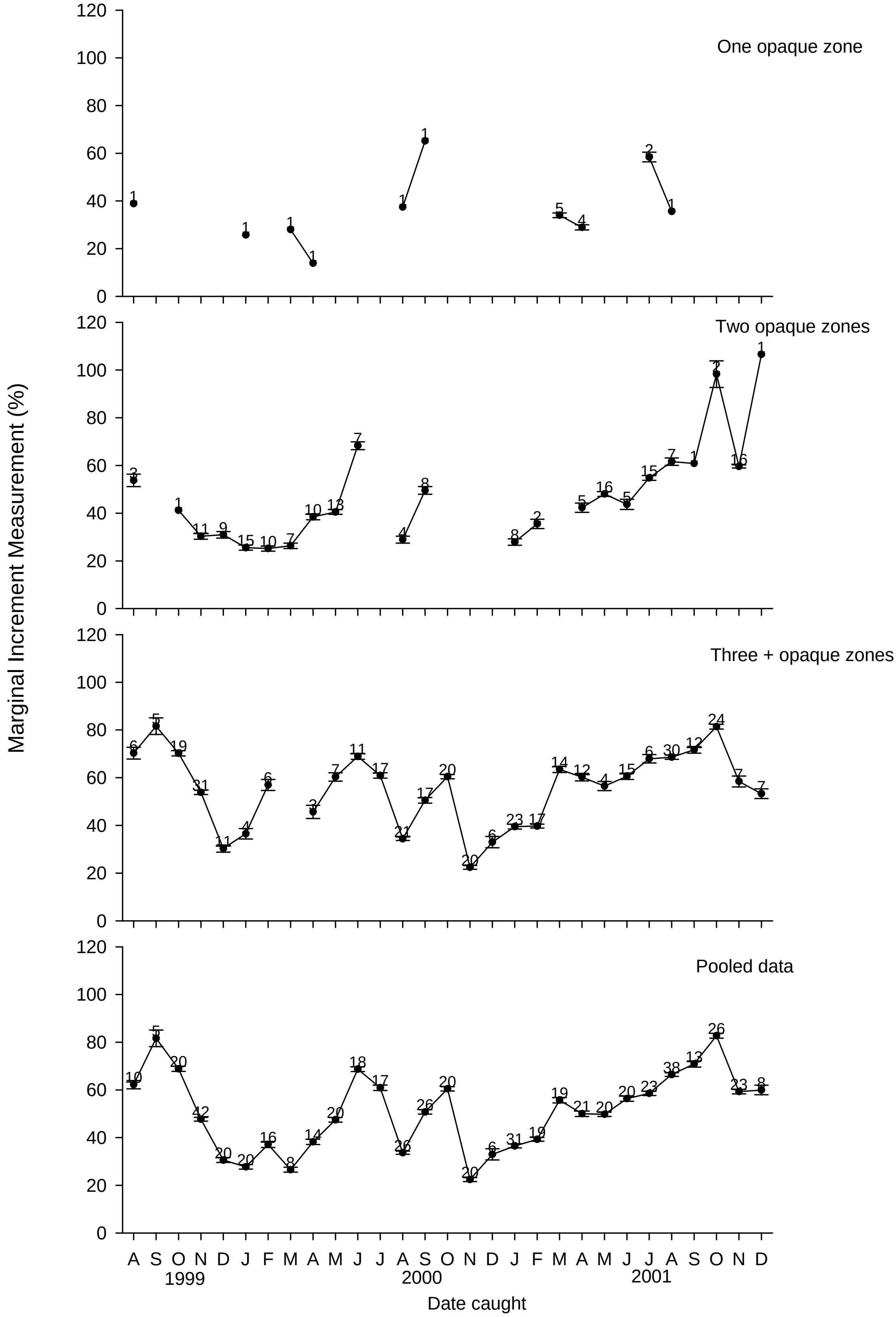

Figure 2.2c. Mean monthly marginal increment measurement (%) ±1 se for otoliths of King George whiting caught in the south region between August 1999 and December 2001.

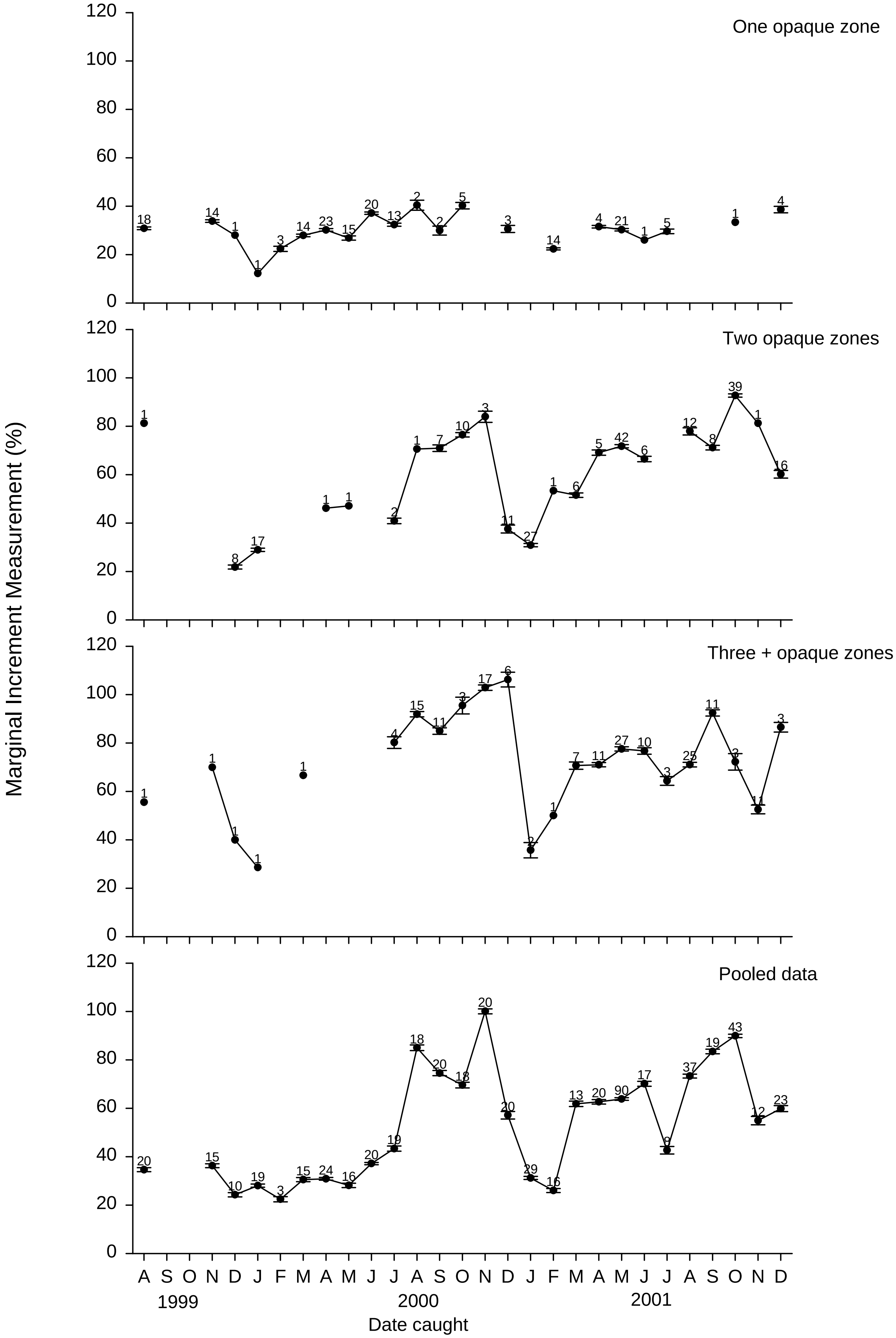

Figure 2.2d Mean monthly marginal increment measurement (%) ±1 se for otoliths of sea mullet caught in the south region between August 1999 and December 2001.

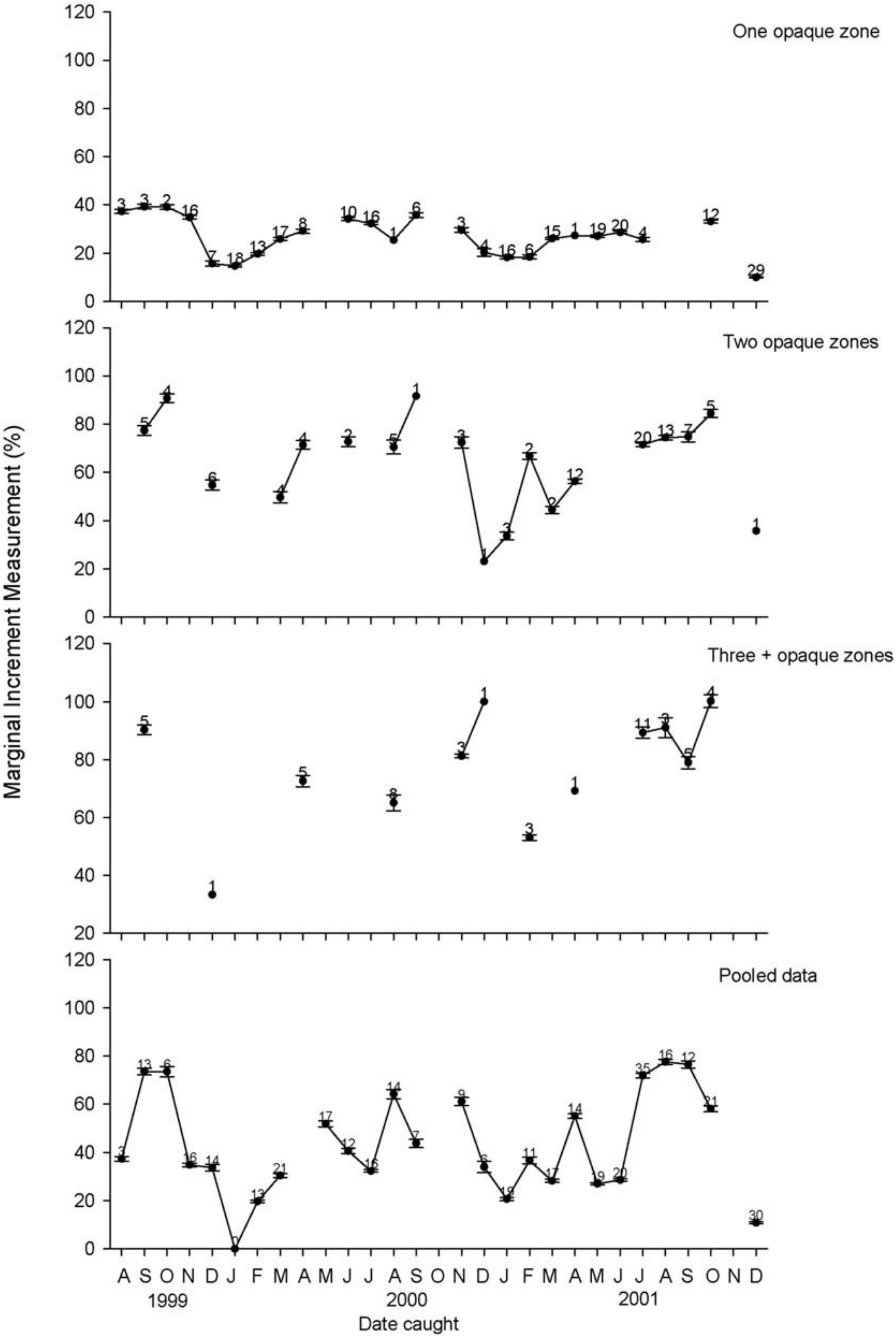

Figure 2.2e. Mean monthly marginal increment measurement (%) ±1 se for otoliths of sea mullet caught in the west region between August 1999 and December 2001.

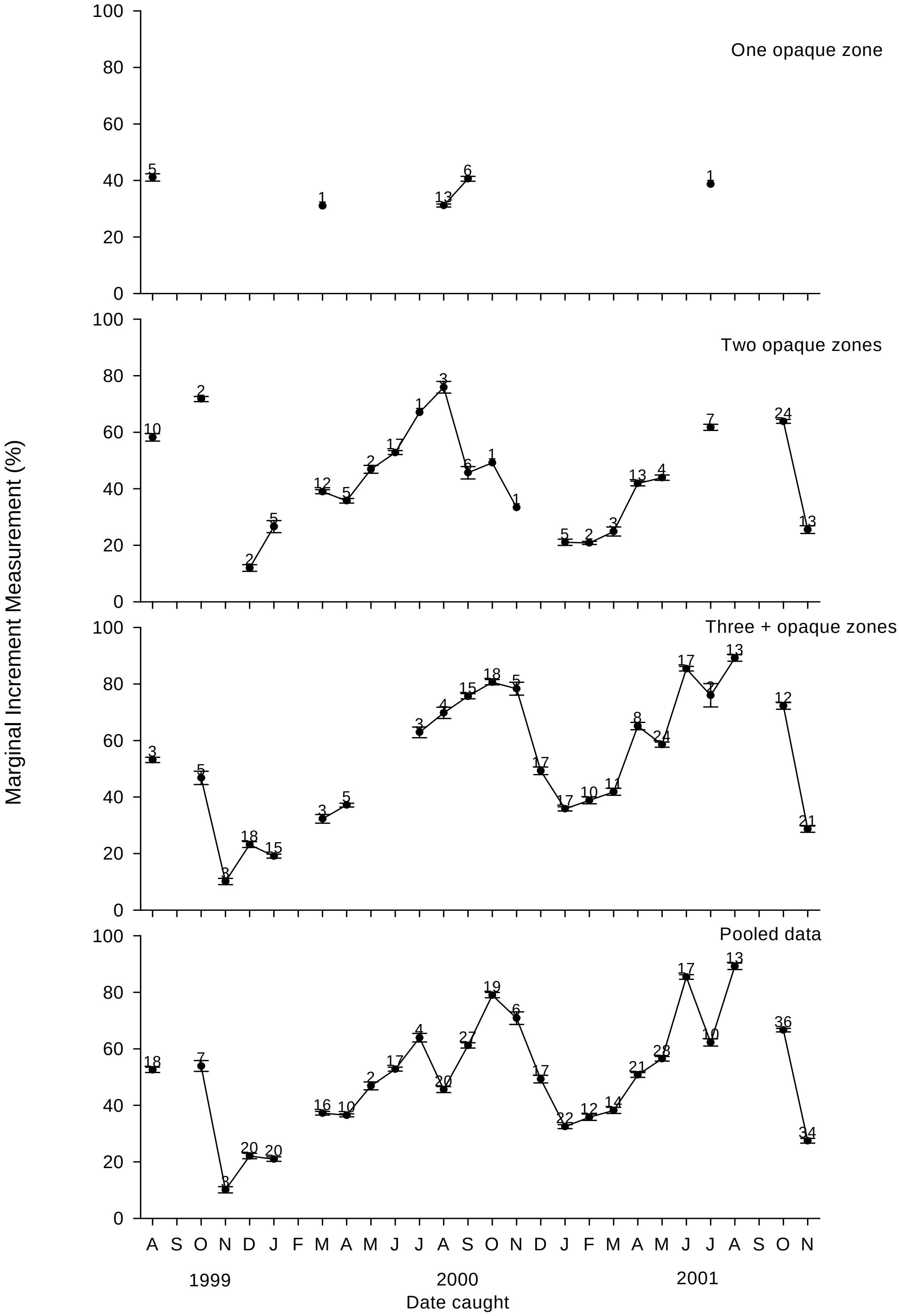

Figure 2.2f. Mean monthly marginal increment measurement (%) ±1 se for otoliths of yellow-eye mullet caught in the south region between August 1999 and December 2001.

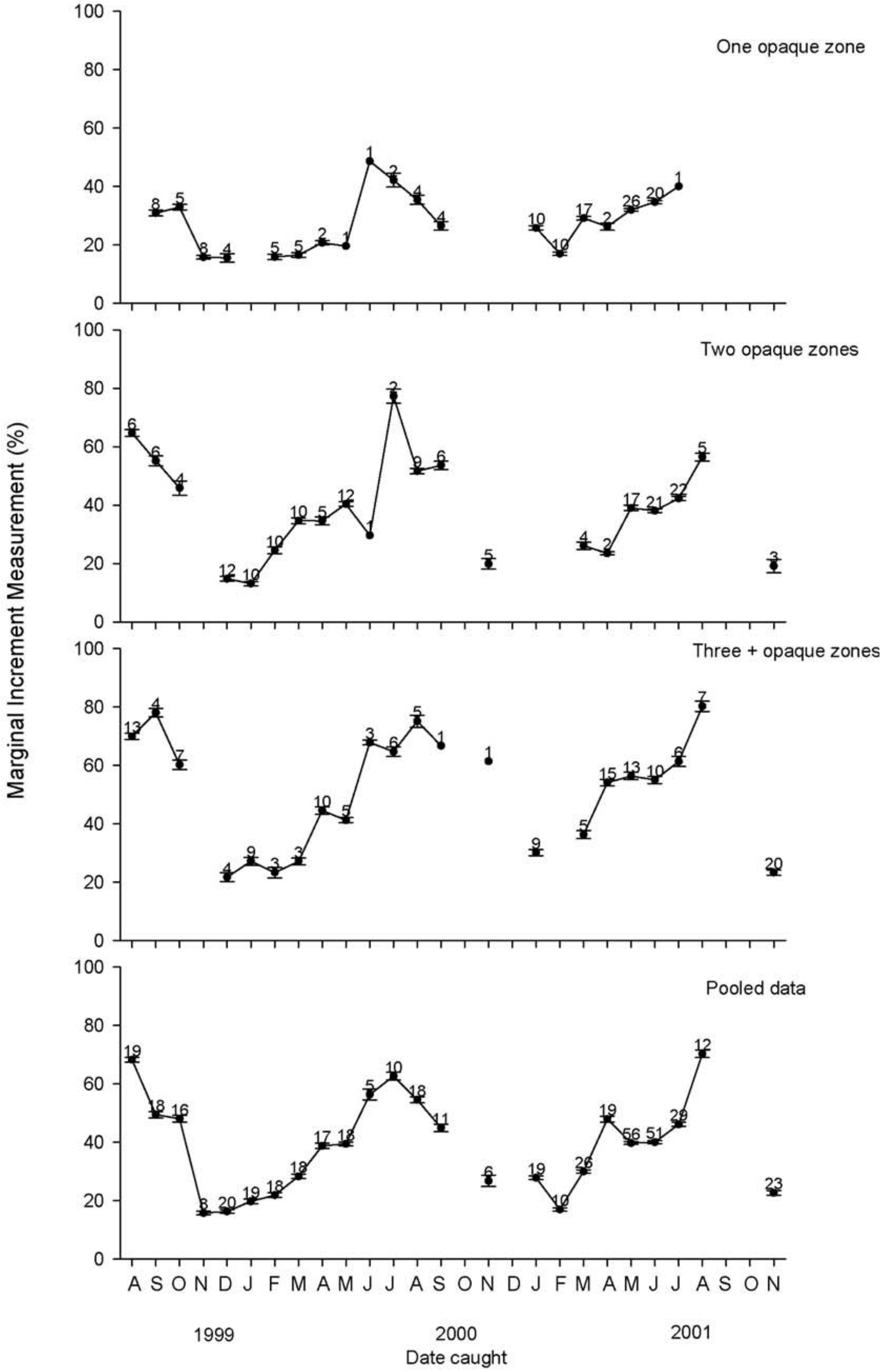

Figure 2.2g. Mean monthly marginal increment measurement (%) ± 1 se for otoliths of yellow-eye mullet caught in the west region between August 1999 and December 2001.

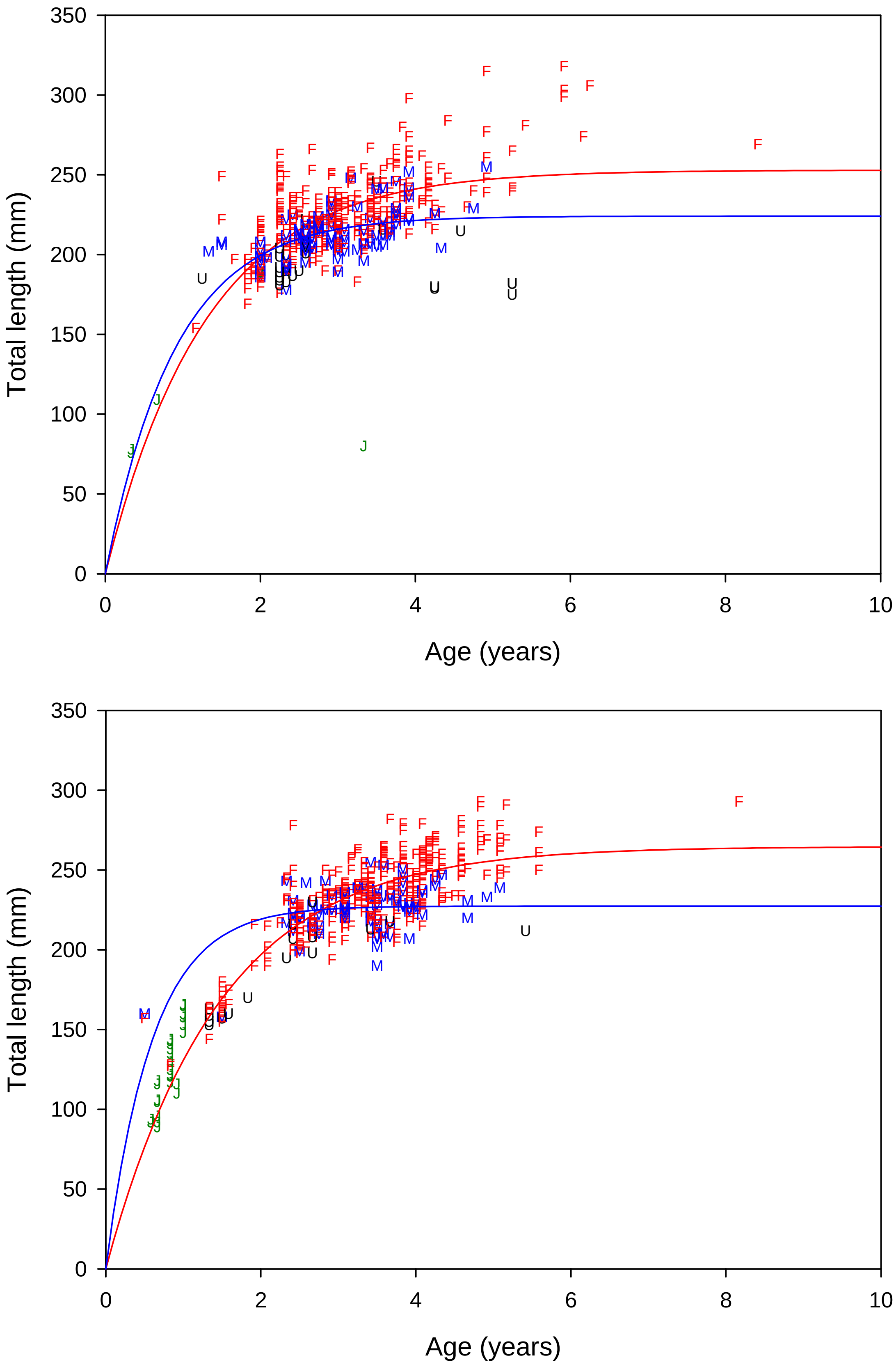

Figure 2.3a. Von Bertalanffy growth curves and age-length data for herring for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

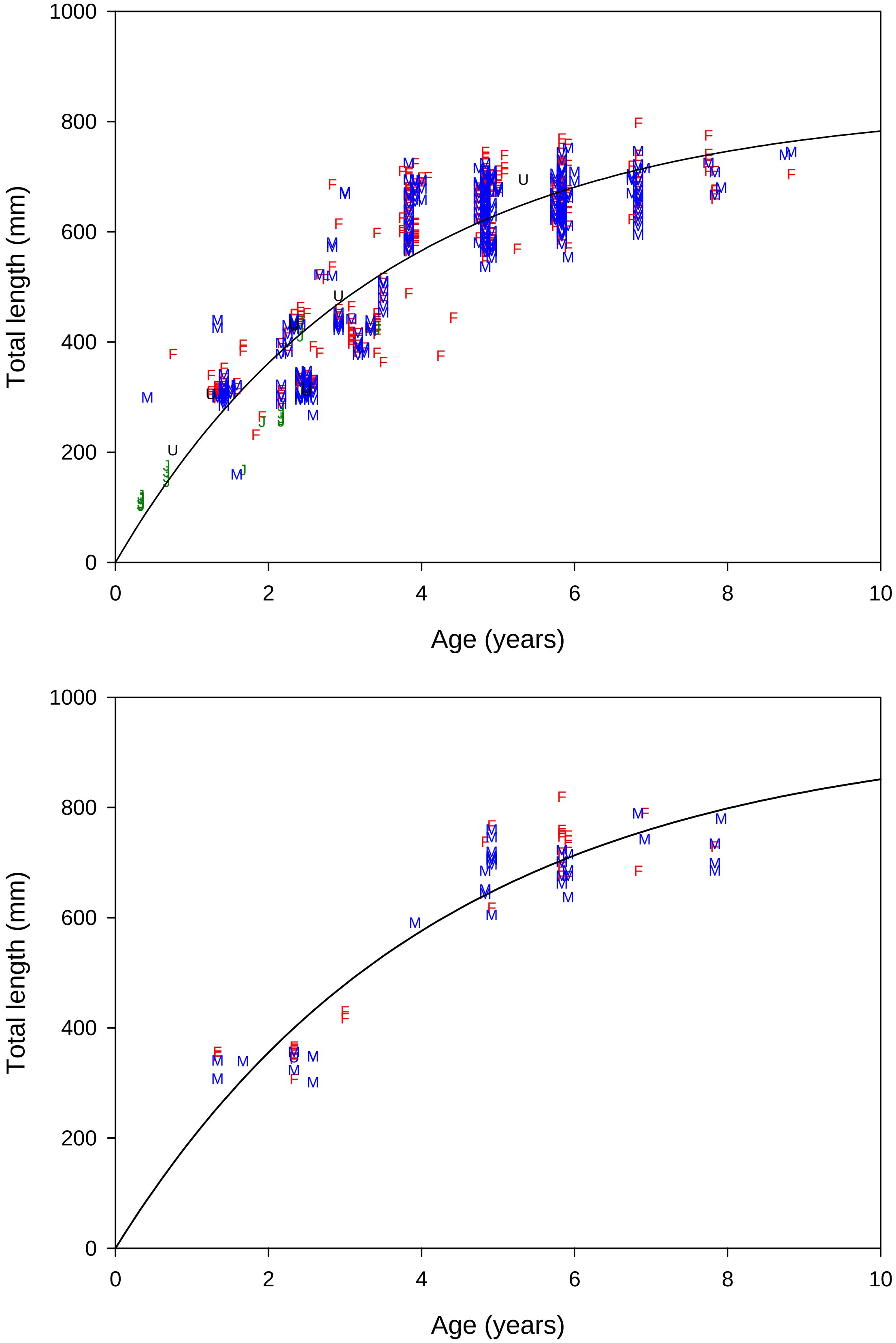

Figure 2.3b.Von Bertalanffy growth curves and age-length data for salmon for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

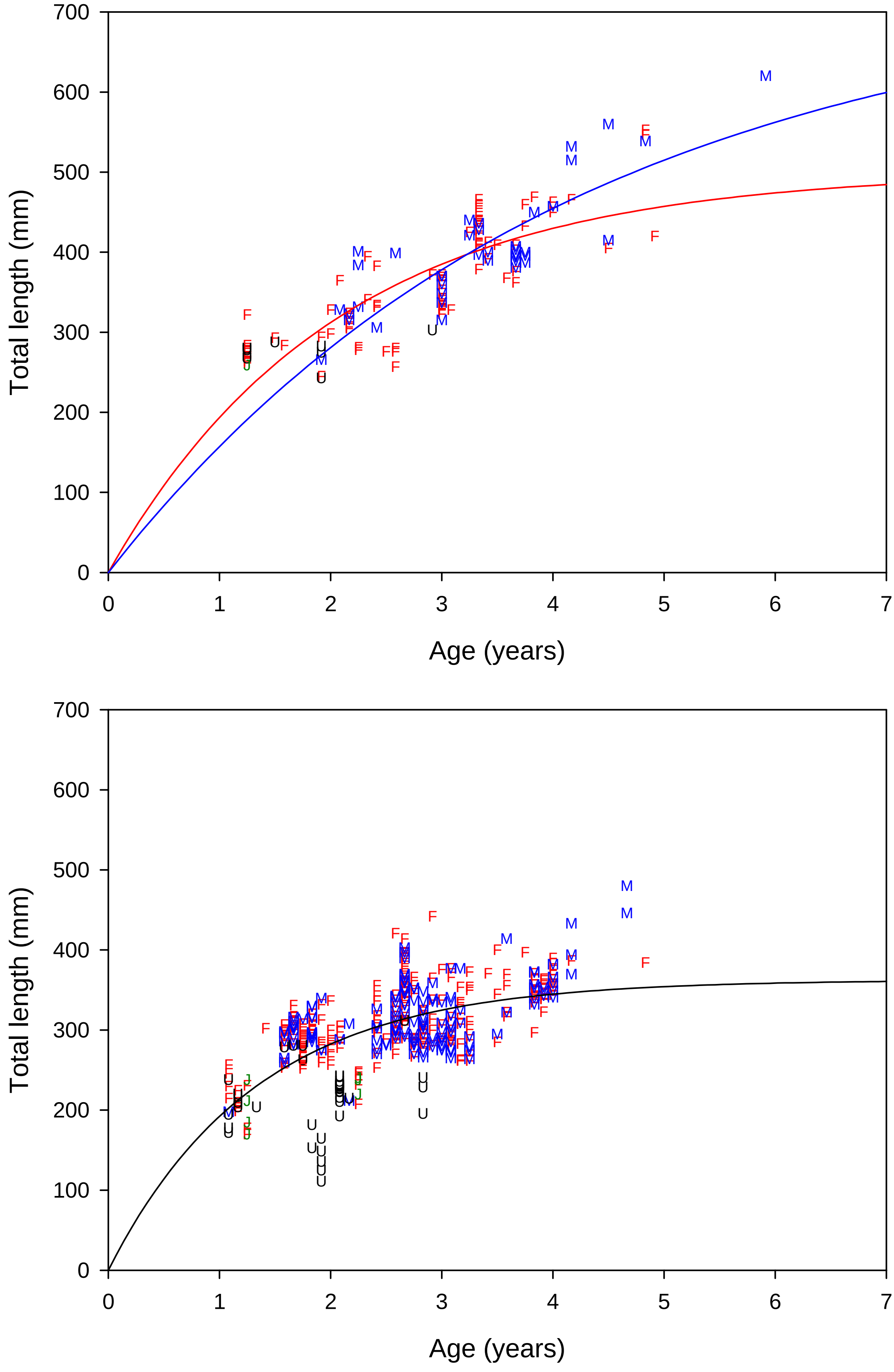

Figure 2.3c. Von Bertalanffy growth curves and age-length data for tailor for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

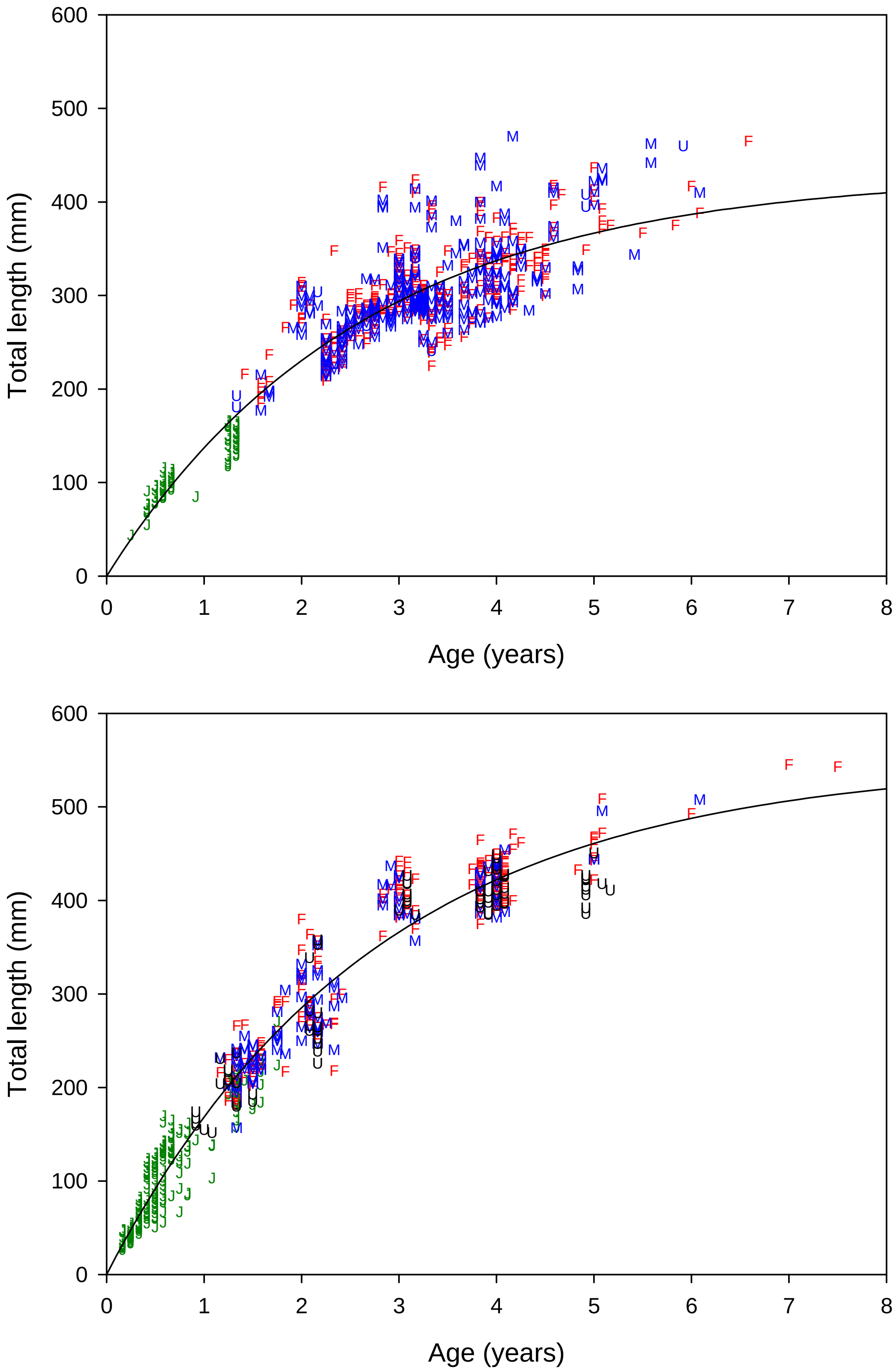

Figure 2.3d.Von Bertalanffy growth curves and age-length data for King George whiting for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

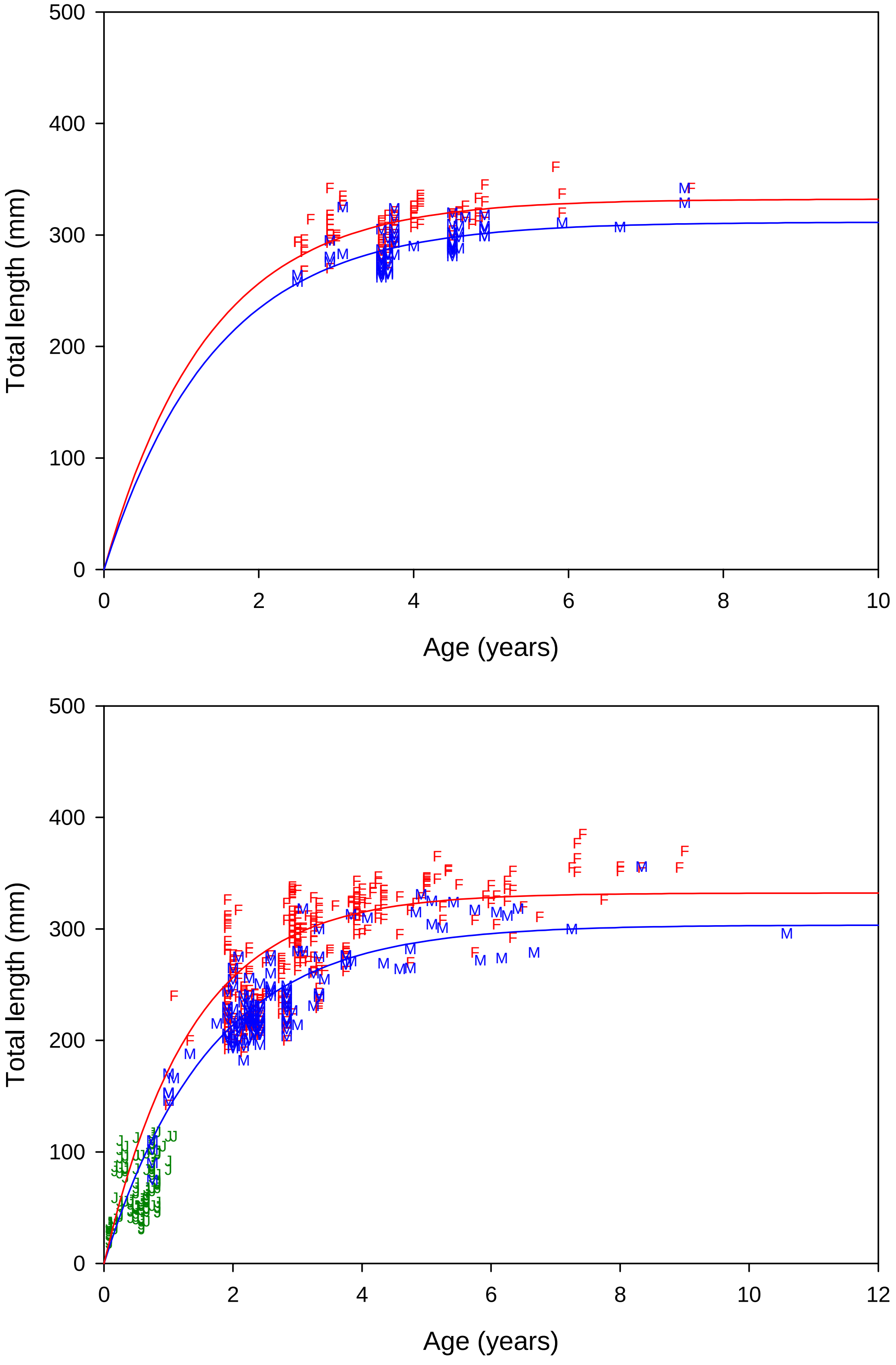

Figure 2.3e.Von Bertalanffy growth curves and age-length data for yellow-finned whiting for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

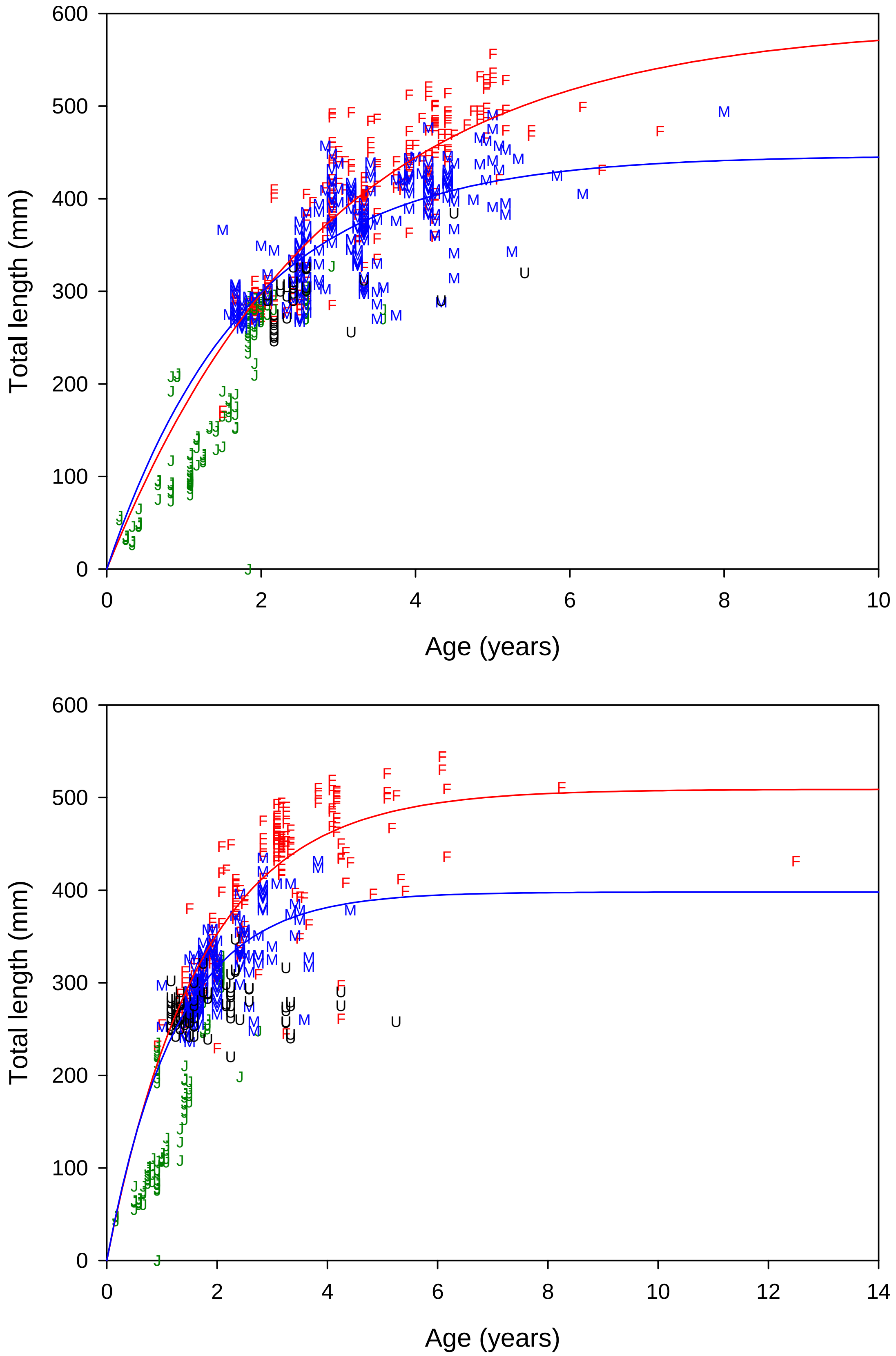

Figure 2.3f.Von Bertalanffy growth curves and age-length data for sea mullet for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

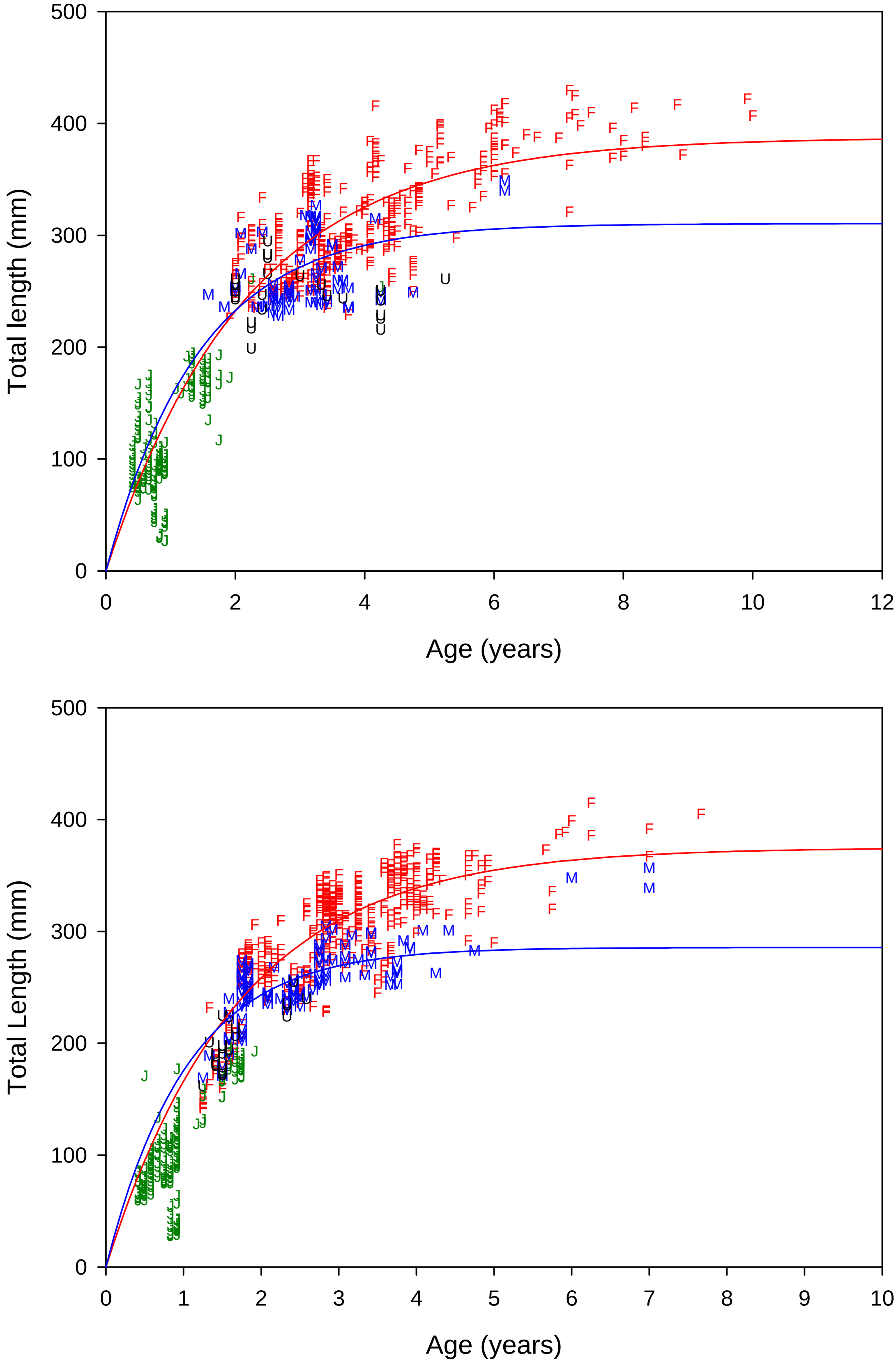

Figure 2.3g.Von Bertalanffy growth curves and age-length data for yellow-eye mullet for the south (top) and west (bottom) regions of Western Australia. (F - females, M - males, J - juveniles, U - unknown)

Estimated von Bertalanffy growth parameters were calculated for each species by region and sex (Table 2.5). The L_∞ of each species, except salmon, differed between the south and west coast regions. Estimated growth rates (K) differed between the south and west coasts for herring, tailor, yellow-finned whiting and sea mullet (Table 2.6). Assuming that the samples obtained were in fact representative of the west and south coast population of the target species, these differences in L_∞ and K confirm that fish from each region should be treated independently for the purposes of this study. These results will be used in the investigation of recruitment indices. However, it is recognized that in those cases were there were discrepancies in the size distributions of fish sampled between the regions that direct comparison of von Bertalanffy parameters for the purpose of inferring biological differences is not appropriate. Thus, while the data can be used to investigate recruitment indices, comparisons of growth rates between regions where size distribution differs would not be valid.

Table 2.5. von Bertalanffy growth parameters for each of the seven inshore species from the west and south regions of Western Australia.

