Development of cost-effective indices to monitor the nearshore fish communities of the Swan Region.

Final report to the Swan Catchment Council

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Forward

Progress towards developing explicit metrics for Resource Condition Targets.

This project is one of three that has been undertaken by the Department of Fisheries (DOF), and funded by the Swan Catchment Council (SCC), that aim to gain a better understanding of the biodiversity and community structure within the Swan region. Ultimately, the goal of the SCC projects is to provide information that will allow development of effective and efficient resource condition targets (RCTs).

While fishing is one of the significant factors that needs to be considered when managing coastal marine ecosystems it is not the only driver of change in these communities. Therefore, the various SCC-funded projects undertaken by DOF not only included a focus on targeted species (e.g. Category 1 angling species, blue swimmer crabs, western rock lobster) but they all (including some other non-SCC projects) have focussed on the most appropriate sampling method (in terms of time, accuracy and cost) to generate information on biodiversity so as to provide a measure for general ecosystem health. They have all provided information on the abundance (or relative abundance) and diversity of species from particular categories (e.g. fish, macro-invertebrates), from particular habitats or regions and at particular time intervals (e.g. seasonal comparisons). They have also addressed one of the key issues pertaining to the development of RCTs for biodiversity and community structure, which is to provide baseline information on natural levels of variability.

It has been widely acknowledged that there is a dearth of broad scale ecological studies within the marine ecosystems of WA. This means that these current, or recently completed, studies are essentially establishing baseline descriptions of these communities or assemblages. Consequently, it is not yet possible to set explicit reference points for the management of marine biodiversity because no adequate metrics have been established. This is in contrast to the generally agreed metrics that are now used for the management of individual stocks of exploited fish. For this, the biomass level of a species is often the metric against which the resource condition target (often termed biological reference points, BRPs) is set (e.g. maintain biomass above 40% of the unfished level). The lack of a common metric for measuring biodiversity (or ecosystem health) limits our ability to set meaningful and defensible RCTs. While aspirational RCTs can be developed, to achieve pragmatic management outcomes it is critical that even these are based on a credible scientific understanding or hypothesis if they are to have any real impact on managing marine systems.

In the near future it is likely that the achievable goals for management might include objectives such as to ensure - no loss of biodiversity; - no change in the community assemblage for a particular group such as fish or algae; - an improvement in habitats or ecosystems deemed to be degraded. Therefore this current suite of studies should be considered as the starting point for the management of biodiversity, not as the end point.

Further work will be required to develop metrics that can "describe" biodiversity and ecosystem structure in a pragmatic and measurable manner. The scope of the current projects did not include the types of comparative tests required to ascertain with confidence which data sets and analyses are most appropriate for developing the required metrics for biodiversity or community structure. Therefore, each of the projects undertaken by DOF for the SCC could undertake further analytical work on the data already available.

Data collected by these three complimentary studies within the Swan region indicates that the habitats within this ecosystem can differ significantly. For example, different categories of benthic cover and demersal scalefish occur at each of the locations examined, which included some areas closed to fishing. Similarly, different beaches along the coast have different assemblages of fish despite the habitats often superficially appearing similar. The ongoing challenge for managing marine ecosystems, therefore, is not only what to measure/monitor, but also at what spatial and temporal scales.

DOF in association with DEC and broader membership of the State Marine Policy Stakeholders Group has been addressing this significant challenge through the development of a risk assessment approach, which is being undertaken within the WAMSI project on ecosystem-based fisheries management (EBFM). This project is identifying all the natural assets within the entire West Coast Bioregion, including the region of specific interest to the SCC. The EBFM project builds on the considerable work undertaken over the past decade to develop a practical system to implement ESD across Australian fisheries. This system, which has full support from all Australian state and federal agencies involved in managing natural marine assets, critically recognises that not all issues (or species, habitats, problems etc) can be dealt with at a highly detailed level, so the only practical solution is to prioritise issues based on their risks (see www.eafm.com.au for more details).

The risk assessment approach, which forms the basis of the EBFM project, follows nationally agreed standards and methods to help identify priorities. The outcomes from this and the other SCC projects (and other activities focussed on assessing baseline of biodiversity) are now being utilised within the context of the EBFM project, the state's regional marine planning process and any other relevant planning processes. This is being done to ensure the newly acquired information is used to help assess risk status for different habitats within ecosystems as well as to help develop pragmatic metrics for RCTs to underpin the effective management of our marine resources.

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Section 1. Introduction

Shallow, inshore aquatic environments, such as surf zones and seagrass beds, are widely recognised as critical habitats for fish, particularly because of their role as nursery areas (Pollard 1984, Beck *et al.* 2003). These inshore areas are often able to provide a greater abundance of food and shelter for juvenile fish and reduce the incidence of predation (Brown and McLachlan 1990, Ruiz *et al.* 1993, Clark 1997, Heck *et al.* 2003). In WA a large proportion of commercial and recreational fishery species use shallow habitats in estuaries and sheltered embayments as juvenile nurseries (Lenanton and Potter 1987).