Species	Region	Sex	L_∞ (mm)	K	n
Australian herring	South	Female	252.89	0.765	330
		Male	224.08	1.103	104
	West	*Female*	*264.63*	*0.681*	*351*
		Male	*227.34*	*1.661*	*81*
Australian salmon	South	Female	813.33	0.309	378
		Male	832.15	0.276	340
	West	*Female*	*1012.45*	*0.210*	*30*
		Male	*881.06*	*0.269*	*35*
Tailor	South	Female	500.80	0.488	80
		Male	736.73	0.240	40
	West	*Female*	*353.29*	*0.909*	*227*
		Male	*344.94*	*0.982*	*152*
King George whiting	South	Female	410.15	0.425	291
		Male	414.89	0.415	281
	West	*Female*	*562.60*	*0.359*	*194*
		Male	*571.90*	*0.345*	*124*
Yellow-finned whiting	South	Female	332.15	0.740	89
		Male	311.59	0.695	71
	West	*Female*	*348.15*	*0.560*	*272*
		Male	*303.55*	*0.610*	*147*
Sea mullet	South	Female	588.39	0.352	230
		Male	446.57	0.552	245
	West	*Female*	*508.86*	*0.590*	*170*
		Male	*397.96*	*0.793*	*177*
Yellow-eye mullet	South	Female	387.43	0.457	360
		Male	310.45	0.692	85
	West	*Female*	*374.87*	*0.585*	*406*
		Male	*285.63*	*0.953*	*119*

Table 2.6. Probability levels for comparisons of the von Bertalanffy parameters between the west and south regions of Western Australia.

Species	$p\left(\hat{L}_{\infty,\text{West}} - \hat{L}_{\infty,\text{South}}\right)$	$p\left(\hat{k}_{\text{West}} - \hat{k}_{\text{South}}\right)$	n (west)	n (south)
Australian herring	**0.000**	**0.040**	477	468
Australian salmon	0.066	0.112	66	750
Tailor	**<0.001**	**<0.001**	431	129
King George whiting	**<0.001**	0.349	688	694
Yellow-finned whiting	**<0.001**	**0.001**	568	160
Sea mullet	**0.008**	**0.000**	545	670
Yellow-eye mullet	**0.002**	0.573	804	692

Size at maturity

The size at maturity and the 95% confidence intervals of the seven key species are presented in Table 2.7. There were too few Australian salmon sampled to reliably calculate the size at maturity. The Legal Minimum Length (LML) for both the commercial and recreational fishing sector is smaller than the size at L_{50} maturity for all species, except yellow-finned whiting.

Table 2.7. Size at maturity L_{50}, plus 95% confidence intervals (CI) for the key species. The legal minimum lengths for commercial fishers (LML comm.) and recreational fishers (LML rec.) are included for comparison. All lengths are mm total length.

Species	L_{50} (mm)	Lower 95% CI	Upper 95% CI	LML (comm.)	LML (rec.)
Australian herring	221.5	203.9	234.5	180	No size
Australian salmon*				300	300
Tailor	442.9	415.4	491.0	250^{+}	250^{+}
King George whiting	518.2	485.7	883.2	250/280$^{\sim}$	250/280$^{\sim}$
Yellow-finned whiting	199.1	170.0	218.9	220	No size
Sea mullet	372.8	354.8	391.9	240	No size
Yellow-eye mullet	248.8	238.1	258.0	230	No size

* not calculated due to insufficient data.
$^{+}$ Tailor LML was 250 mm during the study, but from 1 October 2003 is 300mm.
$^{\sim}$ West coast (250mm) / South coast (280mm) LML during the study; from 1 October 2003 is 280mm state-wide.

Maximum Length at Age

The von Bertalanffy model for each species was used to estimate the upper length limit for each age class (Table 2.8). The upper length limit for 0^{+} of each species were subsequently used to estimate recruit abundance in the experimental intensive sampling (Chapter 3).

Table 2.8. Upper limit of size (mm) for each year class of the seven species pooled for sex and for separate sexes for the south and west coast of WA derived from the von Bertalanffy equation.

Species	Coast	Sex	0+	1+	2+	3+	4+	5+	L_∞
Herring	South	All	139	198	223	234	239	240	242
		Females	135	198	227	241	247	250	253
		Males	150	199	216	221	223	224	224
	West	All	137	200	230	243	250	253	255
		Females	131	197	230	247	256	260	265
		Males	184	219	226	227	227	227	227
Salmon	South	All	207	362	478	566	632	681	830
		Females	216	375	491	577	640	686	813
		Males	201	353	469	556	623	673	832
	West	All	199	355	479	576	653	713	938
		Females	192	347	473	575	658	725	1012
		Males	208	367	488	581	652	706	881
Tailor	South	All	184	306	386	439	474	497	542
		Females	193	312	385	430	457	474	501
		Males	157	281	378	455	515	562	737
	West	All	192	282	325	345	354	359	362
		Females	211	296	330	344	350	352	353
		Males	216	297	327	338	342	344	345
King George whiting	South	All	137	230	294	337	367	387	430
		Females	142	235	296	335	361	378	410
		Males	141	234	295	336	363	380	415
	West	All	168	285	366	422	461	488	548
		Females	170	288	371	429	469	497	563
		Males	167	285	369	428	470	500	572
Yellow-finned whiting	South	All	175	253	289	304	311	315	317
		Females	174	257	296	315	324	328	332
		Males	156	234	273	292	302	307	312
	West	All	135	219	271	303	323	336	356
		Females	149	235	283	311	327	336	348
		Males	139	214	255	277	289	296	304
Sea mullet	South	All	160	275	359	419	463	495	578
		Females	175	297	384	444	487	517	588
		Males	189	299	361	397	418	430	447
	West	All	190	311	388	437	468	488	523
		Females	227	352	422	461	482	494	509
		Males	218	316	361	381	390	395	398
Yellow eye mullet	South	All	132	220	279	318	344	361	396
		Females	142	232	289	325	348	362	387
		Males	155	233	272	291	301	306	310
	West	All	140	234	297	340	369	389	429
		Females	166	259	310	339	355	364	375
		Males	175	243	269	279	283	285	286

2.4 Discussion

The aim of this section of research, to use established and new ageing protocols to determine the age composition of each of seven species caught in the inshore commercial fishery, was successfully completed. The von Bertalanffy parameters estimated in this section will be used in the development of appropriate databases required for the analyses of potential relationships between the 0^+ age group and the adult commercial stock (in Chapter 5). The growth parameters will be applied to the length frequency data so as to generate age composition estimates for each of the seven species and to estimate age and size at recruitment into the commercial fishery. However, as is often the case in biological studies of fish, the differences in size distribution between regions for some species made direct comparison of growth parameters difficult. Further sampling and reanalysis of age-length data (e.g. using an approach other than the von Bertalanffy model that would allow inflexions in the growth curve; concentrate on filling gaps in size distribution from one region or the other etc.) will subsequently need to be undertaken to generate better estimates of growth parameters.

The annual periodicity observed by the marginal increment on the whole otoliths for Australian herring (Fairclough *et al.* 2000a), and King George whiting (Hyndes *et al.* 1998 and this study); and from sectioned otoliths for Australian salmon, tailor, yellow-finned whiting (Hyndes and Potter 1997), sea mullet and yellow-eye mullet demonstrated that it is valid to use the number of zones to help age individuals of the particular species, but this must be undertaken with caution for the following reasons. Firstly, if marginal increment analysis had previously shown that annuli could be used to determine age for Australian herring (Fairclough *et al.* 2000a; west and south coasts), King George whiting (Hyndes *et al.* 1998, west coast) and yellow-finned whiting (Hyndes and Potter 1997, west coast), no further analyses were undertaken during this study. Secondly, it was not possible to obtain samples from each of the seven species for each month and region for several reasons. These reasons include a lack of availability of particular species to the fisher, low market demand, lack of fishing effort due to inclement weather. This impacted both the number of fish available in each size/age class, and the examination of the monthly trends in marginal increment analysis within a size/age class. Therefore, there were not sufficient samples to conduct marginal increment analysis for yellow-finned whiting from the south coast and regional otolith data had to be pooled for Australian salmon and tailor.

With these precautions in mind, it is possible to look for overall trends in the periodicity of the marginal increment pooled data for each species and where possible by region. Australian salmon data, pooled by number of opaque zones and region, indicates the completion of opaque zone formation by the early summer months. The variation about this trend results from a large proportion of the fish coming from the samples exhibiting only one opaque zone (e.g. July 2000 and 2001 and October 2001). These samples have a lower marginal increment and, when presented as pooled data, the marginal increment appears to decline. The timing of the opaque zone is in line with the September through December formation of opaque zones in the congener, the Australian herring, caught along the south-western region of WA (Fairclough *et al.* 2000a).

Due to their limited presence in the commercial catch, the number of tailor from each coast was not sufficient to examine the otolith data by region. The pooled data for the monthly marginal increment demonstrates that between late 1999 and mid 2000 the trend line reflected that for one opaque zone. Subsequently, there was a decline in the monthly marginal increment measurement in late spring of 2000, marking the completion of opaque zone formation. The 2001-2002 information is less clear due to the low number of otolith samples available. This finding, for those years with sufficient data, is supported by recent research on age validation in Queensland tailor (Brown *et al.* 2003) that demonstrated annulus deposition on otoliths by late September. Along the Queensland coast, assessment of marginal increment analysis showed translucent zones forming between October and January (Hoyle *et al.* 2000); they therefore designated November 1 as the birth date of tailor. Additionally, tailor studies by Krug and Haimovici (1989) in Brazilian waters found ring formation completed on scales by the end of winter. Govender (1999) off South African waters also found annulus formation by late spring.

The age structures and growth of six species of commonly occurring whiting (Sillaginidae) in the coastal marine environment of WA have been extensively studied (Hyndes *et al.* 1996, Hyndes and Potter 1997; Hyndes *et al.* 1998). The current study replicated these published ageing protocols for King George whiting caught along the south coast of WA and independently determined that there is seasonal periodicity in the annulus formation. Although there was some variation between years, opaque zone formation was completed during the late spring and early summer months, which corroborates the Hyndes *et al.* (1998) findings for the west coast.

Yellow-finned whiting age structures have been examined previously by Hyndes and Potter (1997b). In this study, fish collected from the lower west coast demonstrated annual periodicity in the monthly marginal increment measurements, with a decline occurring only once per year in December. This study was unable to collect enough samples from the south coast to develop a marginal increment analysis. Based on the results from the west coast, it was assumed that annulus formation occurred only once a year, and was completed by the late summer for yellow-finned whiting from the south coast.

Sea mullet monthly marginal increment measurements from the west and south coast of WA demonstrated a single annulus deposition each year, suggesting the annulus count was a valid proxy for age. While there was variation noted for the timing of the decline in marginal increment measurements from both regions, partially as a result of the high proportion of one opaque zone fishes in the sample, annulus formation was completed by the end of the summer season. Similarly, yellow-eye mullet opaque zone formation occurred once each year and was completed by the end of the summer season.

For each of the seven finfish species examined by this study the marginal increment analysis demonstrated that ring formation occurred annually and was completed by the late spring through to the summer months. This timing may be in association with decreased water temperature at the end of the winter.

The estimated von Bertalanffy growth parameters, asymptotic length (L_∞) and growth coefficient (K), for Australian herring from the west and south coasts are highly comparable to those calculated by Fairclough *et al.* (2000a) across the entire south-western region (L_∞ = 26.2 cm female and 23.9 cm male: K= 0.813 female and 0.992 male). The similarity in values provides confidence in the accuracy and precision of these growth parameter estimates. In both studies, female fish were found to grow larger than males, however growth rates were slower in this study for females and faster for males.

Australian salmon L_∞ values reported from this study were larger, while *K* was lower than previously described by Nicholls (1973) from fish collected from the same regions. The small number of large fish collected from the west coast in this study may represent sampling bias as few fish over 5^+ years were sampled. The shift in the estimated asymptotic length to larger fish over this 30 year period is counter to expectations if fishing practices had impacted the size/age structure of the stocks. Alternatively, the scarcity of fish < 5+ years may have resulted from several years of low recruitment.

Growth curves fitted for tailor sampled from the south and west coast regions demonstrated highly different values for the L_∞ and *K* parameters. The lower west coast L_∞ values reflect the nature of fishery dependent samples from the Swan River estuary system where reproductively immature fish comprise the catch. Alternatively, the south coast fishery dependent samples were collected from a combination of estuarine and open coastal sites and these fish have greater L_∞ values. The smaller west coast fish display a greater growth coefficient. However sampling biases have influenced the values of these parameter estimates. Hoyle *et al.* (2000) have estimated the asymptotic growth parameters of tailor collected from fishery dependent and –independent sources in Queensland that indicated L_∞ values for males of 79.5 cm fork length and females of 127.5 cm fork length. The female growth curve was best approximated by a straight line and showed no tendency to reach an asymptotic length. Beyond significant sampling biases and perhaps inappropriateness of the von Bertalanffy growth model for tailor, there is no further explanation about this seemingly aberrant parameter value.

King George whiting move offshore from coastal waters as they mature at approximately 3^+ to 4^+ years old. Along the west coast, fishery-dependent samples of mature fish could be obtained from Geographe Bay. This was not the case from the south coast where it was not possible to obtain samples of these larger, mature fish. This sampling bias may explain the greater asymptotic growth parameter, L_∞, from the west coast (male: 571.9 mm, female: 562.9 mm) than from the south coast (male: 414.9 mm, female: 410.2 mm). The results in this study calculated higher values than those for King George whiting on the west coast by Hyndes *et al.* 1998) of L_∞ of 500.1 mm and 532.4 mm for males and females respectively.

Female and male yellow-finned whiting demonstrated contrasting results for the asymptotic growth, L_∞, values. Females were characterised by a higher value from the west coast than the south coast; however males showed the opposite trend. The west coast parameter values of 348.2 mm for females and 303.6 mm for males is similar to the asymptotic lengths of 333 mm for females and 325 mm for males reported by Hyndes and Potter (1997). The ability to contrast growth parameters was particularly hampered by regional differences in size distribution for this species.

Sea mullet caught from west and south coast marine and estuarine waters had larger L_∞ than sea mullet from New South Wales (males: 359 mm, females: 413 mm) (Smith and Deguara 2002). Female asymptotic growth values were larger than males in both WA and New South Wales. Similarly, L_∞ for female yellow-eye mullet was greater than for males; and south coast females and males obtained a greater L_∞ than on the west coast.

Lastly, the length at 50% maturity was calculated when possible, and compared to the current commercial and recreational LML regulations for both commercial and recreational fishers.

The comparison of the LML applicable to the commercial and recreational fisheries and the length at 50% maturity for each species, except yellow-finned whiting, suggests that the current LMLs are not protecting these finfish from capture prior to reproduction.

2.5 Summary

- A monthly program was undertaken to collect a representative sample of each of seven inshore species from the commercial fishery for age and growth determination. While the program was successful it was not possible to collect adequate samples of each species in every month.

- Traditional and novel approaches were taken to establish ageing techniques and marginal increment analysis for each species. In some cases the research developed collaborations with other Australian institutions, such as for tailor ageing with the Queensland Department of Primary Industry, while in other cases the research relied upon established procedures such as those for Australian herring (FRDC Report 96/105) and King George whiting.

- Information on the ages and lengths of individuals from each species were used to develop von Bertalanffy growth equation parameters, L_{∞}, the asymptotic length and *K*, the growth coefficient. The parameters will allow an analysis of the proportion of each age class within the fishery and a size at age key. This will be used in Chapter 5 of this report.

- Except for yellow-finned whiting, LML appears to be too low for the key inshore finfish species.

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CHAPTER 3.0 Factors affecting the abundance and distribution of recruits (0+) of seven inshore fish species from south-western Australia

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Objective 3. Determine the effect of spatial and temporal factors (e.g. geographic location, season, day time, lunar cycle, tidal cycle, temperature, salinity and wind) on the abundance of each species.
Objective 4. Determine the local depletion and recovery rate after intensive sampling for each species.

3.1 Introduction

This chapter examines (1) catches and catch rates of young-of- the-year (0^+ recruits) of the seven species under investigation so as to determine the spatial and temporal distribution of sampling that would optimise their catch. The potential for the sampling strategy and methods to bias the results is also investigated using intensive sampling over short time periods to (2) assess whether there is a lunar influence on catch rates, (3) compare day and night catch rates, and to (4) determine if the sampling causes a significant level of depletion sufficient to impact on the reliability of catch rate data from subsequent sampling in any one site.

3.2 Materials and Methods

Distribution and abundance – catches and catch rates

Sampling

Monthly sampling for 0^+ (and older juveniles) of the seven species was conducted at 7 sites along the west and south coasts of Western Australia: Pinnaroo Point (west), Mangles Bay (west), Warnbro (west), Koombana Bay (west), Quindalup (west), Emu Beach (south) and Poison Creek (south), between July 1999 and June 2002 (Figure 3.1). This sampling continued that undertaken in the previous three years, which was conducted as part of FRDC Project 96/105, giving a six-year data-set for most sites and species. In Project 96/105 a wider range of sites were sampled, with the best sites for the species investigated in this study chosen.

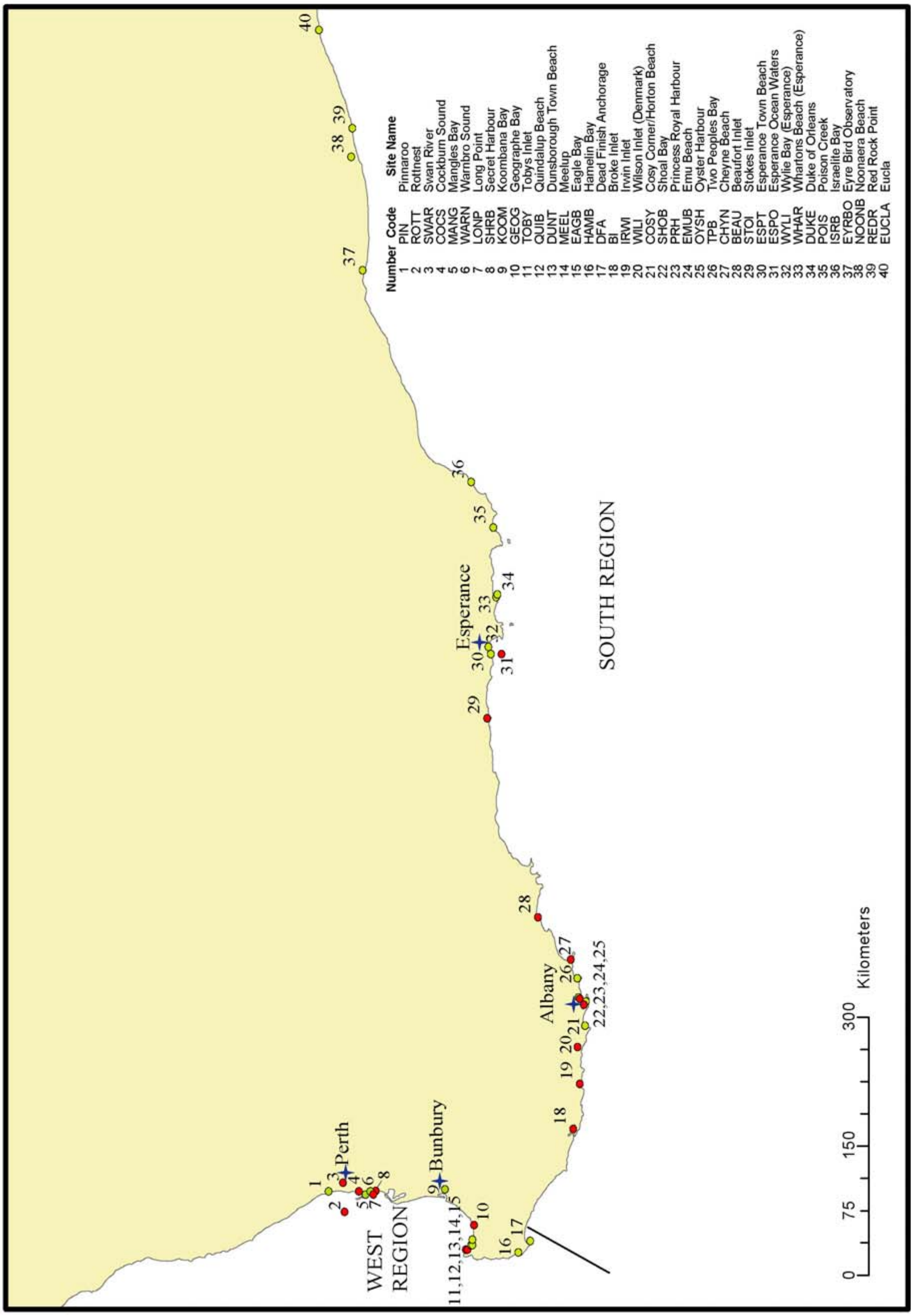


Figure 3.1. Sampling locations on the west and south coasts of Western Australia of recruit and adult fish of the seven species collected between July 1996 and June 2002. Green circles denote recruit sampling sites and red circles denote adult sampling sites.

The study area on each beach was divided into two blocks. Within each block was one fixed site and two or three random sites. The protocol involved sampling the fixed site and randomly choosing one of the random sites in each block. The second block was sampled in the same sequence, giving four seine hauls overall. Sampling times were standardised with the first haul starting three hours after sunrise and each of the subsequent three seine net hauls beginning at 45 minute intervals. A 61 m seine net was used with 29.1 m wings (22 mm mesh) and a 2.4 m bunt (8 mm mesh) that sampled to a depth of 2 metres. The seine net was deployed from a small dinghy and when set in this fashion swept an area of 592.2 m^2. All individuals from the seven key species were removed from the net and returned to the laboratory. Individuals from the seven species were counted and each fish measured (total length to the nearest mm) and weighed (to the nearest 0.01 g). Whenever possible each individual was sexed.

Data analysis

The annual recruitment index for each of the seven species is being described by the 0^+ catch rate. The 0^+ catch rate data describes the mean of the number of 0^+ fish of each species per seine haul across the selected sites and chosen time period. Only individuals below the upper length limit for 0^+ of each species, as determined from the von Bertalanffy models (Table 2.8), were used to estimate recruit abundance. Annual catch rates were calculated (i) by region (i.e. south coast; west coast) and (ii) by key sites and combinations of key sites for each species over (ii.a) all months of the 12 month periods and (ii.b) indicative subsets of the 12 month periods. For a given species, we defined a key site as a site comprising at least 1% of the total number of recruits.

To calculate the annual mean catch rate series for each species, the starting month of the 12 month period is selected by detecting an increase in recruit abundance following the seasonal low point of the year. There is no requirement for the annual catch rates to be normally distributed, however the Central Limit Theorem dictates this will generally be the case. For example, the calculation of the annual mean catch rates over 12 month periods with four hauls per month at a particular site generates 48 observations. Even if the distribution of these observations is heavily right-skewed, as is often the case, the distribution of the mean of these 48 observations will be more centralised.

Factors affecting catch rates

A regime of intensive beach-seine sampling was designed to ascertain if the sampling strategy produced biased results by affecting the abundance of fish, i.e. whether or not there was a lunar influence, if there was a difference between sampling at day or night, and any carry-over effects.

The lunar and tidal cycle experiment was conducted during February and March in both 2000 and 2001 at Pinnaroo Point (north of Perth) and Koombana Bay (near Bunbury). At each beach, the sampling regime included sampling every other day for the two month period, following the same seining methods as described under ‘Distribution and abundance – catches and catch rates’. The experimental design was the same as that described above with respect to division of the beach into blocks, with fixed sites and random sites. Sampling times were standardised with the first haul starting at 9:00 am each day for the two months and each of the subsequent three seine net hauls beginning at 45 minute intervals.

An experiment was designed to test the hypothesis that there are no differences in the abundance of the seven key species between day and night collections. The experimental design also allowed for a carry-over-effect analysis to examine whether repeated sampling has an effect on subsequent catches. A pilot trial of the day/night sampling was carried out in November and December 1998. The protocol consisted of two experiments of six consecutive days (one in each month) with sampling at Koombana Bay in Bunbury. The timing of the experiments was chosen so that it covered the days around the full moon of each month. During the 2000 sampling period, two sites were sampled, one at Mangles Bay (greater metropolitan area) and the other at Koombana Bay (Bunbury). The sampling protocol was extended to two periods of 8 days of sampling during November and December of 2000. One sampling period occurred around the time of the full moon and the other was at the time of the new moon.

For the 1998 experiment, on days 1, 2, 4, and 6, four day-time and four night-time seine net hauls were completed. On day 3, only four day-time samples were collected and day 5 was a 'no sampling' day. The beach was divided into two blocks, and in each block, one fixed site (F1 and F2 for blocks 1 and 2 respectively) and two or three random sites (R1, R2, R3 and R4, R5, R6 for blocks 1 and 2 respectively) were established. During the day, F1 was sampled first, followed by one of the randomly selected sites in block 1, then F2 was sampled and one of the randomly selected sites in block 2. During the night-time samples, one of the randomly selected sites in block 1 was sampled, followed by F1, and then one of the randomly selected sites in block 2 and finally F2. The day-time seine hauls occurred at half hourly intervals between 8:00 and 10:00 and the night seine hauls between 20:00 and 22:00 (Table 3.1).

Table 3.1. Experimental sampling design for day-night sampling of the seven key species in the 1998 experiment at Koombana Bay.

Time (hr)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
8:00-8:30	F1	F1	F1	F1		F1
8:30-9:00	R1, 2, 3	R1, 2, 3	R1, 2, 3	R1, 2, 3		R1, 2, 3
9:00-9:30	F2	F2	F2	F2		F2
9:30-10:00	R4, 5, 6	R4, 5, 6	R4, 5, 6	R4, 5, 6		R4, 5, 6
20:00-20:30	R1, 2, 3	R1, 2, 3		R1, 2, 3		R1, 2, 3
20:30-21:00	F1	F1		F1		F1
21:00-21:30	R4, 5, 6	R4, 5, 6		R4, 5, 6		R4, 5, 6
21:30-22:00	F2	F2		F2		F2

During the 2000 experiment, the experimental design with respect to day and night hauls was the same for the first six days of sampling. However, the experiment was extended by 2 days, with day 7 consisting of only the 4 night-time seine hauls and day 8 being sampled both for day and for night hauls. As for the 1998 experiment, four seine hauls were taken at half hourly intervals commencing at 8:00 (Day) and 20:00 (Night) (Table 3.2).

In this experiment, the beach was again divided into two blocks, and in each block, one fixed site (F1 and F2 for blocks 1 and 2 respectively) and two random sites (R1, R2 in block 1 and R3, R4 for block 2) were established. During the day, F1 was sampled first, followed by one of the randomly selected sites in block 1, then F2 was sampled and then one of the randomly selected sites in block 2. During the night-time hauls, F1 was sampled, followed by one of the randomly selected sites in block 1, then F2, and finally one of the randomly selected sites in block 2.

Table 3.2. Experimental sampling design for day-night sampling of the seven key species in the 2000 experiment at Mangles Bay and Koombana Bay.

Time (hr)	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
8:00-8:30	F1	F1	F1	F1		F1		F1
8:30-9:00	R1, 2	R1, 2	R1, 2	R1, 2		R1, 2		R1, 2
9:00-9:30	F2	F2	F2	F2		F2		F2
9:30-10:00	R3, 4	R3, 4	R3, 4	R3, 4		R3, 4		R3, 4
20:00-20:30	F1	F1		F1		F1	F1	F1
20:30-21:00	R1, 2	R1, 2		R1, 2		R1, 2	R1, 2	R1, 2
21:00-21:30	F2	F2		F2		F2	F2	F2
21:30-22:00	R3, 4	R3, 4		R3, 4		R3, 4	R3, 4	R3, 4

The abundance and distribution of the seven key species at each beach, and between day and night sampling periods was examined with the standard research seine net, as described above. All individuals of the seven key species were removed from the net and returned to the laboratory. Individuals of the seven species were counted and each fish measured (total length to the nearest mm) and weighed (to the nearest 0.01 g).

A suite of environmental variables was recorded for each seine net haul and lunar day was reported for the sampling day (Figure 3.2).

ENVIRONMENTAL SHEET

DATE	LOCATION	AREA	STATE	METHOD	NET
			WA	BS	61

SHOT NUMBER	**1**	**2**	**3**	**4**
SHOT CODE e.g. F# or R#				
TIME STARTED				

WATER TEMPERATURE				
SALINITY				
TURBIDITY (Secchi depth in metres)				
WATER DEPTH (in metres)				

WATER CONDITION (Beaufort Scale)				
WIND DIRECTION				
WIND STRENGTH (Beaufort Scale)				
CLOUD COVER e.g. 0=1-10%; 1=11-20%; 9=91-100%				
RAIN Nil (A); Light (B); Moderate (C); Heavy (D).				

TIDE (height in metres), and High (A); High rise (B); High fall (C); Low rise (D); Low Fall (E); Low(F).				
LUNAR CYCLE New Moon = day 1				

WEED VOLUME (Recorded in L)				
BROWNS (%)				
REDS (%)				
GREENS (%)				
SEAGRASS (%)				

Figure 3.2. The data sheet used during the beach seine sampling program to record environmental conditions.

Data analysis

The von Bertalanffy model for each species was used to estimate the upper length limit for each age class (Table 2.8) at the end of the 0^+ year; as such, individuals below this length were deemed to be 0^+ and hence only these fish were used to estimate recruit abundance.

The influence of the independent factors (i) sampling day, (ii) day versus night, (iii) site, (iv) F1 versus the other locations, (v) carry-over effects between seine net hauls, and a suite of measured environmental variables, on the abundance and distribution of the seven key species was assessed using analysis of variance. General linear models were used to select the model with the best combination of predictor variables. The selection method was a model reduction technique, commencing from the full model, and then iteratively eliminating the least significant variable or factor level, until the p-values of all variables or factor levels were ≤ 0.10. Independent consideration of every possible linearly independent factor level enabled higher explanatory power in the day-night model and reduced the non-homogeneity of some factor definitions.

The controls used in the model were

site = Koombana,

day/night = day,

day = 1,

Fixed/random = fixed sites,

location = fixed-site 1,

tide = high,

wind direction = W,

wind speed = 0,

rain = nil,

year = 1998,

rep = 1 and

water condition (Beaufort Scale) = 0.

3.3 Results

Distribution and abundance – catches and catch rates

Abundance of recruits

Abundance of the seven species at key sampling sites is shown in Figure 3.3a-g. For each species there was considerable variability in abundance over the study period.

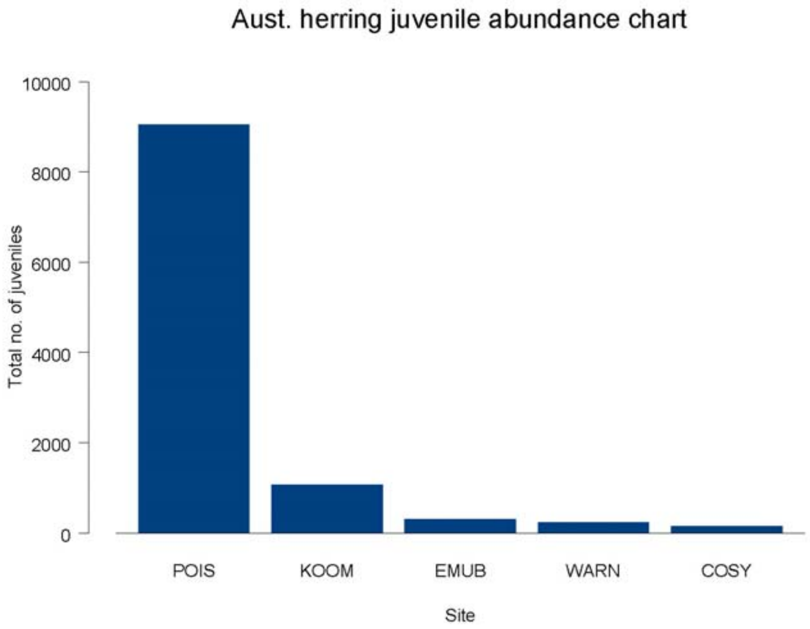
The abundance charts of the key sampling sites for the seven species highlights the distinct spatial distribution of most of the species (Figure 3.3a-g). Both the Australian herring and Australian salmon show a distinct preference for Poison Creek site on the south-east coastline of WA (Figure 3.3a and b). Recruits of both species were most abundant in a sheltered corner adjacent to a headland of this otherwise exposed south-eastern facing beach. The second site at which both species were abundant was Koombana Bay on the lower west coast. The remainder of the sites were not as numerically influential and represented a mix of west and south coast sites. Australian herring were only collected from five beaches during the sampling program, while Australian salmon were found at ten sites.

Tailor were most abundant at two west coast north-west facing beaches, Koombana Bay on the lower west coast and Pinnaroo Point, north of Perth. The remainder of the sites contributed few tailor (Figure 3.3c).

King George and yellow-finned whiting recruits were collected almost exclusively at Mangles Bay, a very sheltered embayment just south of Perth (Figure 3.3d and e). King George whiting recruits were collected at four west coast sites only. Similarly, yellow-finned whiting were collected from five west coast sites (Figure 3.3e).

Sea mullet were collected at five sites during the sampling program. Fish were most abundant at Mangles Bay followed by Koombana Bay and Emu Beach, near Albany (Figure 3.3f). Yellow-eye mullet were more ubiquitous across sampling sites than its congener the sea mullet, being abundant on both west and south coast beaches (Figure 3.3g).

(a)



(b)

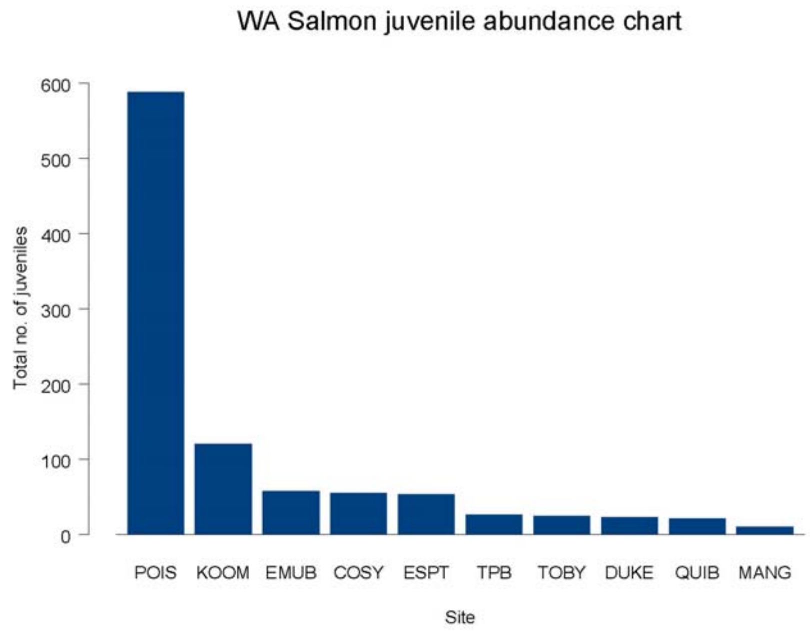
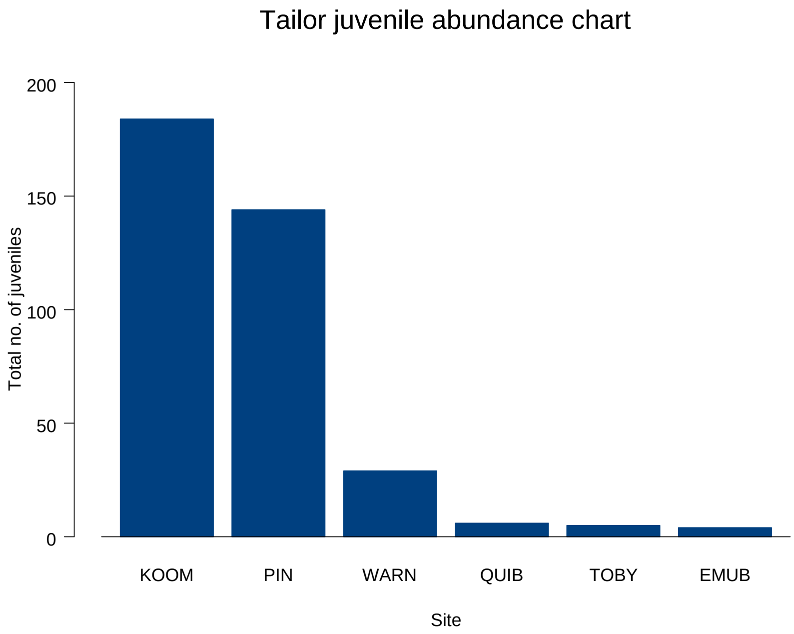


Figure 3.3a-g. cont.

c)



(d)

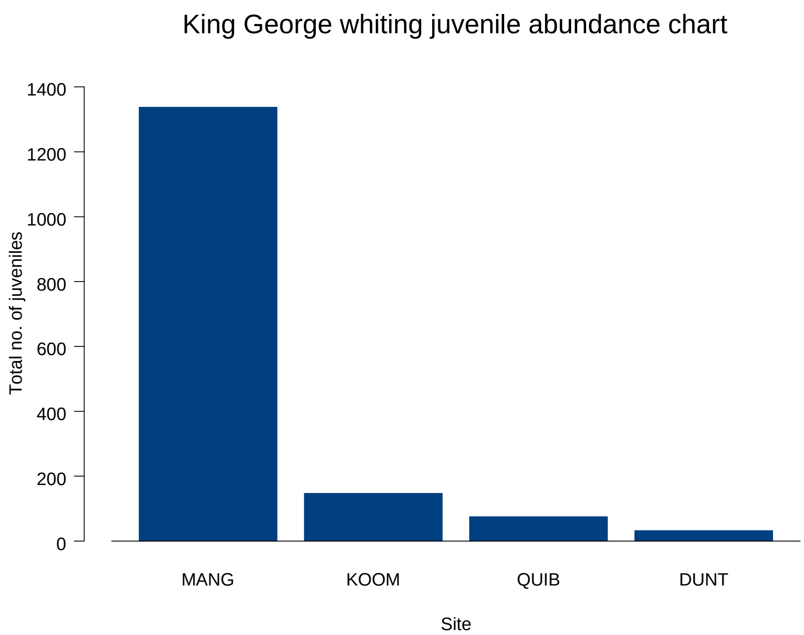
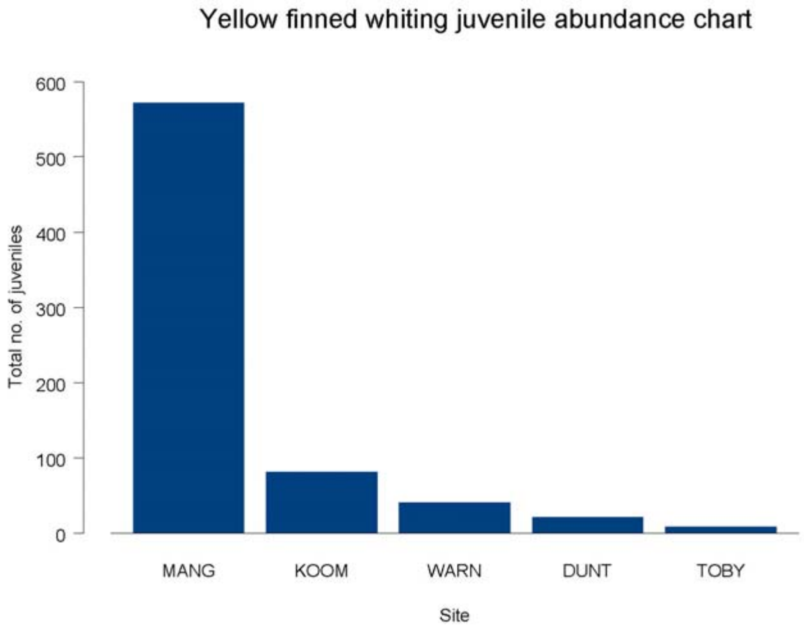


Figure 3.3a-g. cont.

(e)



(f)

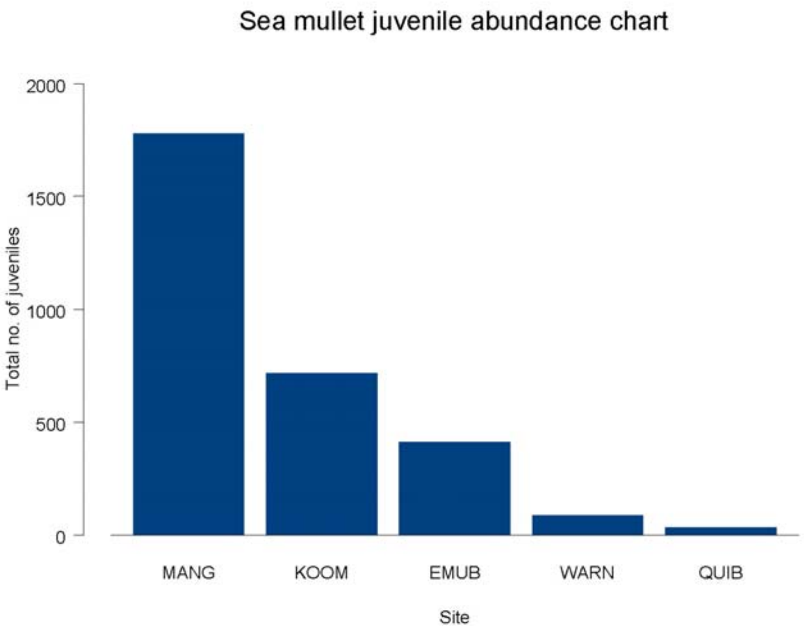


Figure 3.3a-g. cont

(g)

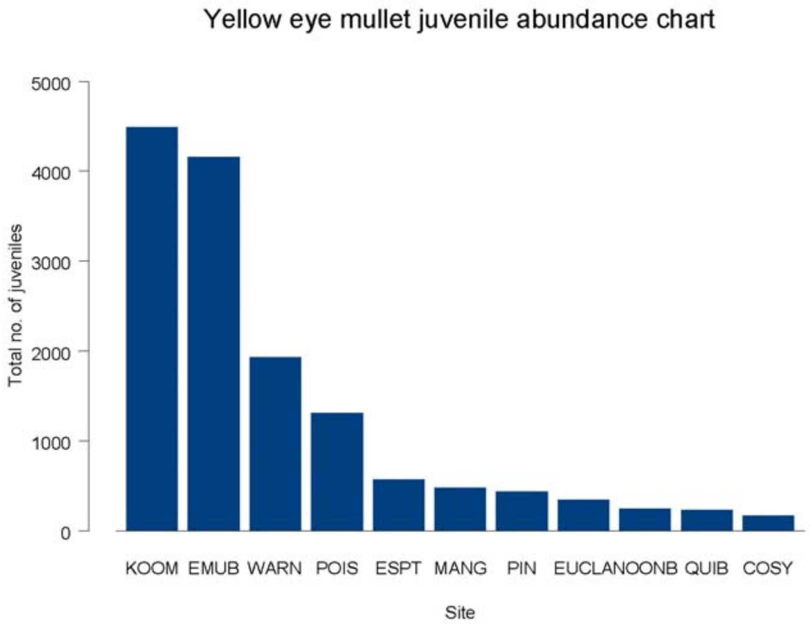


Figure 3.3a-g. Total numbers of seven species of fish caught from sites on the west and south coasts of Western Australia. Only sites which accounted for >1% of the total catch are shown. The sites are ordered by abundance and not by geographic location.

Catch rates of recruits: Selection of the recruiting season

Australian herring 0^+ catch rates were consistently higher from south coast beaches than the west coast. The mean catch rate across years shows the commencement month of the recruitment season to be September and the main recruitment period was September to March (Figure 3.4a).

The 0^+ catch rates for Australian salmon start to increase from annual lows in July both along the south and west coasts, so the commencement month of the recruitment season was set to July. The main recruitment period was July through to November for both the south and west coasts (Figure 3.4b).

It is difficult to detect a distinct seasonal pattern in tailor recruitment along the lower west and south coasts (Figure 3.4c). The catch rates of the 0^+ age class along the south coasts were too low to be considered for further analysis. The west coast graph illustrates that the peak recruitment period on the west coast was December with high values in the autumn and spring; however recruits appear to be abundant along the west coast most of the year.

Recruitment data for King George whiting and yellow-finned whiting were available on the west coast only (Figures 3.4d and e). These graphs show that the recruitment season for King George whiting was from October to April. The recruitment season for yellow-finned whiting was less well defined with some levels of recruitment for most of the year; although recruitment was low in November and December, the spawning season was set as September to February.

The main recruitment season for sea mullet for the south coast was May to October, with a peak from August to September (Figure 3.4f). Recruitment on the west coast lasted from June to November, but with recruits collected through to February.

Yellow-eye mullet 0^+ occurred all-year round (Figure 3.4g). There was an increase in abundance starting from June along the south coast, but not until October along the west coast. The recruitment seasons extended through to December in the south and to March in the west.

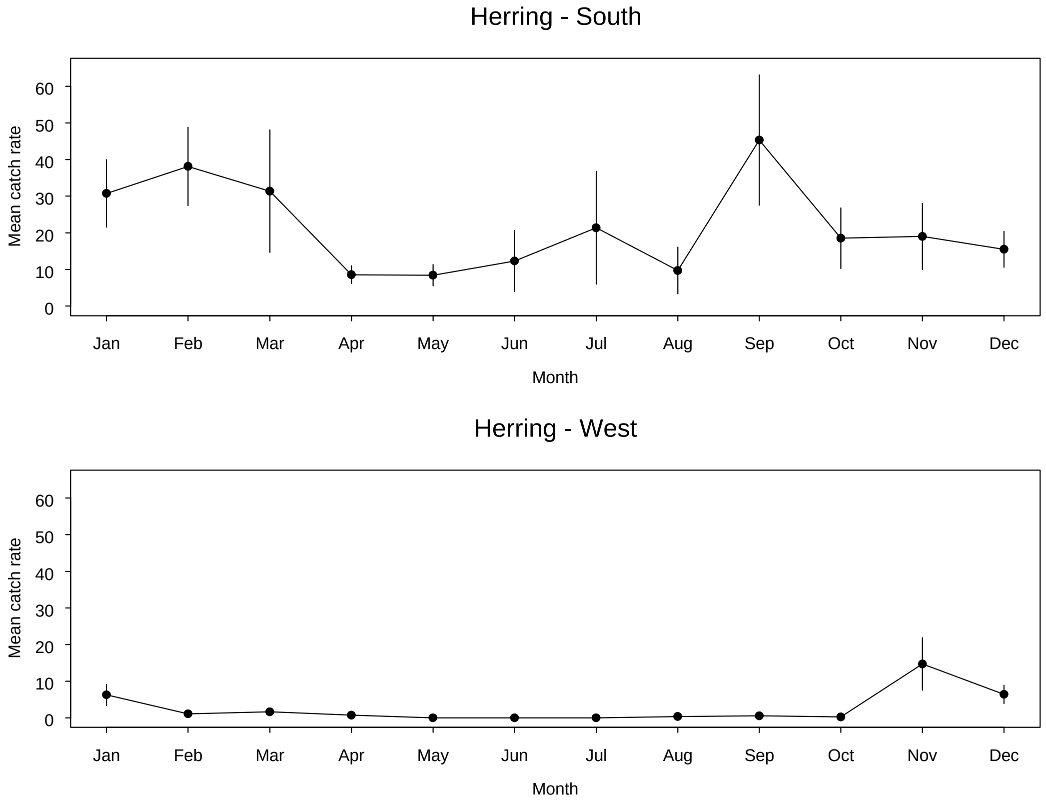


Figure 3.4a. Mean monthly (± 1 std deviation) 0^+ catch rate for Australian herring from the south and west regions of WA between June 1999 and June 2002.