In 1993, the WA Department of Fisheries (DoF) commenced large scale, annual surveys of juvenile fish abundance at numerous shallow coastal sites along the lower west and south coasts of WA. These ongoing surveys aimed to monitor the annual recruitment of juveniles of various fishery species, in order to assess relative stock abundance and potentially predict fishery landings. The recruitment indices subsequently proved effective in predicting fishery catch rates and have assisted in stock assessments for various species.

Since 2005, the DoF recruitment monitoring program has targeted seven key fishery species (tailor, Australian herring, Western Australian salmon, King George whiting, yellow-finned whiting, sea mullet and yellow-eye mullet). The sites and sampling times currently used by the program have been 'optimised' to provide cost-effective recruitment data specifically for these target species.

Historically, DoF recruitment monitoring program has captured a wide range of species and, despite the current focus on only seven species, the program still routinely captures numerous additional species. A total of 111 fish species have been recorded since sampling commenced in 1993. Prior to this report, raw data for all captured species had been archived but only those data relating to the seven key species had been collated and analysed (Gaughan *et al.* 2006).

In 2007-08, the Swan Catchment Council (SCC) funded DoF to undertake a review of archived recruitment data from the Perth region. It was anticipated that archived data would contain information about long-term trends in the abundance of many individual fish species and trends in the composition of fish communities at a range of shallow water sites on the west and south coasts. It was anticipated that the data would also yield valuable new biological information (e.g. spatial and temporal patterns of nursery habitat use, growth rates, spawning and larval recruitment) about many species. Such information has various potential applications in the management of fisheries and inshore environments in this region.

In the Perth region, inshore fish communities have considerable value as targets for recreational and commercial fisheries and tourism, providers of ecological services (e.g. regulating food webs (Holmlund and Hammer 1999)) and indicators of ecosystem health. Unfortunately, inshore fish in this region are subject to the ongoing impacts of strong fishing pressure and environmental degradation. Sustainable management of inshore fish in the Perth region would benefit from a comprehensive annual monitoring program that provided real-time data to fishery and habitat managers on spatial and temporal changes in community composition. This would provide managers with the information needed to develop appropriate management arrangements and policies and to determine if current management is adequate to maintain these communities at acceptable levels. Knowledge of the biological characteristics and ecological requirements of the species within these communities would be critical to the success of such a monitoring program.

The existing DoF fish recruitment monitoring program could potentially be adapted to provide annual monitoring of inshore fish species or communities in the Perth region. It may be more cost-effective to provide additional resources to this existing program than to implement new research to meet future management needs. This report provides an overview of the type of data that has, or could be, collected by the DoF fish recruitment monitoring program. This information will assist in the development of future management strategies for inshore marine habitats of the Perth region.

Objectives

This SCC-funded project had the following major objectives:

1. *Examine archived data to determine their value in assessing long-term change in abundance of nearshore fish communities of the Swan Region.*
2. *Investigate the potential to develop a low-cost index of nearshore fish community status in the Swan Region by expanding the spatial and temporal resolution of the existing DoF recruitment monitoring program.*

More specifically, the objectives of this project were to:

- Review and document information contained within the historical DoF database relating to key inshore fish species in the Perth region.
- Describe fish community composition at inshore sites sampled by DoF in the Perth region.
- Describe the patterns of inshore habitat use by selected species of juvenile fish in the Perth region, including habitat preference and duration of residency in nurseries.
- Examine evidence of long-term changes in abundance of selected inshore species in the Perth region.
- Identify fish species (in addition to the current seven target species) for which the existing DoF recruitment monitoring program could be used to provide a reliable index of recruitment or stock abundance in the Perth region.
- Identify the potential to 'value-add' to the existing DoF monitoring program, including modifications to existing sampling schedules that would enable more effective monitoring of additional species.
- Review published literature and DoF recruitment data to describe aspects of the reproduction and early life history of selected species, an understanding of which is required to interpret the spatial and temporal trends in recruitment of each species.
- Identify important gaps in knowledge.

Section 2. Methods

The Department of Fisheries (DoF) recruitment monitoring program

Since 1993, DoF recruitment monitoring program has sampled inshore fish fauna at a total of 52 sites within three regions of Western Australia, including the West (20 sites), South (9) and South-east regions (15) (Fig. 2.1).

Throughout the program, the sampling methodology employed at each site has remained relatively consistent. Fish were collected in the extreme nearshore zone at each site (i.e. within 50 m of the shore) using a fine-mesh beach seine net. The net was deployed from the beach in an arc. Both ends of the net were hauled back onto the beach, where the catch was sorted. At all sites, the area swept by the net was predominantly bare sand, sometimes interspersed with patches of drifting or fixed vegetation (seagrass or algae).