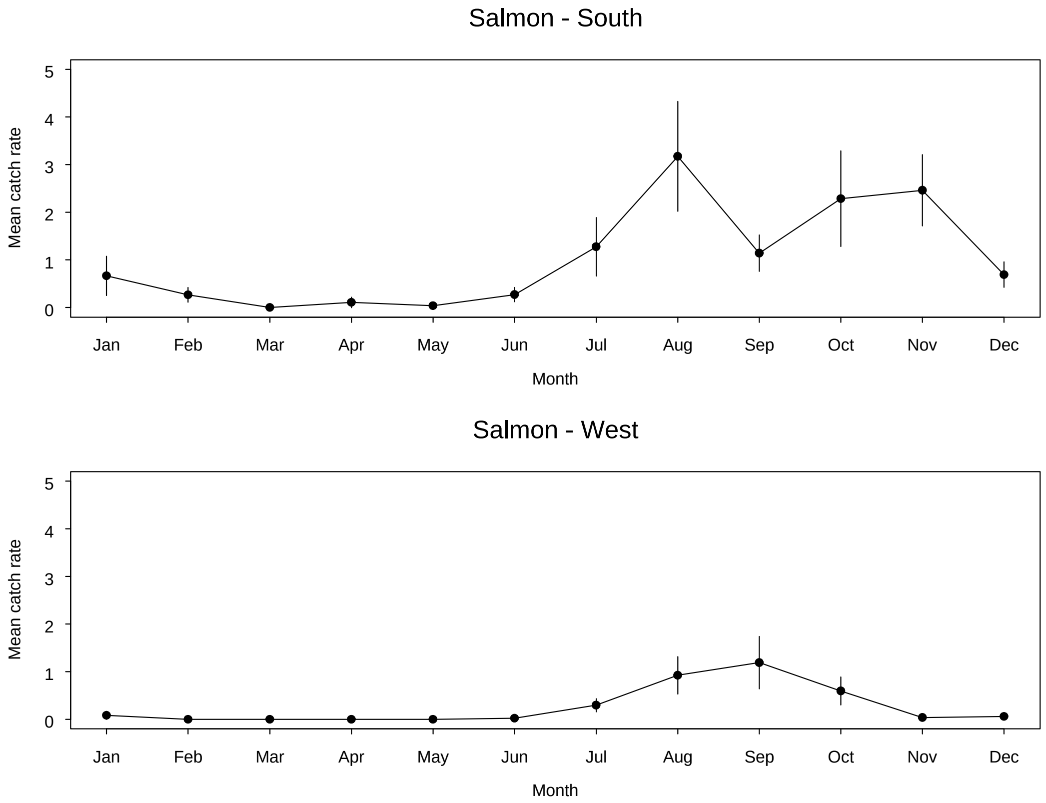


Figure 3.4b. Mean monthly (± 1 std deviation) 0^+ catch rate for Australian salmon from the south and west regions of WA between June 1999 and June 2002.

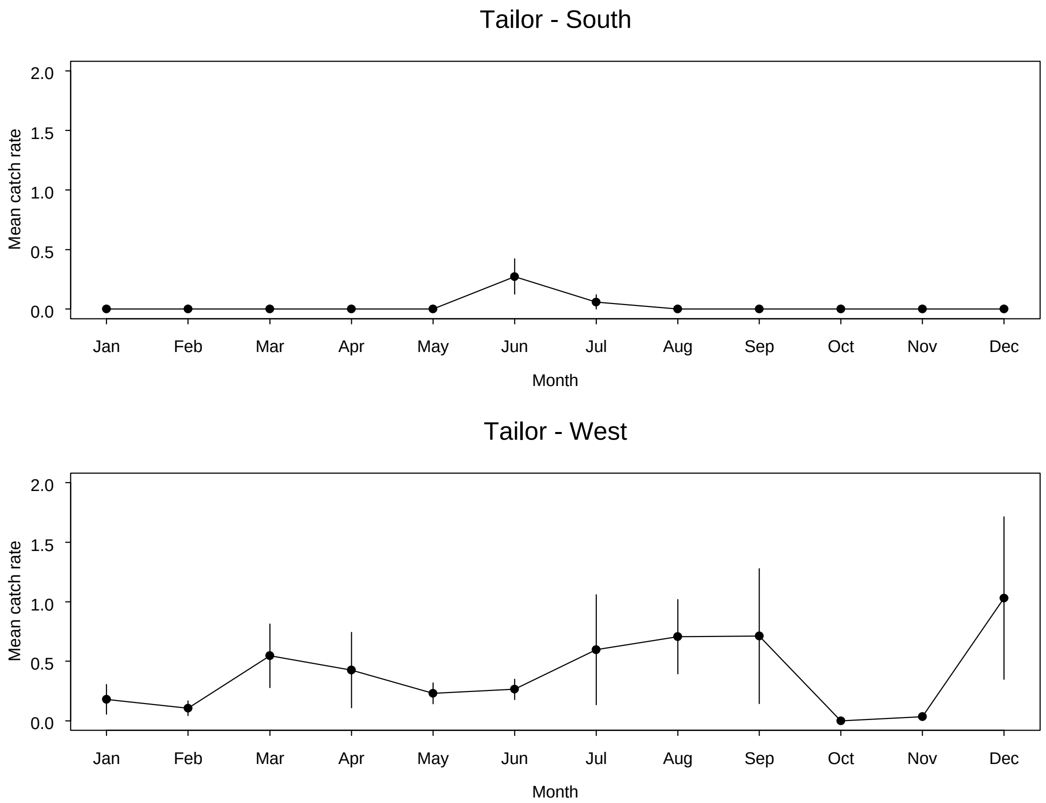


Figure 3.4c. Mean monthly (+ 1 std deviation) 0^+ catch rate for tailor from the south and west regions of WA between June 1999 and June 2002.

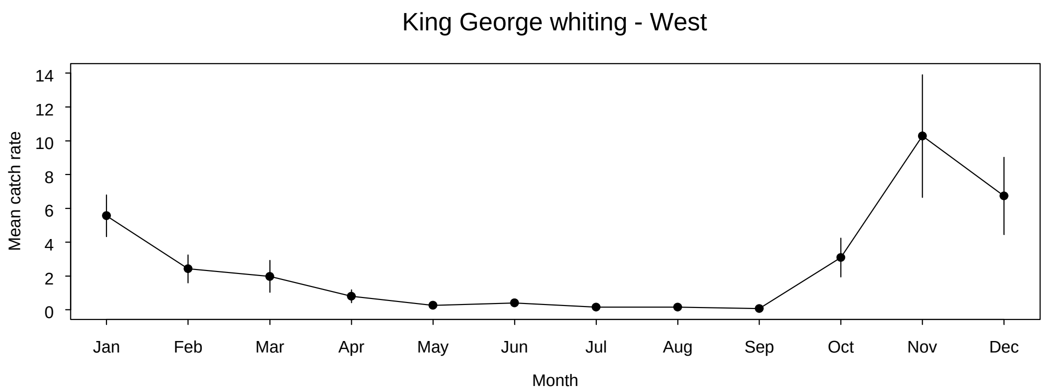


Figure 3.4d. Mean monthly (+ 1 std deviation) 0^+ catch rate for King George whiting from the west region of WA between June 1999 and June 2002.

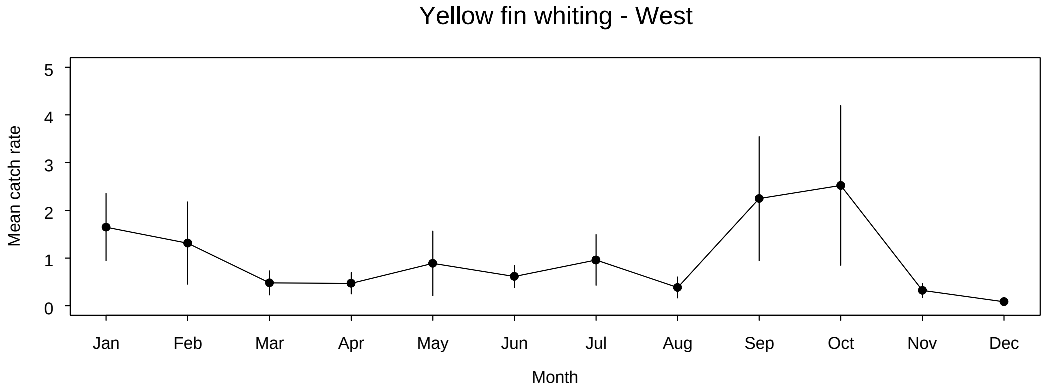


Figure 3.4e. Mean monthly (+ 1 std deviation) 0^+ catch rate for yellow-finned whiting from the west region of WA between June 1999 and June 2002.

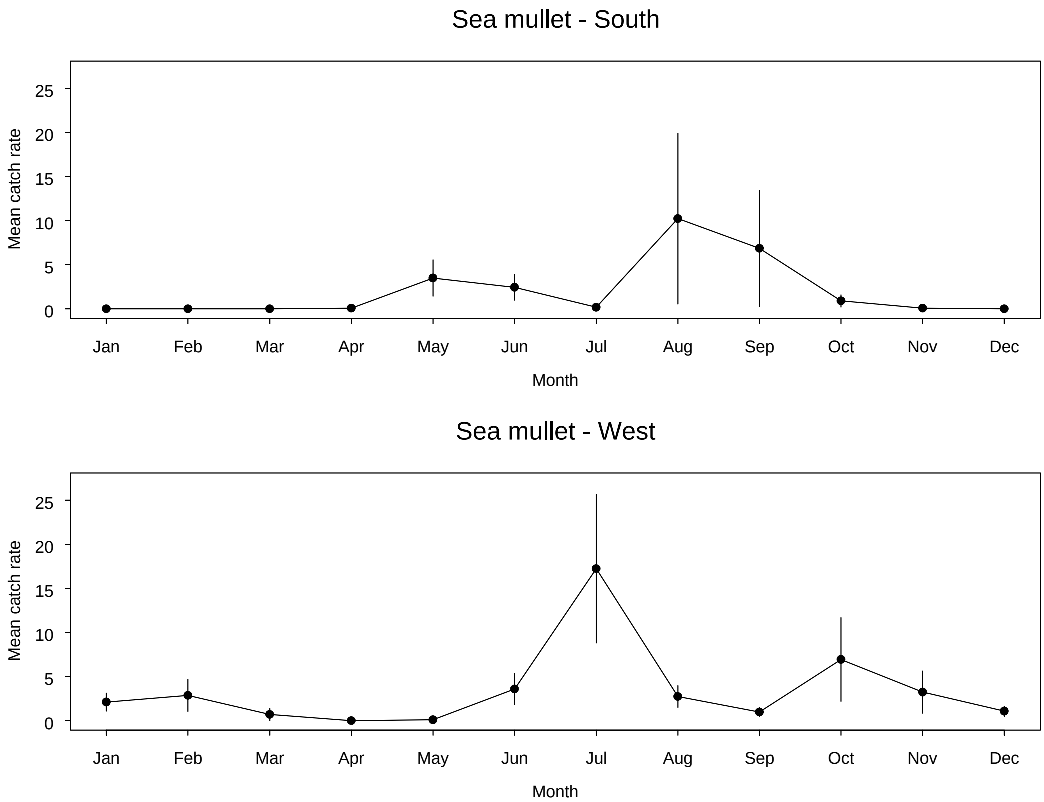


Figure 3.4f. Mean monthly (+ 1 std deviation) 0^+ catch rate for sea mullet from the south and west regions of WA between June 1999 and June 2002.

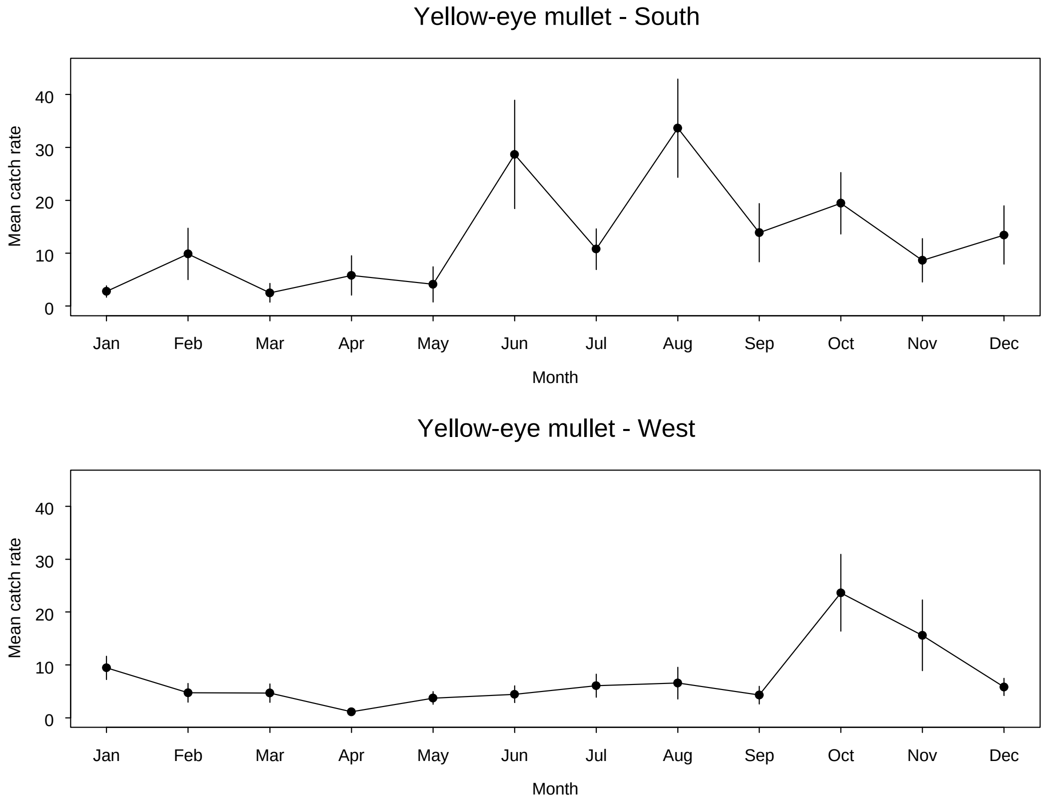


Figure 3.4g. Mean monthly (± 1 std deviation) 0^+ catch rate for yellow-eye mullet from the south and west regions of WA between June 1999 and June 2002.

Annual Catch Rates

Line plots of annual recruit catch by region are presented for each of the seven species (Figure 3.5a-g). They are defined by year-round catches taken from respective commencement of recruitment month(s). The triangular points joined by dotted lines represent the mean annual catch rates of all key sites that comprise >1% of the total annual recruitment. These plots used all the available data: the full line represents mean annual catch rates calculated over the sites that were sampled consistently over the six years, noting that some sites were sampled for shorter periods. Thus, Esperance, Eucla, Noonera Bay, Cosy Corner, Toby Inlet, Dunsborough Town Beach, Two Peoples Bay and Duke of Orleans Bay were sampled at most during the first 3 years (1996-1999 as a part of FRDC project 96/105), Mangles Bay was sampled through the latter 2 ½ years only, Quindalup Beach was sampled over the last 5 years, while other sites (viz. Poison Creek, Emu Beach, Koombana Bay, Warnbro Sound, Pinnaroo Point) maintained indices over the 6 year period.

Australian herring catch rates were highest during 1996/97 for the south coast and then gradually declined to a mean catch rate of 10 fish in 2001/02. Along the west coast the peak catch was in 1997/98 with a subsequent decline in 1999/2000. The low mean catch rate of approximately 2 recruit Australian herring remained stable during the three years of the study (Figure 3.5a).

The annual mean catch rates for Australian salmon from sites along the south and west coasts showed a similar pattern, however the absolute number of fish collected was greater at south coast sites (Figure 3.5b). There was an increase in the mean annual catch rate between

1996/97, peaking in 1998/99 then declining to the lowest values reported during the time period in 1999/2000. The annual mean catch rate remained stable between 1999/2000 and 2001/02 on the south coast and increased in 2001/02 on the west coast.

The annual mean catch rates for tailor along south coast sites during this time period were insignificant (Figure 3.5c). Along the west coast, while the catches were low in most years, the mean catch rate rose to over 1 fish during 1998/99 (Figure 3.5c). Subsequently, the catch rate declined over the next three years to the lowest value during 2001/2002.

The King George whiting annual mean catch rates for the west coast peaked in 1999/2000, followed by a decline to pre-1999 levels. The annual mean catch rate from the key sites (dotted line) shows the same peak in 1999/2000 as for all sites, however the decline is not as marked as for all sites (Figure 3.5d). Similarly, yellow-finned whiting recruit annual mean catch rates peaked during 1997/98 followed by a decline in 1998/99 (Figure 3.5e). The all-sites mean catch rate remained low for the remaining period while the key sites demonstrated an increase in the mean catch rate.

Unlike the annual mean catch rates for the previous species, the sea mullet catch rates between the south and west coasts demonstrated different catch histories (Figure 3.5f). The south coast sites showed a high catch rate in 1996/97, followed by a decline in 1997/98, and a rise in 1998/99 before sustained low recruitment from 1999/2000 to 2001/2002. Along south coast sites, recruitment was low in 1996/97 and 1998/99 and peaked in 2000/01.

Yellow-eye mullet were always present in the catches from both regions (Figure 3.5g). Along the south coast there is good agreement between the all-sites and key-sites results, except in 1998/99 where all-sites produced a lower mean annual catch rate. The peak catches for both indices occurred during 1999/2000. There was good agreement between all sites and the key sites for the west coast for all years. The catch rates are similar between the south and west coast sites except for 1998/99 and 1999/2000 when the south coast catch rate increased and the west coast catch rate decreased.

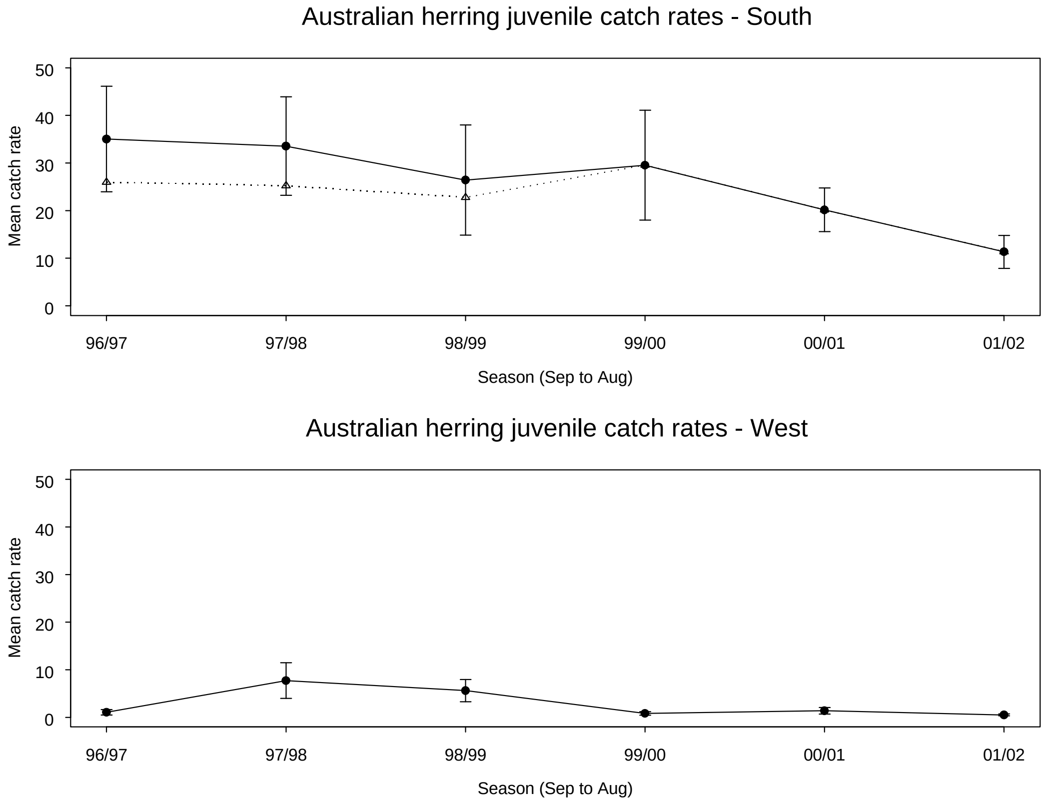


Figure 3.5a. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ Australian herring from the south and west regions of WA between June 1999 and June 2002.

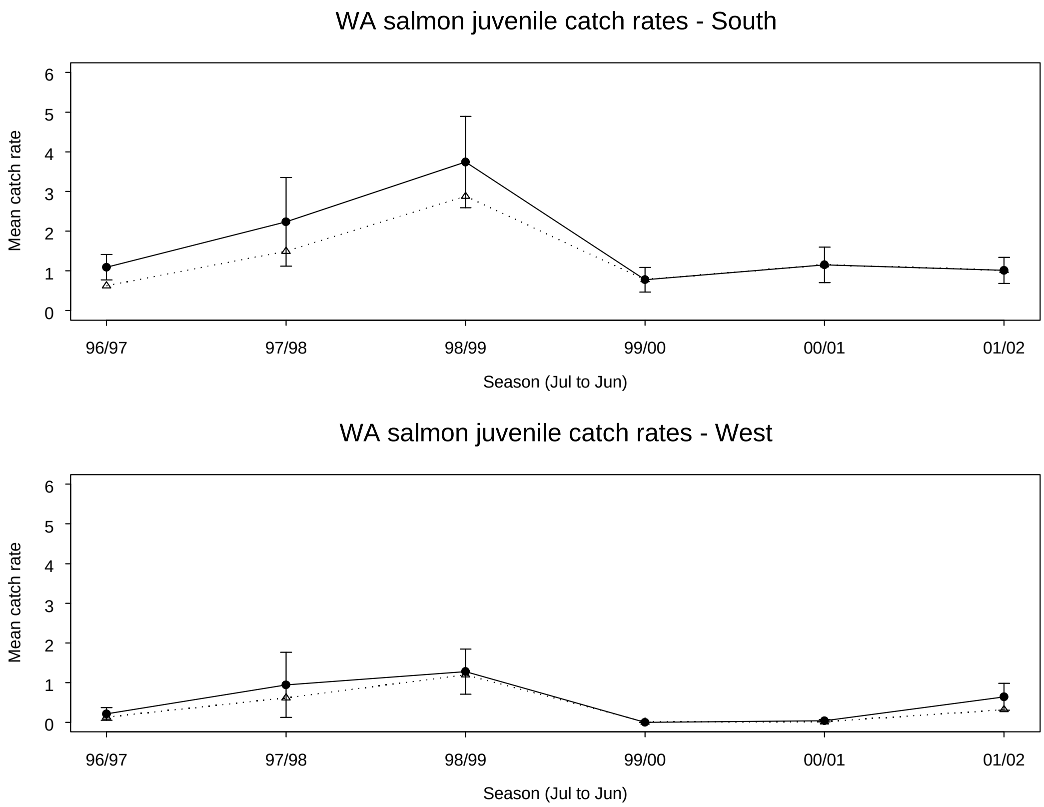


Figure 3.5b. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ Australian salmon from the south and west regions of WA between June 1999 and June 2002.

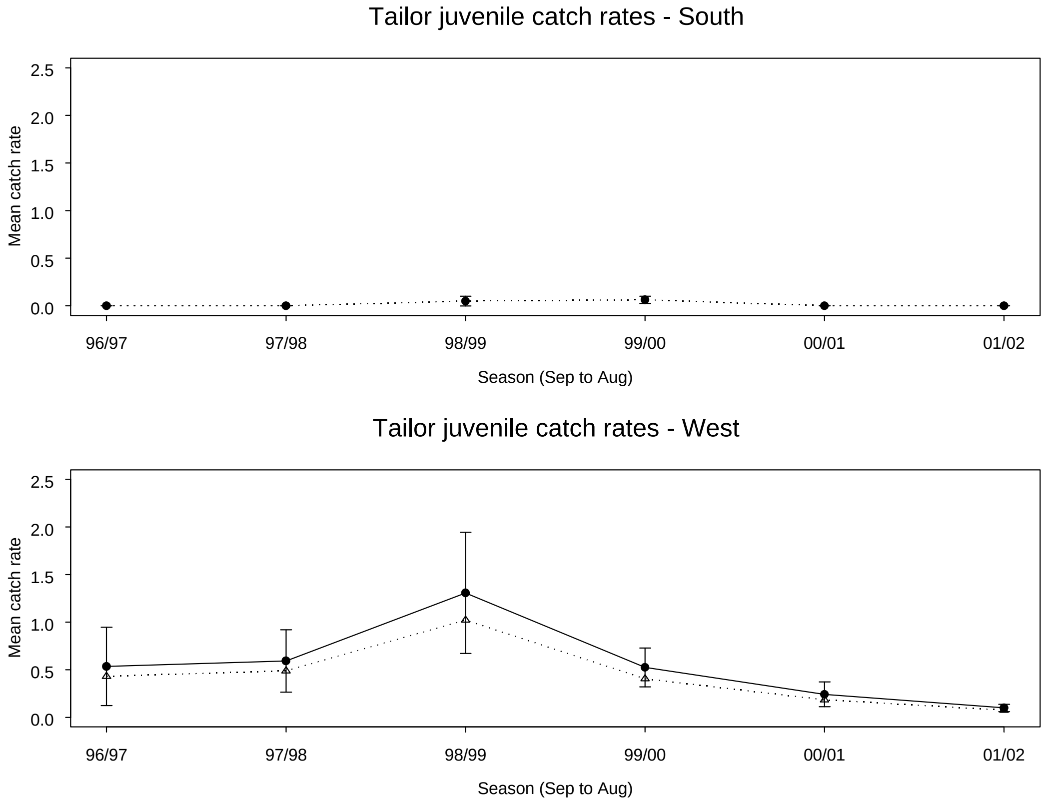


Figure 3.5c. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ tailor from the south and west regions of WA between June 1999 and June 2002.

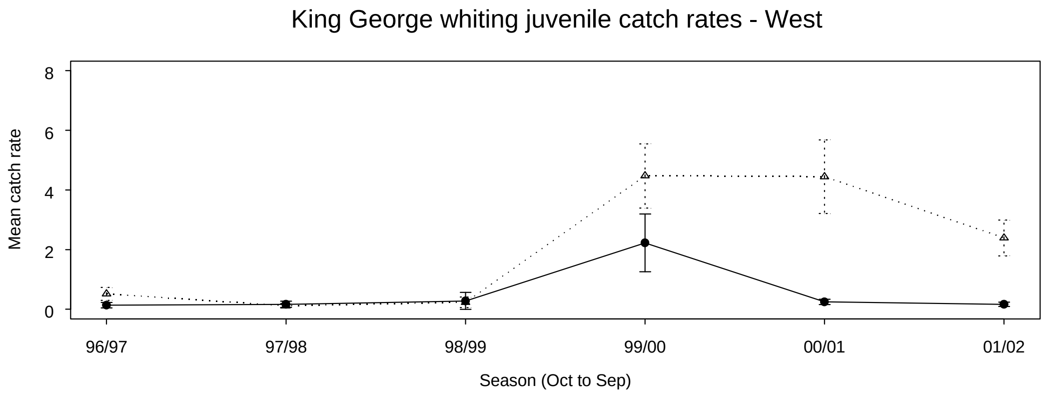


Figure 3.5d. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ King George whiting from the west region of WA between June 1999 and June 2002.

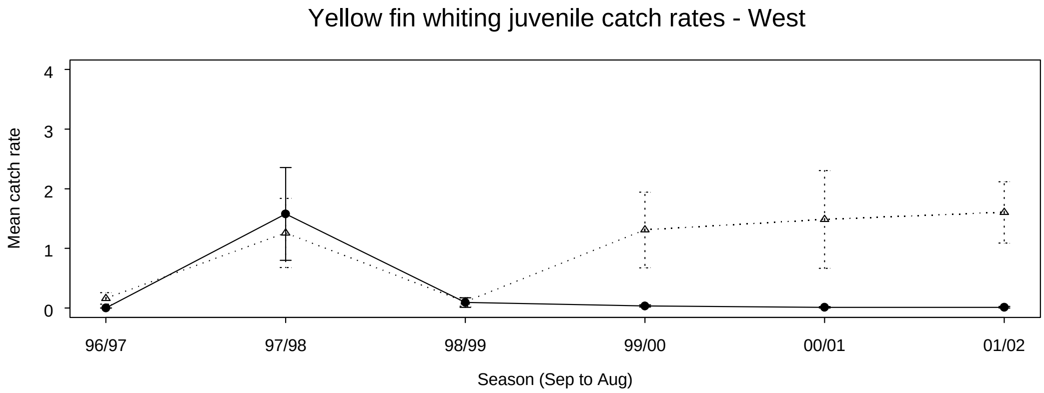


Figure 3.5e. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ yellow-finned whiting from the west region of WA between June 1999 and June 2002.

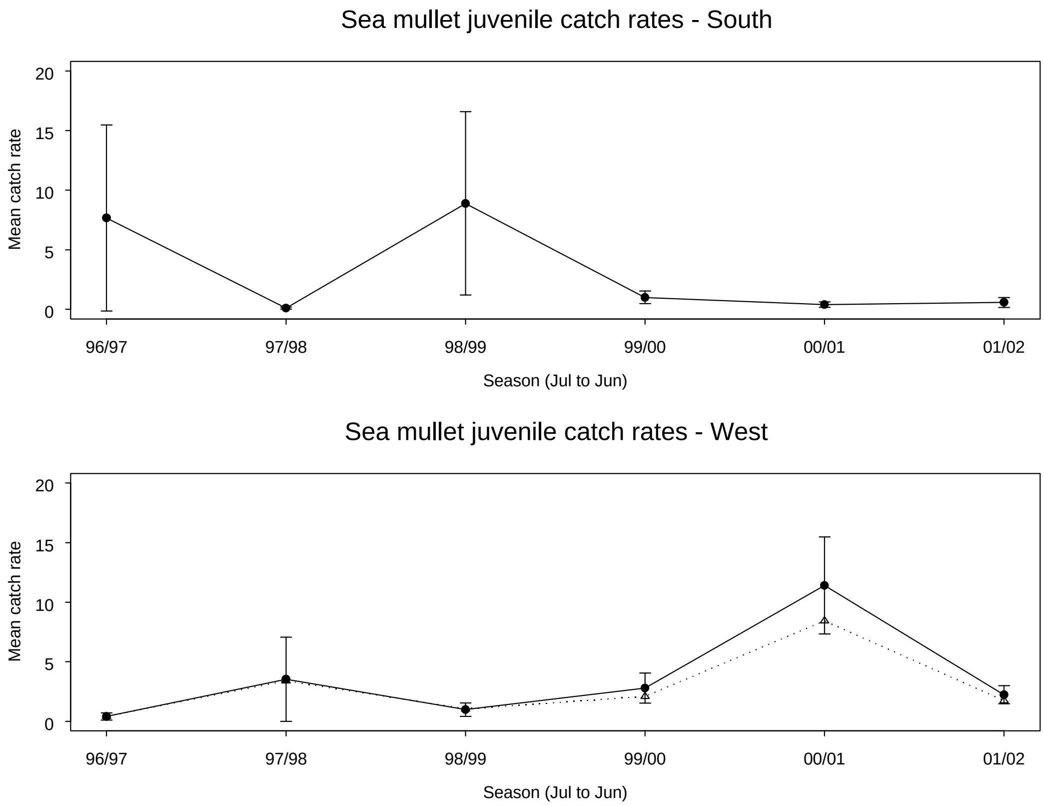


Figure 3.5f. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ sea mullet from the south and west regions of WA between June 1999 and June 2002.

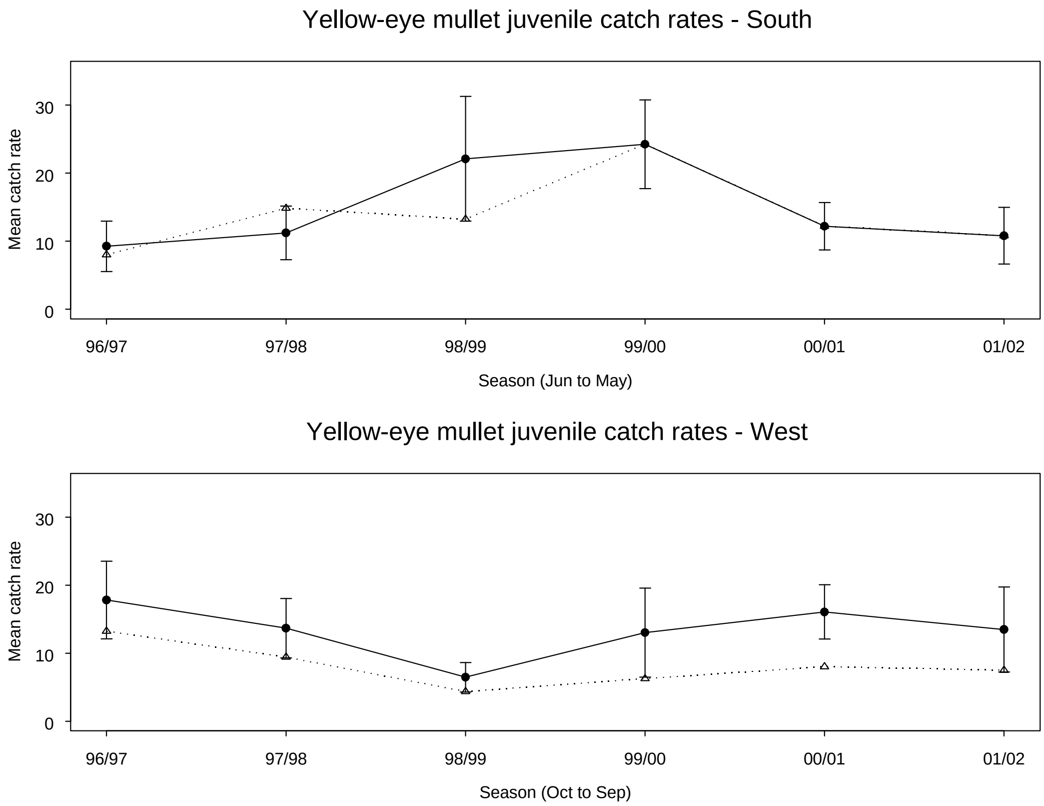


Figure 3.5g. Annual mean catch rate (number of fish caught per seine net haul) for 0^+ yellow-eye mullet from the south and west regions of WA between June 1999 and June 2002.

Lunar cycle with carry-over effects

At Pinnaroo Point, a north-westerly facing sandy beach, four of the seven key species were caught: tailor, yellow-finned whiting, sea mullet and yellow-eye mullet. Koombana Bay, a north-westerly facing embayment in Bunbury is a more protected site than Pinnaroo Point. Six of the seven key species were captured at this location during February and March: Australian herring, tailor, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet. The total abundance of the key species was more variable at Pinnaroo Point than in Koombana Bay (Figure 3.6a). Both locations showed a greater total abundance of key species following the full moon in February and March (Figure 3.6b-g). No salmon were caught during this sampling.

Preliminary correlation analyses between catches of each species versus water temperature, salinity, turbidity, water condition, wind strength and direction showed very little evidence to suggest that the catches were significantly affected by any of the measured environmental variables. To avoid model overfit (i.e. to simplify the model), it was decided that as well as the experimental-design factors (e.g. site, location, month), the general linear model would include only factors which were thought to be directly related to lunar phase. The variables considered in the reduced general linear model were (i) site, (ii) fixed-site one (iii) year, (iv) month, (v - viii) lunar phase (the four quarters with centres at new, full, first and last quarters), (ix) 1st haul, (x) haul carry-over, (xi) day carryover, (xii - xiii) tide and (xiv) depth effects. The results from this analysis are shown in Table 3.3.

Site effect: Catches of tailor were marginally higher in Pinnaroo Point than in Koombana Bay (Figure 3.6c).

Location (fixed-site 1) effect: While much of the sampling beach in Koombana Bay is homogenous, fixed-site 1 is positioned next to a rocky groyne which extends approximately 50 m to sea. This structure provides shelter for recruit fishes. There was significantly higher catches of Australian herring and King George whiting from fixed-site 1 at Koombana Bay than from the three other sampling locations.

Year effect: Catches of King George whiting and yellow-finned whiting were greater in 2000 than in 2001. (Figure 3.6d, e)

Month: Catches of each species were similar during February and March.

Lunar cycle effect: The lunar cycle results need to be interpreted in the appropriate context: sampling did not occur at night hence the impact of the lunar cycle phase may reflect tidal height differences rather than night-time illumination. Additionally, the power of the statistical analyses is low due to the sparseness of some species and the high variability of catches of other species. Catches of yellow-finned whiting peaked during the first quarter of the lunar phase (Figure 3.6e).

1st haul effect: The first seine haul catch of Australian herring produced a significantly greater number of fish than the other three hauls. The first seine haul was located in fixed-site 1 at both Koombana Bay and Pinnaroo Point.

Haul carry-over effect: There was a positive haul carry-over effect for Australian herring.

Day-to-day carry-over effect: There was a positive day-to-day carry-over correlation for King George whiting and tailor.

Tide effect: Catches of Australian herring and yellow-eye mullet were significantly higher during a low rising tide.

Depth effect: Catches of King George whiting and yellow-finned whiting were marginally higher from shallower waters.

Table 3.3. Statistically significant relationships between the abundance of each of the six species and a suite of variables from the lunar-cycle effects experiment as described in the text. The number indicates the magnitude (number per haul) of the effect, e.g. there were on average 1.02 more tailor per haul at Pinnaroo Point than at Koombana. Numbers in brackets are standard errors standard errors of the effects. (***, p<0.001; **, p<0.05; *, p<0.1).

FACTORS	SPECIES					
	Herring (KOOM only)	**Tailor**	**King George whiting (KOOM only)**	**Yellow-finned whiting**	**Sea mullet**	**Yellow-eye mullet**
Model Intercept	5.73*** (1.15)	1.18** (0.61)	22.57** (7.88)	0.15** (0.06)		6.65*** (1.22)
i. Site	N/A	1.02* (0.61)	N/A			
ii. Loc = F1 (Koombana)	2.28*** (0.48)		4.59*** (1.07)			
iii. Year			– 5.10 *** (0.94)	– 0.02 ** (0.01)		
iv. Month						
v. Lunar (full)						
vi. Lunar (3rd qtr)						
vii. Lunar (new)						
viii. Lunar (1st qtr)				0.03** (0.01)		
ix. 1st haul effect	2.97** (1.19)					
x. Haul carryover	0.09** (0.03)					
xi. Day carryover		0.40*** (0.04)	0.14** (0.06)			
xii. Tide (high rise)						
xiii. Tide (low rise)	1.19** (0.51)					3.14** (1.22)
xiv. Water depth			– 7.38 * (3.98)	– 0.06 ** (0.03)		

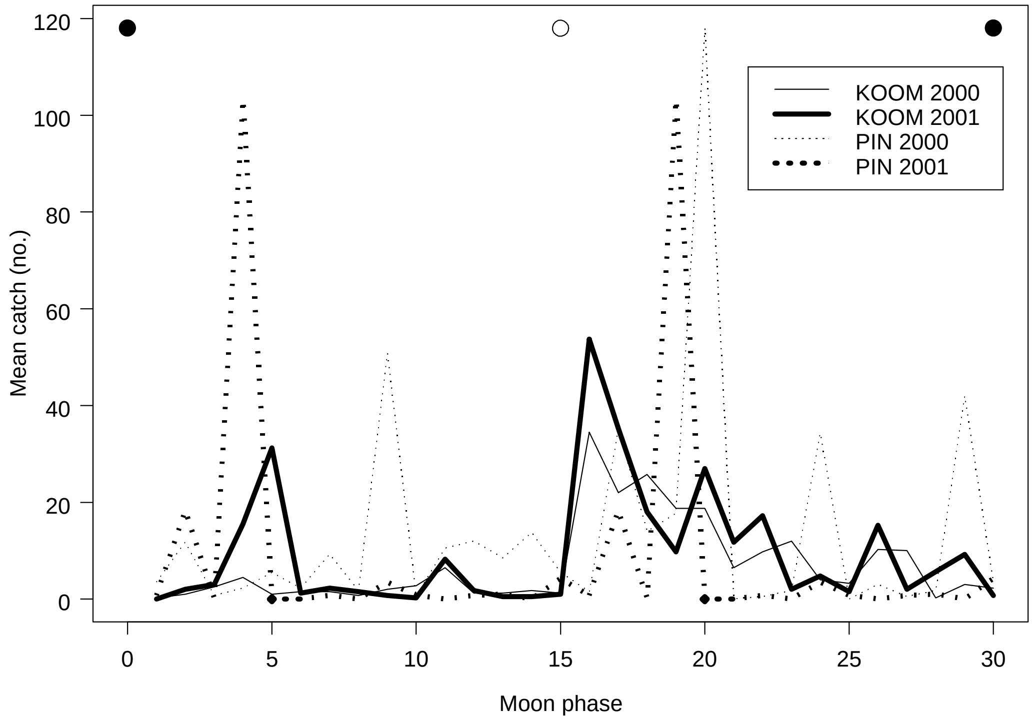


Figure 3.6a. Catch of total finfish relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

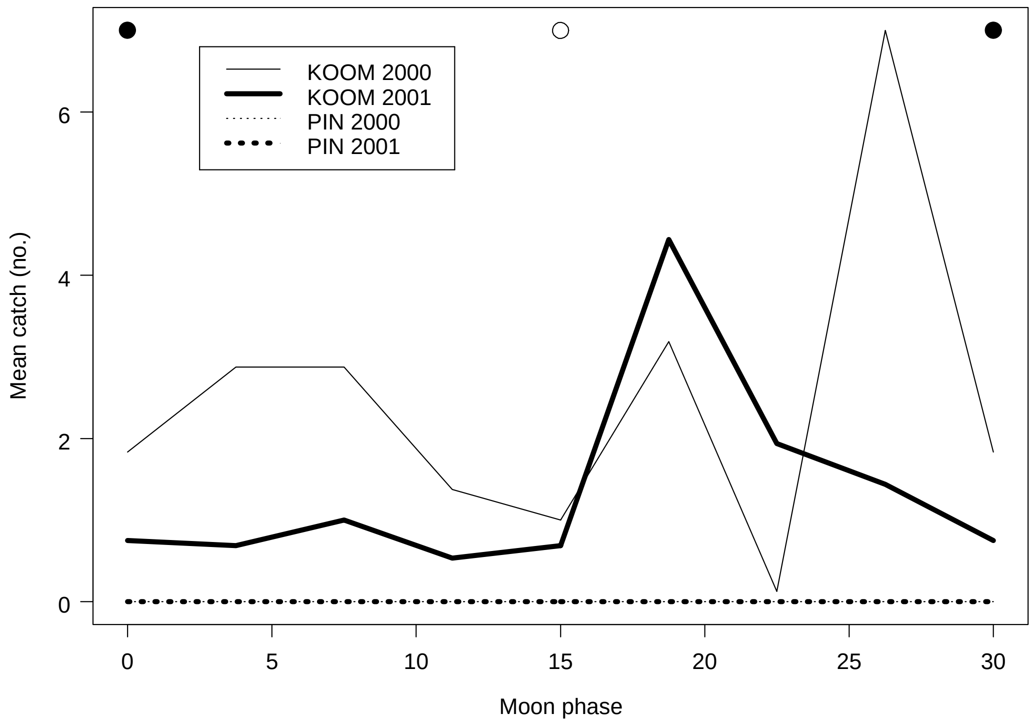


Figure 3.6b. Catch of Australian herring relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

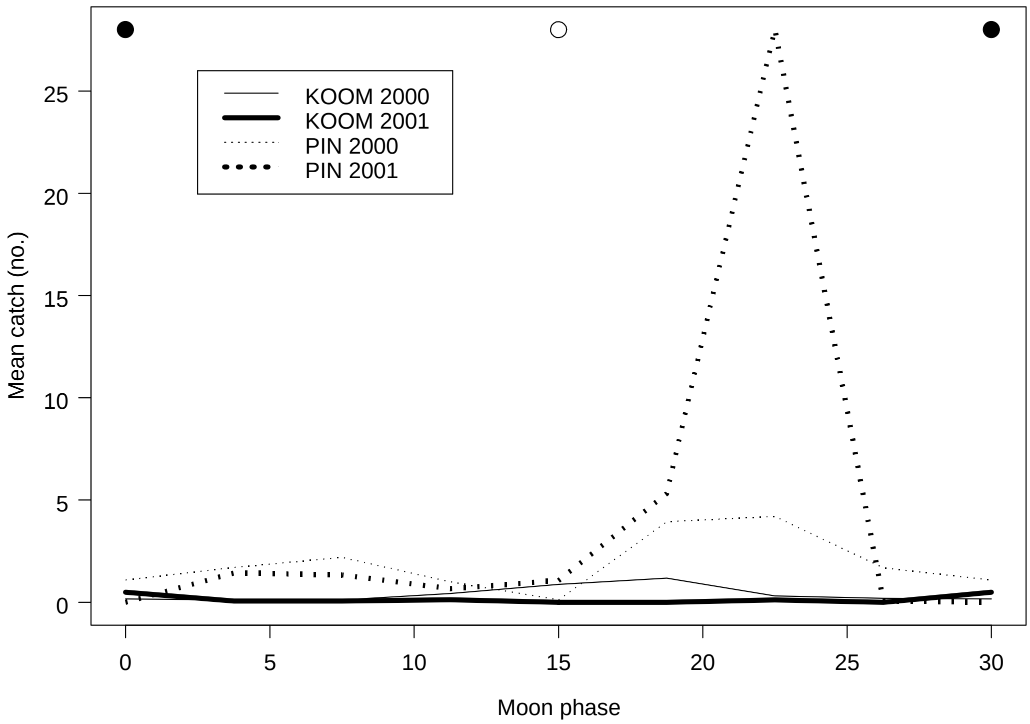


Figure 3.6c. Catch of tailor relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

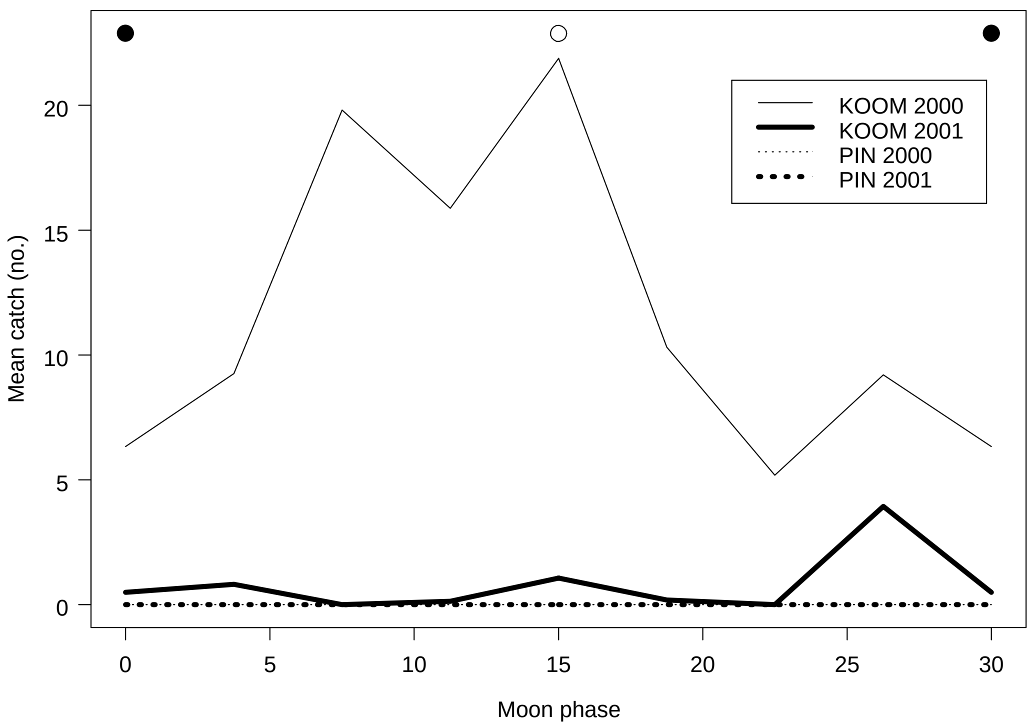


Figure 3.6d. Catch of King George whiting relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

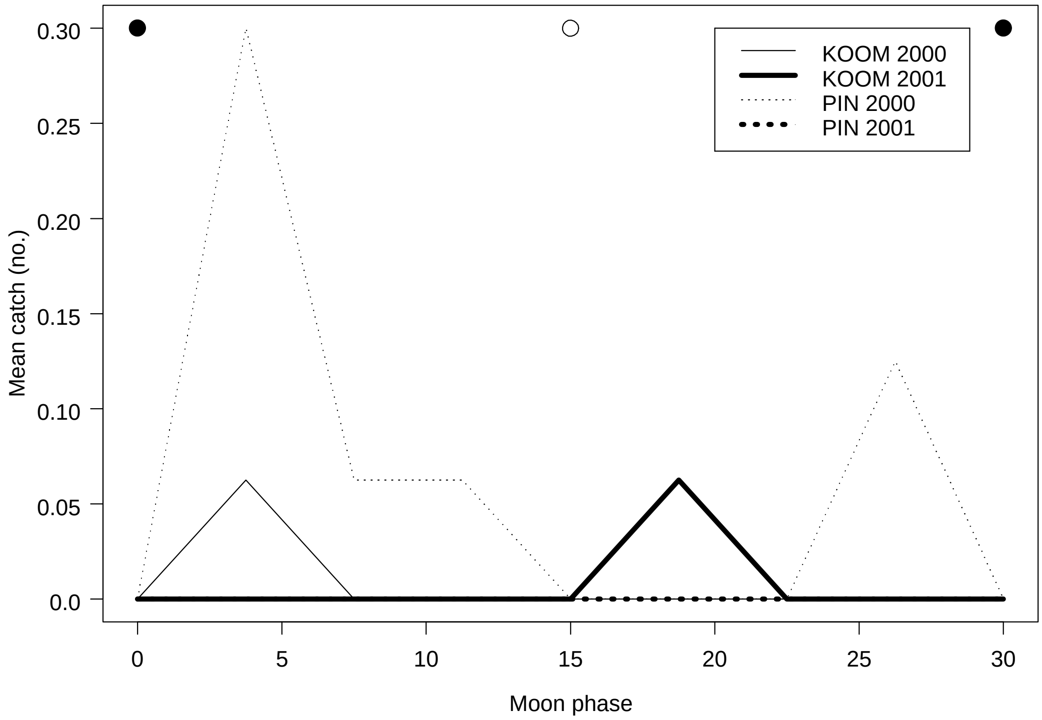


Figure 3.6e. Catch of yellow-finned whiting relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

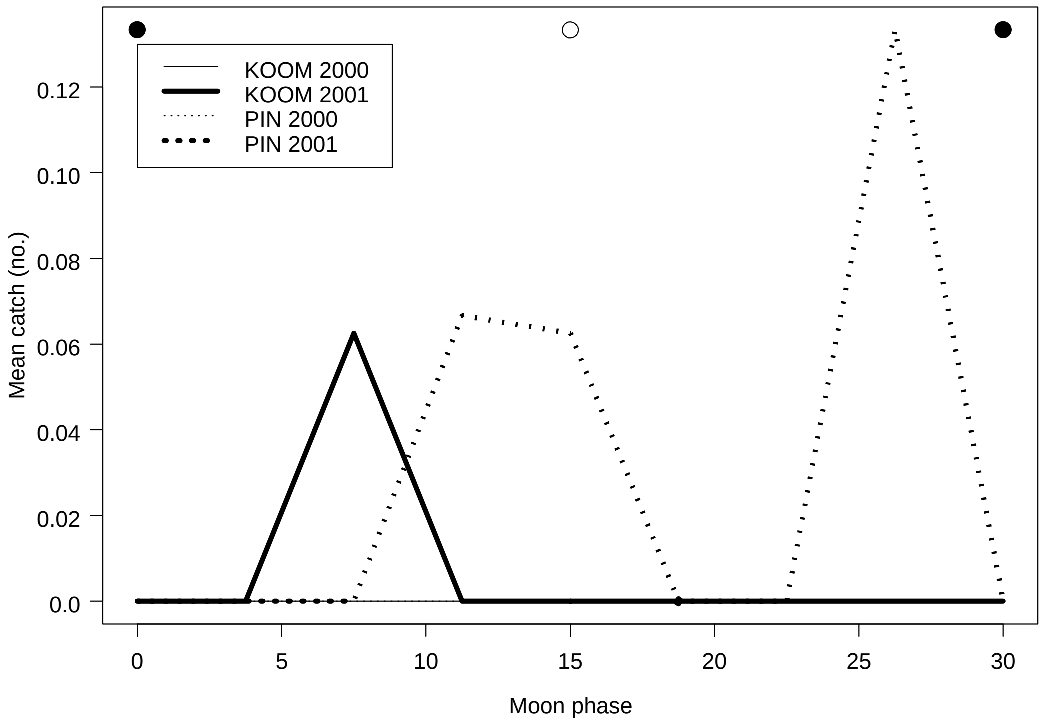


Figure 3.6f. Catch of sea mullet relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

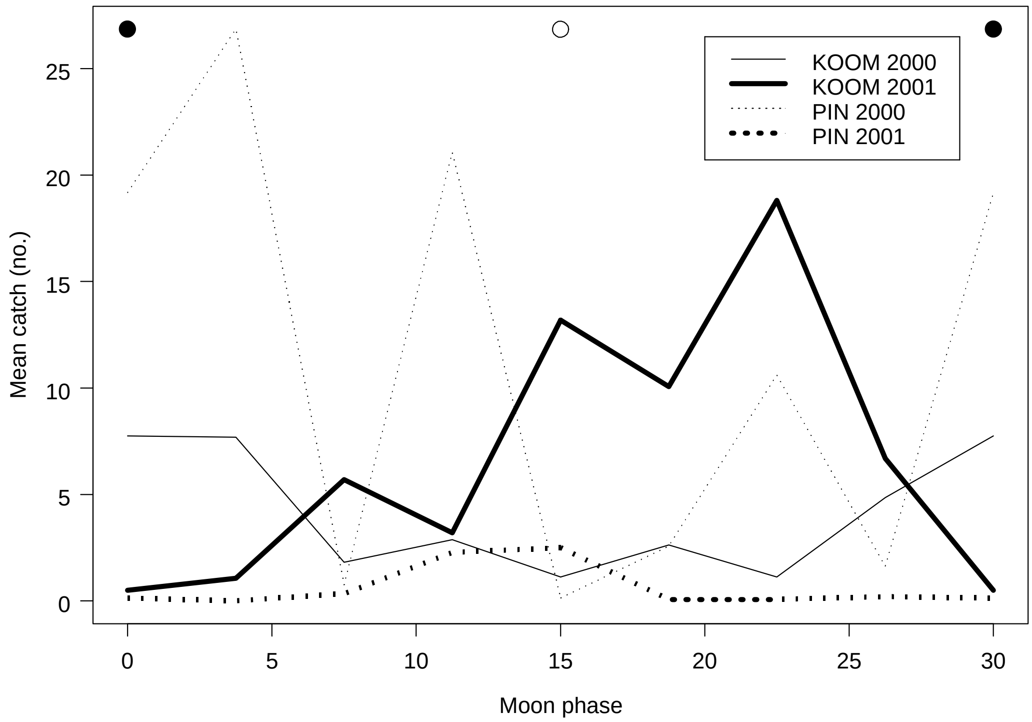


Figure 3.6g. Catch of yellow-eye mullet relative to lunar cycle during the intensive sampling experiments in 2000 and 2001. KOOM = Koombana Bay (Bunbury); PIN = Pinnaroo Point (Perth).