Since the commencement of the program, the number of sites sampled per year and the frequency of sampling at each site (i.e. number of days per month and number of replicate hauls per day) has varied considerably, depending on DoF research priorities and the level of resources available each year. Several net types have also been used during the program, although the vast majority of samples have been collected by the following two net types:

1. **Large seine net**: *(hereafter referred to as the "61 m net")* total length of 60.6 m and height of 2.0 m, comprising two wings of length 29.1 m (22 mm stretched mesh) plus a bunt of length 2.4 m (8 mm mesh). The area swept by this net was approximately 592 m² per haul. Four replicate hauls per day were executed at sites where this net was used. The net was deployed from a small dinghy rowed in a semicircle from/to the beach. Sampling was conducted during daylight.

2. **Small seine net**: *(hereafter referred to as the "21 m net")* total length of 21.5 metre and height of 1.5 m, comprising two wings of length 10.0m (6 m of 9 mm mesh and 4 m of 3 mm mesh) plus a bunt of length 1.5 m (3 mm mesh). The area swept by this net was approximately 338 m² per haul. Three replicate hauls per day were executed at sites where this net was used. The net was deployed by hand - the net was waded out 21 m from shore (measured by length of net), one end was held in position while the other was dragged in an arc extending away from the shore, then both ends were dragging back to the beach. Sampling was conducted during daylight. This 21m net was used at sites where shallow water or restricted access prevented effective deployment of the larger net.

Since 1993, a total of 4,497 net hauls have been executed, the majority (3,444 hauls or 77%) being undertaken by the 61 m and 21 m nets at various sites in the West, South or South-east region (Table 2.1). Sampling effort by these nets was concentrated in the West region (78% of hauls), particularly at Koombana Bay (22%), Pinnaroo (17%) and Warnbro Sound (13%). Twelve percent of hauls were executed in the South region (mainly at Emu Point (8%)) and 11% in the South-east region (mainly at Poison Creek (7%)).

From mid-2002 to mid 2005, the sampling program was suspended due to lack of resources. In mid-2005, sampling recommenced, but with a reduced number of months and number of sites being sampled annually, compared to previous years. This new sampling regime was intended to provide cost-effective monitoring of the annual recruitment of seven key fishery species (tailor, Australian herring, Australian salmon, King George whiting, yellow-fin whiting, sea mullet, yellow-eye mullet). The methodology was developed during two major DoF projects (Ayvazian *et al.* 2000, Gaughan *et al.* 2005).

The 'optimised' annual sampling regime that has been employed since mid-2005 includes 6 sites, each sampled during various months from September to April. Sampling occurs at 4 sites within the West region (Pinnaroo, Mangles Bay, Warnbro Sound, Koombana Bay), 1 site in the South region (Emu Point) and 1 site in the South-east region (Poison Creek). The number of months sampled each year varies between sites, ranging from 4 to 7 months per site.

At each site, 4 replicate hauls using a 61 m seine net are undertaken each month. Replicate hauls are completed within a single day and swept adjacent, but non-overlapping, areas of habitat at each site. At the completion of each haul, the net is hauled onto the beach, where the fish are removed and placed in an aerated tub of seawater. All fish and macro-invertebrates in the catch are identified to the lowest possible taxon (usually species) and measured (total length, to the nearest mm) before being released alive where possible. Blue swimmer crabs are counted, sexed and the carapace length measured to the nearest mm. Very abundant species are subsampled before being counted and measured. Fish are released after all hauls are completed to avoid any recaptures. Temperature, salinity, turbidity and weather conditions are recorded for each sample.

Sampling in 2007/08

In 2007/08, the sampling regime that has been employed by DoF since mid-2005 was continued. In addition, sampling effort within the Perth region was substantially increased by i) increasing the sampling frequency at existing sites to monthly (i.e. from 4-6 months to 9 months per site during 2007/08), and ii) undertaking monthly sampling at 4 new sites at Woodman Point, Point Peron, Challenger Beach and Safety Bay (Fig. 2.2). No sampling occurred from June to August because of poor weather.

Data Analysis

This report is primarily concerned with the inshore fish communities of the Perth region. However, most inshore fish species in the Perth region have distributions that extend into other regions (lower west coast and south coast) and so a substantial amount of information collected by DoF recruitment surveys in other regions has been included because of its relevance to the inshore fish species of the Perth region.

All recruitment survey data collected by DoF since 1993 was collated and error-checked. During this process, it became evident that captures of some 'low priority' species had not been recorded during sampling in some years. Thus, archived data provided incomplete information about diversity and abundance in various years. All captures of fish and invertebrates were fully recorded in 2007/08 and so fish diversity, abundance and community composition at sites in the Perth region were described for the 2007/08 sampling period, but not for previous years.

Diversity was represented by the Shannon-Weiner diversity index (H) (Krebs 1980):

$$H = -\Sigma_i \, p_i \log(p_i),$$

where p is the proportion of total abundance represented by species i.

Multivariate statistical techniques were used to compare similarities in the composition of inshore fish communities between sites and between months. Analyses were performed using PRIMER software (Clarke and Warwick 2001). Prior to analysis, the catches from replicate hauls were pooled to create a single monthly 'sample' per site. Abundances of species in each sample were subjected to a square root transformation, which reduced the influence of very abundant species. A matrix of Bray-Curtis similarities between samples was created from transformed species-abundance data.