Day/night sampling and carry-over effects

Site effect: Of the two west coast locations examined during this experiment, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet were more abundant at Mangles Bay than at Koombana Bay (Table 3.4), while tailor and Australian herring were more abundant at Koombana Bay. The abundance of salmon was too low at either site for factors to be tested.

Day-night effects: A key question was whether abundances of each of these species were greater during the day or night. Numbers of Australian herring, tailor and yellow-eye mullet were significantly higher during the day than during the night. Night catches of yellow-eye mullet were significantly higher from Mangles than from Koombana.

Day effect: Day 2 (day and night) hauls and day 3 (day hauls only) showed decreased catches of Australian herring, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet. Catches of Australian herring recovered following the "rest" day (day 5).

Location effect: Fixed-site 1 in both locations had significantly lower catches of King George whiting and yellow-finned whiting, but significantly higher catches of yellow-eye mullet and tailor. A significant *location (F1) X year* interaction showed a lower catch of herring in the second year at F1.

Tide effect: A low rising tide showed significantly decreased catches of Australian herring but increasing catches of King George whiting, yellow-finned whiting and sea mullet. Australian herring catches significantly declined more generally at low tide.

Wind effect: South-westerly and westerly winds significantly increased catches of herring, yellow-finned whiting and yellow-eye mullet. Australian herring catches also increased with north-easterly wind, while south to south-easterlies generated higher tailor and yellow-eye mullet catches.

Replicate effects: Following replicate 1, catches of Australian herring, King George whiting and yellow-finned whiting were significantly lower in subsequent replicates.

Water condition effects: Deteriorating water conditions significantly decreased numbers of King George whiting, yellow-finned whiting, tailor and yellow-eye mullet, but increased the numbers of Australian herring.

Water temperature effect: There was a significant decrease in abundance of yellow-eye mullet and increase in yellow-finned whiting with increasing water temperature.

Salinity effect: More saline waters increased the chances of catching Australian herring and tailor.

Depth effect: There was a significant increase in the abundance of Australian herring and yellow-eye mullet with increasing water depth.

Cloud cover effect: There were significantly fewer yellow-finned whiting collected with increasing cloud cover.

Turbidity effect: Tailor catches were significantly lower in turbid water.

Weed effect: Brown algae accumulation led to higher catches of tailor and yellow-eye mullet, while green algae accumulation increased the chances of catching yellow-eye mullet. Increased volumes of weed other than brown algae were associated with decreased catches of tailor.

Rain effect: Rain had very little effect on catches of any of the six species.

Carry-over effects: The carryover effect between successive seine hauls varied for the six species (Figures 3.7a-g). The full model indicated an increase in abundance of yellow-eye mullet over successive seine hauls, however abundance of Australian herring and tailor decreased (Table 3.4). Abundance of sea mullet increased between day and night seine hauls at the same location, indicating a carryover effect.

The depletion plots in Figure 3.7 indicate that there were few discernible patterns; catches were highly variable. The only significant patterns on these plots are shown by a fitted line(s). The depletion experiment indicated that fish at Mangles Bay (Experiments 5 and 6) could be depleted by the sampling. It may be relevant that Mangles Bay, a very sheltered site within Cockburn Sound, appears to be more susceptible to bias induced by carry-over effects of the sampling.

Water condition effect: Rougher water conditions lead to decreases in catches of tailor, King George whiting, yellow-finned whiting and sea mullet. Australian herring also exhibited a decrease when water condition deteriorated, but this species was then more abundant as conditions further deteriorated.

Table 3.4. Statistically significant relationships between the abundance of each of the six species and a suite of variables from the day/night effects experiment as described in the text. The number indicates the magnitude (number per haul) of the effect, e.g. there were on average 4.08 less herring per haul at Pinnaroo Point than at Koombana. Numbers in brackets are standard errors standard errors of the effects. (***, p<0.001; **, p<0.05; *, p<0.1). N/A (not applicable) indicates that the effect could not be modelled due to insufficient data and or model violations; however, note that in some cases this does not mean there was not an effect, e.g. King George whiting were more abundant at Mangles Bay, but the very low numbers caught at Koombana precluded statistical testing. Refer to text.

FACTORS	SPECIES					
	Herring	**Tailor (KOOM only)**	**King George whiting (MANG only)**	**Yellow-finned whiting (MANG only)**	**Sea mullet**	**Yellow-eye mullet**
Model Intercept	−165.08** (75.91)	−272.28** (77.14)		−5.95* (3.00)		36.38** (13.04)
Site	−4.08* (2.16)	N/A	N/A	N/A	N/A	7.02** (2.13)
Day/night	−15.49*** (2.71)	−2.71** (0.95)				−5.93*** (1.23)
Site × Day/night	N/A	N/A	N/A	N/A	N/A	2.80 (1.06)
Day=2	−3.72** (1.61)			−0.46* (0.24)		−2.26* (1.26)
Day=3			−28.61** (10.09)	−1.23** (0.37)	−24.36** * (8.74)	
Day=4						
Day=6	3.94** (1.87)					
Day=7	4.91* (2.68)					
Day=8						−2.81* (1.56)
Fixed/random						
Location=F1	4.59** (1.75)	2.46** (0.97)	−23.51*** (6.13)	−1.00** (0.38)		4.16*** (1.13)
(Loc = F1) × Yea	−6.54*** (1.48)					
Tide=high, rising	−3.38* (1.81)					
Tide=high, falling			N/A	N/A	N/A	
Tide=low, rising	−12.48*** (3.05)		33.82*** (5.66)	0.83*** (0.21)	23.22** (5.26)	
Tide=low, falling	−17.73** (5.66)		N/A	N/A	N/A	
Tide=low	−13.72*** (3.66)		N/A	N/A	N/A	
Wind dir=SE						4.52** (1.43)
Wind dir=S		4.06** (1.09)				6.79*** (1.80)
Wind dir=E						
Wind dir=SW	4.35** (1.50)			0.52** (0.20)		6.20*** (1.55)
Wind dir=N						

FACTORS	SPECIES					
	Herring	**Tailor (KOOM only)**	**King George whiting (MANG only)**	**Yellow-finned whiting (MANG only)**	**Sea mullet**	**Yellow-eye mullet**
Wind dir=W				0.92** (0.38)		5.88** (2.65)
Wind dir=NE	27.74*** (4.91)					
Wind dir=NW						
Rain=light			N/A	N/A	N/A	
Rain=moderate			N/A	N/A	N/A	
Rain=heavy			N/A	N/A	N/A	
Year			N/A	N/A	N/A	
Rep=2			−17.31** (6.28)	−1.31** (0.41)		
Rep=3	−3.70** (1.61)		−20.21** (6.14)	−1.43** (0.40)		
Rep=4	−4.71** (1.61)			−0.87** (0.40)		
Salt	4.59** (2.01)	7.57** (2.17)				
Water temp				0.23* (0.12)		−1.49** (0.57)
Water depth	7.12* (3.69)					11.72*** (2.96)
Water depth – se		−5.84** (2.76)	N/A	N/A	N/A	
Water cond=1		−6.93*** (1.61)	−23.28*** (5.83)	−0.41** (0.19)		
Water cond=2	−3.19** (1.52)	−4.62** (1.80)				−2.93 (1.23)
Water cond=3	10.18*** (2.67)	−8.39*** (2.17)	−35.37** (12.92)			
Water cond=4			N/A	N/A	N/A	
Water cond=5			N/A	N/A	N/A	
Cloud				−0.23** (0.09)		
Weed		−0.15* (0.09)				
$b \times weed/100$		1.25** (0.54)				0.18* (0.10)
$r \times weed/100$			N/A	N/A	N/A	
$g \times weed/100$						0.24* (0.14)
Carry-over (successive hauls)	−0.17** (0.06)	−0.22** (0.08)				0.13** (0.06)
Haul carry-over (day to night)					0.48** (0.16)	

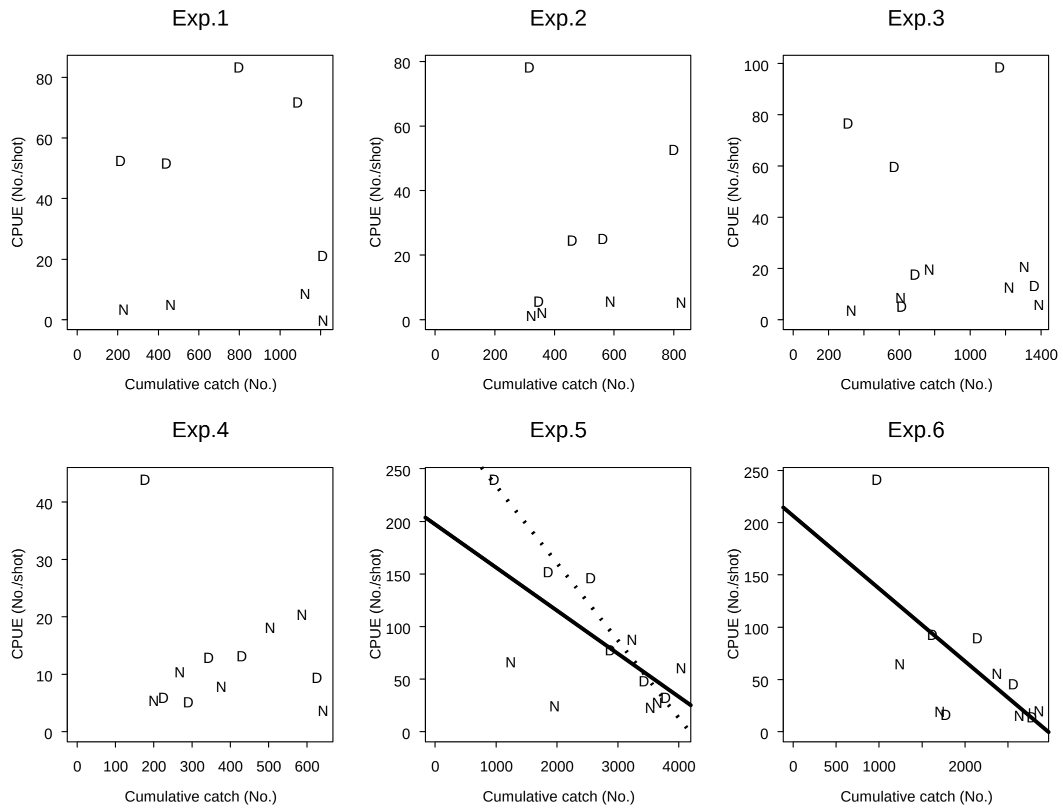


Figure 3.7a. Depletion plots for total catches during the day-night sampling experiments. Exp 1: Nov 1998 & Exp 2: Dec 1998 (Koombana); Exp 3: Nov 2000 & Exp 4: Dec 2000 (Koombana); Exp 5: Nov 2000 & Exp 6: Dec 2000 (Mangles Bay). Symbols: D = day, N = night. A solid line represents significant day and night depletion. A dotted line represents significant day depletion.

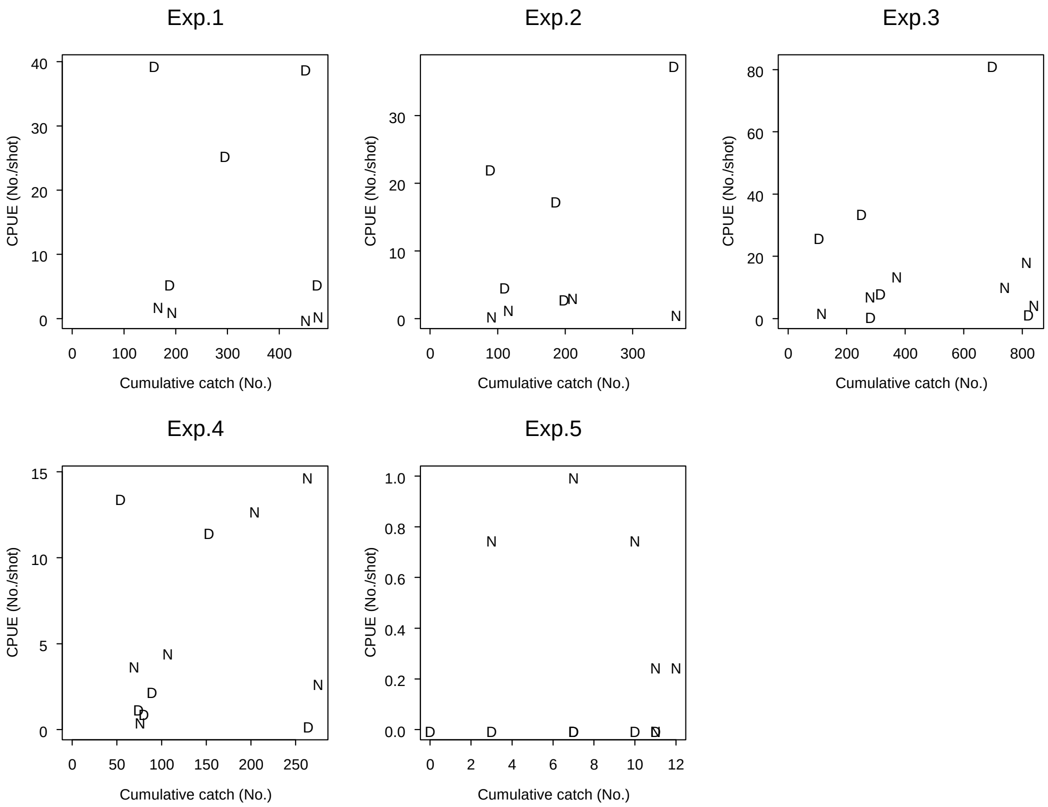


Figure 3.7b. Depletion plots for herring catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

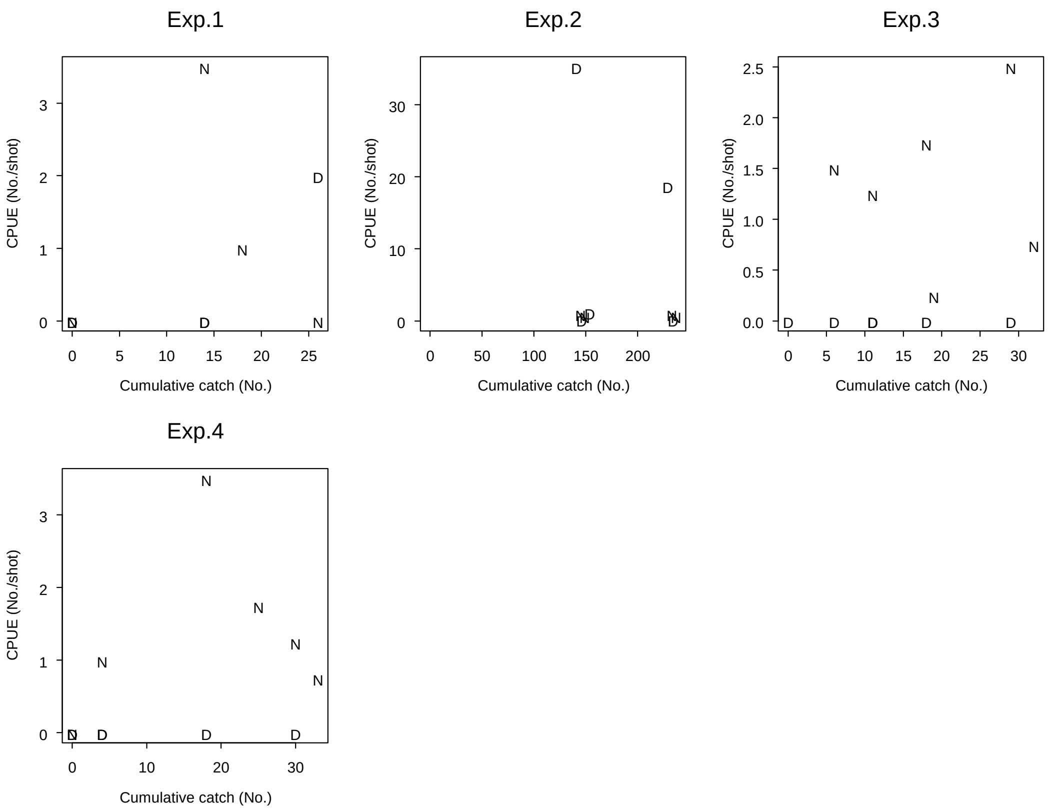


Figure 3.7c. Depletion plots for tailor catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

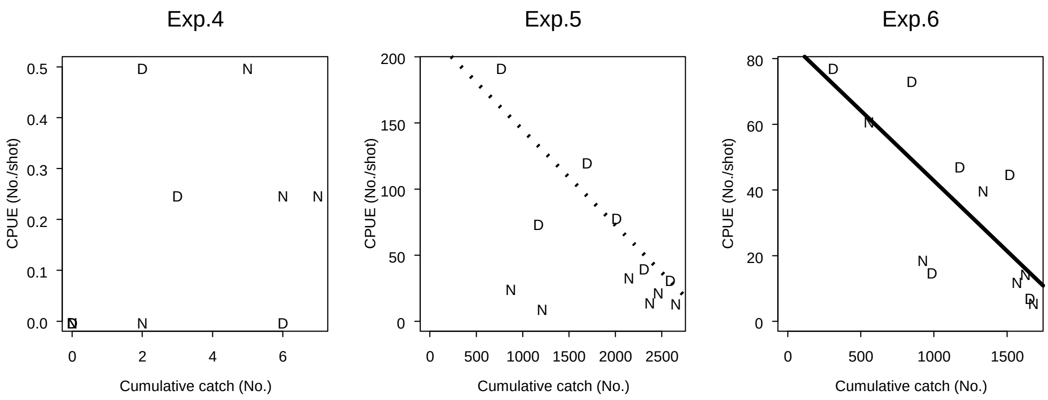


Figure 3.7d. Depletion plots for King George whiting catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

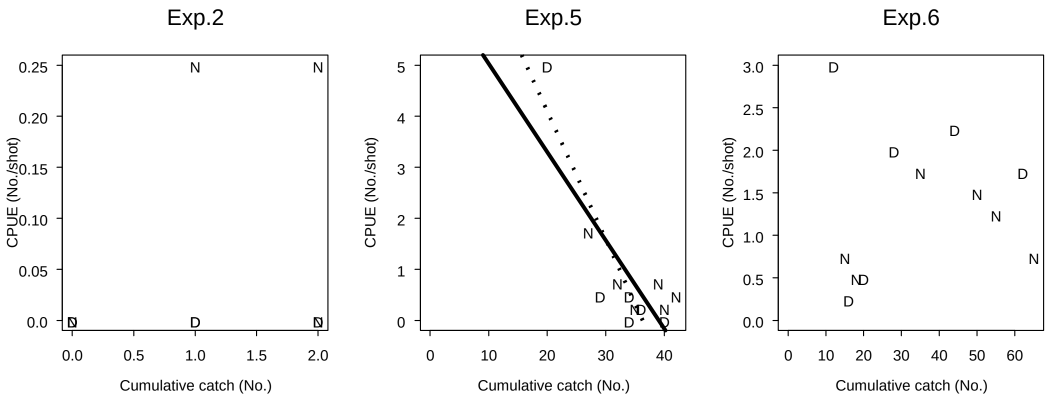


Figure 3.7e. Depletion plots for yellow-finned whiting catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

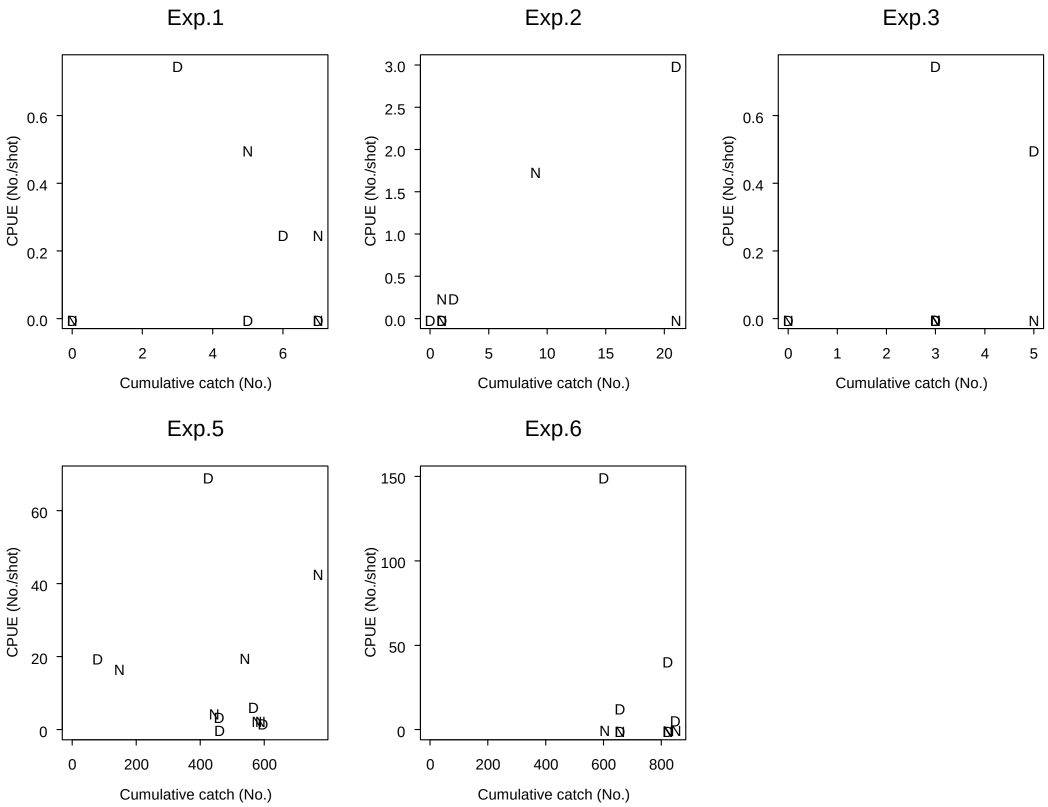


Figure 3.7f. Depletion plots for sea mullet catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

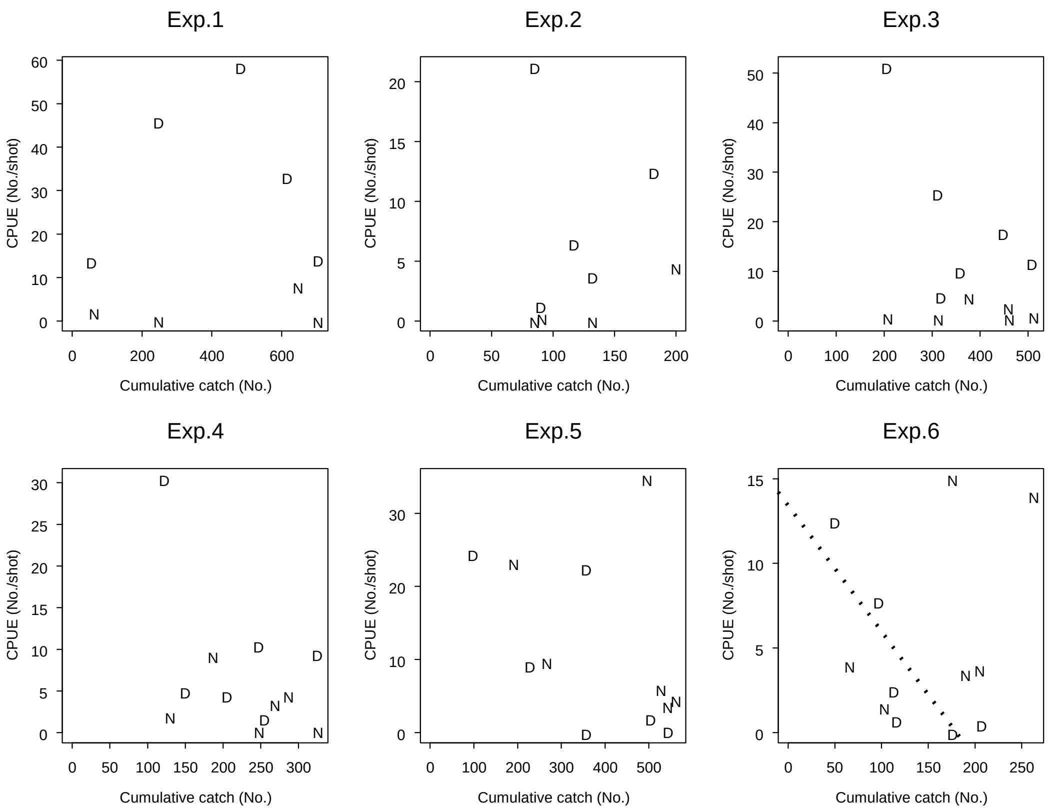


Figure 3.7g. Depletion plots for yellow-eye mullet catches during the day-night sampling experiments. (See Figure 3.7a for explanation of symbols).

3.4 Discussion

Monthly and annual patterns in abundance of recruits: optimising time of year, month and location to maximise catch of recruits

The high variability in total abundance of the seven species between sampling sites in south – western Australia indicates that not all sites will be equally representative of recruitment. In terms of maximising catch of recruits, sampling of 1 – 3 sites would be sufficient. However, for most species, recruitment occurred over many months of the year. Only in the cases of west coast herring, west coast salmon, south coast tailor, south coast King George whiting and west coast yellow-eye mullet were there reasonably distinct seasonal recruitment peaks. Other species exhibited bi- or multi-modal patterns of recruitment. These latter cases in particular justify the need to undertake the recruitment-index analyses for each species presented in Chapter 5. These subsequent analyses will attempt to assess if annual recruitment levels, developed from the monthly data, are an appropriate basis for deriving recruitment indices, or whether a subset of monthly data would provide a better starting point (see Chapter 5).

The annual trends in recruit abundance will also provide a basis for assessing whether or not catches of adults respond in a similar manner, a required outcome for a successful recruitment index. For some species, the trends at key sites differed to those representing all sites. Again, these aspects of the abundance data for recruits will contribute to the development of recruitment indices in Chapter 5.

Factors affecting abundance of recruits: optimizing sampling to maximise catch of recruits

The analyses of factors affecting abundance indicate only a modest impact of site (within a location), lunar and tidal variables on abundance of these species. Australian herring and yellow-eye mullet did show a pattern of abundance based on the tidal phase, while yellow-finned whiting depended on the lunar phase. However the other species were equally abundant at all lunar and tidal phases.

In relative terms, there were both immediate (successive replicates) and lasting (successive days) carry-over effects of sampling that need to be considered when developing an optimal sampling program. Such depletion will also be considered in the development of recruitment indices for each species.

The results from Chapter 5 will determine the optimal months and locations to sample recruits of each species with respect to collecting data most relevant for calculating recruitment indices. These results will dictate when and where field-sampling programs are conducted. Once these macro-level plans have been made, the micro-level strategy, based on the analyses presented, will then come into play. The entire suite of factors that significantly affected abundance of the seven species will thus provide the basis for fine-tuning the sampling strategy both prior to and during a sampling trip. For example, at the planning stage, a particular lunar phase may be selected, followed by selecting a sampling time that coincides with (or avoids) a certain tidal phase. Once a sampling trip has commenced at a particular site in a particular month, consulting a checklist of the other factors significant for the target species will permit real-time optimization specifically tailored to the conditions on that day. Because conditions for sampling can often vary (e.g. degree of weed accumulation, change in wind strength and direction), and as such cannot be predicted before arrival at the sampling site, the checklist will dictate how the sampling strategy balances the potential positive and negative influences on abundance of recruits. Finally, once the samples have been collected, knowledge gained in this project on the factors affecting abundance can be used to weight the data before it is applied to the recruitment index.

CHAPTER 4.0 The length-weight relationships and length frequency distributions of seven inshore fish species from south-western Australia

Montgomery Craine, Henry Cheng, Suzanne Ayvazian and Gabrielle Nowara

4.1 Introduction

An understanding of variability in length-frequency distributions is essential for developing and assessing a recruitment index that aims to utilise minimal sampling but which must then be applicable across a broad geographic range. Furthermore, knowledge of length-weight relationships is a prerequisite for constructing stock assessment models. In this chapter we model the monthly length frequency distribution of each of the seven species and examine their length-weight relationships. The seven species of interest to be examined here are Australian herring, Australian salmon, tailor, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet. For each of the seven species we have modeled the monthly length frequency distribution of fish sampled from the commercial fishery using a general linear modeling procedure to determine whether the sampling region, habitat, year, or time of year influenced the observed monthly length frequencies. The length frequency distribution of fish sampled by research staff (fishery independent samples) are presented here for the benefit of the general readership.

Length-weight relationships have been developed using all available data for each species. The results of these analyses are also presented here for the benefit of the general readership.

4.2 Materials and Methods

Collection and preliminary processing of samples of recruits (fishery independent sampling) and adults (commercial sampling) of the seven key species are described in Chapters 2 and 3. Both fishery independent and fishery dependent samples were collected from coastal and estuarine sites along the south-western coast of Western Australia (WA) from the Perth metropolitan area to east of Esperance, representing a wide geographic range.

Data analysis

Length variability

The length frequency distributions for each species caught using fishery independent sampling were plotted by region (south vs west coast) and for two periods of the year (Jan. – Jun. vs Jul. - Dec.).

Mean lengths for the commercial catches of each of the seven species were analysed using general linear model procedure with AIC criterion to select the best model with the best combination of predictor variables. The variables tested were sampling region (west coast versus south coast), habitat (estuary versus ocean), year (1999, 2000, 2001, 2002), and time of year (Jan. – Jun. vs Jul. - Dec.).

Length-weight relationships

The relationship between length and weight was defined as

$$W = aL^b \qquad (1)$$

where W is the weight of an individual fish and L is the length of the fish in millimetres. a and b are parameters to be estimated.
For simplicity, sex, year, season and region factors were tested separately. The length-weight relationship model was extended as follows :-

$$W = (a + a_i S)L^{(b+b_i S)} \qquad (2)$$

where S = 0 if an individual fish was a female, S = 1 if male. The dummy variable S can be replaced by other dummy variables such as Y, where Y = 0 if the year was 1999, Y = 1 if the year was 2000; SN, where SN = 0 if the fish was caught in summer or autumn, otherwise SN = 1; R, where R = 1 if the fish was found in a particular region, otherwise R = 0.

Initial starting points are required for fitting non-linear models. The initial starting points were estimated by a least square linear regression with the log-transformed data. The S-plus *nls* function has been used to do the estimation. The level of significance used for the two tailed students t-test was 5% (t-value $\approx$ 2).

4.3 Results and Discussion

Length variability

The upper length limits for 0^+ fish, as estimated from the von Bertalanffy models, have been overlaid on the length frequency distributions for fishery independent samples. The following descriptions for fishery independent samples apply only to the 0^+ fish.

Australian herring

Fishery independent sampling

0^+ Australian herring were approximately ten times more abundant on the south coast (Figure 4.1a), but there was no consistent difference in abundance between the first and second halves of the year (Figure 4.1b). 0^+ Australian herring collected between January and June were longer than those from July to December fish.

Fishery dependent sampling

There was no difference in the mean monthly lengths between west and south coast commercially caught Australian herring (p=0.09) (Table 4.1, Figure 4.1c). Estuarine fish were longer than ocean caught fish (p<0.00). There was no significant difference in monthly lengths between 1999, 2000 and 2002 (p<0.99 and p<0.048, respectively), but the 1999 fish were longer than those from 2001 (p<0.00). Commercially caught fish were longer in the January to June period than in the July to December period (p<0.00).

Australian salmon

Fishery independent sampling

0^+ Australian salmon were more abundant on the south coast (Figure 4.1d) and more abundant in the second half of the year (Figure 4.1e). The 80-120 mm size- interval dominated south coast catches in those years when reasonable numbers were caught (1999 – 2001). The 2001 west coast catch of 0^+ salmon consisted mainly of 40 – 100 mm fish. In 2001, 0^+ Australian salmon were longer from January to June than in the July to December period (Figure 4.1e).

Fishery dependent sampling

The monthly lengths of commercially caught Australian salmon showed a significant relationship between regions and habitats (Table 4.1, Figure 4.2f). The south coast Australian salmon had a greater monthly length than on the west coast ($p<0.001$). Similarly, the oceanic fish had a greater monthly length than their estuarine counterparts ($p<0.001$). The 1999 mean lengths were significantly less than for either 2000 or 2001 ($p<0.001$ and $p<0.001$, respectively). Monthly lengths did not differ with time of year ($p=0.293$).

Tailor

Fishery independent sampling

There were not enough fishery-independent tailor collected from the spatial and temporal sampling combinations to allow for statistical testing of the monthly length frequency (Figures 4.1g, h).

Fishery dependent sampling

Tailor were caught on both the west and south coasts (Table 4.1, Figure 4.1i), with significantly larger fish from the latter region ($p<0.001$). There was insufficient tailor caught from both habitats to allow a comparison of estuarine and oceanic influences. Lengths of tailor were similar in 1998 and 1999 ($p<0.286$); however tailor from 1998 were significantly smaller than in 2000, 2001 and 2002, ($p<0.001$, $p<0.001$, and $p<0.001$ respectively). Tailor collected from January through June were longer than those from July through December ($p<0.001$).

King George whiting

Fishery independent sampling

No 0^+ King George whiting were caught on the south coast (Figure 4.1j) and insufficient numbers were caught in estuaries to make a comparison with oceanic fish. Lengths were similar across years, but with very few <60 mm caught in 2002. 0^+ King George whiting collected between January and June were longer than in the July to December period (Figure 4.1k). The length frequency distributions in the latter half of each year appear to represent a distinct cohort.

Fishery dependent sampling

There was no statistically significant difference in the monthly length of adult King George whiting between regions ($p<0.46$) (Table 4.1, Figure 4.1l). Oceanic King George whiting were significantly longer than estuarine fish ($p<0.001$). Analysis of the yearly data showed a complex picture. While there was no difference in length between 1998 and 2002 ($p=0.134$), there was a significant difference between 1998 and 1999, and between 2000 and 2001

($p<0.001$). KGW from July to December were longer than those from January to June fish ($p<0.05$).

Yellow-finned whiting

Fishery independent sampling

0^+ yellow-finned whiting were caught only on the west coast of WA, so no comparisons can be made to the south coast. Additionally, there were not enough yellow-finned whiting collected in estuaries to make a comparison with oceanic fish. 0^+ yellow-finned whiting were longer in 1999 than in each of 2000, 2001 and 2002. For 2000 and 2001, recruits were larger in the second half of the year (Figure 4.1m). These results demonstrate that, to date, a nursery area for this species has not been found on the south coast; hence, the recruit data are based on west coast samples only.

Fishery dependent sampling

Older yellow-finned whiting were caught on both the west and south coasts (Table 4.1, Figure 4.1n). Fish on the west coast were larger than on the south coast ($p<0.001$). There was also a significant difference between the estuarine and ocean fish, with larger yellow-finned whiting caught in estuaries. Yellow-finned whiting were of similar size in 1999, 2001 and 2002. However there was a significant difference between 1999 and 2000 fish with the latter attaining a greater monthly length ($p<0.001$). Fish caught during January to June were larger than those from July to December ($p<0.05$).

Sea mullet

Fishery independent sampling

0^+ sea mullet were more abundant along the west coast (Figure 4.1o). Except for the south coast in 2001, most sea mullet were <80 mm long. Sea mullet <80 mm long dominated catches in both halves of the year, except in Jan, - Jun of 2001 when the 80 – 120 mm size interval was well represented (Figure 4.1p).

Fishery dependent sampling

Sea mullet were caught at both west and south coast sites (Table 4.1). South coast sea mullet were longer than those on the west coast ($p<0.001$) (Figure 4.1q). There was no significant difference in lengths between the estuarine and ocean sites. Length was greater in each of 2000, 2001 and 2002 than in 1999. Commercially caught sea mullet were significantly larger in January to June than in the second half of the year. The larger adults found on the south coast were present at both estuarine and oceanic sites.

Yellow eye mullet

Fishery independent sampling

0^+ yellow-eye mullet were abundant along both the west and south coasts. Lengths were similar on the south and west coast in1999, but in each of the other years the length frequency distributions of 0^+ fish differed (Figure 4.1r). For example, in 2002 there were more fish in the 60 – 100 mm size interval on the west coast (Figure 4.1r). Also, fish collected during 2000, 2001 and 2002 were represented by a broader range of lengths than in 1999. There were no consistent differences in size of 0+ yellow-eye mullet at different times of the year (Figure 4.1s).

Fishery dependent sampling

There was no significant difference ($p<0.056$) in length of adult yellow-eye mullet caught in the two regions (Table 4.1, Figure 4.1t). There were not enough fish sampled to assess the influence of habitat, estuarine versus ocean, on length. Fish from 2001 and 2002 had a significantly greater monthly length ($p<0.05$ and $p<0.001$, respectively) than those from 1999; however fish from 2000 were not significantly different from 1999 ($p=0.315$). There was also a significantly greater size in July to December than in the first half of the year ($p<0.05$).

Table 4.1. The analysis of variance with AIC criteria applied to the monthly length frequency data from the commercially caught (fishery dependent) seven species by region, habitat, year and time of year. The comparisons are of mean length. For example, "estuary>ocean" indicates that mean length was greater for estuary-captured fish. NS= not sufficient samples. 1st season = Jan-Jun.; 2nd season = Jul – Dec. West and south regions refer to the west and south coasts of WA (see text).

	Habitat	**Season**	**Region**	**Year**
Australian herring	estuary>ocean (p<0.001)	1st>2nd (p<0.001)	west=south (p<0.09)	1999=2000 (p<0.99) 1999=2002 (p<0.048) 1999>2001 (p<0.001)
Australian salmon	estuary<ocean (p<0.001)	1st=2nd (p=0.293)	west<south (p<0.001)	1999<2000 (p<0.001) 1999<2001 (p<0.001)
Tailor	NS	1st>2nd (p<0.001)	west<south (p<0.001)	1998=1999 (p=0.286) 1998<2000 (p<0.001) 1998<2001 (p<0.001) 1998<2002 (p<0.001)
King George whiting	estuary<ocean (p<0.001)	1st<2nd (p<0.05)	west=south (p=0.046)	1998>1999 (p<0.001) 1998>2000 (p<0.001) 1998>2001 (p<0.001) 1998=2002 (p=0.134)
Yellow-finned whiting	estuary>ocean (p<0.001)	1st>2nd (p<0.05)	west>south (p<0.001)	1999<2000 p(<0.001) 1999=2001 p(=0.058) 1999=2002 p(=0.104)
Sea mullet	estuary=ocean (p=0.372)	1st>2nd (p<0.001)	west<south (p<0.001)	1999<2000 (p<0.001) 1999<2001 (p<0.05) 1999<2002 (p<0.001)
Yellow-eye mullet	NS	1st<2nd p(<0.05)	west=south p(=0.056)	1999=2000 (p<0.315) 1999<2001 (p<0.05) 1999<2002 (p<0.001)

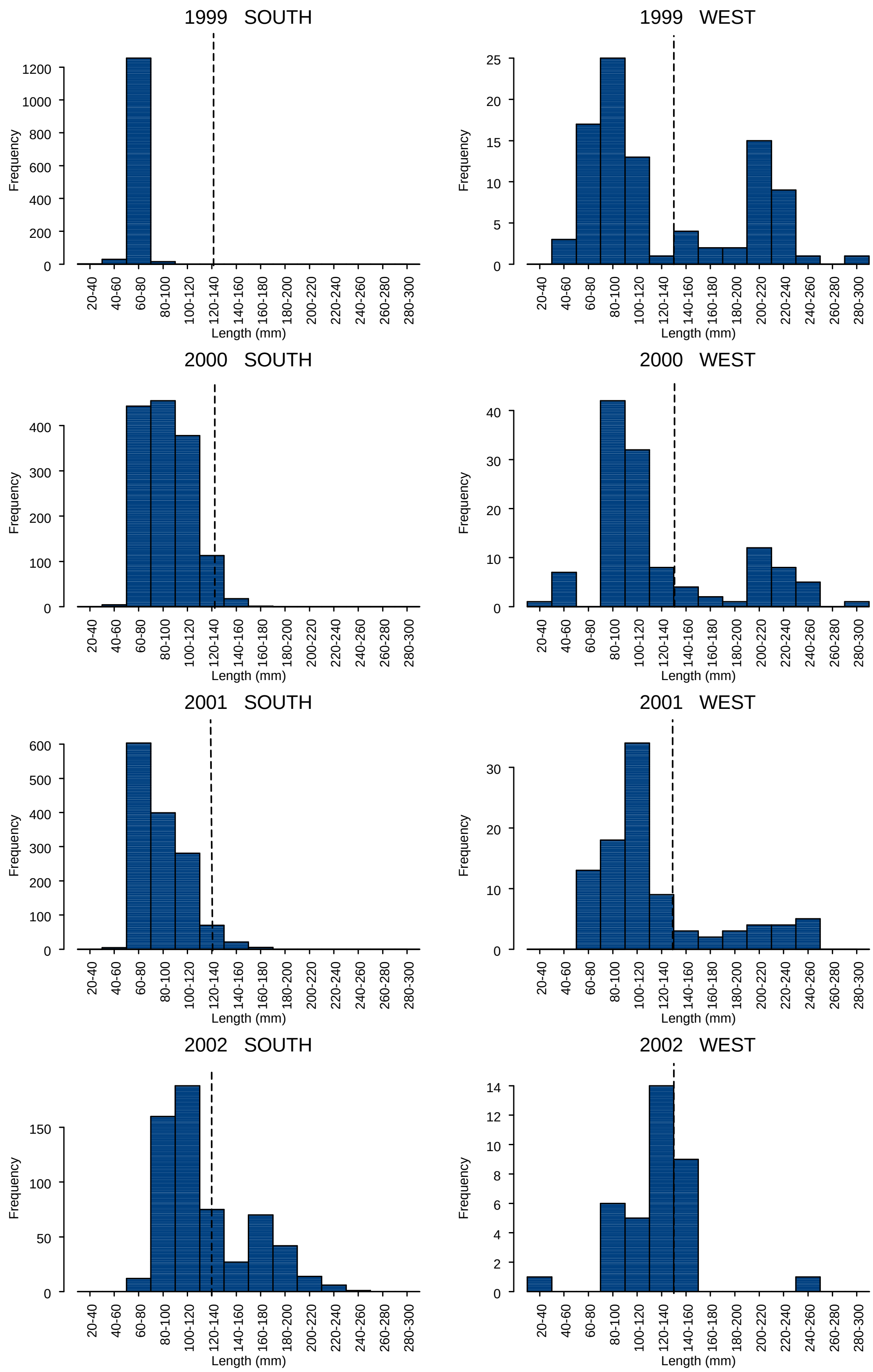


Figure 4.1a. Length frequency distribution (total length in mm) for fishery-independent Australian herring by region and year of capture. The approximate upper length for 0+ fish is shown.

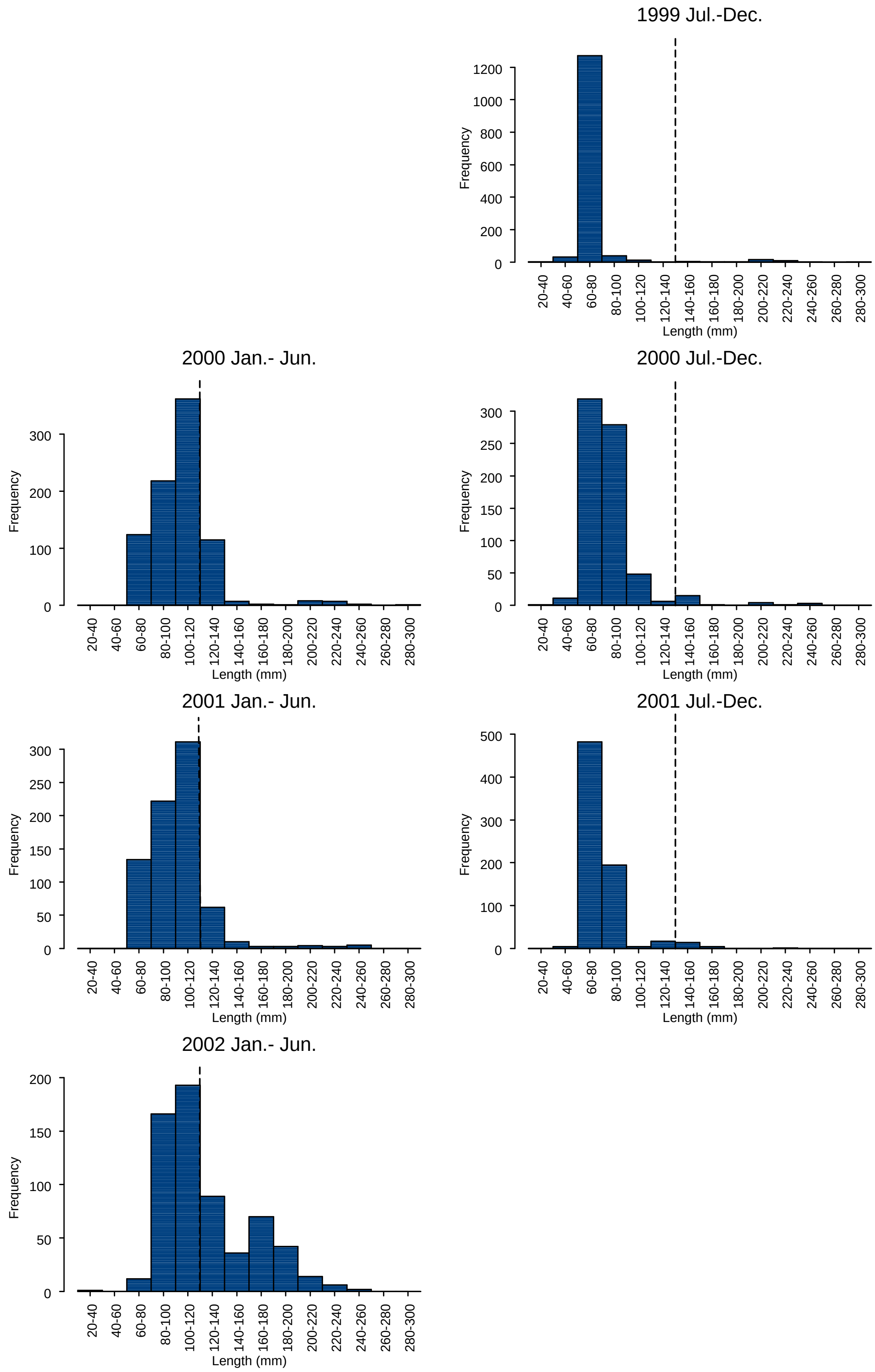


Figure 4.1b. Length frequency distribution (total length in mm) for fishery-independent Australian herring by time of year. The approximate upper length for 0+ fish is shown.

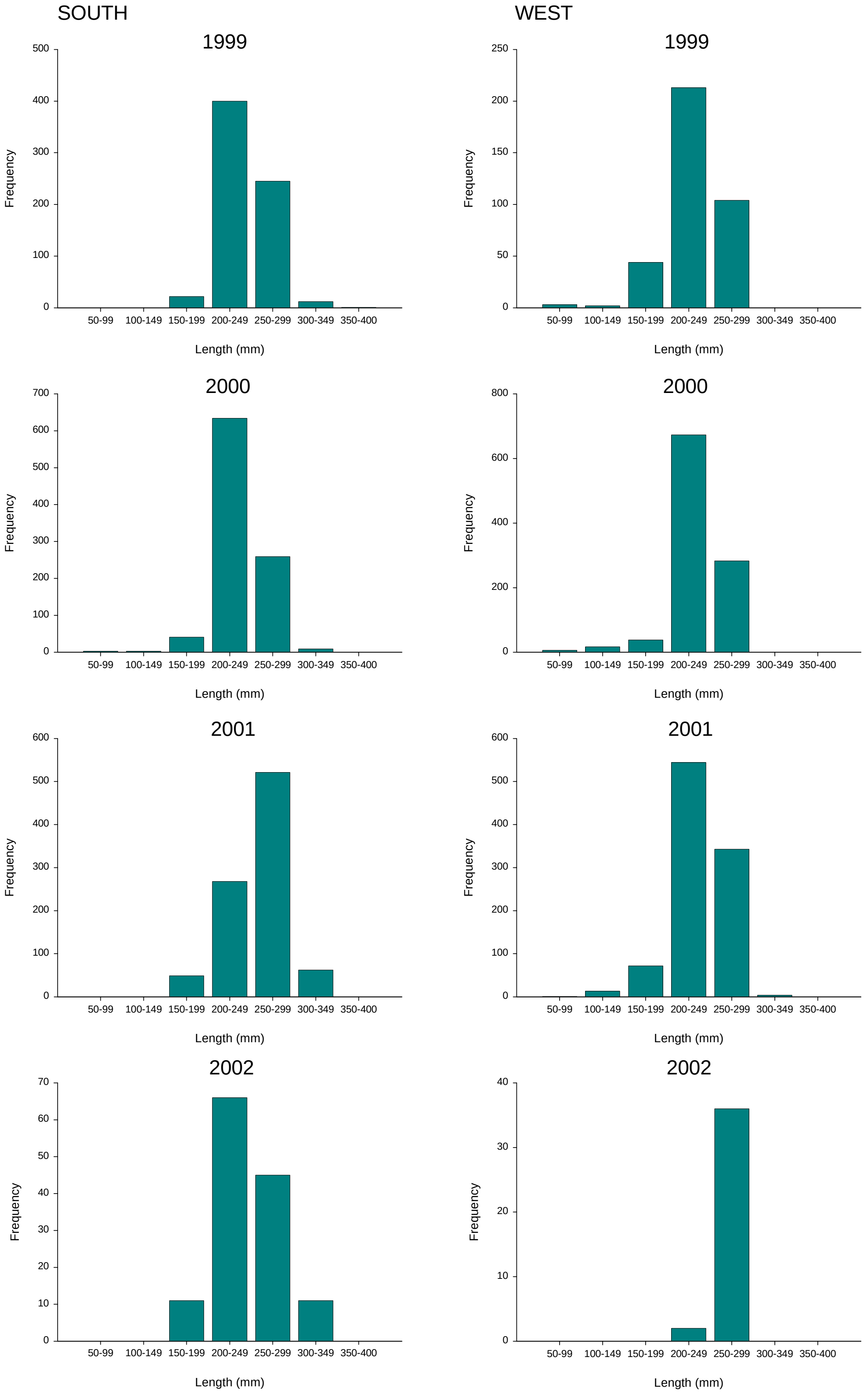


Figure 4.1c. Length frequency (50 mm intervals) of commercial catch of herring sampled for the west and south regions of WA for 1999 to 2002.

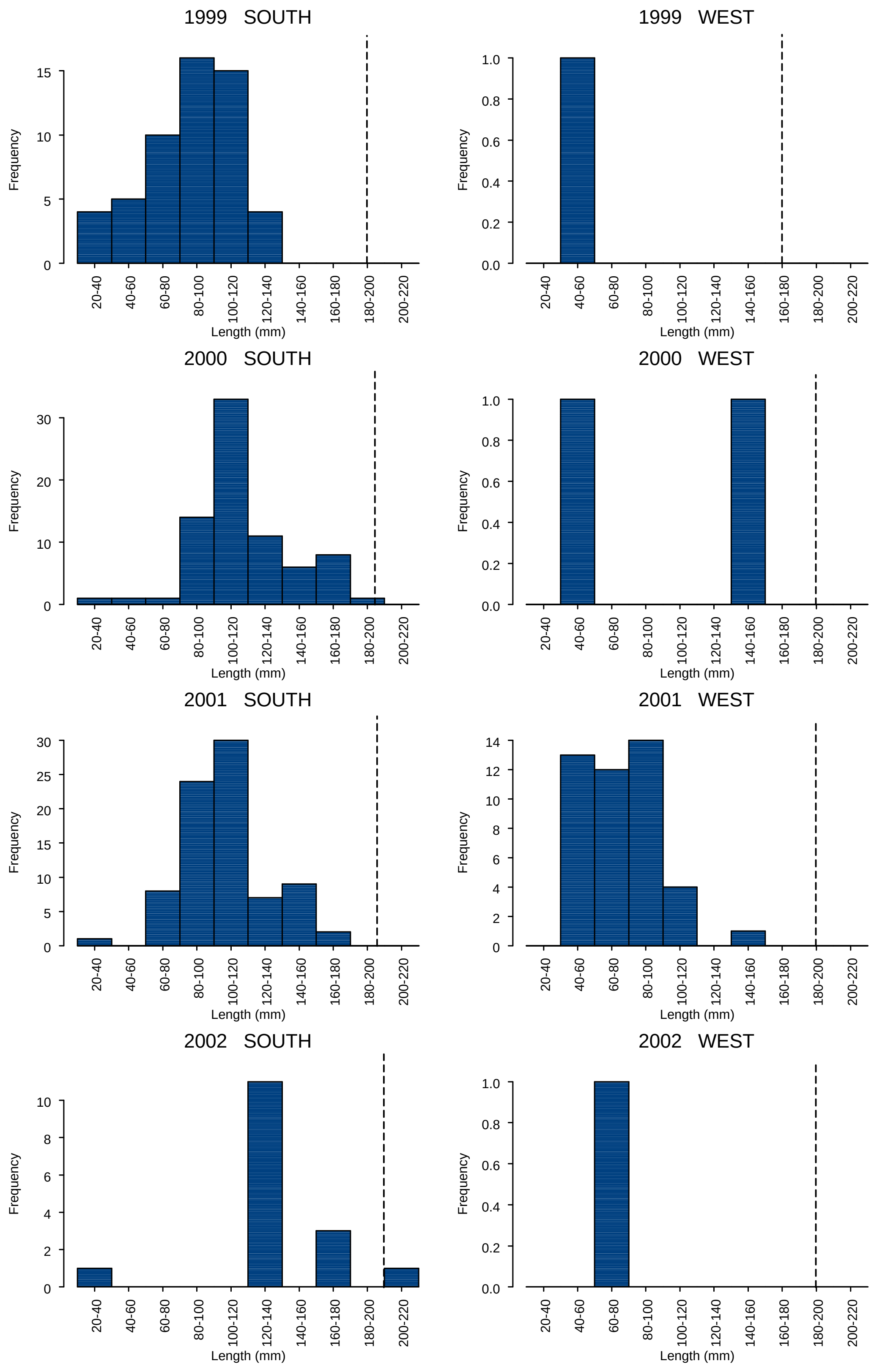


Figure 4.1d. Length frequency distribution (total length in mm) for fishery-independent Australian salmon by region and year of capture. The approximate upper length for 0+ fish is shown.

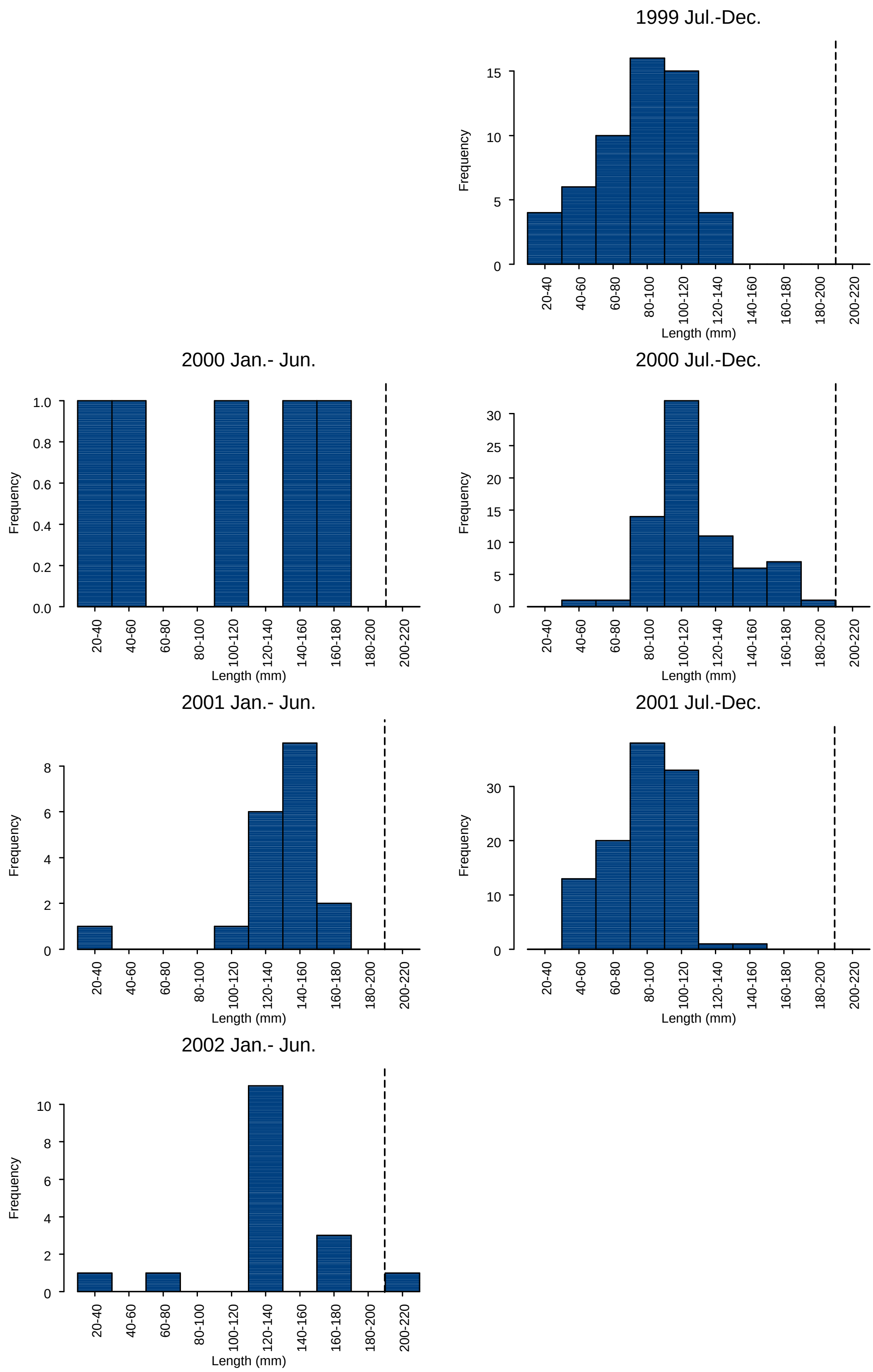


Figure 4.1e. Length frequency distribution (total length in mm) for fishery-independent Australian salmon by time of year. The approximate upper length for 0+ fish is shown.

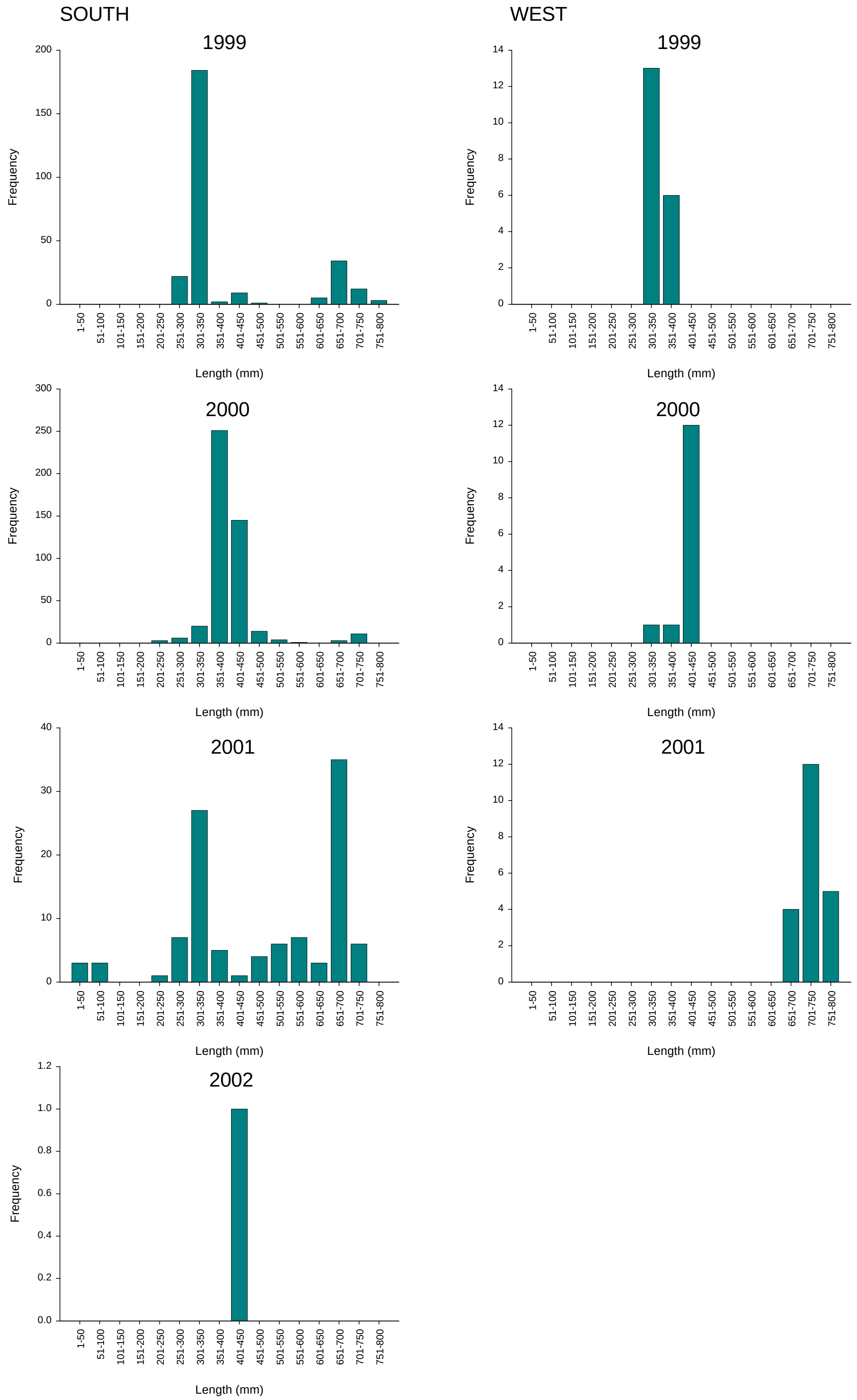


Figure 4.1f. Length frequency (50 mm intervals) of commercial catch of salmon sampled for the west and south regions of WA for 1999 to 2002. The approximate upper length for 0+ fish is shown.

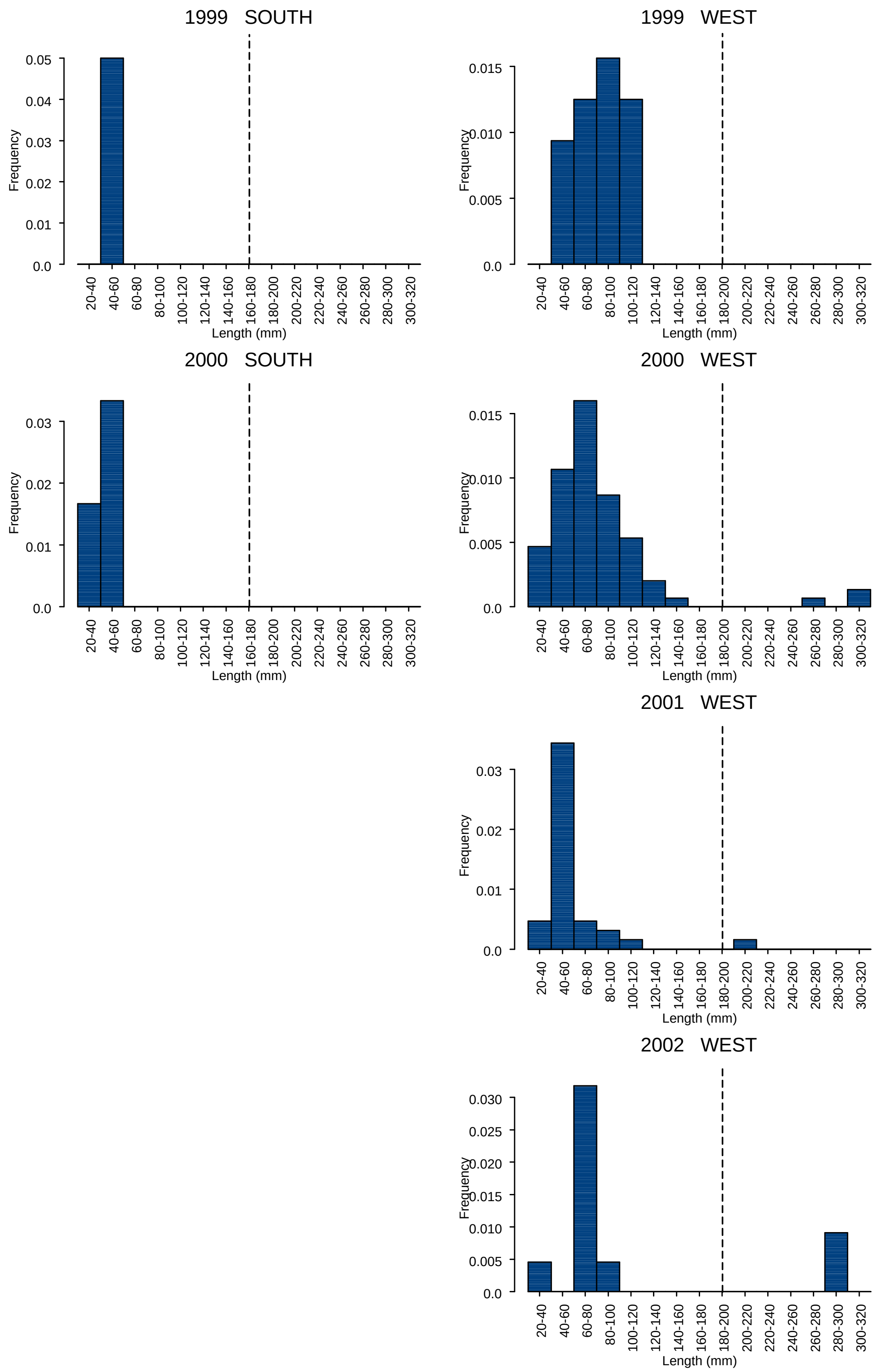


Figure 4.1g. Length frequency distribution (total length in mm) for fishery-independent tailor by region and year of capture. The approximate upper length for 0+ fish is shown.

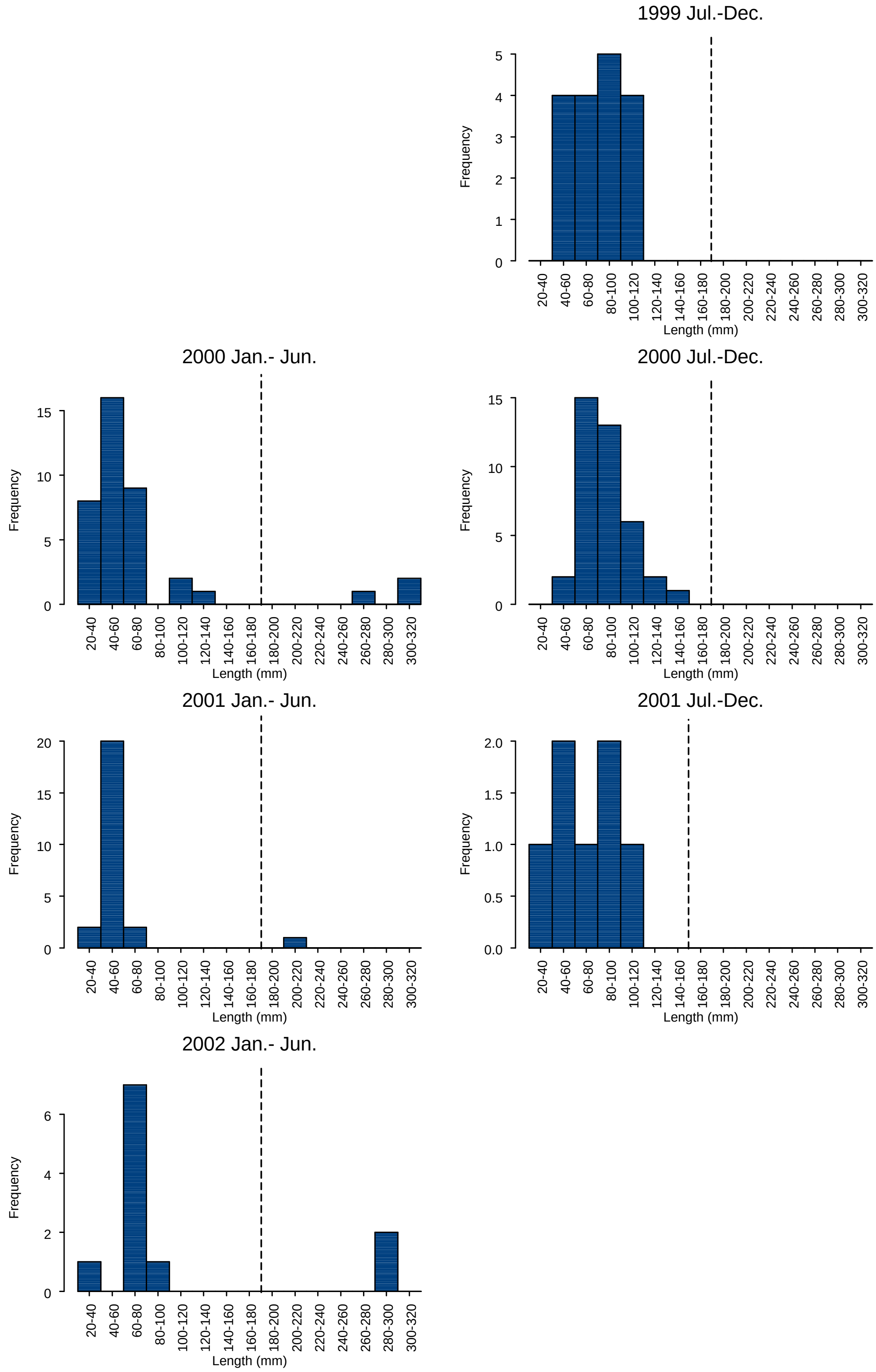


Figure 4.1h. Length frequency distribution (total length in mm) for fishery-independent tailor by time of year. The approximate upper length for 0+ fish is shown.

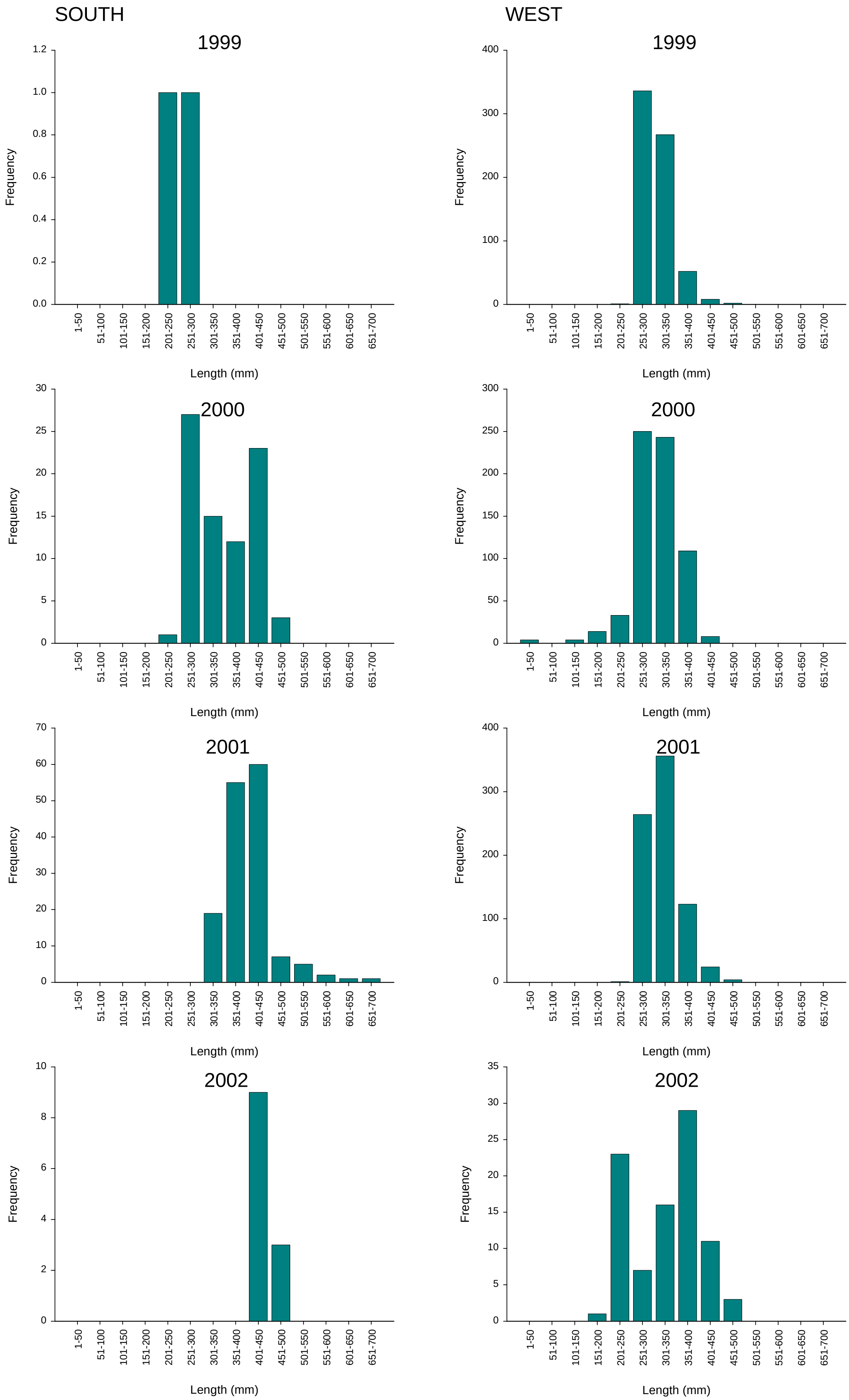


Figure 4.1i. Length frequency (50 mm intervals) of commercial catch of tailor sampled for the west and south regions of WA for 1999 to 2002.

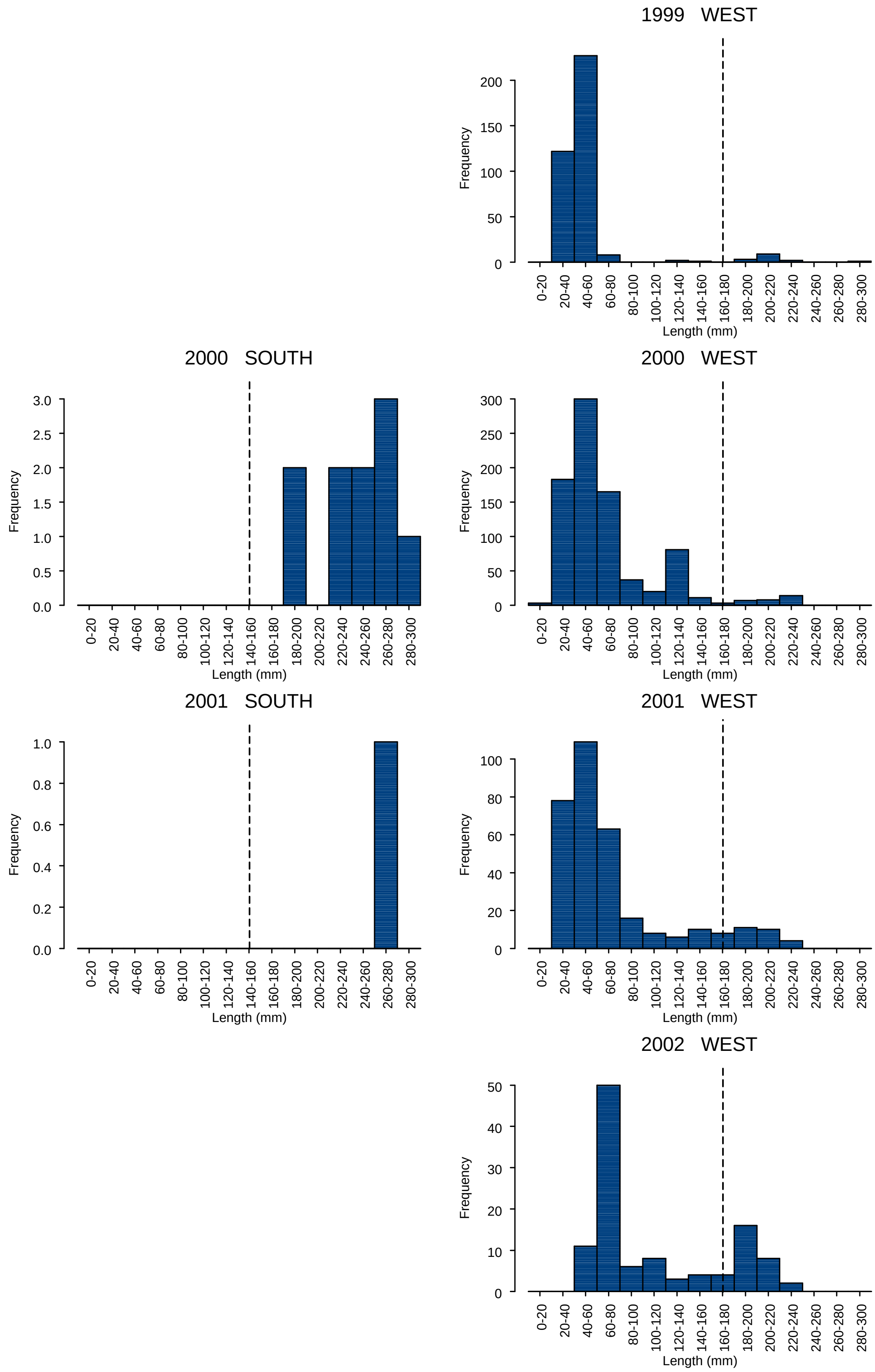


Figure 4.1j. Length frequency distribution (total length in mm) for fishery-independent King George whiting by region and year of capture. The approximate upper length for 0+ fish is shown.

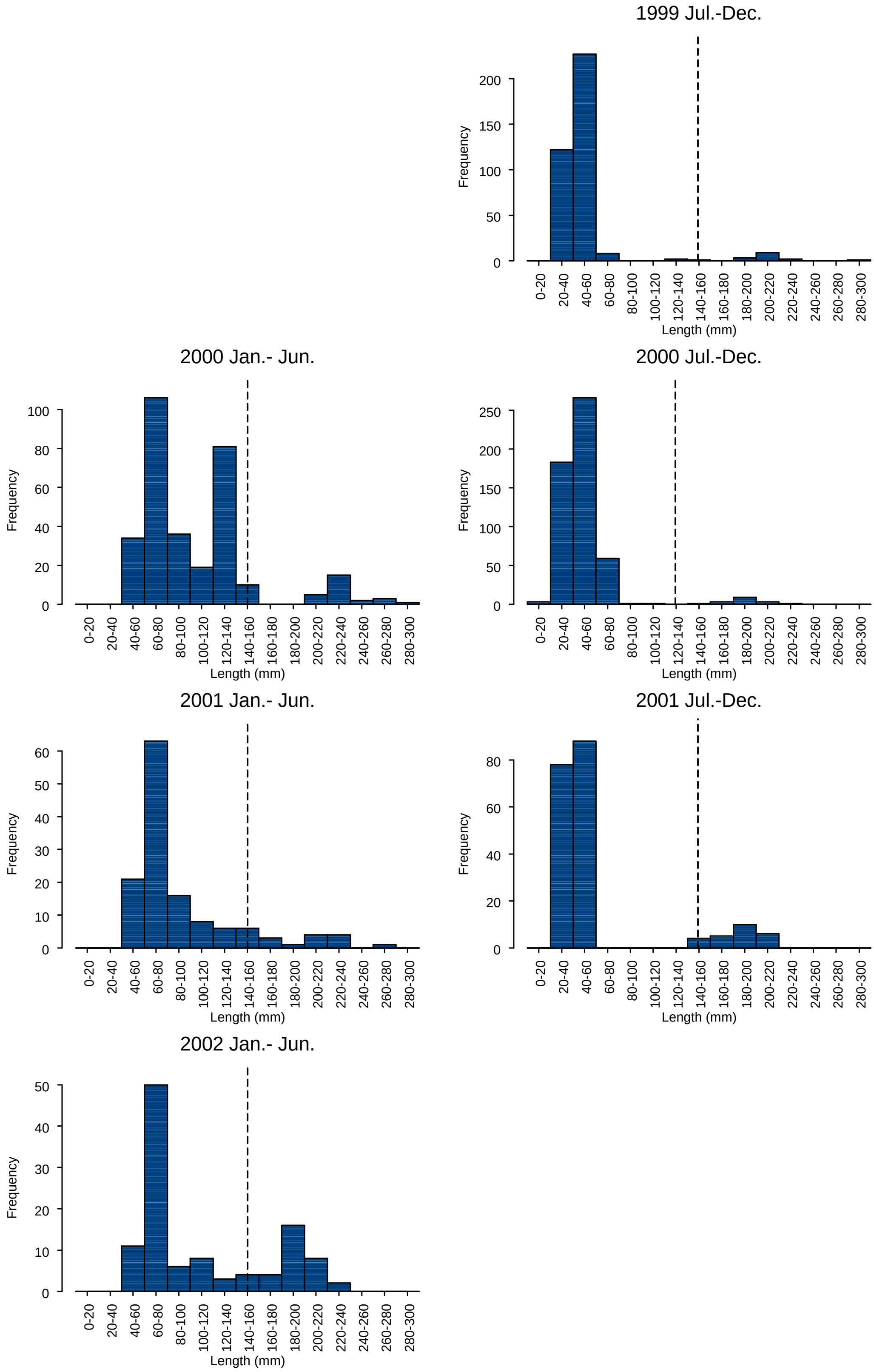


Figure 4.1k. Length frequency distribution (total length in mm) for fishery-independent King George whiting by time of year. The approximate upper length for 0+ fish is shown.

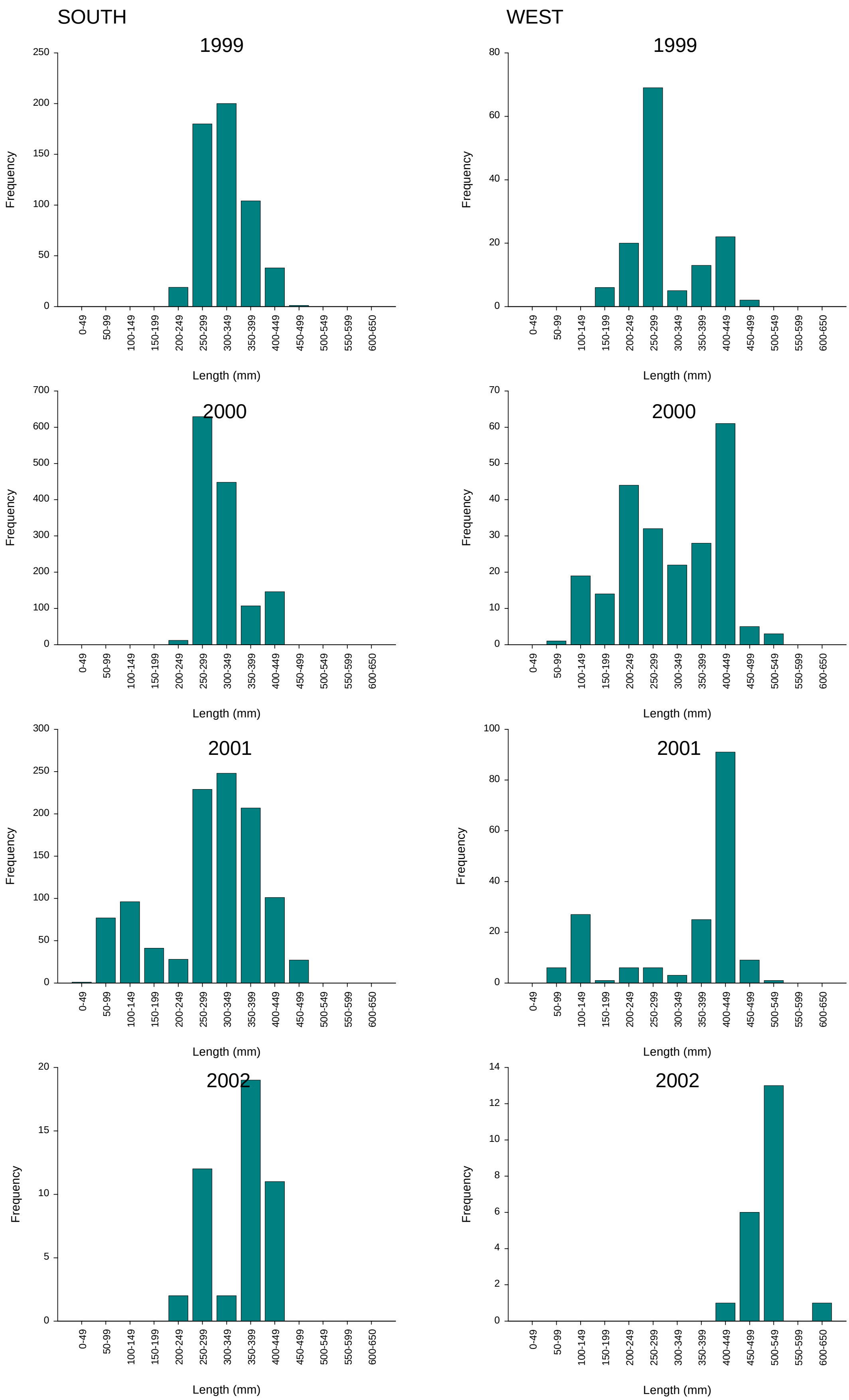


Figure 4.1l. Length frequency (50 mm intervals) of commercial catch of King George whiting sampled for the west and south regions of WA for 1999 to 2002.

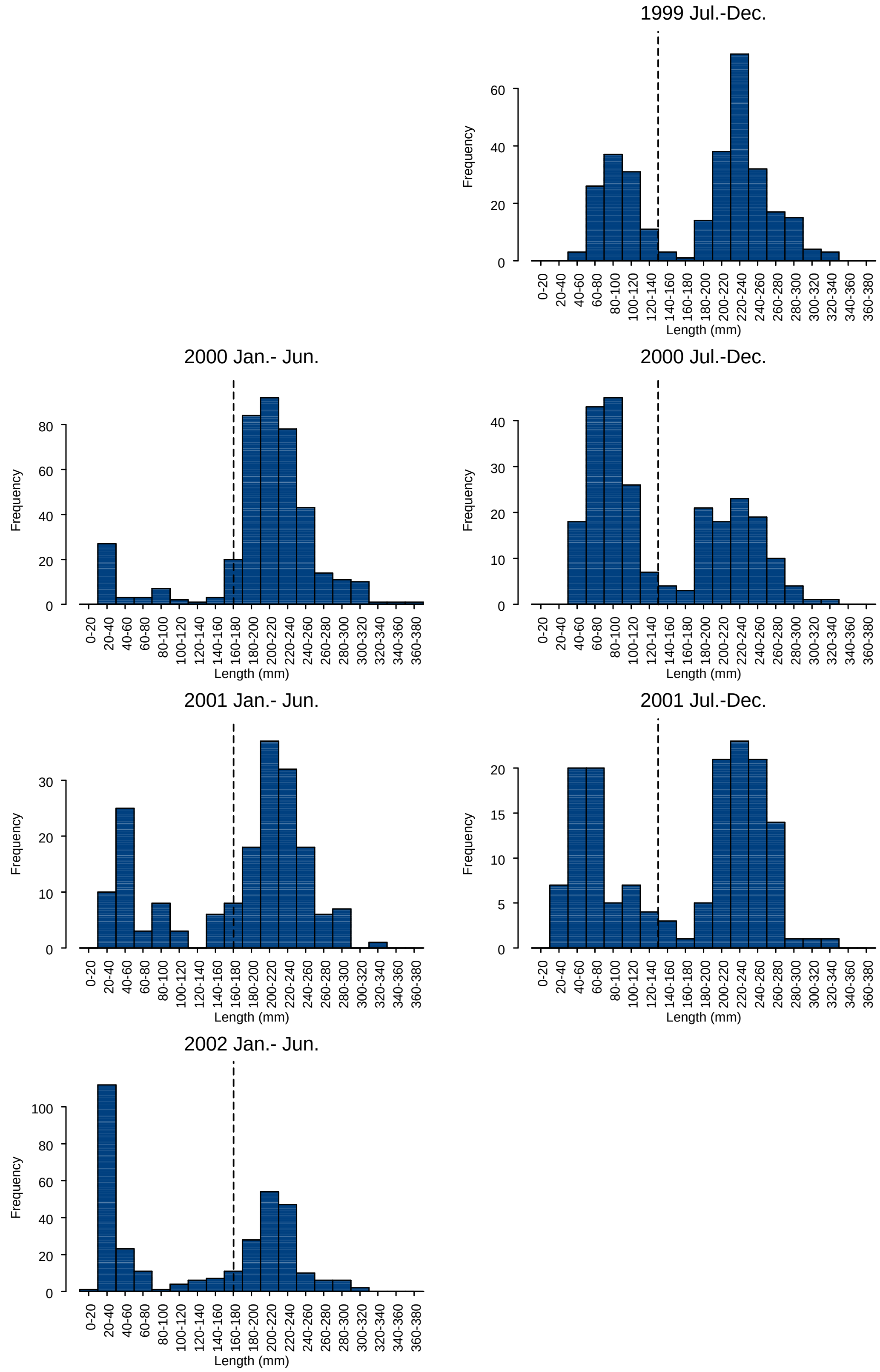


Figure 4.1m. Length frequency distribution (total length in mm) for fishery-independent yellow-finned whiting by time of year. The approximate upper length for 0+ fish is shown.