Similarities between samples were graphically represented by non-metric multi-dimensional scaling (MDS) ordinations (Kruskal 1964). Stress values on each ordination indicate how well the two-dimensional plot represents relationships among samples in multi-dimensional space. Stress values <0.2 indicate a good fit. MDS ordinations may be arbitrarily rotated and so axes are not labelled. Significant differences in rank similarities between groups of samples were tested by analysis of similarities (ANOSIM) (Clarke and Green 1988).

Detailed reports were compiled for nine species, selected on the basis of high abundance and/or fishery significance in the Perth region. For each species, a summary of the

- fishery or ecological significance,
- distribution,
- spawning and egg/larval phase,
- spatial and temporal recruitment pattern,
- juvenile growth pattern, and
- nursery habitat

was compiled using information from published literature and from DoF recruitment data.

Analysis of length frequencies was used to assess monthly patterns in the timing of recruitment and habitat use of each species. The average monthly catch rate (number per haul) of recently recruited juveniles of each species was used as an index of recruitment. Catch rates were calculated for fish collected by the 61 m net only. Length was used to classify each fish as either ‘juvenile’ or ‘adult’, based on published length-age-maturity relationships for each species, where available.

Sites sampled within the Perth region were assessed as to their value as a nursery area for selected species, based on relative abundance and residency period of each species in each habitat. Sampling regimes required to effectively monitor future recruitment by each species were recommended.

Section 3. Environmental conditions

In the south-west region of WA there are two main currents that can potentially transport eggs and larvae of coastally-spawned fish.

Leeuwin Current – a warm water current of tropical origin. It flows southwards along the west coast, and then eastwards along the south coast of Australia. Flow is typically strongest in autumn/winter and during La Niña conditions (typically high Southern Oscillation Index (SOI)). Flow is typically weakest in summer and during El Niño conditions (typically low SOI).

Capes Current – a cold water current, flowing mainly November-March. This current originates as upwelled water in the Capes region that is transported northward against the coast (i.e. inshore of the Leeuwin Current), perhaps as far as the Abrohlos Islands. This current is higher in salinity (35.37–35.53‰) and cooler (21.0ºC–21.4ºC) than the Leeuwin Current.

Sea level at Fremantle and the SOI both provide an index of the strength of the Leeuwin Current. Since the commencement of DoF recruitment surveys in 1993, the strongest annual Current flows have occurred in 1999 and 2000 (Fig. 3.1).

Sites sampled within the Perth region in 2007/08 were assigned a habitat type based on enduring physical features, following the classification scheme of Valesini *et al.* (2004), summarised below:

Type 1 (Highly sheltered, dense seagrass nearby).	Mangles Bay, Safety Bay
Type 2 (Moderately sheltered, patchy seagrass nearby).	Woodman Point, Challenger Beach, Warnbro Sound, Point Peron
Type 4 (Moderately wave-exposed, dense seagrass nearby).	Pinnaroo

Long-term records of temperature and salinity from the DoF recruitment monitoring program indicate that Pinnaroo and Warnbro Sound are hydrologically similar. On average, water temperature at these sites follows a similar monthly trend, ranging from 15 to 24 °C during a 12 month period (Fig. 3.2a). Mangles Bay also exhibits a similar range of temperatures but experiences significantly lower average salinity in winter (Fig. 3.2a, d).

In 2007/08, the maximum temperature recorded at Mangles Bay was considerably warmer than Pinnaroo or Warnbro Sound (Fig. 3.2b, c). High maximum temperatures were also recorded at Safety Bay and Point Peron in 2007/08 (Fig. 2.2b).

Section 4. Overview of inshore fish communities within the Perth region at sites sampled by DoF in 2007/08

Two sites within the Perth region (Pinnaroo and Warnbro Sound) have been sampled since 1995 during ongoing recruitment surveys by DoF. A third Perth site (Mangles Bay) was added in 1999. These three sites, plus an additional four sites in the Perth region, were sampled in 2007/08 as part of this SCC-funded project. Sampling at each site was conducted monthly from September 2007 to May 2008. Sampling was not undertaken at any site in June-August due to unfavourable weather in this period preventing the use of sampling gear. Some sites were also not sampled in other months due to high volumes of drifting weed that preventing the use of nets (Table 4.1)

The average diversity and abundance of fish communities differed between sites within the Perth region in 2007/08 (Table 4.2). Mangles Bay hosted the greatest number of species and the fish community at this site was typically the most diverse (Fig. 4.1a, b). The fish communities at Woodman Point, Warnbro Sound and Pinnaroo were typically the least diverse.