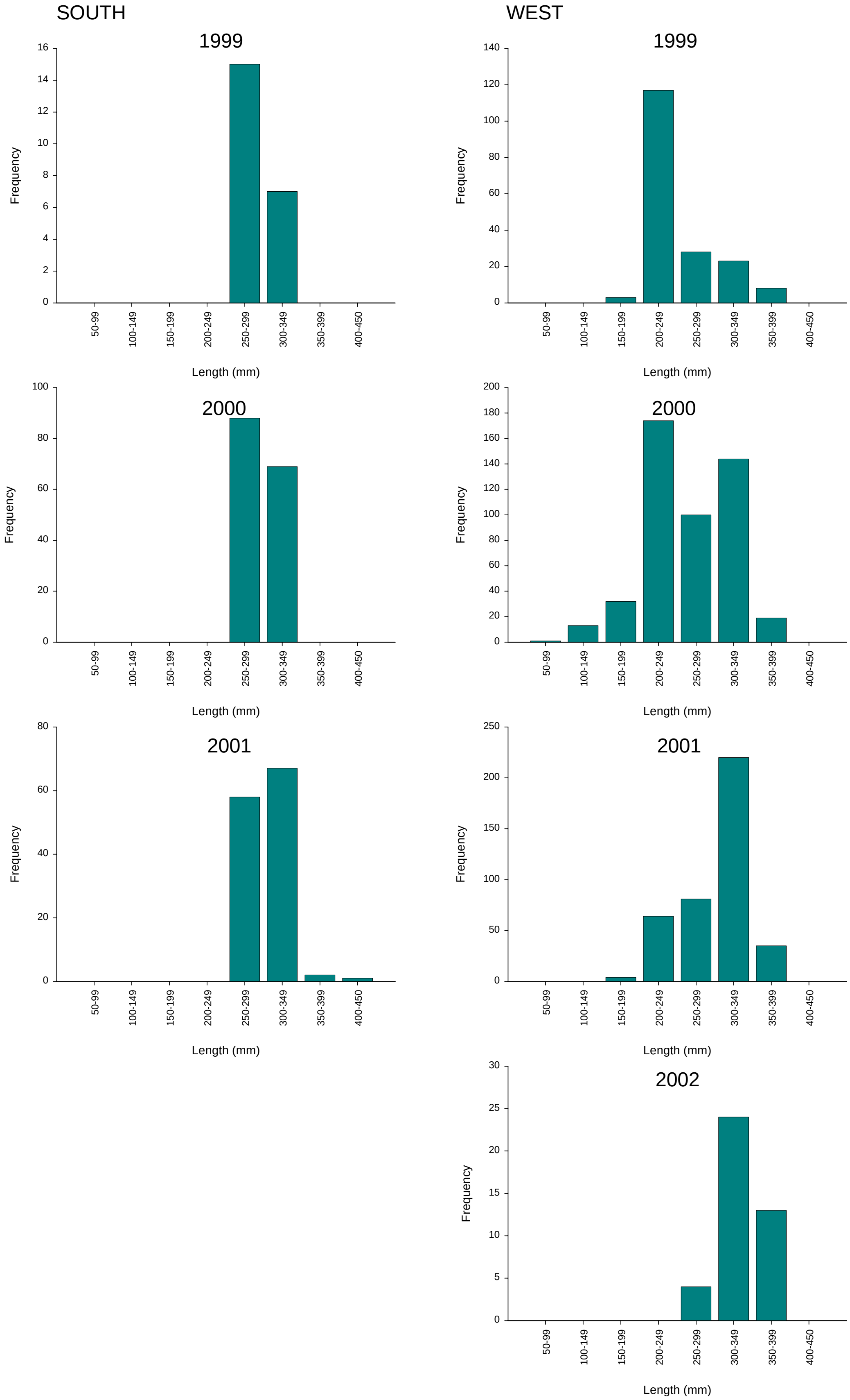


Figure 4.1n. Length frequency (50 mm intervals) of commercial catch of yellow-finned whiting sampled for the west and south regions of WA for 1999 to 2002.

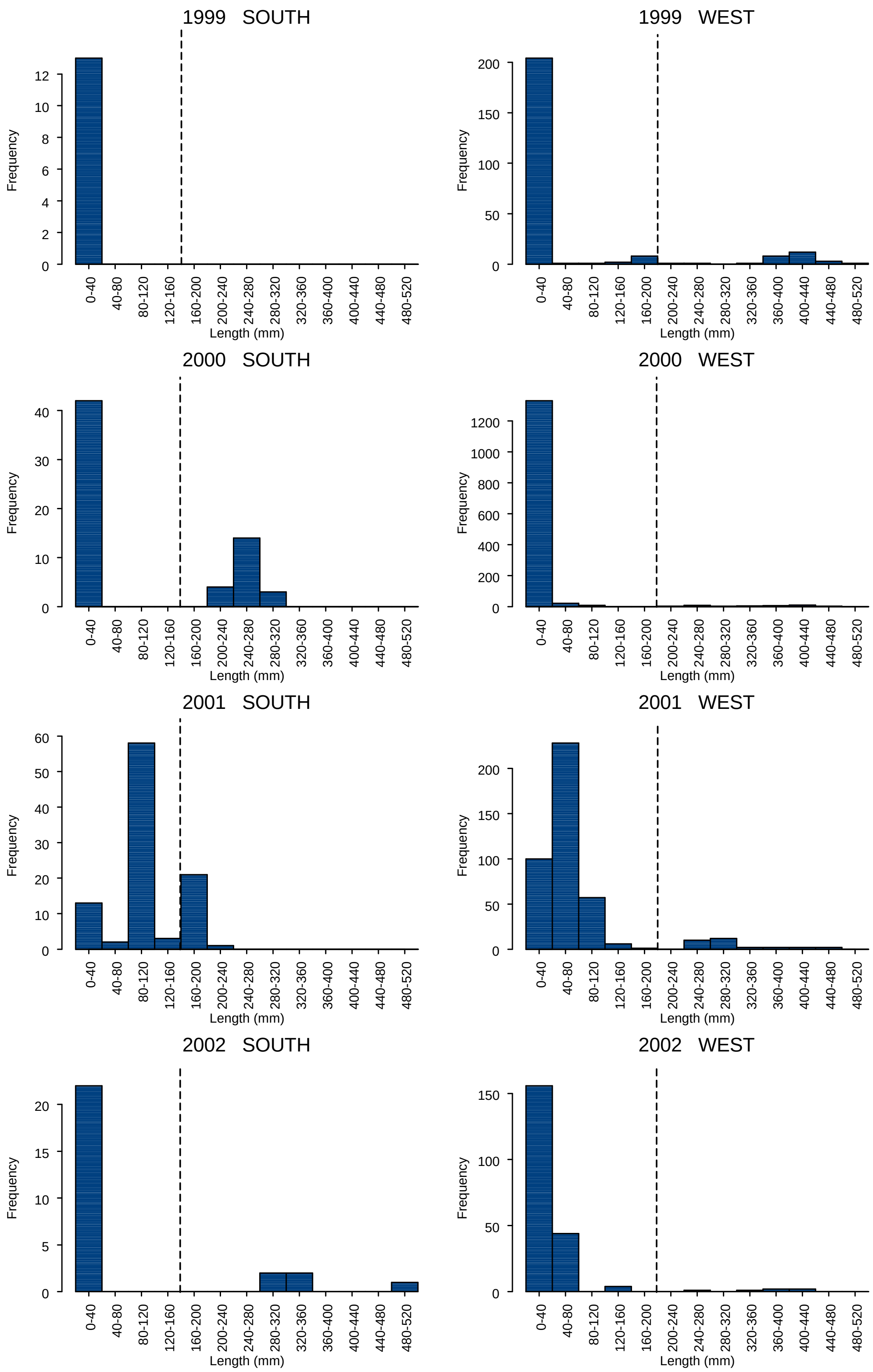


Figure 4.1o. Length frequency distribution (total length in mm) for fishery-independent sea mullet by region and year of capture. The approximate upper length for 0+ fish is shown.

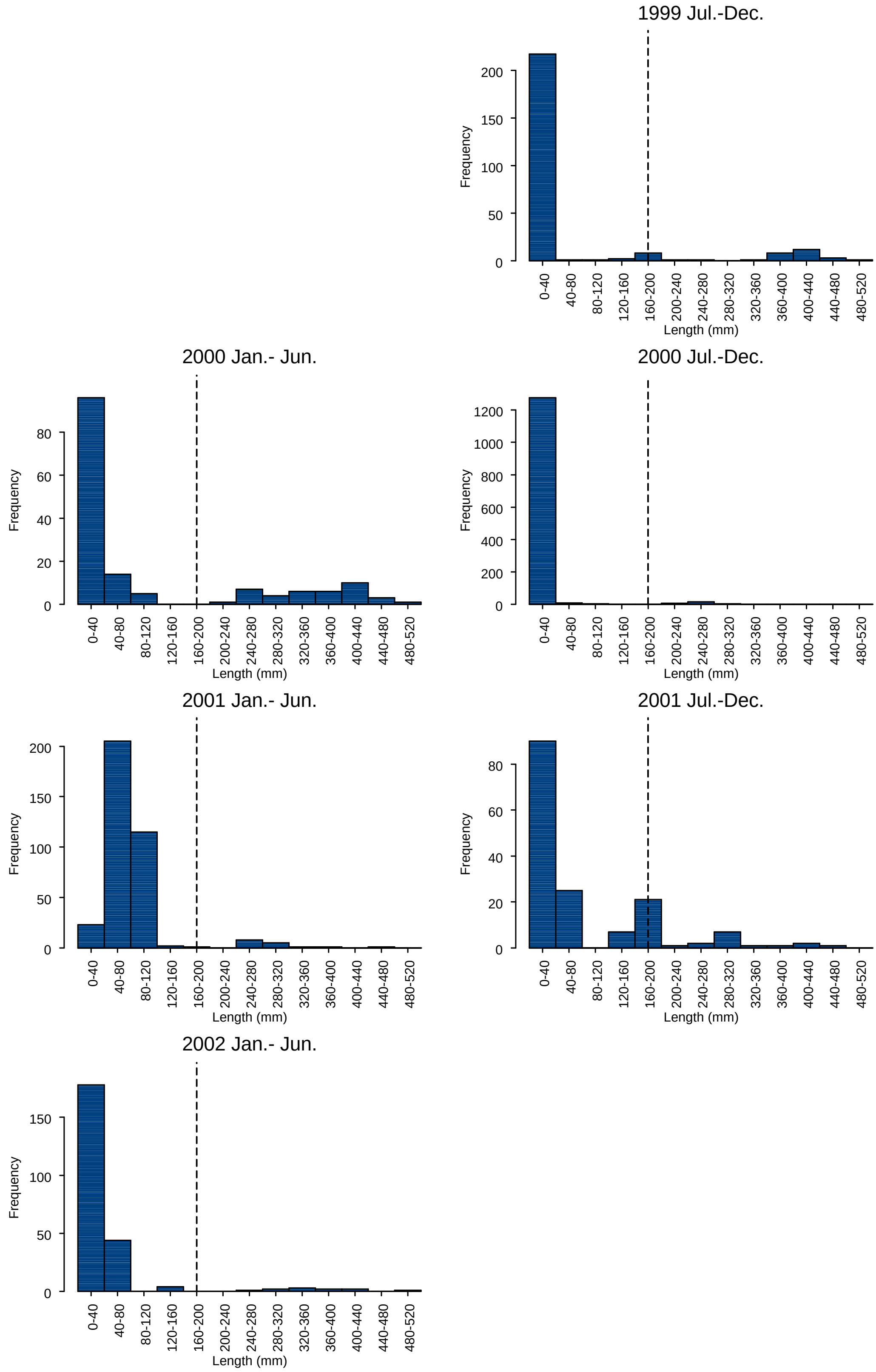


Figure 4.1p. Length frequency distribution (total length in mm) for fishery-independent sea mullet by time of year. The approximate upper length for 0+ fish is shown.

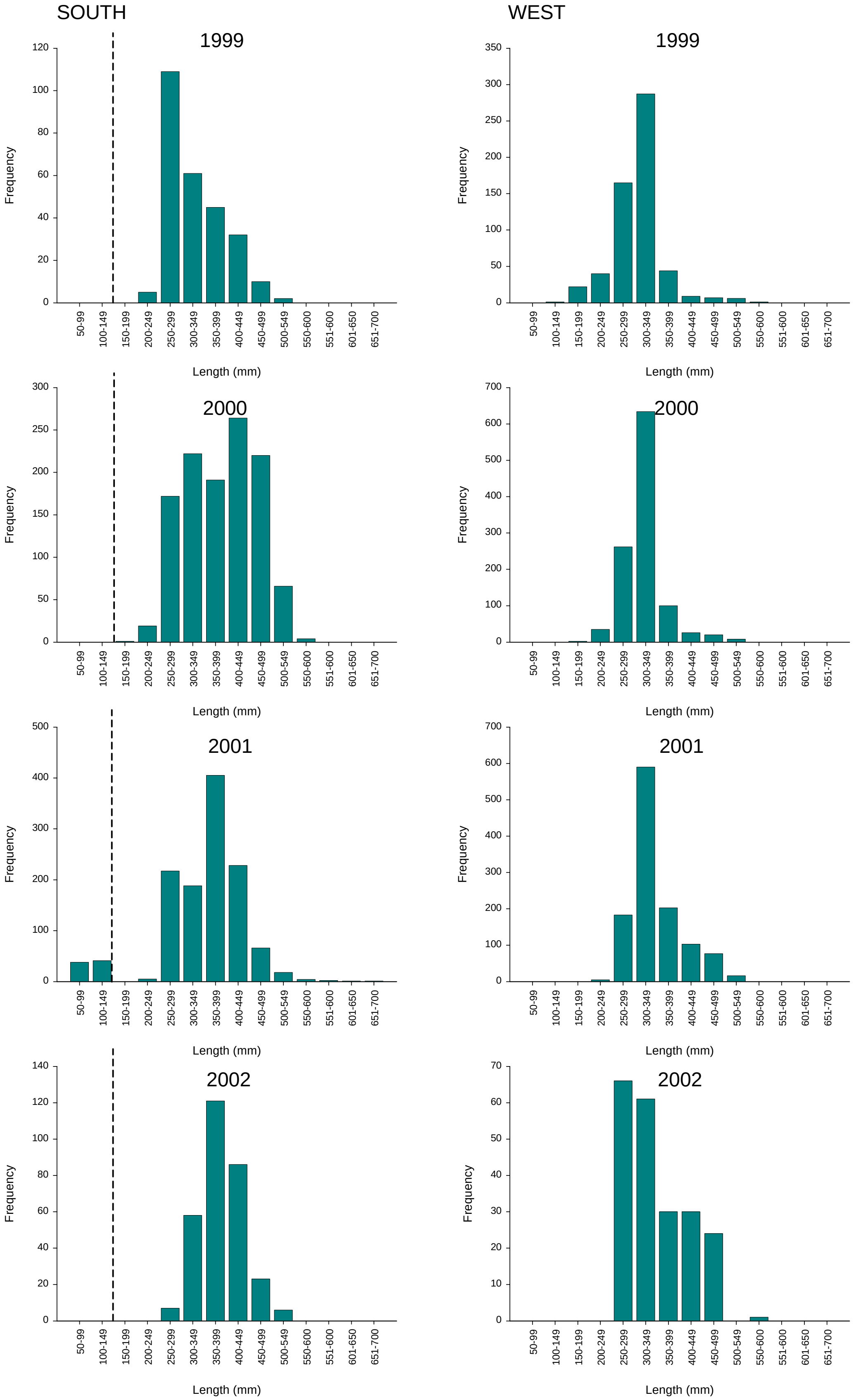


Figure 4.1q. Length frequency (50 mm intervals) of commercial catch of sea mullet sampled for the west and south regions of WA for 1999 to 2002.

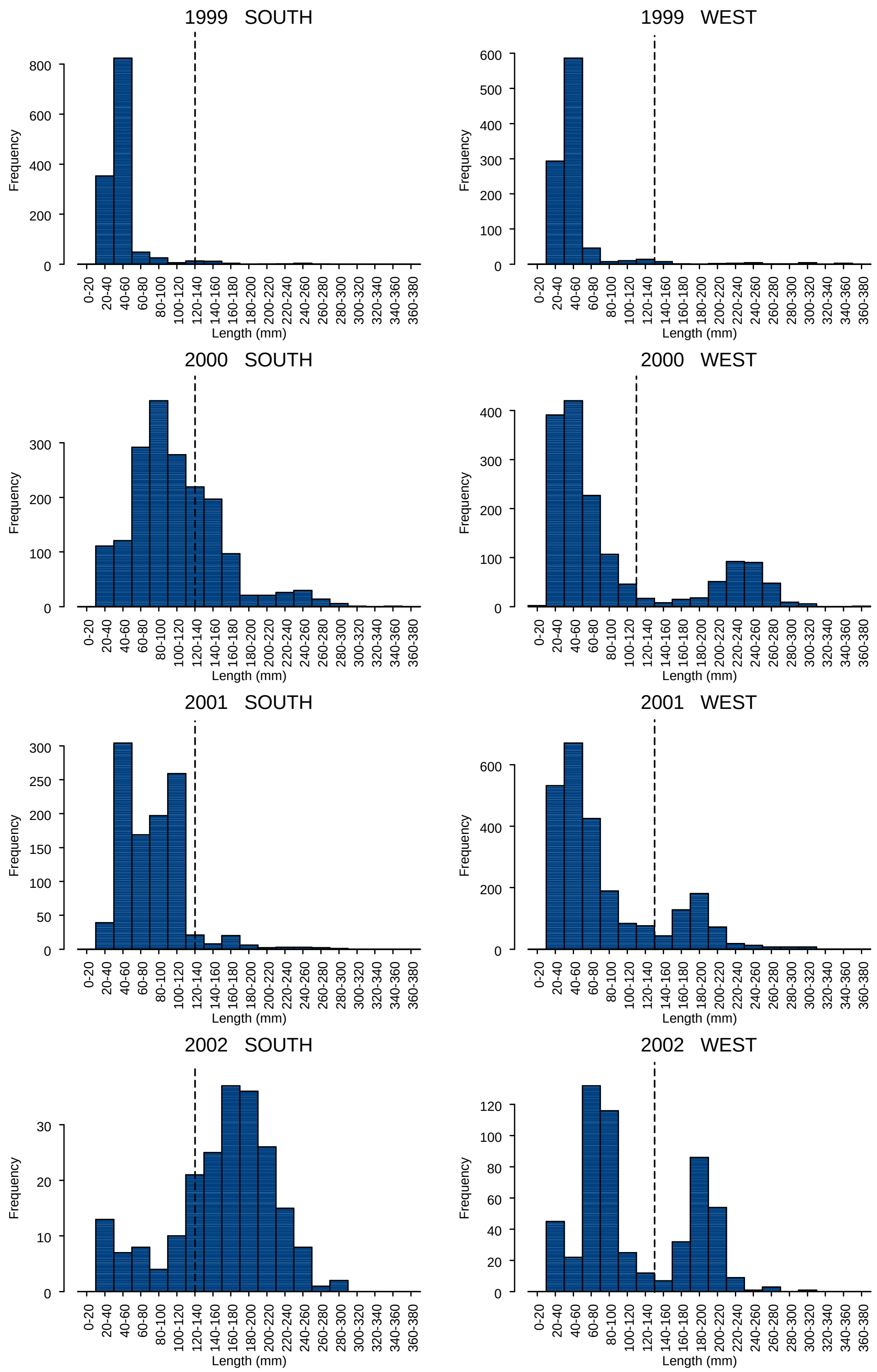


Figure 4.1r. Length frequency distribution (total length in mm) for fishery-independent yellow-eye mullet by region and year of capture. The approximate upper length for 0+ fish is shown.

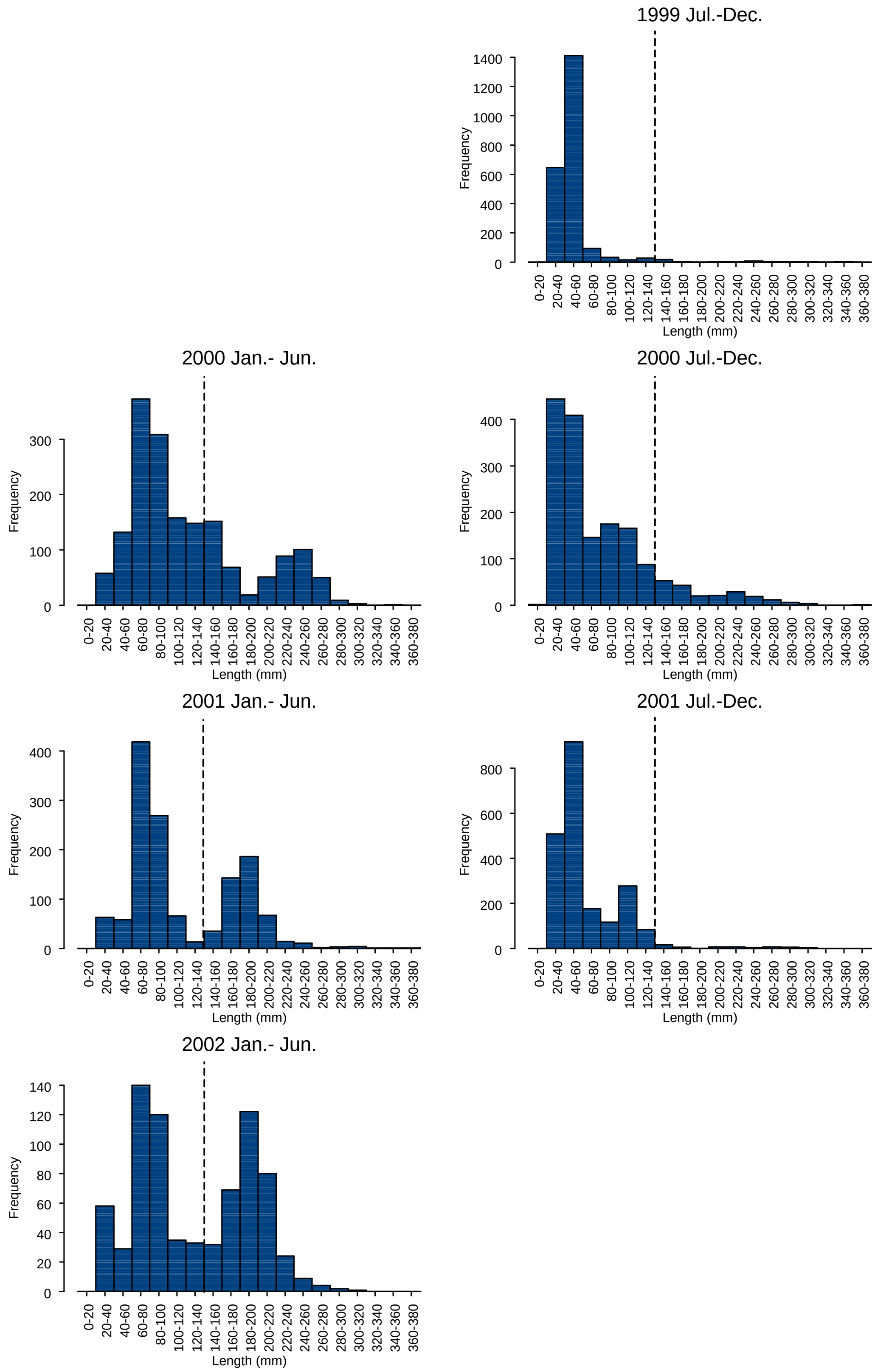


Figure 4.1s. Length frequency distribution (total length in mm) for fishery-independent yellow-eye mullet by time of year. The approximate upper length for 0+ fish is shown.

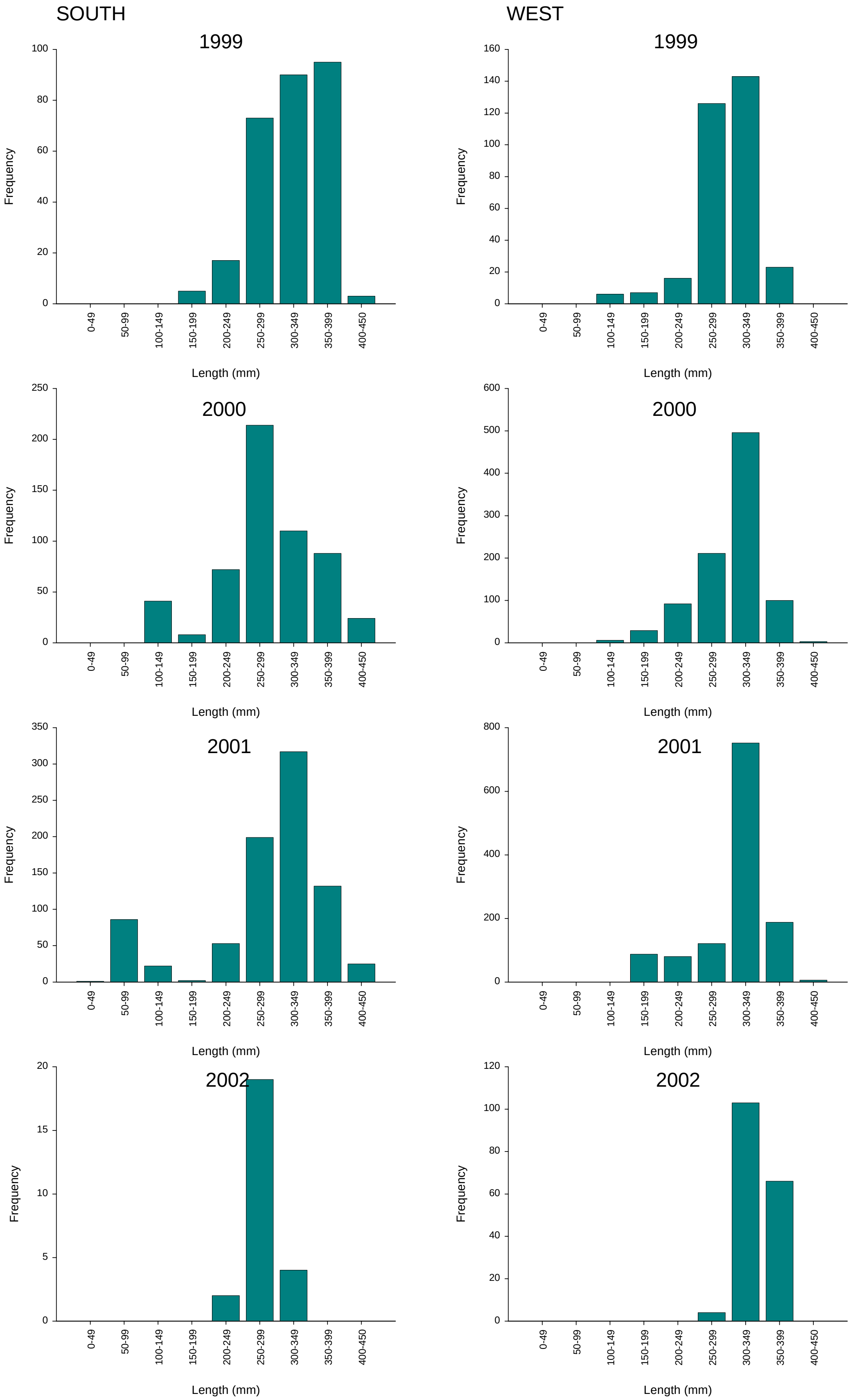


Figure 4.1t. Length frequency (50 mm intervals) of commercial catch of yellow-eye mullet sampled for the west and south regions of WA for 1999 to 2002.

Length-weight relationships

The analyses demonstrated that sex (male vs. female) was not a significant factor in the length-weight relationship for any of the seven species (Figure 4.2a-g). This result is not unexpected as it is not an uncommon situation for temperate water finfish that, in general, do not show sexual dimorphism regarding size.

Most samples were collected during 1999 and 2000. There was no significant difference in the length-weight relationship between 1999 and 2000 for Australian herring (Figure 4.2a), yellow-fin whiting (Figure 4.2e), sea mullet (Figure 4.2f) and yellow-eye mullet (Figure 4.2g). There were not adequate Australian salmon samples available for analysis (Figure 4.2b).

Both tailor and King George whiting were longer and heavier in 2000 than in 1999 (Figures 4.2c, d). While it is difficult to explain this result, we believe it is an artefact of sampling; as our network of commercial fishers grew over the last two years of the project we are able to obtain a greater number of fish collected from a wider diversity of locations for both tailor and King George whiting.

Temporal analysis by season (summer and autumn versus winter and spring) demonstrated that larger yellow-finned whiting were found in the winter and spring while larger sea mullet were collected during the summer and autumn. Season of capture was not a significant factor in the length-weight relationship for Australian herring, Australian salmon, tailor and yellow-eye mullet. There were insufficient data for a seasonal comparison for King George whiting. These results highlight what might be species-specific growth rates as well as the availability of various size classes of fish to the research and commercial fishing gear during different seasons.

Lastly, we examined spatial differences between fish collected from the west and south coasts. There was a significant difference between the samples collected from the west coast and the south coast for Australian herring, tailor and sea mullet. Larger Australian herring and tailor were collected from the south coast while larger sea mullet were sampled from the west coast. There was no significant difference found for yellow-eye mullet. There were insufficient samples from both regions to analyse the data for Australian salmon, King George whiting and yellow-finned whiting.

Table 4.3. Length-weight relationships for the seven key species. Weight is in grams and length is total length in mm.

Australian herring (n=2,963)	weight = 1.44 * 10^{-5} * $\text{length}^{2.94}$
Australian salmon (n=196)	weight = 1.30 * 10^{-6} * $\text{length}^{3.36}$
Tailor (n=337)	weight = 1.15 * 10^{-5} * $\text{length}^{2.97}$
King George whiting (n=1099)	weight = 1.10 * 10^{-6} * $\text{length}^{3.29}$
Yellow-finned whiting (n=934)	weight = 2.02 * 10^{-6} * $\text{length}^{3.24}$
Sea mullet (n=860)	weight = 4.72 * 10^{-6} * $\text{length}^{3.15}$
Yellow-eye mullet (n=4,236)	weight = 7.72 * 10^{-6} * $\text{length}^{3.02}$

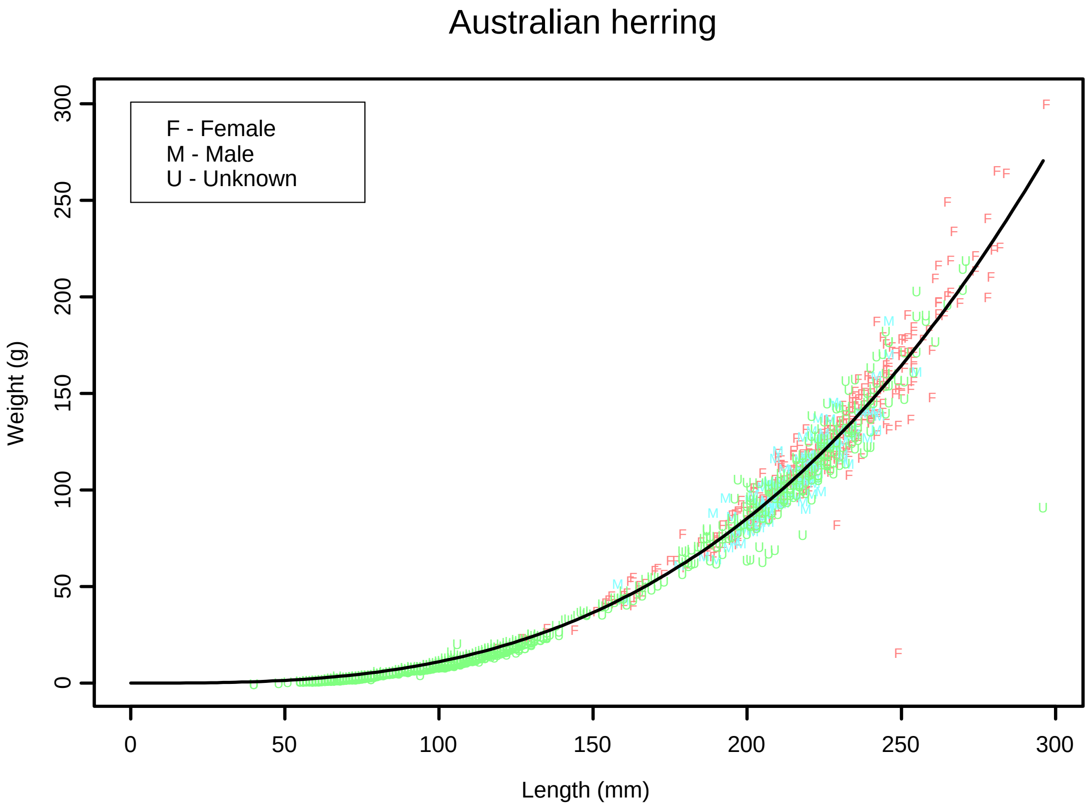


Figure 4.2a. Length-weight relationship for all Australian herring collected during the project.

Western Australian salmon

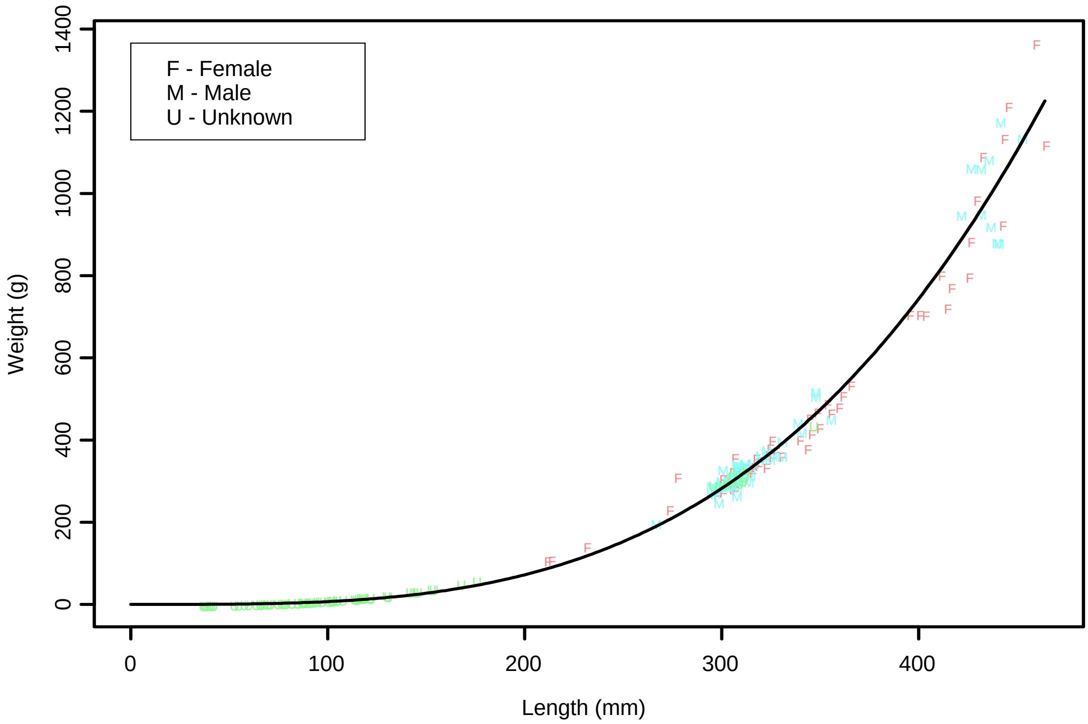


Figure 4.2b. Length-weight relationship for all Australian salmon collected during the project.

Tailor

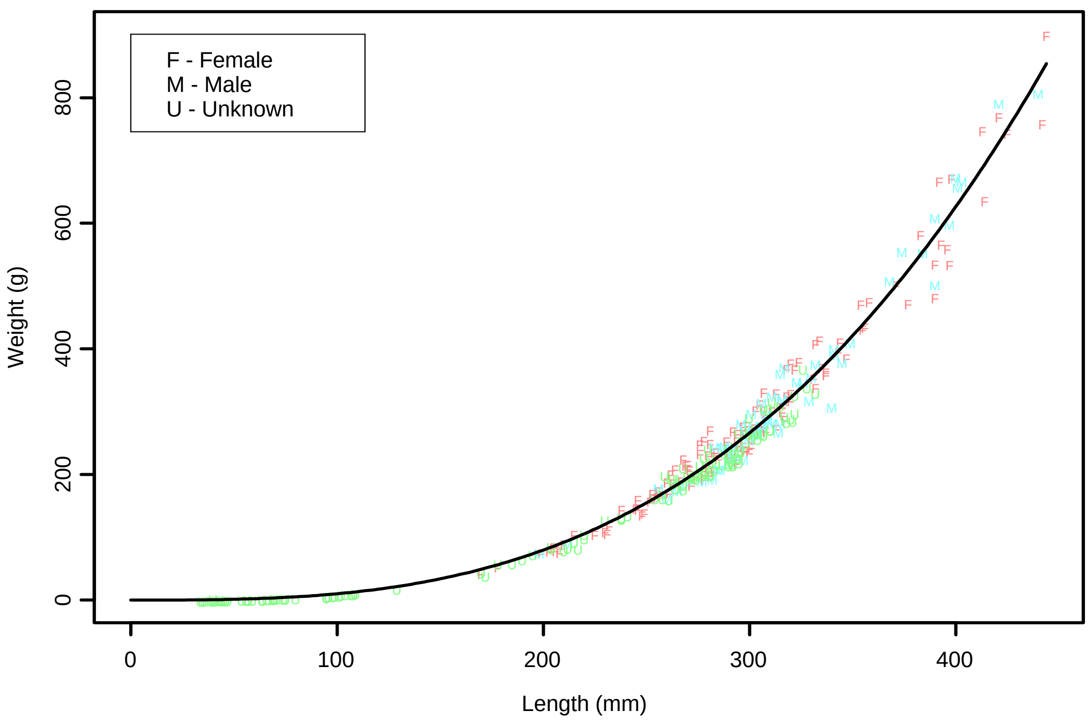


Figure 4.2c. Length-weight relationship for all tailor collected during the project.

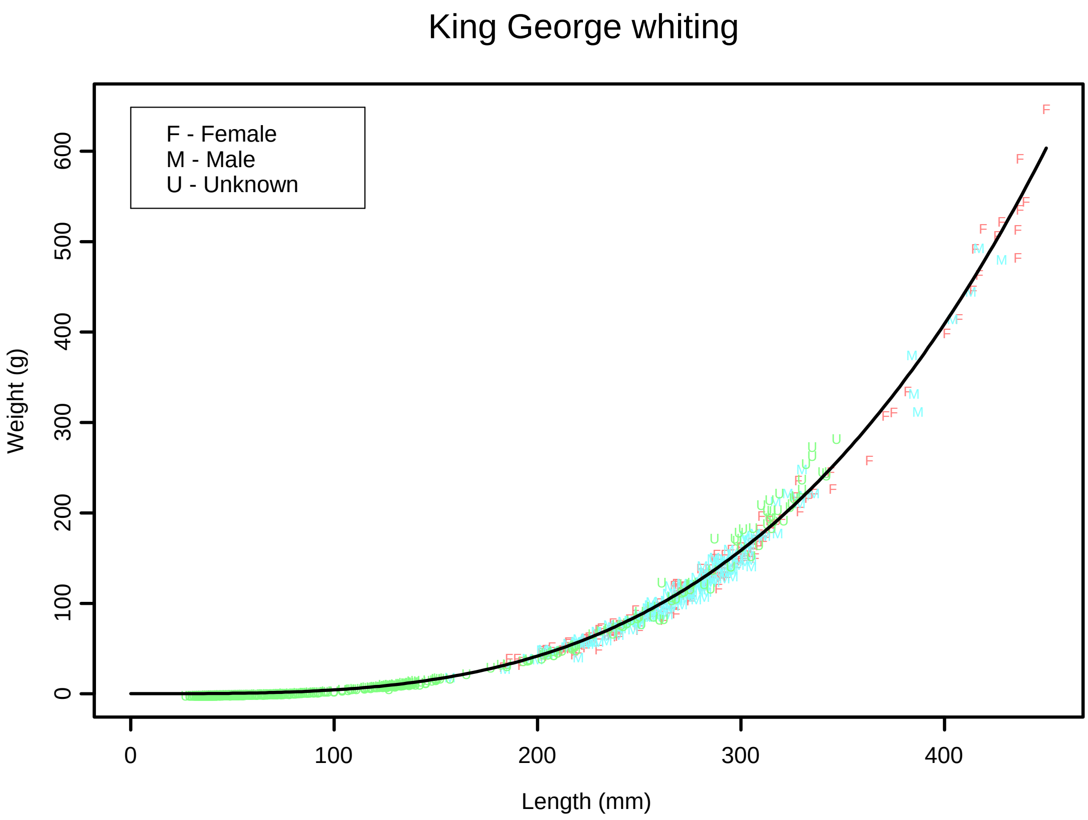


Figure 4.2d. Length-weight relationship for all King George whiting collected during the project.

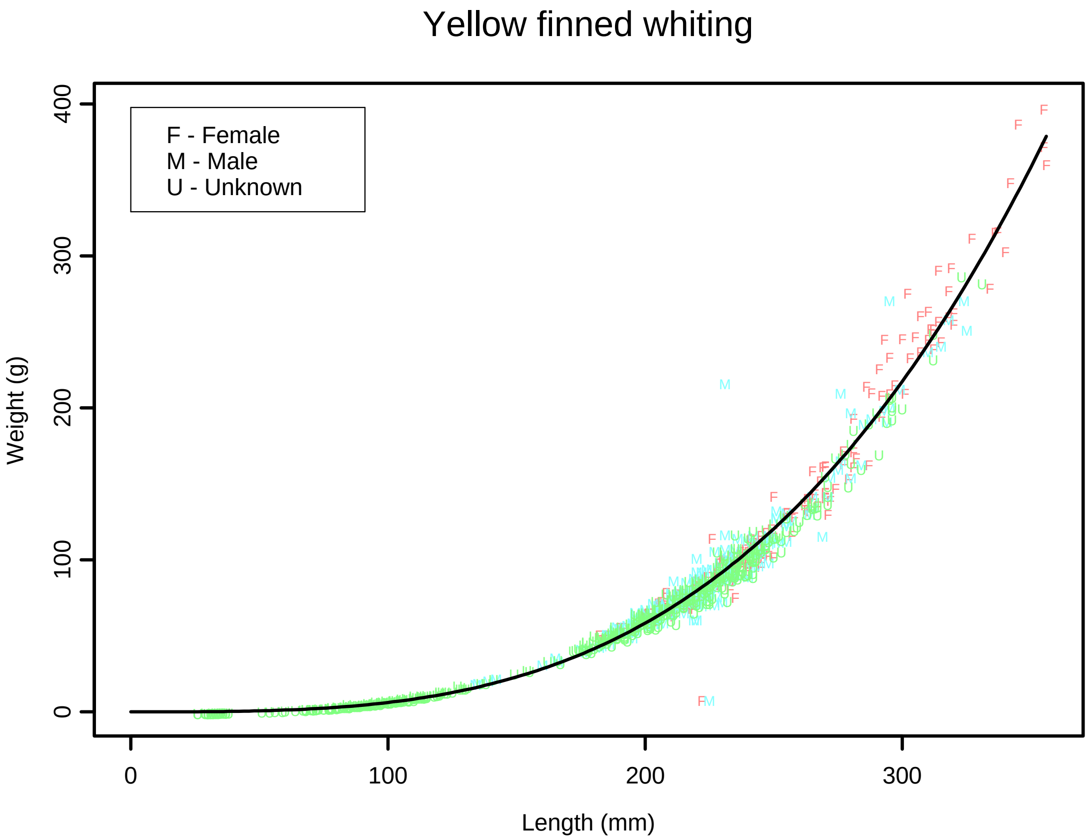


Figure 4.2e. Length-weight relationship for all yellow-finned whiting collected during the project.

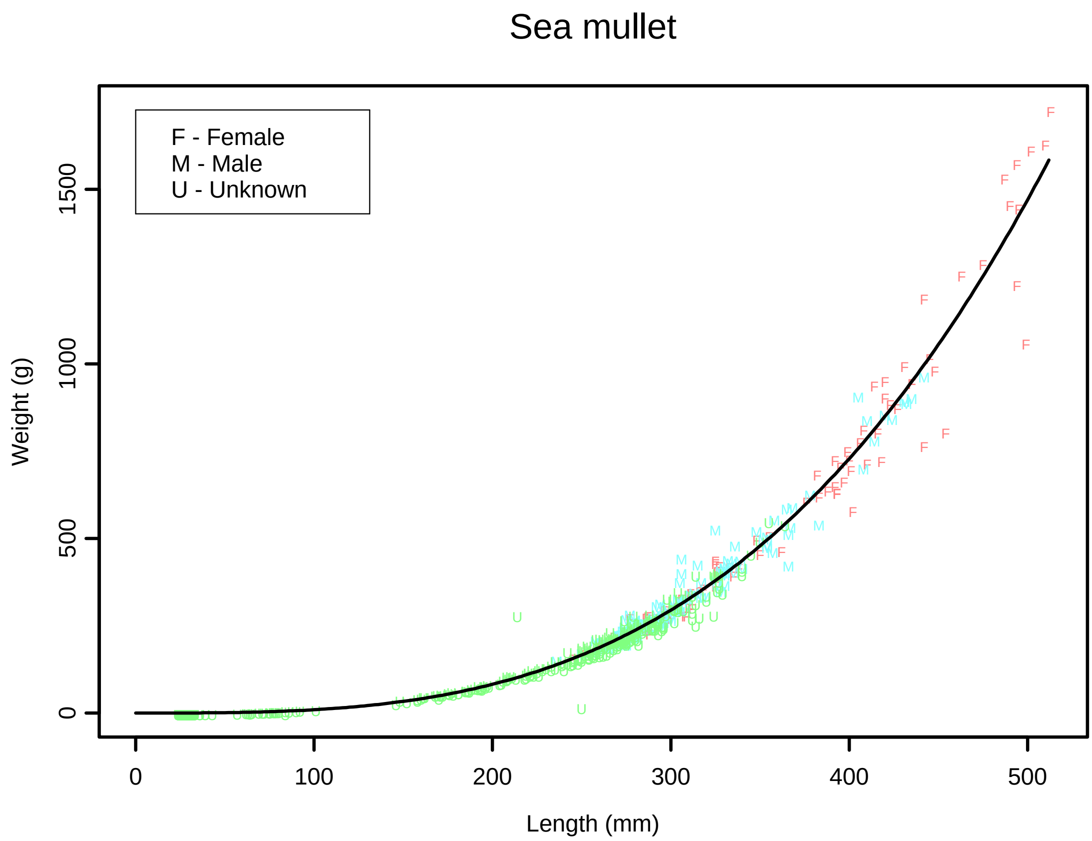


Figure 4.2f. Length-weight relationship for all sea mullet collected during the project.

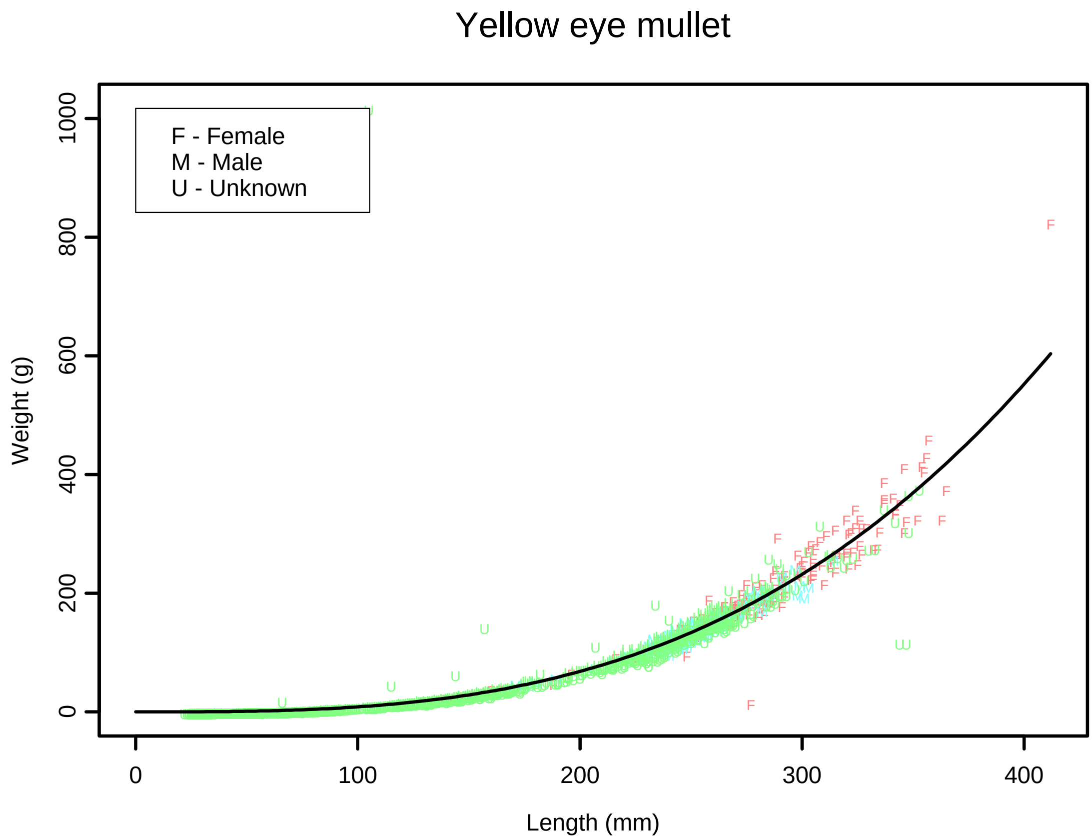


Figure 4.2g. Length-weight relationship for all yellow-eye mullet collected during the project.

4.4 Discussion

Length variability

Spatial differences in lengths of 0+ fish related to biological variability and or sampling biases between regions. Possible influences on the results include regional variations in recruitment patterns, habitat usage, or accessibility of nursery areas to the sampling program. For example, the Mangles Bay west coast site is one of the most important King George whiting nursery areas, where the smallest 0^+ fish were collected. On the south coast we only 'discovered' valuable nursery areas during the later part of the study and we have fewer 0^+ fish from those sites.

Interannual variability in lengths of 0^+ fish was common, but the patterns differed between species. The simplest explanation is that recruitment varies temporally between years. This can result from variable success during the spawning season; thus, some periods of the spawning season may give rise to higher proportions of recruitment than others. Furthermore, recruitment for some fish species can occur in pulses; due to natural environmental and biological variability, the number and timing of recruitment pulses can also vary between years. Depending on the occurrence and timing of such pulses, monthly sampling may in some cases not be adequate to sample these intermittent but potentially important recruitment events.

Young of the year of each of the seven species exhibited differences between the Jan- - Jun. and the Jul. – Dec. periods. 0^+ herring, salmon, King George whiting were larger in the first half of the year than in the second half of the year, while the opposite occurred for yellow-finned whiting and yellow-eye mullet. These seasonal differences were attributable to the timing of the spawning period whereby there is a change in vulnerability of newly settled 0^+ fish. Subsequently, lowered abundance of newly settled fish coupled with the fast growth typical of young fish resulted in larger fish in one or the other of the alternate six-month period. For example, because Australian herring spawn during May-June, their greater size in the January-June period reflects the fact that they are 6 months to 1 year old, whereas those caught from July to December were predominantly <6 months old.

Adults typically exhibited interannual differences in mean length. There may have been several causes for this; furthermore, the causes for interannual differences may have varied between species. These differences may have resulted from either biological, environmental or fishery-related factors, or a combination of these. The simplest possibilities are as follows. Annual variability in recruitment strength is well recognised as a factor that can cause variations in average size of fish in a population, as has been documented for the Australian pilchard *Sardinops sagax* (Gaughan *et al.*, 2002). Alternatively, environmental variability can cause changes in the distribution of fish available to commercial operators. Finally, changes in markets, or changes in availability can cause significant changes in behaviour of fishers, which could also result in changes in size classes of fish caught. These possibilities highlight the need to minimise the effects of those factors that can be controlled. A key factor that requires close attention is the sampling program. In this study the sampling of adults was constrained by the behaviour of the commercial fishers (and their markets), hence the possibility that this factor influenced the size distribution of the catch. Preliminary investigation of the variability in commercial fishing should be undertaken prior to this type of research to ensure that the sampling will be adequate. A good knowledge of the inshore commercial fishery of south-western Australia before this project started and the undertaking of fishery-independent sampling using commercial methods together provided the basis for developing an adequate "adult" sampling program. Nonetheless, the dynamic nature of the commercial fishery and the markets meant we were unable to fully control variability from fishery related factors.

The differences in mean length between the south and west coasts were attributable to spatial characteristics of the life history and fishery characteristics. In the case of Australian salmon, samples of adults were dominated by those obtained during the early part of the year from the main salmon fishery on the south coast ocean beaches, with these contributing the majority of the large fish. For King George whiting, commercial fishers working on the west coast routinely caught large mature fish routinely at offshore sites in Geographe Bay, whereas on the south coast King George whiting are targeted as younger (sub-adults) in Wilson Inlet and Oyster Harbour (Albany). Generally, the larger Geographe Bay fish were caught during the winter months, as the adult fish were moving offshore in preparation for spawning.

While it is difficult to assess the reason for the significant difference in the monthly length frequency by year, with Australian herring the larger adults caught during the first half of the year include those partaking in the March-May spawning migration, thus comprised of many older and larger fish preparing for spawning.

Length-weight relationships

The spatial differences in the length-weight relationship noted for some of the seven species may be explained by differences in the season of capture, available food resources and water temperature. These data were provided here for the benefit of the reader.

4.5 References

Gaughan, D.J., Fletcher, W.J. & McKinlay, J.P. (2002). Functionally distinct adult assemblages within a single breeding stock of the sardine, *Sardinops sagax*: management units within a management unit. *Fisheries Research* 59: 217-231.

CHAPTER 5.0 The development of a rigorous sampling method for determining an index of recruitment for seven inshore fish species from south-western Australia

Suzanne Ayvazian, Montgomery Craine, Gabrielle Nowara and Dan Gaughan

Objective 1. Develop a robust, low cost, effective sampling method for an on-going recruitment index for seven key inshore finfish species from south-western Australia.

5.1 Introduction

Uncertainty around the mechanisms and life stages that provide the most accurate prediction of year class strength and future catches (Sundby *et al.* 1989) has contributed to a lack of consistent methods to study such relationships, which has hampered stock assessment development in some cases (Shepard, 1997). The cod (*Gadus morhua*) is one of the few fish for which detailed temporal, spatial and environmental information exists for recruitment indices, mortality rates of early life-history stages and relationships between recruitment and future catches (Campana *et al.* 1989, Sundby *et al.* 1989, Myers and Cadigan 1993a, Helle *et al.* 2000 and others). Some of this stock-prediction research was developed to aid efforts in understanding the causes of the decline in cod stocks from the north-western Atlantic; while research on Arcto-Norwegian cod stocks has been initiated in an effort to recommend a consensus approach amongst researchers for assessing recruitment-catch relationships. This issue was addressed by the ICES Working Group on the Methods of Fish Stock Assessment convened in the mid- 1980s and resulted in the use of a regression and combination methods assessment (Shepard 1997).

At present, there is no single mechanism or life-history stage identified to explain variation in year class strength either between stocks of a single species or between species. The inter-annual variability in year class strength for cod stocks have been variously attributed to mortality at all life history stages. One difficulty in presenting this information in a concise and comparable format is the lack of consistent definitions for the life history stages for cod. Despite this difficulty in semantics, it has been proposed that the greatest influence on the determination of year class strength comes from variation in the egg and early larval stages, the larval and early juvenile stages, the juvenile stage (sometimes differentiated into pelagic and settled juveniles) and the 0^+ age group (Hjort 1914, Bailey and Houde 1989, Campana *et al.* 1989, Sundby *et al.* 1989, Myers and Cadigan 1993a, Helle *et al.* 2000). The inter-annual variability in survival at the early life history stages can be influenced by both density independent and density dependent factors. In a study of several populations of cod and other gadoid and flatfish species, Myers and Cadigan (1993b) demonstrated that estimates of the inter-annual variability in the density independent component of juvenile mortality was negligible compared to recruitment variation, except for the North Sea sole. Further, Myers and Cadigan (1993a) modelled the density dependent components of mortality and concluded that while the juvenile stage is important for population regulation in most species examined, year class strength variation may be attributable to the larval stage or early juvenile stage. Density dependent regulation may be related to competition for food, increased predation, and/or limited availability of juvenile habitat. Additionally, Myers *et al.* (1993) indicated the absolute abundance of some marine fish populations has been attributed to spawning stock biomass.

Variation in year class strength in fish has been attributed to both biological and physical variables and, while a complex problem, understanding some of the dominant features of this problem will be beneficial in resolving stage-specific recruitment issues for the present suite of species. Both density-independent and density-dependent factors influencing specific life history stages can affect year class strength, and these are likely to operate in a cumulative manner. For example, positive effects can be neutralised by equally strong negative effects. Koslow and Thompson (1987) investigated recruitment to cod and haddock stocks in the northwest Atlantic. Regression analysis suggested that year class strength in these cod stocks was determined by large scale meteorological events while haddock recruitment to the Georges Bank fishing grounds was negatively associated with the abundance of 0^+ mackerel. Bogstad *et al.* (1994) investigated cannibalism and year class strength in Atlantic cod across three Arcto-boreal regions (Barents Sea, Iceland and eastern Newfoundland). Their results indicated that many of the cod prey are 0^+ cod. Importantly, the frequency of occurrence of cannibalism by the older cod increases with the abundance of the juvenile cod.

Assumptions of the proportional relationship between spawner biomass and egg production was tested for north-east Atlantic cod (Marshall *et al.* 1998). They conclude that compared with traditional virtual population analysis of spawner biomass, estimation of the total egg production may be an improved index of recruitment. Sundby *et al.* (1989) examined mortality rates during early life history stages of cod off Norway and concluded that year class strength is most influenced before early juvenile stages, and it is these indices that will provide a predictive tool. Helle *et al.* (2000) presented a considered study of recruitment indices developed as an egg abundance index, early juvenile abundance index, 0^+-group abundance index, a bottom trawl and acoustic survey for 1, 2 and 3 year old cod and standard virtual population analysis (VPA) estimates of abundance. Regression analysis of these indices determined that the early juvenile abundance index is the best indication of subsequent stock abundance as 2 and 3 year olds. Campana *et al.*'s (1989) examination of biological factors involved with explaining year class strength in cod and haddock (*Melanogrammus aeglefinus*) off Nova Scotia determined that while egg and larval abundance was not influential, the abundance of pelagic and settled juveniles reflected subsequent year class strength. Further to Campana *et al.* (1989), Anderson and Dalley (1997) indicated that indices based on abundance of the pelagic juvenile stage will predict year class strength for cod stocks off the northeast coast of Newfoundland, and three important measurements are required during this stage: abundance, size and distribution.

Magnússon and Jóhannesson (1997) found significant statistical relationships between the 0^+ age class abundance of redfish stocks (*Sebastes* spp.) in the Greenland Sea and subsequent recruitment to the fishery, assuming a 13 year time lag.

These few studies have been presented to highlight the complex nature of determining an appropriate stage-specific recruitment index.

The aim of the present study was to develop a statistically sound recruitment index that would best predict future commercial catches of seven key estuarine and inshore finfish using the 0^+ life stages. These life stages can be easily collected with standard beach seine nets and in addition to the data collected during this project there are data available from previous research on the biology of the Australian herring. The application of the recruitment index model will be tested on the following seven finfish species: Australian salmon, Australian herring, tailor, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet. These species are targeted by the commercial and recreational sectors along south-western Australia. The approach used here is to 1) compute recruit catch rate indices for each of the seven species; 2) compile the commercial catch data over the same time period for the west and south coast regions; 3) develop prediction models of commercial catch using annual 0^+ catch rate indices lagged by an appropriate time interval calculated from examination of the age structure of the commercial fishery for each species and; 4) refine the prediction model to maintain an adequate statistical relationship while reducing the costs of the recruit sampling program.

5.2 Methods

Adults and recruits of the seven fish species were sampled as described in Chapters 2 and 3, respectively. Distribution of catch rates of recruits was also described in Chapter 2.

Compilation of databases

For each species, the 0^+ age group was established by substituting $t = 1$ year into the von Bertalanffy fitted equation (see Chapter 2) using the age-length data from the 2½ years of commercial sampling. The 0^+ age group for each species was then separated from the other ages in the fishery-independent database, thereby defining a 0^+ database.

The proportional age-structure of commercial catches over the 2 ½ year period for the south coast and west coast regions (Table 5.1) were derived by applying von Bertalanffy age-length growth estimates to all the available length data for each species. However, only the fish exceeding the commercial legal minimum length (LML) regulations are included in the table. Noting this criterion, there was no representation of the 0^+ age class in the commercial data and the proportion of 1^+ in the catch was low. The 2^+ and 3^+ age classes accounted for a large proportion of the commercial catch for each species, with the exception of the Australian salmon. This species became abundant in catches at 4^+ and older. These data were used to estimate the appropriate time-lags between 0^+ recruits and commercial fish, which in some case differed between the south and west coast to reflect the different age structure of the commercial catches between these regions. Because of the high level of variability in age structure among the seven species, the standard procedure used to estimate the lag period for each species was to derive a mean age using the mean length and the von Bertalanffy parameters. This mean age provided the first lag period to be employed in each analysis. A further two lag periods were also employed, these being 1 year either side of the mean age. This procedure was used in recognition that a single lag period may not be adequately representative of the commercial age structure.

Table 5.1. Age structure (proportions) of the commercial catch for each of the seven species by region between 1999-2002. Mean length ($\overline{TL}$), mean ($\bar{t}$) are also shown.

Species	Region	$\overline{TL}$	$\bar{t}$	0^+	1^+	2^+	3^+	4^+	$\geq 5^+$
Herring	South	221	2.9	0.000	0.142	0.466	0.160	0.048	0.184
	West	235	3.3	0.000	0.031	0.379	0.286	0.071	0.233
Salmon	South	567	4.0	0.000	0.153	0.138	0.032	0.205	0.472
	West	590	4.2	0.000	0.227	0.106	0.000	0.091	0.576
Tailor	South	371	2.8	0.000	0.236	0.323	0.283	0.102	0.055
	West	317	2.8	0.000	0.175	0.451	0.123	0.071	0.180
King George whiting	South	312	3.4	0.000	0.000	0.400	0.371	0.113	0.117
	West	381	3.2	0.000	0.163	0.142	0.399	0.253	0.042
Yellow-finned whiting	South	301	3.7	0.000	0.000	0.294	0.281	0.119	0.306
	West	283	3.3	0.000	0.000	0.414	0.216	0.172	0.197
Sea mullet	South	359	3.0	0.000	0.114	0.383	0.272	0.138	0.093
	West	337	2.3	0.000	0.491	0.247	0.096	0.091	0.076
Yellow-eye mullet	South	303	3.6	0.000	0.000	0.369	0.292	0.124	0.215
	West	299	3.0	0.000	0.015	0.465	0.371	0.133	0.017

Recruitment indices

Recruitment indices were obtained by maximizing the correlation coefficient between the catch rates for the commercial catches and the year-round mean catch rates of recruits at individual sites and over combinations of sites. At this time it was not possible to account for the potential effects of mortality or sampling efficiency on recruit abundance. Correlations against commercial catch were assessed against the recruit catch rates in the south, in the west or as a total. The commencement months of the recruitment seasons are pre-determined by the previous recruit catch rate plots (Chapter 3). This first series of analyses were undertaken because we do not have any evidence that suggests particular months of recruitment subsequently contribute more to the adult population than others. These analyses, which therefore use the annual mean recruitment (i.e. catch rates), provide a baseline for developing an optimal sampling strategy (i.e. reduced from the full 12-month program).

Because an aim of this project was to develop an optimal sampling strategy, the above analyses were followed by a second series of analyses that included criteria to reduce the number of samples required to represent recruitment. Therefore, we deliberately permitted a maximum sampling period of only six months and a maximum of only three locations for each species to keep potential sampling costs at a reasonable level. The criteria adopted for selecting a reduced sampling program explicitly recognise that the fit of the relationship may well be inferior to that provided by considering a whole year of sampling. However, with seven species to consider, poorer fits between abundance of recruits and adults will need to be considered so that all species can be monitored. For example, obtaining wider confidence limits for all seven species is considered a better option than having the tightest possible confidence intervals for fewer species. It must be recognized that the central aim with this study was to reduce the costs of the recruit sampling program (by sampling fewer months and or sites) but while maintaining adequate statistical relationships. This approach is in keeping with the need to develop sampling strategies that can realistically be implemented given logistical and economical constraints. For each species, the recruit catch rates for every possible period of three consecutive months were iteratively tested against the commercial catches.

Linear correlation coefficients and corresponding *p*-values are provided for each relationship. Relationships are linear or nonlinear depending on the location of the origin relative to the observations or the curvature of the observations. The nonlinear relationships are of the Beverton-Holt form:

$$C(t) = \frac{a\,r(t-l)}{b\,r(t-l)+1} + \varepsilon(t),$$

where *t* corresponds to the season, *l* is the lag factor, *r* is the recruitment index function, *C* is the commercial catch function, *a* and *b* are parameters to be estimated and $\varepsilon \sim N(0, \sigma^2)$ is the error function. A *t*-test of $b \neq 0$ effectively tests the nonlinearity of the relationship. Explanations for nonlinear relationships include density-dependent mortality (especially for species involving longer lags) or missing recruitment information. All correlation coefficients quoted are linear correlation coefficients. These only give a guide for the nonlinear cases.

Once the analyses have been undertaken to identify both the theoretical “unrestricted” and “reduced” optimal sampling strategies, the results for both are considered together to produce the most likely achievable sampling program.

5.3 Results

Annual mean catch rates of recruits

Annual mean catch rates of 0^+ recruits have been calculated for a six-year period where possible (Table 5.2). For Australian herring, yellow-eye and sea mullet there were enough data to derive separate west coast and south coast recruitment indices; however comparison of these regional annual means did not reveal any trends. Additionally, there were no obvious relationships between species and years of high/ low recruitment. The Australian herring recruitment from Poison Creek/Emu Beach was ~10-15 times greater than at Warnbro Sound/Emu Beach; however the former annual mean also had substantial variation associated with it, as opposed to the latter. The 1998/99 recruitment values punctuated the between-species variability over the six-year time series. Mean annual recruitment was highest for west coast herring, Australian salmon from the south coast and tailor from the west coast in 1998/99, while recruitment of yellow-eye mullet from the west and south coast were the lowest for the six-year time period.

Table 5.2. Annual 0^+ catch rates (using all months) for each of the seven species from key sites.

Collection year	96/97	97/98	98/99	99/00	00/01	01/02
Herring –POIS/EMUB	35.07	33.57	26.44	29.56	20.18	11.36
Herring – WARN/EMUB	1.37	1.61	2.12	1.33	1.34	1.34
Salmon – POIS/EMUB	1.56	2.53	5.10	0.79	1.17	1.03
Tailor – KOOM/PIN	0.79	0.90	1.679	0.79	0.35	0.13
KG Whiting – MANG	NA	NA	NA	11.00	11.98	6.42
Yellow-finned whiting – MANG	NA	NA	NA	3.65	4.31	4.75
Sea mullet – EMUB/POIS	3.35	0.04	4.38	0.46	0.29	0.47
Sea mullet – WARN/PIN/KOOM	0.31	2.54	0.19	2.81	0.30	0.25
Yellow-eye mullet – EMUB	29.29	19.00	6.60	41.36	12.18	11.00
Yellow-eye mullet – WARN/PIN/KOOM	11.93	12.24	4.79	10.78	11.61	8.85

Recruitment indices

The capability of each of the annual recruitment levels to predict the commercial catch, using the appropriate time lag, varied between species and regions. In some cases it was possible to achieve a statistical relationship of equal or improved statistical significance using an optimised recruitment index (not all 12 months required). The recruit catch rates of Australian herring, assuming recruitment commenced in September and continued throughout the year, is presented for Poison Creek/Emu Beach versus the commercial catch along the south coast and for Warnbro Sound/ Emu Beach versus the west coast commercial catch (Figure 5.1a, b). In both cases the relationships were marginally significant ($0.05<p<0.1$), but a lack of contrast in the latter model (Figure 5.1b) resulted in a clustering of data points that undermines the efficacy of the fit. However, justification of the use of the index based on catches from Poison Creek and Emu Point on the south coast to predict Australian herring commercial catches along the west coast (Figure 5.1c) results from the highly significant positive correlation between the recruitment sampling sites Warnbro Sound and Emu Point.

The two south coast sites of Poison Creek and Emu Beach yielded high abundances of Australian salmon (Figure 5.1d). The curvilinear fit between the 0^+ abundances and the total commercial catch of Australian salmon was marginally significant. The correlation coefficient based on a linear model clearly showed a relationship.

There were two statistically significant relationships developed for the abundance of tailor recruits and the commercial catches. The abundance of tailor recruits caught from Koombana Bay on the lower west coast showed a linear relationship with the catches from the south coast (Figure 5.1e); and the combined Koombana Bay and Pinnaroo Point recruit abundance was significantly related to the tailor catch from the west region (Figure 5.1f) although this was a curvilinear relationship. Both of these relationships cover a wide range of both recruit and adult catches during the time series.

A linear relationship was demonstrated between the recruit catch rate of King George whiting from west coast site Mangles Bay and the commercial catch for the west coats region applying a 2-3 year lag period (Figure 5.1g). There were too few data to formulate a correlation statistic.

Similarly, a linear relationship was observed for the annual mean recruit catch rate of yellow-finned whiting collected from Mangles Bay and the commercial catch from the west region using a 2-3 year time lag (Figure 5.1h). However at this time there are limited data showing minimal contrast, therefore a statistical relationship was not developed.

The relationship between the annual mean recruit catch rate of sea mullet from the combined south coast sites of Poison Creek and Emu Beach and the commercial catches from the south coast was non-significant. Although catch rate data for commercial catch were lagged as described above, due to the poor relationships for sea mullet we also attempted to derive a relationship using a 3-4 year lag period. This produced a better relationship (Figure 5.1i), but one which nonetheless remained unsatisfactory for the purposes of this study.

The rationale for developing relationships between west coast sea mullet recruit catch rates for predicting sea mullet catches in the south coast was based upon the statistically significant positive correlation between the west and south coast indices (Figure 5.1j).

Two statistically significant relationships were developed between the annual mean recruit catch rate of yellow-eye mullet and the subsequent commercial catches. The first demonstrates the recruit catch rate from south coast site Emu Beach and the commercial catch on the south coast using a 2-3 year time lag (Figure 5.1k). This relationship is curvilinear and the linear statistical is meant as a guide only. The second linear relationship shows the recruit catch from the combined west coast region sites of Warnbro Sound, Pinnaroo Point and Koombana Bay versus the commercial catch from the west coast region (Figure 5.1l).

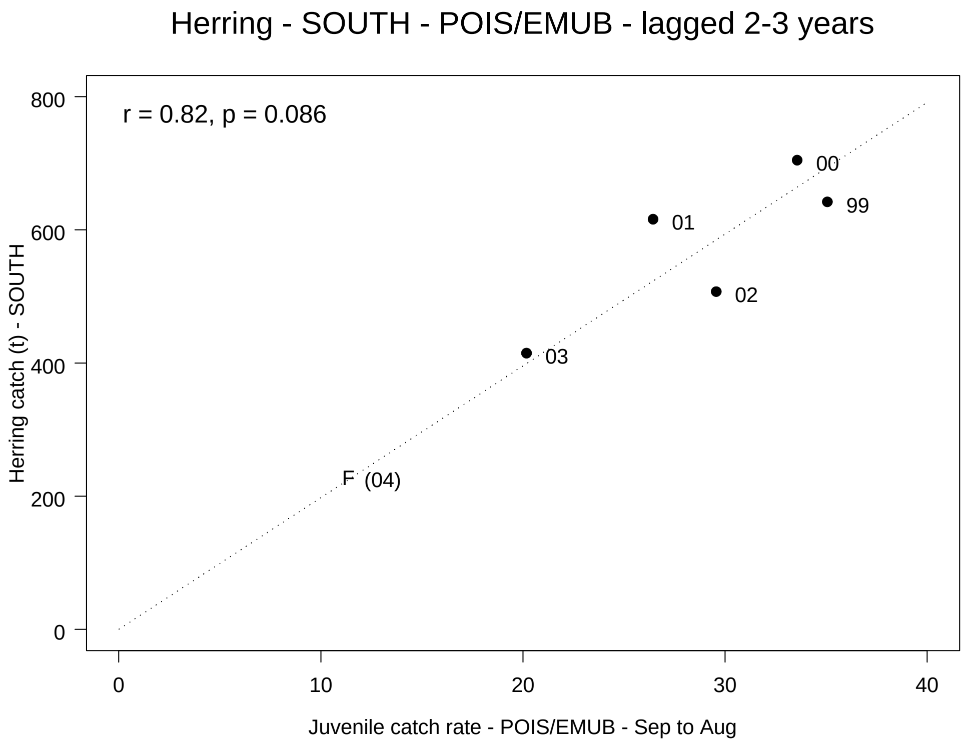


Figure 5.1a. Annual mean recruit catch rate of Australian herring from south coast sites Poison Creek and Emu Beach versus the total commercial catch of Australian herring from the south region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

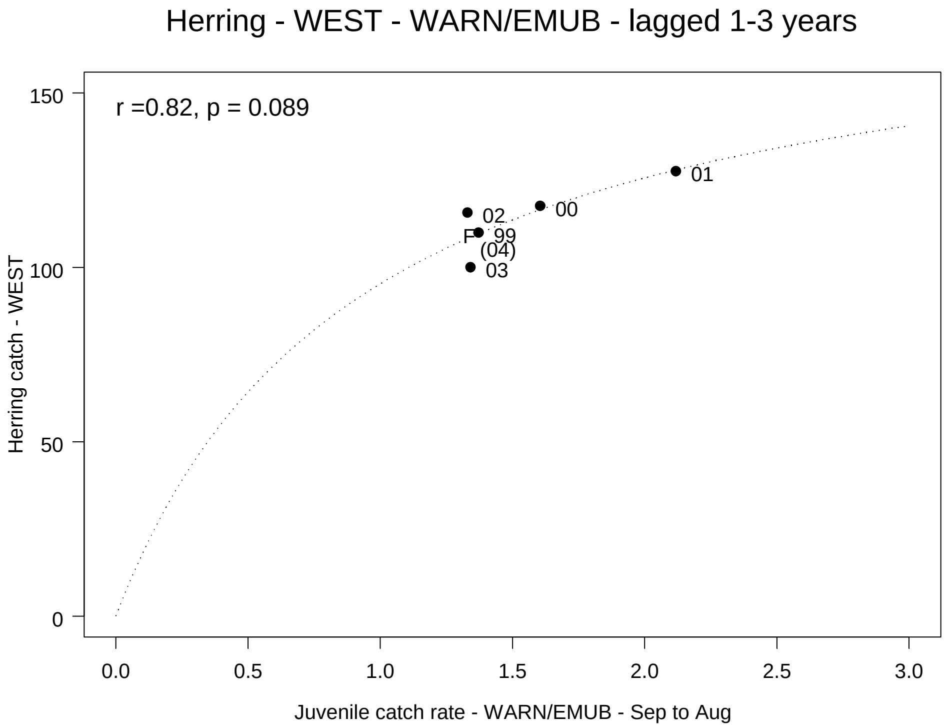


Figure 5.1b. Annual mean recruit catch rate of Australian herring from west and south coast sites Warnbro Sound and Emu Beach, respectively, versus the total commercial catch of Australian herring from the south region applying a 1-3 year time lag. F(04) is the forecast catch for 2004.

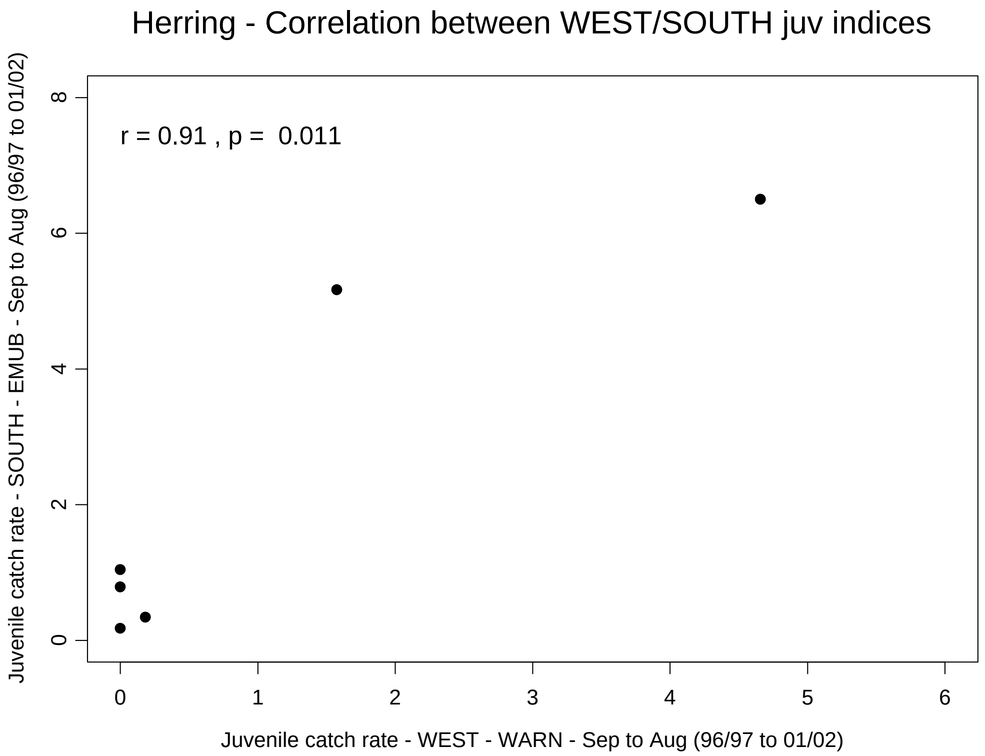


Figure 5.1c. Correlation between the west and south coasts recruit catch rates of Australian herring.

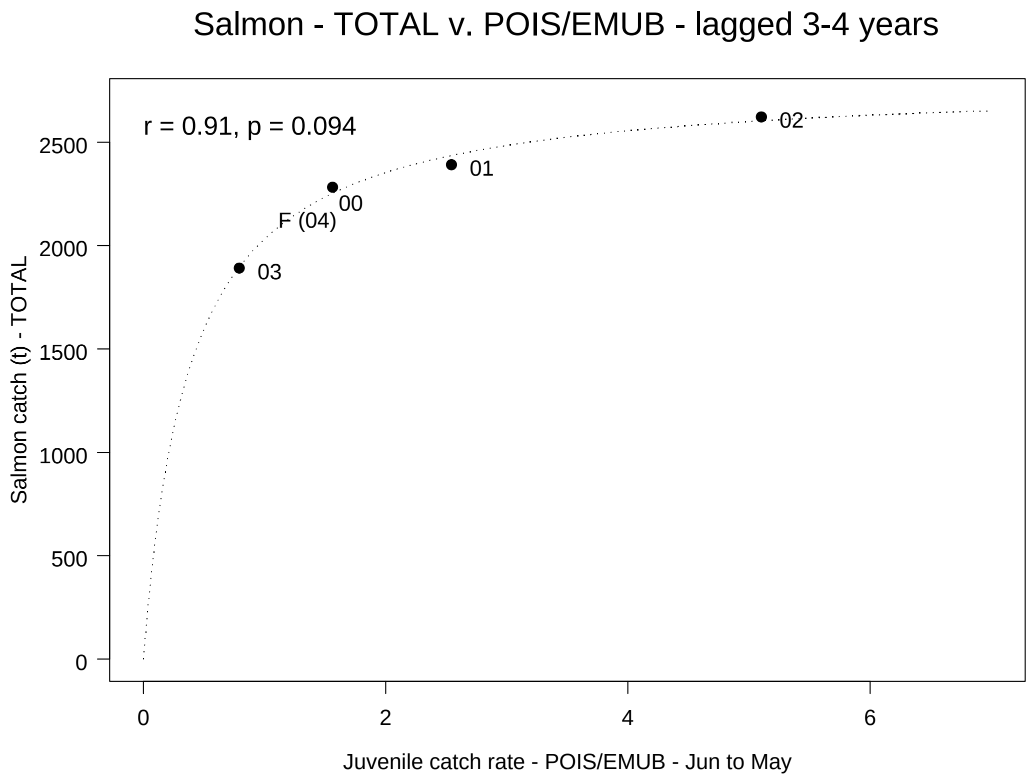


Figure 5.1d. Annual mean catch rate of recruit aged Australian salmon from south coast sites Poison Creek and Emu Beach versus the total commercial catch, applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

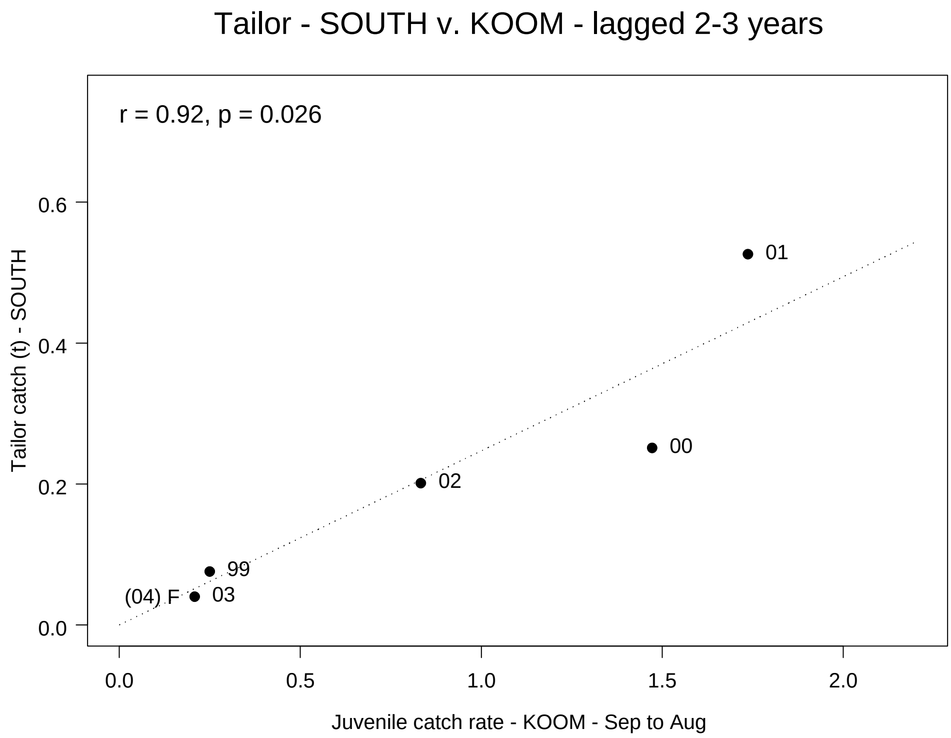


Figure 5.1e. Annual mean recruit catch rate of tailor from west coast site Koombana Bay versus the total commercial catch of tailor from the south region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

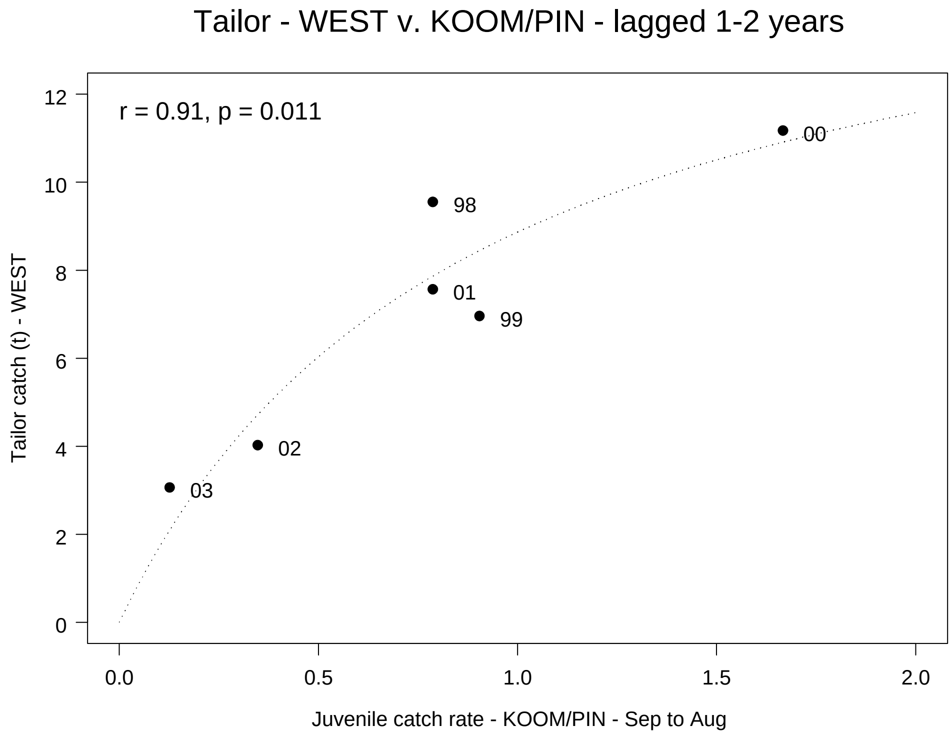


Figure 5.1f. Annual mean recruit catch rate of tailor from west coast sites Koombana Bay and Pinnaroo Point versus the total commercial catch of tailor from the west region applying a 1-2 year time lag.

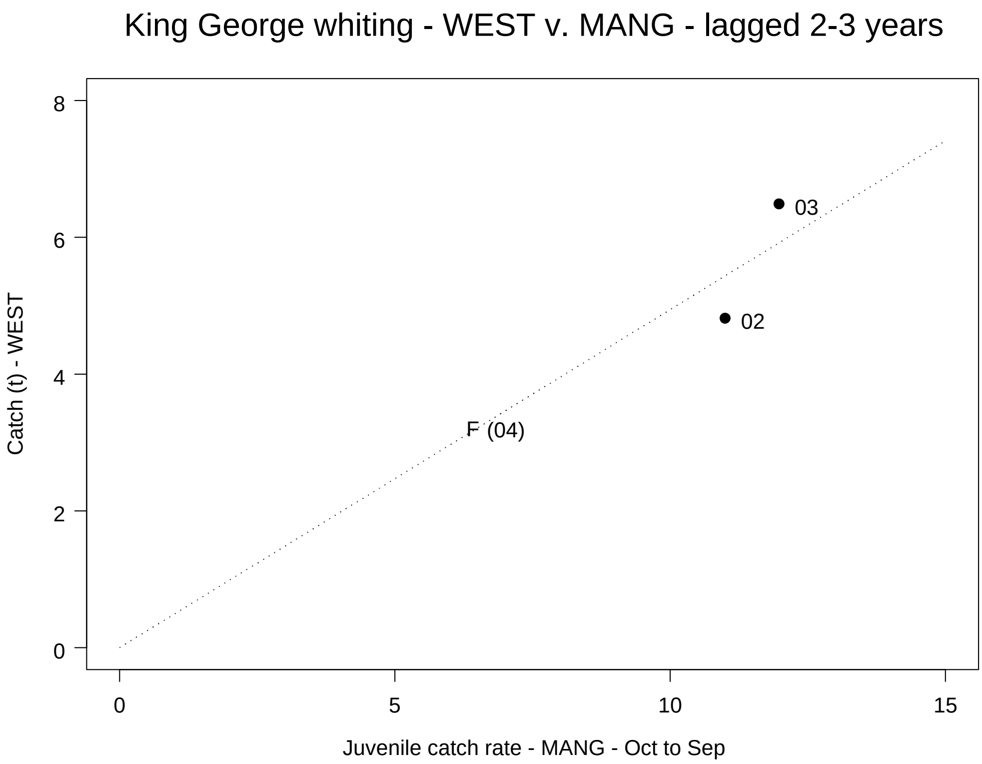


Figure 5.1g. Annual mean recruit catch rate of King George whiting from west coast site Mangles Bay versus the total commercial catch of King George whiting from the west region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

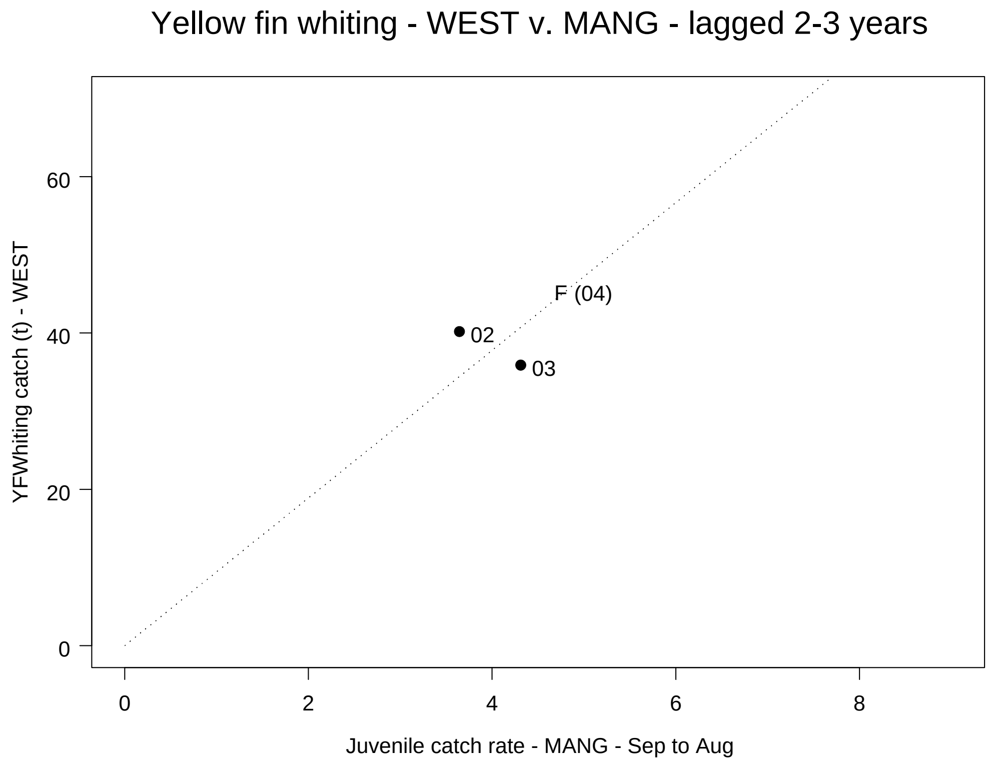


Figure 5.1h. Annual mean recruit catch rate of yellow-finned whiting from west coast site Mangles Bay versus the total commercial catch of yellow-finned whiting from the west region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

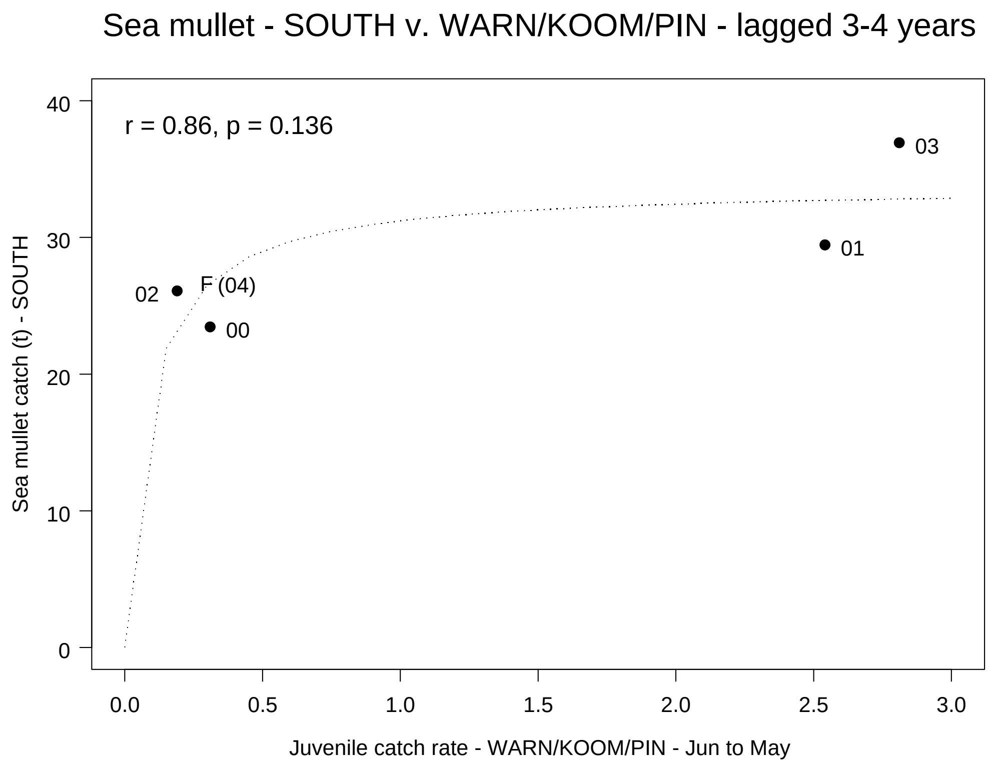


Figure 5.1i. Annual mean recruit catch rate of sea mullet from combined west coast sites, Warnbro Sound, Pinnaroo Point and Koombana Bay versus the total commercial catch of yellow-eye mullet from the south region applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

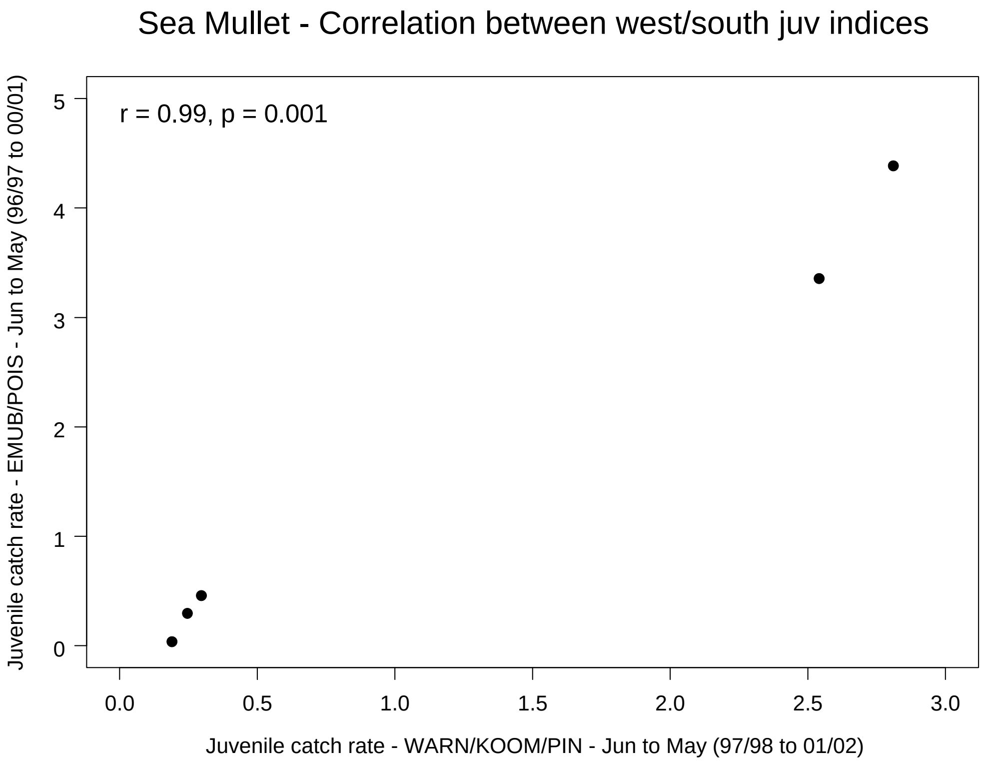


Figure 5.1j. Correlation between the west and south recruit indices for sea mullet.