The average number of fish per month was highest at Woodman Point, Pinnaroo and Safety Bay (Fig. 4.1c). However, total fish abundance was strongly influenced by the presence/absence of *Spratelloides robustus*, which often formed very large schools in inshore waters. When *S. robustus* was excluded, the average number of fish per month was greatest at Safety Bay and Mangles Bay (Fig. 4.1d). The number of fish sampled at most sites was highly variable among months, highlighted by the high standard deviations estimated at most sites.

In 2007/08, there were some significant differences in fish community composition among sites. In particular, the community at Mangles Bay was consistently dissimilar to the communities at other sites sampled by the 61 m net in 2007/08 ($p<0.1\%$, ANOSIM pair-wise comparisons) (Fig. 4.2a). Over the same period, the communities at Pinnaroo and Warnbro Sound were very similar.

Of the sites sampled by the 21 m net, Safety Bay and Woodman Point hosted communities that were significantly different to each other in 2007/08 ($p=0.8\%$, ANOSIM pair-wise comparisons) (Fig. 4.2b). Few conclusions could be drawn about the community at Point Peron because only four samples (September-December) were taken at this site.

Within each site, the composition of the fish community varied among months (Fig. 4.3). In particular, there was a shift in community composition at many sites between December and January, which coincided with a marked increase in temperature and salinity (Figs. 4.4, 4.5). When samples from all sites were grouped by these periods (i.e. group 1 = samples collected September-December; group 2 = samples collected January-May) the composition of samples were significantly different ($p=0.1\%$, ANOSIM).

The timing of these changes (i.e. in mid-summer) has implications for future sampling of inshore fish communities. Some previous surveys of fish communities in south-western Australia have employed a traditional seasonal sampling regime (i.e. spring = September to November, summer = December to February, etc), with the assumption that the overall level of similarity among samples within a season will be greater than among seasons (e.g. Valesini *et al.* 2004). The monthly trends in inshore fish communities observed by DoF in 2007/08 suggest that this assumption may sometimes be invalid in the Perth region and that traditional seasonal sampling could generate misleading information about spatial and temporal patterns in fish communities. A sampling pattern based on hydrological 'seasons' may be more appropriate. Ongoing monitoring of environmental conditions in inshore habitats would be required to define such 'seasons' within and between years.

Section 5 – Individual species

Individual species described in detail in this section have been selected because they are relatively abundant and/or have fishery significance in the Perth region (Table 4.2). Collectively these species encompass a range of distributions, trophic levels and biological characteristics. The distribution and abundance of these species provide indicators of various environmental conditions and/or stock status. The list of species included in this section is not exhaustive. Additional species within the DoF recruitment database will be reviewed in a similar fashion and included in a future DoF Research Report.

Mugil cephalus (Sea mullet)

Significance

- Major commercial fishery target species.
- *Mugil cephalus* are efficient exploiters of primary protein. Juveniles and adults feed primarily by benthic grazing, consuming phytoplankton, zooplankton and detritus (Cardona *et al.* 1996). *Mugil cephalus* are prey for numerous larger predatory fish (e.g. sharks, mulloway, flathead and tailor), dolphins and sea birds (Thomson 1957d, Kailola *et al.* 1993).
- In south-western Australia, the majority of *M. cephalus* spend their entire juvenile phase and most of their adult phase in estuaries or rivers and so can be considered ‘estuarine-dependent’. This species is likely to be impacted by declines in the 'health' of estuarine and riverine habitats throughout south-western Australia associated with factors such as eutrophication, hypoxia and loss of vegetated habitats. *Mugil cephalus* abundance in the Swan Estuary has been declining since the 1980s.

Distribution

Mugil cephalus has a world-wide distribution, in temperate and tropical waters, from approximately 42°N to 42°S (Thomson 1963). They are found in all Australian states, but are most common on the east coast from Townsville (Qld) to Fowlers Bay (SA), and on the west coast from Port Hedland to Esperance (Kailola *et al.* 1993). Individuals display strong schooling behaviour at larval, juvenile and adult stages.

Mugil cephalus occur at all latitudes along the western Australian coast, where they occur in coastal waters and in estuaries/rivers. Juveniles and adults are tolerant of a wide range of temperatures and salinities, including hypersaline and fresh waters (Smith and Deguara 2002). *Mugil cephalus* is capable of completing it's life cycle in marine waters, but individuals tend to occur in estuaries where available and seasonally migrate into marine waters to spawn during autumn/winter.

Mugil cephalus comprise a single stock along lower west coast. Limited genetic differences are evident between fish sampled from various marine and estuarine sites on the lower west coast (Watts 1991). The population in the region is well mixed due to the spawning migrations undertaken by adults and the dispersal of pelagic eggs and larvae in coastal waters.

In south-western Australia, adults typically reside in estuaries except during the spawning season. In spring/summer, a large proportion of adults migrate downstream and aggregate in the middle or lower parts of estuaries (Chubb *et al.* 1981). In late summer/autumn, these fish migrate to oceanic waters where they spawn in autumn/winter. Some older (non-spawning) juveniles may participate in this migration, but most fish probably remain in the estuary for the duration of their juvenile phase (Smith and Deguara 2002). Some adults do not spawn every year and also remain in the estuary during the spawning season. On the west coast, adults tend to migrate northwards in coastal waters prior to spawning (Thomson 1951). There is no evidence of a significant return (southward) migration and so adults probably do not return to the same estuary after spawning.