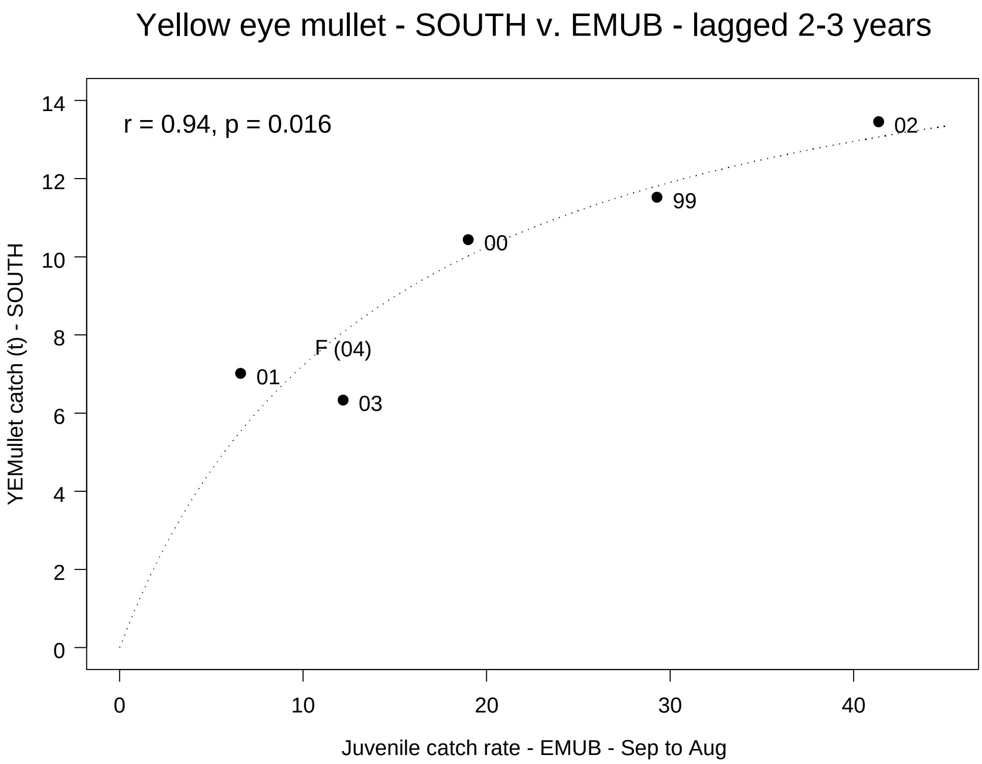


Figure 5.1k. Annual mean recruit catch rate of yellow-eye mullet from south coast site Emu Beach versus the total commercial catch of yellow-eye mullet from the south region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

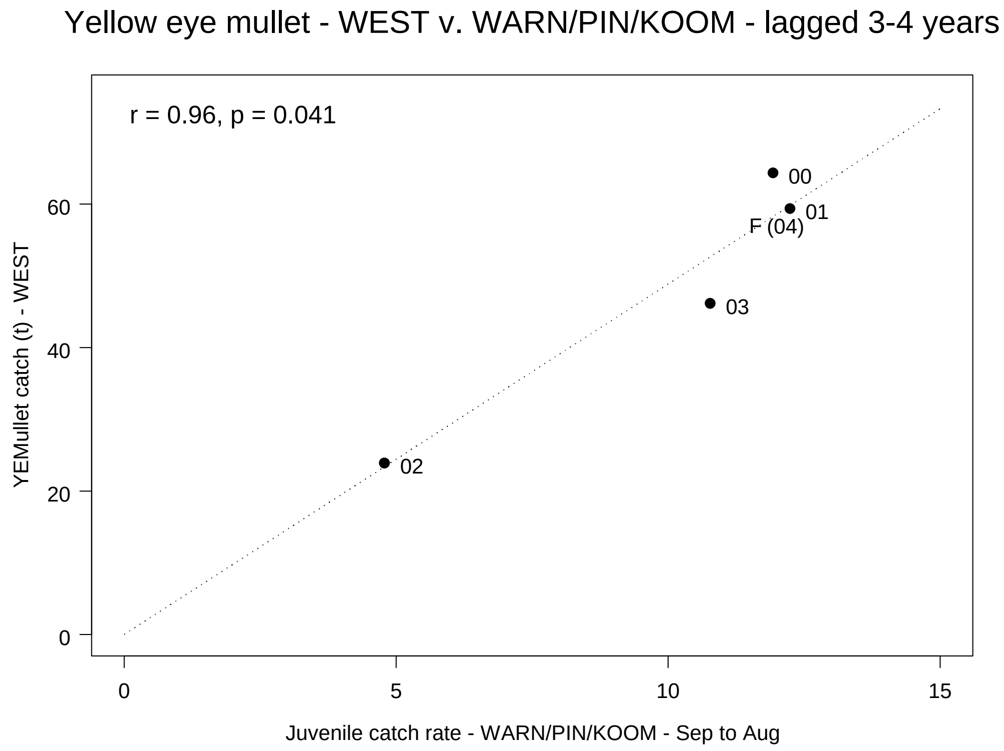


Figure 5.1l. Annual mean combined recruit catch rate of yellow-eye mullet from three west coast sites versus the total commercial catch of yellow-eye mullet from the west region applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

Relationships from a reduced number of sampling months

For Australian herring, reducing the sampling program from every month over the course of the year, to February through to April, provided a decrease in the correlation coefficient between the south coast recruitment index and the south coast commercial catches (Figure 5.2a). The curvilinear relationship ($p<0.2$) was not particularly strong, but was accepted as the basis for developing a sampling schedule for Australian herring. The relationship for west coast Australian herring improved when restricted to three months of sampling, with the January to March period providing the best fit (Figure 5.2b). However, the lack of contrast in the data again limited the usefulness of this result.

There was also an improvement in the correlation coefficient ($r = 0.99$, $p = 0.014$) for the relationship between the recruit Australian salmon catch rate from key south coast sites and the commercial catch from the south coast, with the survey period reduced by several months to a September to November timeframe (Figure 5.2c).

There was no improvement in the south coast tailor catch predictions. However, the west coast tailor relationship improved when sampling was restricted to October to December only (Figure 5.2d).

Reducing the sampling period for King George whiting recruits at Mangles Bay to the three months of October through December produced an improved linear relationship. Again, there were too few data to develop a statistical relationship (Figure 5.2e).

Improvement in the linear relationship between the catch rate of yellow-finned whiting recruits from Mangles Bay and the commercial catch from the west coast could not be achieved when restricted to a three month sampling period. However, improvement was achieved when the monthly year round sampling period was reduced to the period September to January. However, a lack of data prevented the development of a statistical relationship (Figure 5.2f).

The statistical relationship between the annual mean catch rate of sea mullet recruits from the south coast sites Emu Beach and Poison Creek and the south coast commercial catches lagged by 4-5 years could not be improved by reducing the sampling months (Figure 5.2g). The same was found for the relationship between the combined west coast year round monthly sampling sites of Warnbro Sound, Koombana Bay and Pinnaroo Point and the south coast commercial catch, lagged 3-4 years (Figure 5.2h).

For yellow-eye mullet, the relationship between catch rates of recruits from key west coast sites and commercial catches from the west coast remained similar when sampling was reduced to the three month period of September to November (Figure 5.2i). No improvement could be found for recruit catch rates from Emu Beach versus commercial catches for yellow-eye mullet from the south coast.

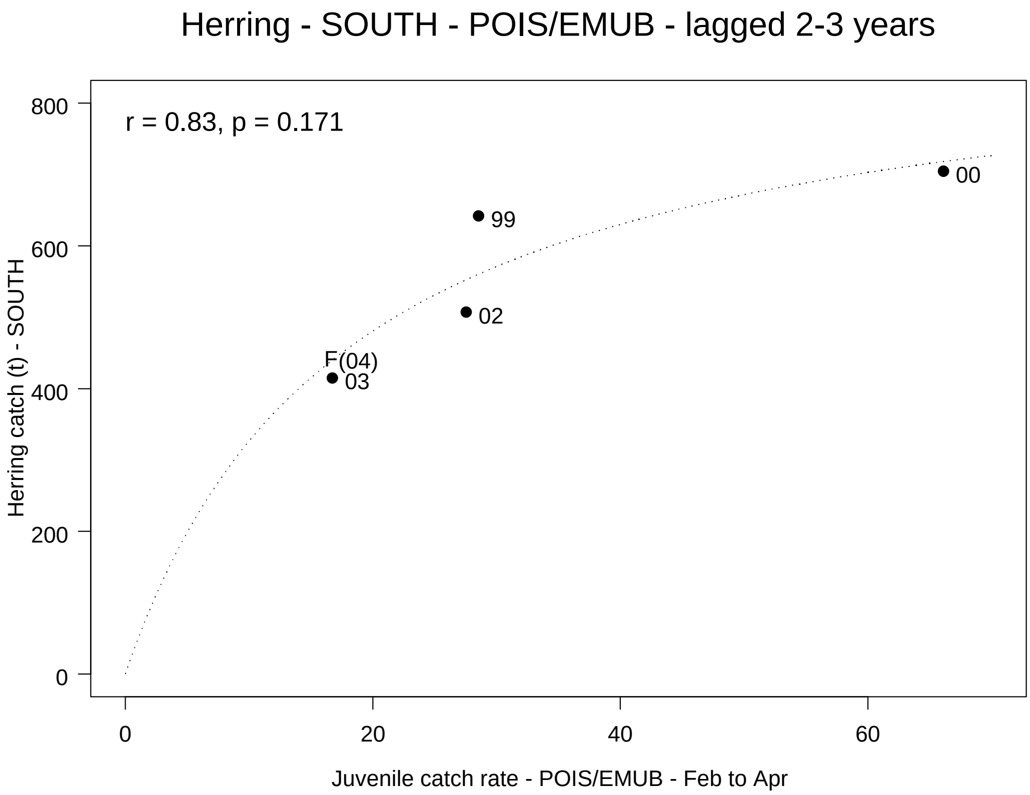


Figure 5.2a. Restricted (3 month maximum) recruit catch rate of Australian herring from south coast sites Poison Creek and Emu Beach versus the total commercial catch from the south region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

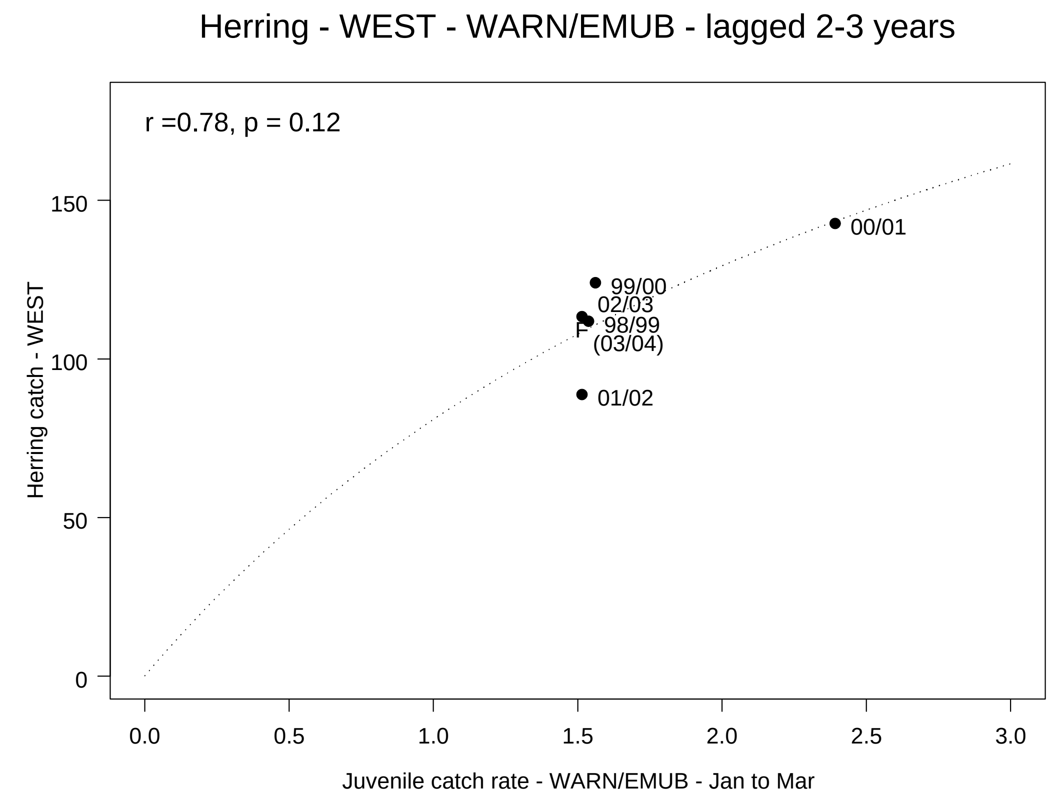


Figure 5.2b. Restricted (3 month maximum) recruit catch rate of Australian herring from west and south coast sites Warnbro Sound and Emu Beach, respectively, versus the total commercial catch from the south region applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

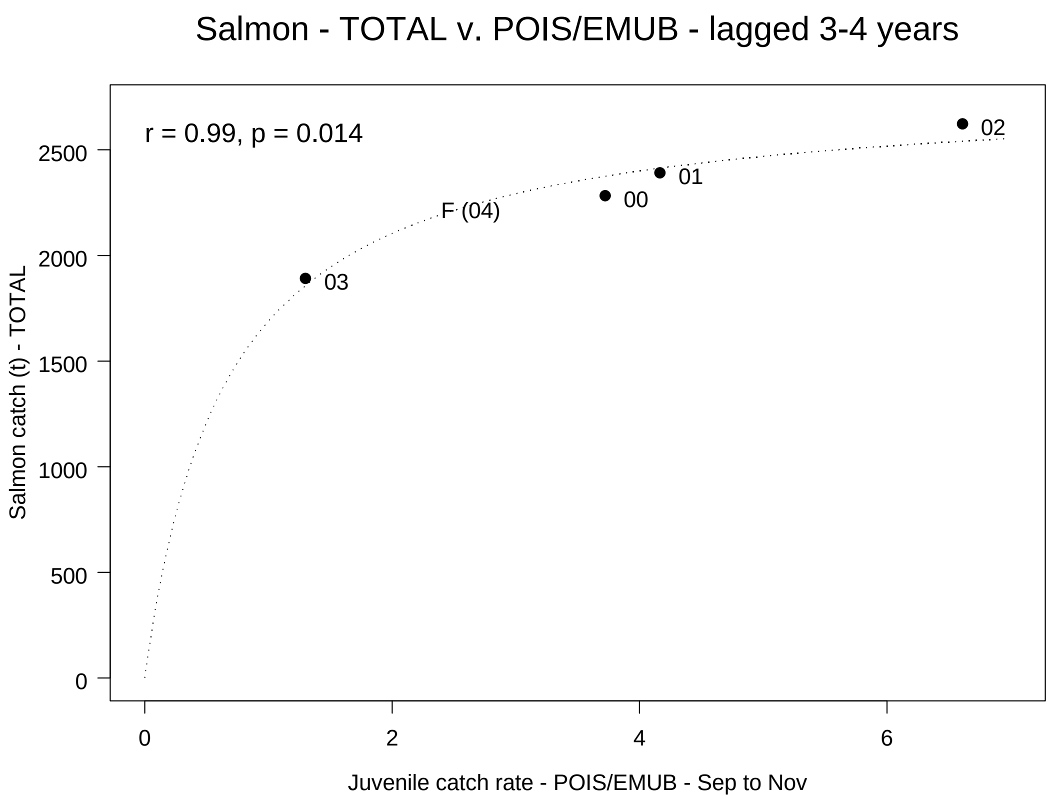


Figure 5.2c. Restricted (3 month maximum) recruit catch rate of Australian salmon from south coast sites Poison Creek and Emu Beach versus the total commercial catch applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

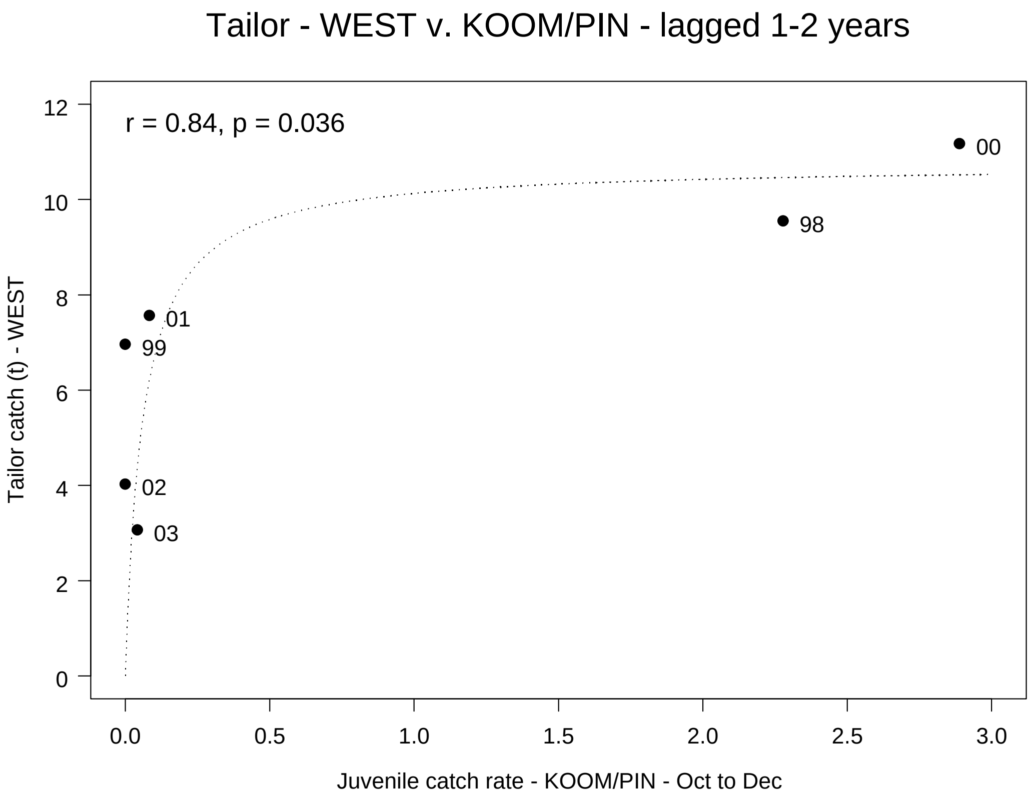


Figure 5.2d. Restricted (3 month maximum) catch rate of tailor from west coast sites Koombana Bay and Pinnaroo Point versus the total commercial catch of tailor from the west coast applying a 1-2 year time lag.

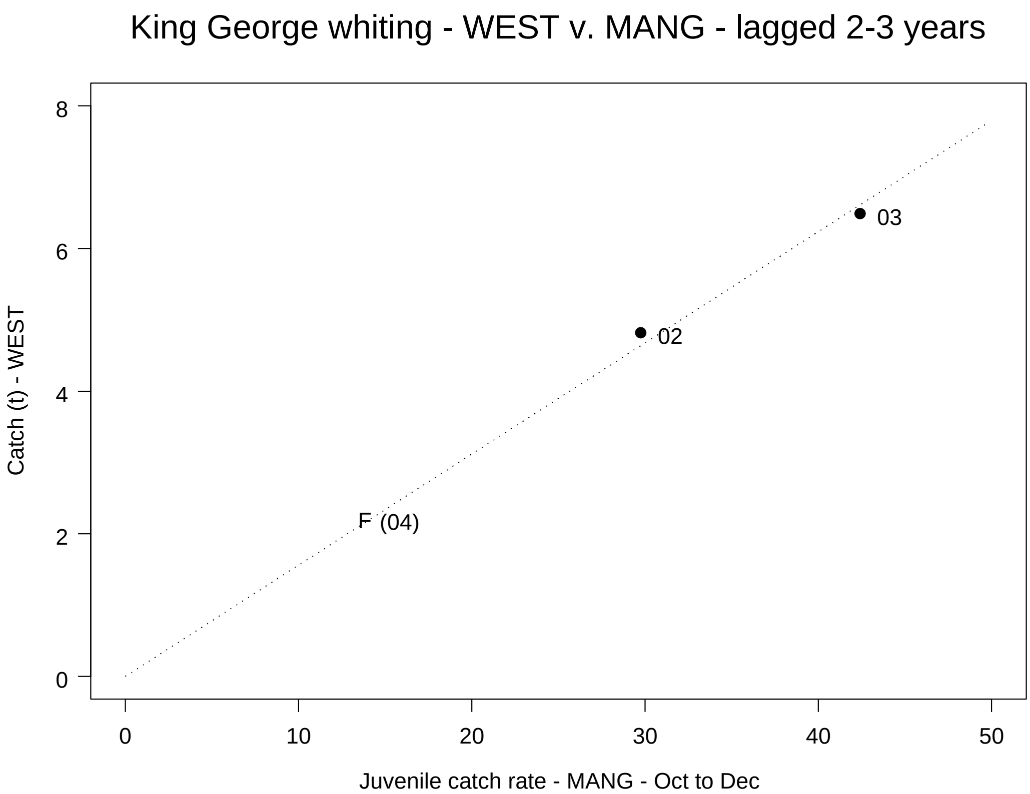


Figure 5.2e. Restricted (3 month maximum) catch rate of King George whiting from west coast site Mangles Bay versus the total commercial catch from the west coast applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

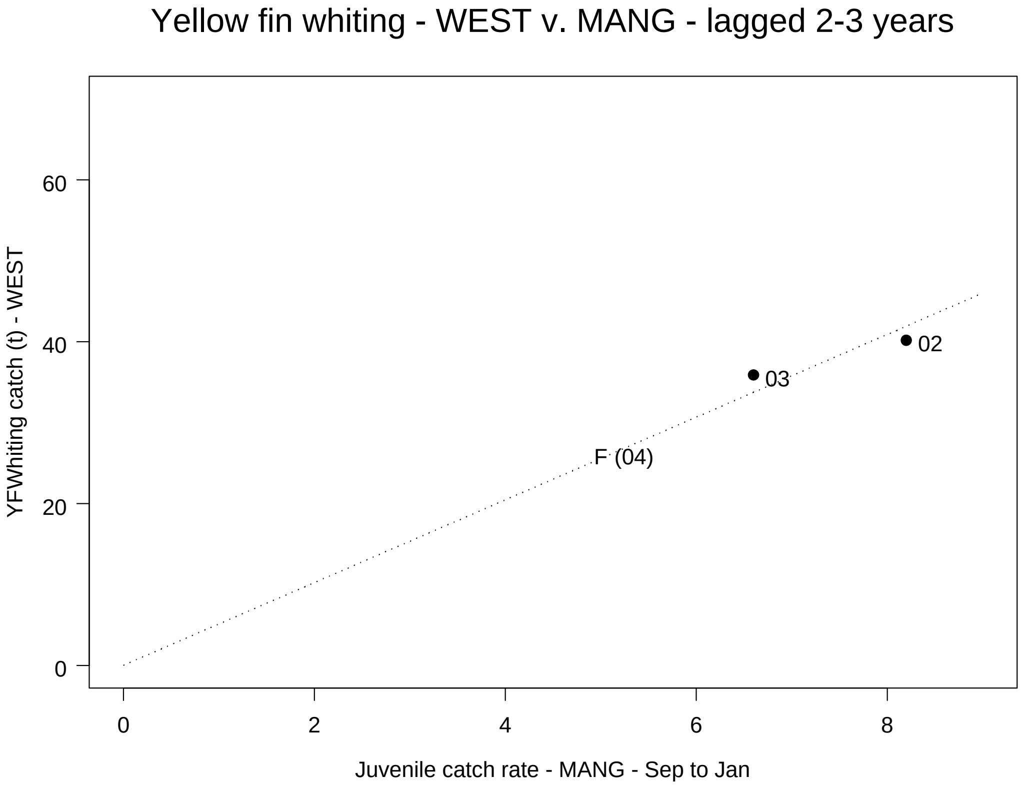


Figure 5.2f. Restricted (5 month) catch rate of King George whiting from west coast site Mangles Bay versus the total commercial catch from the west coast applying a 2-3 year time lag. F(04) is the forecast catch for 2004.

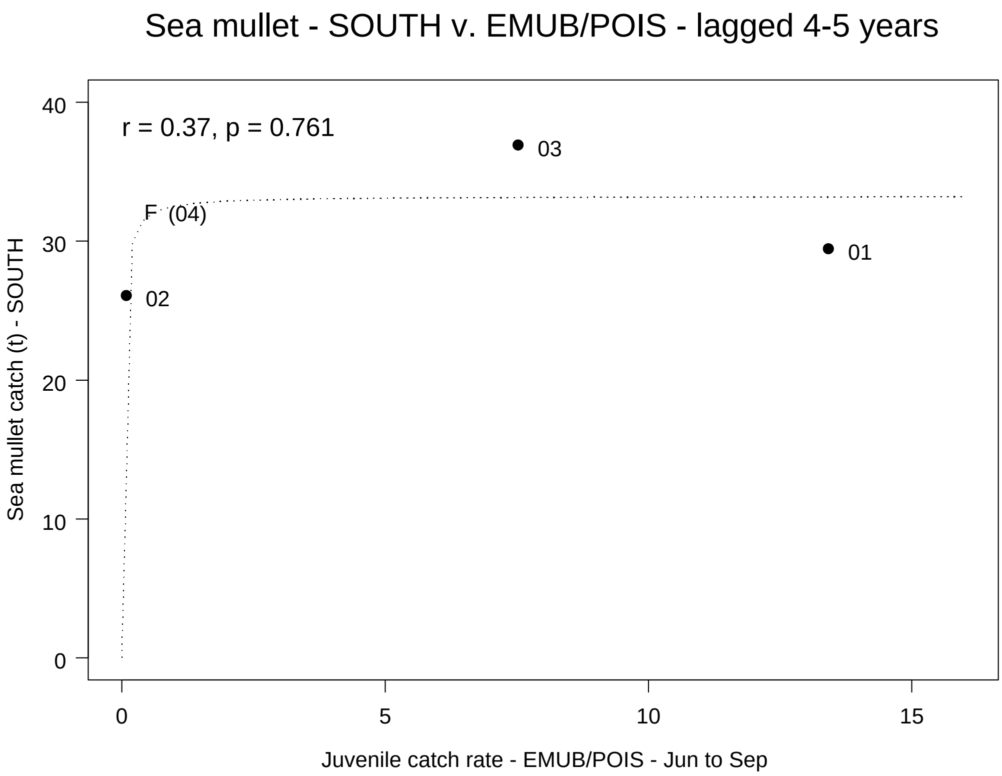


Figure 5.2g. Restricted (4 month) catch rate of sea mullet from combined south coast sites, Poison Creek and Emu Beach versus the total commercial catch from the south coast applying a 4-5 year time lag. F(04) is the forecast catch for 2004.

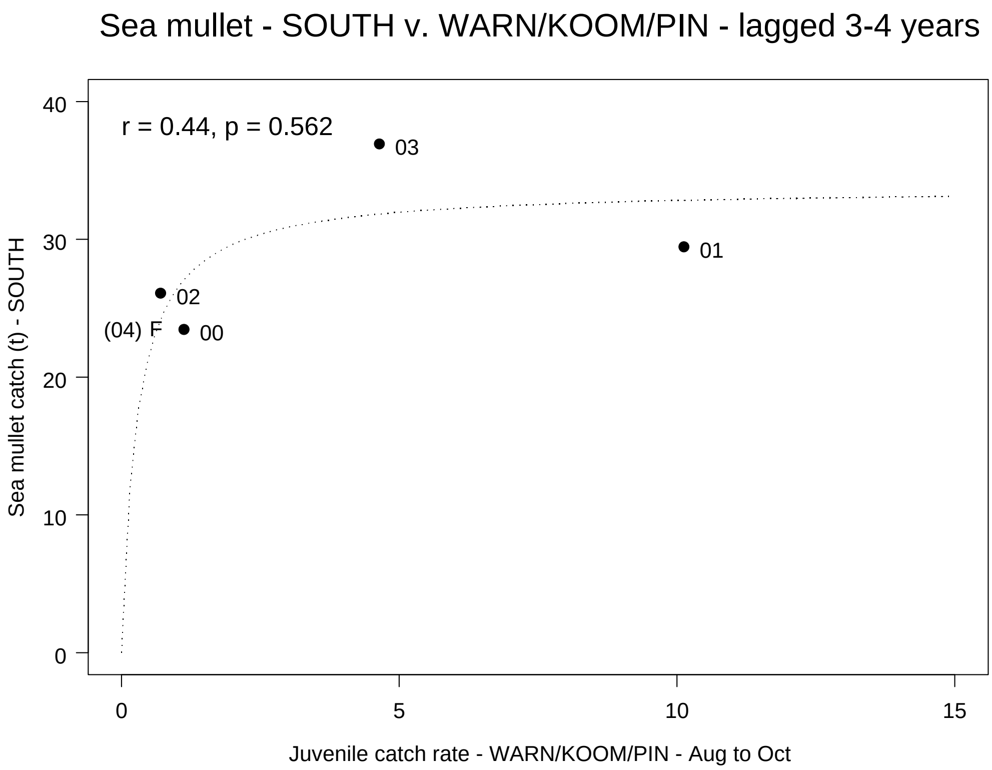


Figure 5.2h. Restricted (3 month maximum) catch rate of sea mullet from combined west coast sites, Warnbro Sound, Pinnaroo Point and Koombana Bay versus the total commercial catch from the south coast applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

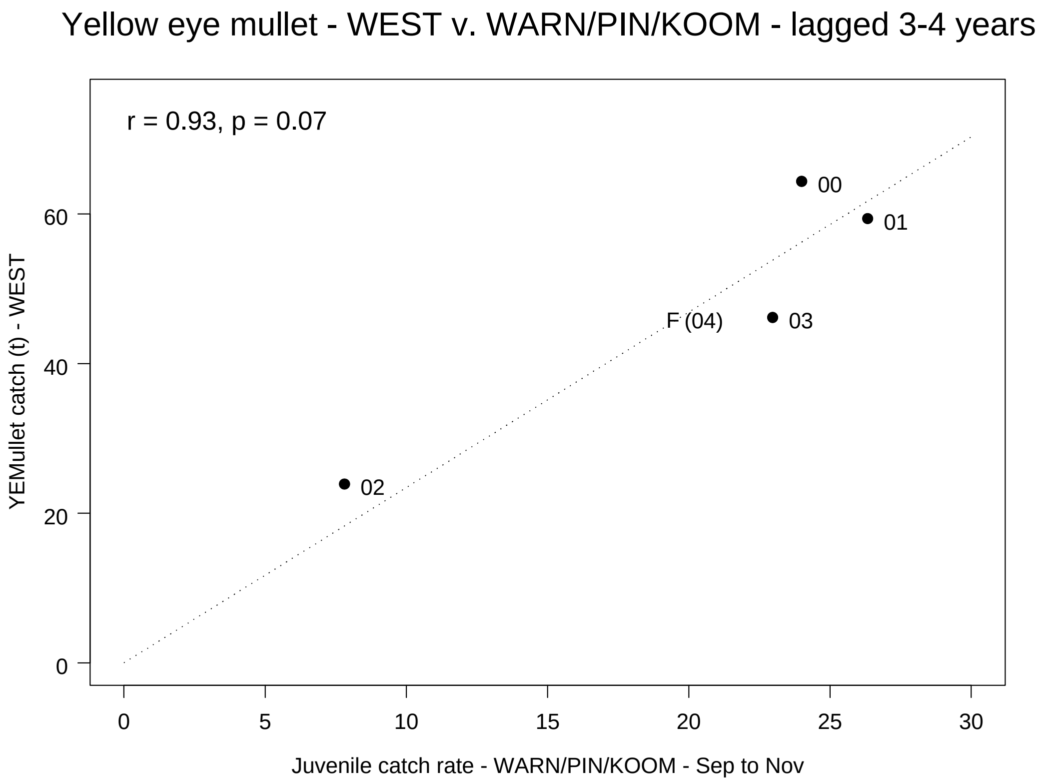


Figure 5.2i. Restricted (3 month maximum) recruit catch rate of yellow-eye mullet from combined west coast sites Warnbro Sound, Pinnaroo Point and Koombana Bay versus the total commercial catch from the west coast applying a 3-4 year time lag. F(04) is the forecast catch for 2004.

Optimal sampling months

Adequate recruitment relationships could not be established for yellow-finned whiting nor for sea mullet. For the other species, a three month sampling program is sufficient to provide reliable estimates of recruit abundance necessary for predicting commercial catch from at least one of the south or west coast regions (Table 5.4). The species for which commercial catch could only be predicted from annual (12 month) recruit catch rates were south coast tailor and south coast yellow-eye mullet. The sampling months and number of sites required to be sampled on the south and west coast are shown in Table 5.5.

In developing an annual sampling plan, the relevant management priority of the species must be considered. The WA Department of Fisheries considers that sea mullet and yellow-eye mullet are not currently facing any significant threats to stock levels; this is fortuitous given that to cover these species on the south coast would require 12-month sampling programs. Similarly, obtaining data on recruits to forecast south coast tailor catches would also require year round sampling, but tailor are a considerably less important part of the catch on the south coast, so focus on this species can be restricted to the west coast region. Also, because some species share the same recruitment months and key sites, these species can be sampled simultaneously. Given these “eliminations” and sampling synergies, the proposed sampling program for Australian herring, Australian salmon, tailor, King George whiting and west coast yellow-eye mullet can be reduced to six key sites across eight months of the year (Table 5.6).

The west coast sites of Warnbro, Mangles Bay and Pinnaroo Point are all in the Perth metropolitan area so can be sampled as day trips, allowing savings on travel-allowance and accommodation costs. The remaining west coast site, Koombana Bay, is about a 2.5 hour drive from Perth so would need an overnight trip to complete the required sampling. The south coast sites require a significant portion of a day to reach from Perth; however, as there are only two sites to sample on the south coast, only a day is required to sample each. Including two days of travelling time, the south coast can thus be sampled in a four day period for any given month.

Table 5.4. Optimal sampling locations and months as predicted by the relationship with adult catches from the region specified. Coastal regions refer to the south or west coast of south-western Australia between the Perth and Esperance areas. Locations of the key sampling sites for recruits are shown on Figure 2.1 (West Coast: Koombana Bay, Mangles Bay, Pinnaroo Point; South Coast: Poison Creek, Emu Beach). The recruitment period refers to the sampling months for which recruit catch rate data could be related to commercial catch. The number of months required to sample for recruits to provide reliable data for estimation of a recruitment index, and hence a prediction of adult catch, are shown in brackets. The final column provides a summary of whether or not a reduced sampling program (i.e. fewer months at the same key sites) produced a better or similar relationship than a full 12 month sampling period.

Species	Coastal Region of adult catches	Key Sampling sites	Relationship developed for 12 months of recruit sampling	Recruitment period to optimise sampling (number of months)
Australian herring	south	Poison Creek, Emu Beach	Yes	Feb. – April (3)
	west	Warnbro, Emu Beach	Yes	Poor relationship
Salmon	total	Poison Creek, Emu Beach	Yes	Sep. – Nov. (3)
Tailor	south	Koombana Bay	Yes	Sep. Aug. (12)
	west	Koombana Bay, Pinnaroo Point	Yes	Oct. – Dec. (3)
King George whiting	west	Mangles Bay	Yes	Oct. – Dec. (3)
Yellow-eye mullet	west	Warnbro, Koombana Bay, Pinnaroo Point	Yes	Sept. – Nov. (3)
	south	Emu Beach	Yes	Sep. – Aug. (12)

Table 5.5. The sampling months and number of sites required to be sampled on the south and west coast to estimate recruitment indices for seven finfish species from south-western Australia. The categories X and o corresponded to sampling periods of 3 and 12 months, respectively (see Table 5.4). Only months denoted by X are proposed to be sampled (see Table 5.6).

Species	Coastal Region of adult catches	Number of sites	J	F	M	A	M	J	J	A	S	O	N	D
Australian herring	south	2 (W)		X	X	X								
	west	2 (W & S)	X	X	X									
Salmon	south	2 (S)									X	X	X	
Tailor	south	1 (W)	o	o	o	o	o	o	o	o	o	o	o	o
	west	2 (W)									X	X	X	
King George whiting	west	1 (W)										X	X	X
Yellow-eye mullet	west	3 (W)										X	X	X
	south	1 (S)	o	o	o	o	o	o	o	o	o	o	o	o

Table 5.6. Proposed annual sampling regime. This program represents a compilation of sites and three-month sampling periods (denoted by X, from Table 5.5) that would need to be sampled to provide data on catch rates of recruits of Australian herring, Australian salmon, tailor, King George whiting and west coast yellow-eye mullet. An extra day of sampling in January at Mangles Bay (x) would complete the five-month sampling period required for yellow-finned whiting.

Location	**Month**											
	J	F	M	A	M	J	J	A	S	O	N	D
Poison Creek		X	X	X					X	X	X	
Emu Beach	X	X	X	X					X	X	X	
Koombana Bay									X	X	X	X
Warnbro	X	X	X						X	X	X	
Mangles Bay										X	X	X
Pinnaroo Point									X	X	X	X

5.4 Discussion

Optimal sampling program

The development of a fishery independent finfish index of recruitment as a forecasting tool for subsequent year class strength showed promise for five of the seven species examined. Although better relationships between adult catches and recruit catch rates taken from many months might be expected, reducing the recruit data down to fewer months still gave reasonable results and in some cases provided stronger relationships with adult catch.

It is not surprising that a reduced recruit-sampling program was not possible for all species at both the south and west coasts, given the gaps in our knowledge regarding the fine-scale spatial distribution of recruits of inshore fish species. Indeed, although this study sampled at many locations, only a very small fraction of the coast between Perth and Esperance was swept by the sampling nets. The locations of sampling sites were, however, not chosen at random but rather were selected based on the knowledge that recruits of inshore fish make use of shallow nearshore waters as nursery areas. Furthermore, young fish of many species are known to utilise relatively protected regions of the coast rather than the more exposed regions. While the beach seine sampling program was largely restricted to relatively protected habitats, or to calm conditions at more exposed sites, the recruitment indices estimated for a suite of species were able to be used to develop predictive relationships.

The costs and logistics of any future sampling program dictate that there needs to be a balance between cost and statistical rigour. An *a priori* recognition of the need for cost-effectiveness and for the ability to develop in advance an annual sampling program, lead us to explicitly look for periods of consecutive months that would provide sufficiently robust data on catch rates of recruits. An optimal sampling program which covers five of the seven species has now been developed.

Project overview

The research approach developed in this project involved modelling of a fishery-independent index of recruitment as a predictive tool for subsequent year class strength for seven species of commercial and recreational important finfish in south-western Australia. Those models for which relationships could be fitted (i.e. those whose results are shown in Table 5.4) are thus able to provide a prediction of commercial catch.

Several factors which could have affected the results presented here have not been accounted for in this study, including incorporation of both younger and older individuals within the 0^+ age class, a lack of knowledge of the egg and early larval stage abundances, a lack of knowledge of the catchability of each species and life stage by the beach seine net, the small amount of area surveyed versus the geographical distribution of each species and the fishery, the lack of information on the mortality rate (density dependent and density independent) during the recruit stage that would modify subsequent recruitment and the socio-economic behaviours of these small scale, life-style fisheries in Western Australia.

Our study may benefit from further refinements through classifying the 0^+ fish into, for example, those <6 months old and those >6 months old. At this time, there would be only size-based criteria to assign life stage divisions as we have not read the daily rings on otoliths to assign size-at-age for the 0^+ individuals of these seven species.

The studies presented for cod and other fishes in the *Introduction* to this chapter, predominantly from the northern Atlantic, cover a broad geographical scale. Research by Marshall *et al.* (1998) and Sundby *et al.* (1989) focused on the Barents Sea and areas off the coast of Norway. Campana *et al.*'s (1989) sampling covered extensive areas south of Newfoundland, while Anderson and Dalley (1997) focused on the northeast coast of Newfoundland. All of these studies surveyed vast offshore tracks with trawling gear. In comparison to the cod stocks of the north Atlantic, the finfish species of south-western Australia have limited offshore distributions. This present study used a relatively small 61 m seine net and surveyed a total of 2,400 m^2 along selected west and south coast beaches. Although the area sampled thus represented only a fraction of the total geographic distribution of each of the seven species, previous studies over many years have clearly established that juveniles of the target species utilise the nearshore marine habitat and as such are vulnerable to beach seine sampling gear. However, this does not imply that juveniles of the target species in this study are only found in the nearshore habitat accessible to beach seine gear. The aim of the project was to assess if the numbers found in the nearshore habitat were representative of what subsequently recruits to the fishery. That is, we assumed that if the broader 0^+ cohort for a particular species increased/decreased in a particular year, then this would be reflected by increased/decreased abundance in the nearshore habitat. Similarly, we did not measure the catch efficiency of the seine net to capture the desired life history stages but assumed that a single type of sampling gear would provide an index of catch rates of 0^+ fish that would reflect their broader abundance but not necessarily provide estimates of that broader abundance. Furthermore, because the primary goal of the project was to develop a cost-effective sampling regime, if the project was to result in useable results it was considered crucial that data could be collected in a cost-effective manner. Beach seining is a very cost-effective method of sampling fish and is also very flexible in terms of time and place of deployment.

The multi-species fishery for these species along the south-western coastline of Australia has been referred to as small-scale or a life-style fishery. The catch in the fishery is often at low levels, not due to recruitment to the fishery but reflecting minimal fishing by the participants. This may result from low market demands for these species or better demand for potential alternative sources of income, such as agricultural products. In this situation the catch does not reflect abundance and therefore the index of 0^+ age class recruitment for each of these seven species may be decoupled from the size of future catches. The catches could not be confidently standardised into catch per unit effort, as these multi-species fisheries do not disaggregate effort by species.

While mortality in early life history stages of these seven species of finfish was not considered in this study, there may be several explanations for interannual variation in the abundance of these life history stages and the exploited adult fish. Potential factors include annual variations in the Leeuwin and Capes currents, water temperature, winds, limited essential nursery habitats and a lack of prey items for juvenile fishes.

This research program has developed a wealth of information on the catch rate of recruits from selected sites, for at least three years and in most cases six years, and associated commercial catches. Clearly, one of the most important factors in developing a predictive relationship is a long time series of data. Future research developed from this study could include (1) analysis of daily rings to precisely determine size/age limits of the various life history stages, and (2) examination of the selectivity of the standard seine net by life history stage. Reanalysis of the predictive models may be greatly improved with these two refinements.

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CHAPTER 6.0 Benefits and Adoption

The beneficiaries of this project are the recreational and commercial fishing sectors of south-western Australia, fisheries managers and the general community. The overarching goal of this research programme was to develop a cost-effective means of achieving long-term monitoring and forecasting of the inshore finfish stocks. These stocks are the focus of considerable fishing effort and include the species that are targeted by the majority of anglers in south-western Australia (i.e. Australian herring, tailor, whiting species)

Fisheries managers will benefit from the ability to better prioritize research needs with the knowledge that the relatively cheap method of beach sampling can provide a basis for long term monitoring of the performance of the key inshore finfish stocks. That is, this study provides an informative start for discussions relating to cost-benefit analyses for small-scale fisheries that are nonetheless socially important.

The data collected during the study increased the knowledge of the biology of the seven species, which helps provide the scientific knowledge to underpin any future management decisions. In particular, because this study followed a previous project which also sampled the same seven species with beach seines, we have a six-year time series of recruitment strength for south-western Australia's important inshore fish species.

The general community will benefit from these results through better use of funds for fisheries management.

CHAPTER 7.0 Further Development

The development of recruitment indices has indicated that a beach-seine sampling program can provide predictions of stock performance for five important inshore finfish species in south-western Australia. Given that changes in fisheries management are typically driven by negative aspects within a fishery (e.g. a decline in catch), prior knowledge of low levels of recruitment will allow the fishing sectors to be forewarned of impending low catch rates of adult fish. This will forestall surprises in particular years when low recruitment may flow through to low catches. Being able to demonstrate knowledge of recruitment levels will therefore lead to more practical responses to subsequent low catch rates, rather than implementing unwarranted "crisis management". The predictive capabilities that have been developed here, albeit better for some species than for others, will be built upon from future beach seining programs in an effort to improve the applicability of the models.

Based on the results in this report, a sample-optimization-checklist (SOC) will be constructed for recruits of each species. These SOCs will allow real-time decisions on sampling to be made in an objective manner. They do not however preclude the need to collect all the same types of data that have been found in this study to influence the abundance of recruits. This will ensure that any future results are comparable to those presented here, thus ensuring that future use of the recruitment indices is as robust as is logistically and economically feasible.

The optimal sampling strategies described here will be developed into concise guidelines for planning field trips and then modifying the sampling regime as required depending on conditions for any given day. The ability to precisely construct a sampling program will permit long term planning and hence allow a clear understanding of future costs. The important development to follow this study is that implementation of integrated fisheries management (IFM) in Western Australia can adequately, and accurately, determine the level of resourcing that can be devoted to providing scientific advice for the inshore finfish species; alternative long-term sampling strategies, that differ in the required resources, will therefore be developed for incorporation into the IFM process. The strategy chosen will be balanced against the cost of other IFM requirements (e.g. the off-shore fishing sector).

CHAPTER 8.0 Planned Outcomes

The inshore finfish fishery of south-western Australia encompasses ~800 km of coastline. Obtaining representative samples to assess recruitment of important fish species therefore represents a considerable challenge in terms of logistics and costs. This project focused on reducing the longer-term costs of measuring recruitment; the investment in this project has resulted in a series of predictive relationships (and underlying databases) that are suitable for instigating a cost-effective sampling strategy. The project successfully achieved its primary goal of providing a cost-effective basis for improved long-term management of inshore finfish stocks in south-western Australia.

CHAPTER 9.0 Conclusions

The main objective of this project, and that which reiterates the project title, (i.e. Objective 1: *The development of a rigorous sampling method for determining an index of recruitment for seven inshore fish species from south-western Australia*.) required substantial field and biological sampling to be undertaken to build the necessary databases that would underpin the "final" modelling. This Objective essentially encompassed the whole project and the other Objectives were prerequisites to a successful outcome. As such, Objective 2 was directly aimed at providing data for abundances of recruits and adults of the seven species, the critical parameters that the predictive modelling was based upon. However, the hierarchy of other project components determined how the models would be implemented and how the modelling results would be translated into a rigorous sampling method.

The samples of fish obtained were also used to assess age and growth rates as these would determine the nature of the temporal relationship between recruits and adults. In developing relationships between catch rates of recruits and adults, the appropriate time-lags were estimated for each species from knowledge of the age-structure of catches and growth rates. Furthermore, in some cases the required time-lags between each of the west and south coast regions differed for a single species, reflecting regional differences in age-structures of the commercial catch. An understanding of both growth rates and age-structure of fishery catches is thus essential when developing recruitment indices.

Relationships between abundance of recruits and adults of most fish species can be very complex. Besides the "real" factors affecting such relationships, sampling can also result in biases in the estimation of abundance of recruits, which can hamper identification of relationships. Because abundance of recruits is typically quite variable, and in consideration of the length of coastline for which we wished to develop a rigorous sampling method, a series of intensive sampling experiments were undertaken with the aim of detecting biases in the sampling technique for recruits (Objective 4). These experiments indicated that for some species the sampling regime can bias results (e.g. localized depletion from one sample replicate to another); this knowledge will be used to minimise bias in any future sampling programs. Intensive experiments were also used to assess the influence of environmental affects on catch rates of recruits (Objective 3). These experiments successfully identified the effects of spatial and temporal factors (e.g. geographic location, season, day, time, lunar cycle, tidal cycle, temperature, salinity and wind) on the abundance of each species. Understanding sampling bias and quantifying the effects of factors that vary in space and time are pre-requisites to developing an optimal sampling strategy that aims to estimate recruit abundance for the purposes of developing a recruitment index. Minimizing these sources of variation is required so as to enhance the ability to detect the real variation in recruitment strength.

APPENDICES

Appendix 1.

There is no intellectual property arising from this project.

Appendix 2. Project Staff

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