Since DoF recruitment surveys began in 1993, a total of 5,481 *M. cephalus* have been captured during sampling with the 61 m net. A further 389 have been captured with the 21 m net. Overall, these fish were caught at 17 inshore marine sites extending from Cervantes (West region) to Israelite Bay (South-east region) (Fig. 2.1, Table 5.1). The majority of captures by this monitoring program have occurred at Mangles Bay (58% of fish), Koombana Bay (17%), Emu Point (7%) and Leschenault Inlet (various sites, 6%). The highest average catch rates by the 61 m net were in Leschenault Inlet (76 fish/day), Mangles Bay (54 fish/day) and Shoal Bay (20 fish/day). Relatively high catch rates were also achieved with the 21 m net at sites within Leschenault Inlet and at Safety Bay (10-20 fish/day) (Table 5.1).

Overall, DoF survey data indicate that *M. cephalus* is moderately abundant and has a widespread distribution in coastal and estuarine waters of south-western Australia. Lower DoF catch rates suggest a lower abundance in the South-east region, compared to the West and South regions. The relatively high catch rates achieved in Leschenault Inlet reflects the importance of estuarine habitats for this species. *Mugil cephalus* is abundant in many south-western estuaries (e.g. Loneragan *et al.* 1989, Potter *et al.* 1997, Potter and Hyndes 1994).

Spawning and larval stage

Spawning by *M. cephalus* along the west coast takes place in marine waters, but the exact location of spawning is uncertain. In other regions around the world, there have been various reports of spawning by this species at sites adjacent to the coast, in shelf waters or at the shelf edge (Smith and Deguara 2002). The absence of any *M. cephalus* larvae in ichthyolankton samples taken at the entrances of various south-western estuaries suggests that spawning may occur offshore (Gaughan *et al.* 1990, Neira *et al.* 1992, Neira and Potter 1992a, 1992b, Neira and Potter 1994, Young and Potter 2003b).

Eggs and larvae of *M. cephalus* are pelagic (Smith and Deguara 2002). After reaching an age of about 10 days (approx. length 3.5 mm) larvae tend to occur at the surface and so are highly vulnerable to dispersal by surface currents. Larvae can potentially be dispersed large distances during a larval phase lasting 2-3 months. Eggs and larvae spawned on the lower west coast could potentially be dispersed north or south by coastal currents, depending on time of year and location.

Mugil cephalus has an extended spawning period, lasting up to 7 months in some Australian regions. Spawning typically peaks in autumn/winter but can also occur at other times. In the Perth region, spawning has previously been reported to occur from March to September (Chubb *et al.* 1981). This period was inferred mainly from the occurance of fish 20-30 mm TL (estimated age 2-3 months) from May to November in the Swan Estuary (Chubb *et al.* 1981). In DoF surveys in the Perth region since 1995, 20-25 mm fish were observed from May-December, indicating a slightly longer spawning period (March to October) than previously reported (Fig. 5.1).

There is limited evidence of spawning by *M. cephalus* along the southern coast of WA, particularly in the South-east region. The smallest fish captured by DoF in the West, South and South-east regions were 21, 20 and 32 mm, respectively (Figs. 5.1, 5.2, 5.3). The larger size of recruits in the South-east region might result from a greater distance and duration of oceanic dispersal experienced by larvae prior to recruitment, compared to recruits in the West or South regions. Also, very low catch rates of small fish in the South-east region suggest low rates of larval supply.

Overall, the available evidence suggests that *M. cephalus* spawns in the West region and possibly in the South region, but not in the South-east region. Although very small (20-25 mm) fish occur in the South region, these could be derived from spawning on the west coast. The commencement of spawning in autumn/winter coincides with the peak flow of the southward Leeuwin Current, which could transport larvae from the West region to the South and/or South-east regions. The lack of recruitment (as discussed below) during spring along the south coast (and in the Bunbury region) may be due to the cessation of larval transport by the Leeuwin Current at the end of winter. Larvae spawned in the Perth region during spring would tend to be retained in this area.

The mid-west coast, including the Perth region, may be the main spawning area and source of recruitment for *M. cephalus* in south-western Australia. If so, this would mirror the situation on the lower east Australian coast, where fish migrate northwards to spawn in northern NSW and southern Qld waters (Smith and Deguara 2002). On the west coast, adults also migrate northwards prior to spawning (Thomson 1951).

Recruitment

The catch rate of fish 20-39 mm TL (estimated age <4 months) was used as an index of annual recruitment strength at each site.

At Koombana Bay and Emu Point, the mean monthly catch rate of 20-39 mm fish displayed a consistent seasonal pattern each year, peaking between May and September, suggesting that both sites experienced a similar seasonal pattern of larval supply (Fig. 5.4). Also, the magnitude of catch rates observed at these sites was quite similar (ranging from 0 to 30 fish/haul at each site) suggesting similar abundances of recruits in each location.

Recruitment by *M. cephalus* appears to commence slightly later on the west coast than on the south coast. Very small fish (20-25 mm) were first observed in June in the West region, but were first observed in April in the South region (Fig. 5.2).

Recruitment patterns by *M. cephalus* within the Perth region were difficult to assess due to the relatively low and infrequent catches of small fish at local sites. Limited evidence suggests that the region experienced strong annual recruitment in 1999 and 2000, when high catch rates occurred at Warnbro Sound and Mangles Bay, respectively (Fig. 5.4). These years coincided with peak flows of the Leeuwin Current (Fig. 3.1).

The presence of 20-39 mm fish from June to January within the Perth region indicated recruitment during winter (similar to Koombana Bay and Emu Point), but also indicated additional recruitment in spring. In several years, the catch rates of 20-39 mm fish were relatively high at Mangles Bay and Warnbro Sound between October and January, suggesting spring/summer recruitment is relatively typical in this region. Unfortunately, since mid-2005, these sites have not been sampled in winter and so the relative contributions of recent winter and spring recruitment cannot be assessed. Nonetheless, the available data indicates that the Perth region may typically experience a much longer recruitment period (June-January) than regions further south.

Juvenile Growth and Habitat Use

In Australia, *M. cephalus* attain maximum total length of 76cm TL and a maximum age of at least 11 years, although ages up to 16 years have been reported in other regions, (Kailola *et al.* 1993, Smith and Deguara 2002). The size/age at which *M. cephalus* reach maturity appears to vary between regions. There is some evidence to suggest younger/smaller sexually mature fish occur in warmer regions. On the Australian east coast, fish typically reach maturity at 30/34 cm TL (male/female) at an age of 3-4 y (Smith and Deguara 2002). In WA, fish typically reach maturity around 37 cm (Gaughan *et al.* 2006).

In the Swan Estuary, juvenile *M. cephalus* are reported to attain a total length of 136-209 mm by March (age 11 months, assuming an average birth date in May), 178-222 mm by May (13 months) and about 215 mm by June (14 months) (Chubb *et al.* 1981). *Mugil cephalus* are also reported to attain a length of approximately 200 mm after 12 months in the Peel-Harvey and Leschenault estuaries (Lenanton *et al.* 1984, Potter *et al.* 2000). These growth rates were estimated by examining length frequencies. However, growth rates estimated by this method are likely to be imprecise due to the extended period of recruitment by *M. cephalus* (resulting in a wide range of ages within a length class) and the loss of faster growing fish from samples due to emigration and/or net avoidance (resulting in an underestimate of growth rate).

The modal length of *M. cephalus* in samples collected by DoF at inshore sites in the West and South regions was approximately 100 mm in May (Figs. 5.1, 5.2). Similarly, a mean length of about 100 mm has previously been observed in May in the Blackwood River estuary (Lenanton 1977). These values suggest a growth rate of about half that reported for fish in other west coast estuaries. It is not clear whether these smaller fish were growing more slowing or were spawned later than the fish observed in west coast estuaries. Otolith-based estimates of age are required to develop a better understanding of variations in growth of *M. cephalus* between regions.

In the West and South regions, fish <40 mm have comprised the majority of all *M. cephalus* captures since sampling commenced in 1993 (Figs. 5.1, 5.2, 5.3). At all sites, the catch rates of fish >40 mm were relatively low. Typically, the monthly catch rate of 20-40 mm fish peaked sharply over a 1-2 month period at each site each year (Fig. 5.4), suggesting that small fish inhabit shallow coastal site for very brief periods (<2 months) and then migrate to other habitats. Similarly, juvenile *M. cephalus* make temporary use of shallow habitats in the lower parts of estuaries. In the Swan Estuary, small fish briefly occur in the lower estuary as they migrate to the middle and upper estuary and to freshwater tributaries (Chubb *et al.* 1981).

Overall, small (<40 mm) *M. cephalus* appear to be highly mobile. They migrate rapidly through coastal waters and the lower parts of estuaries, using shallow sites in these areas as temporary nurseries, on their way to more permanent nurseries in upper estuaries.

Small (<40 mm) *M. cephalus* were caught at four of the seven sites sampled by DoF in the Perth region (Fig. 5.5). Average catch rates were highest at the most sheltered sites (Mangles Bay and Safety Bay) and lowest at the more exposed sites (Pinnaroo and Warnbro Sound). This suggests that sheltered coastal sites are preferred by small *M. cephalus*. This is consistent with previous findings of higher densities of juvenile *M. cephalus* at sheltered sites than at wave-exposed sites in the Perth region (Valesini *et al.* 2004).

Small numbers of older juveniles and adults were also taken in DoF samples at Mangles Bay, suggesting that this site may be a permanent nursery and adult habitat for some fish, i.e. some small juveniles may recruit permanently to this site rather than migrating into nearby estuaries.

Future Sampling

The relatively high catch rates of very small (<40 mm) *M. cephalus* during DoF surveys indicates that the shore-based seine netting method employed by DoF is effective at catching new recruits of this species. However, the highly migratory nature of small fish and their temporary residency at inshore sites results in limited opportunities to catch them. High frequency sampling over the residency period at inshore sites would be appropriate for future monitoring of *M. cephalus* recruitment.

In the Perth region, catch rates of new recruits peak in winter and spring. Relatively frequent (monthly or fortnightly) sampling over this period would be desirable to monitor annual recruitment. Sampling in winter would be logistically difficult at exposed sites due to unfavourable weather. However, new recruits of this species occur at highest densities at sheltered sites, where winter sampling would be feasible. In the Perth region, relatively high average catch rates at Mangles Bay and Safety Bay suggest that these would be suitable sites for future monitoring of recruitment by *M. cephalus.*

Aldrichetta forsteri (Yellow-eye mullet)

Significance

- Commercial and recreational fishery target species.
- Juveniles and adults are omnivorous, consuming a range of small invertebrates and aquatic vegetation (Thomson 1957a, Lenanton 1982b, Platell *et al.* 2006).

Distribution

Aldrichetta forsteri occur across southern Australia from the Hunter River (NSW) to Shark Bay (WA), including Tasmania (Kailola *et al.* 1993). They also occur in New Zealand. They are a schooling fish that inhabits bays, estuaries and coastal waters to a depth of 20 m. In south-western estuaries, *A. forsteri* are most abundant in the lower parts of estuaries, although they also occur in the brackish waters of tributaries (e.g. Potter *et al.* 2000).

Two distinct stocks of *A. forsteri* occur in Australia. These are distinguished by morphological differences and differences in the time of spawning (Thomson 1957c, Pellizzari 2002). A western stock occurs in WA and SA, while an eastern stock occurs from SA eastwards to Victoria, NSW and Tasmania. New Zealand fish are similar to the eastern Australian stock. The western stock spawns in winter, whereas the eastern stock spawns in summer. Genetic differences between populations are yet to be determined.

In south western WA, *A. forsteri* are probably a single genetic stock, due to the dispersal and mixing of pelagic eggs and larvae following spawning in marine waters. However, there is some evidence to suggest limited movement of adults between regions. Very limited (n=17) recaptures of tagged *A. forsteri* in marine waters suggested that fish may remain within the same coastal region for extended periods (Thomson 1957a). This is also supported by slight differences in otolith microchemistry between populations in some regions (Edmonds *et al.* 1992).

Since DoF recruitment surveys began in 1993, a total of 33,138 *A. forsteri* have been captured during sampling with the 61 m net. A further 922 were captured with the 21 m net. Overall, the fish were caught at 29 coastal sites extending from Point Peron (West region) to Eucla (South-east region) and also at sites within the Swan and Leschenault estuaries (Fig. 2.1, Table 5.2). The majority of captures occurred at Koombana Bay (31% of fish), Emu Point (17%), Pinnaroo (11%), Warnbro Sound (10%) and Poison Creek (10%). The highest average catch rates by the 61 m net were achieved at Eucla (174 fish/day), Noonaera Beach (124 fish/day) and Leschenault Inlet (111 fish/day). The next highest catch rates by the 61 m net were achieved at Israelite Bay, Emu Point, Koombana Bay and Poison Creek (50-86 fish/day). The highest average catch rates by the 21 m net were achieved at Leschenault Inlet – Pelican Point (173 fish/day) and Leschenault Inlet – Town Site (47 fish/day).

Aldrichetta forsteri have been caught by DoF at many locations, indicating a widespread distribution across south-western WA, and relatively high catch rates at various sites suggest that this species is relatively abundant in each region. *Aldrichetta forsteri* has previously been reported to have a widespread, relatively uniform distribution across the south-west region (Ayvazian and Hyndes 1995). DoF data also suggest that this species is equally abundant in inshore marine and estuarine waters of the west coast.

Spawning and larval stage

Aldrichetta forsteri spawn in coastal waters and protected marine embayments. Whilst there is some evidence to suggest estuarine spawning in some regions (see Harris 1968, Webb 1973), *A. forsteri* do not appear to spawn within estuaries in WA (Chubb *et al.* 1981, Orr 2000).

Prior to spawning, mature individuals in estuaries move to coastal areas and form large pre-spawning aggregations in marine waters (Chubb *et al.* 1981). Fish in spawning condition have been observed emigrating from the Swan Estuary, WA, and migrating northwards along the coast (Chubb *et al.* 1981). Reports from commercial fishers fish suggest that *A. forsteri* from the Swan Estuary aggregate to spawn each year in a small bay approximately 20 km north of the estuary mouth. In this bay, spawning is reported to occur over a reef area 20 m from shore (Chubb *et al.* 1981).

Female *A. forsteri* produce a single batch of eggs per season (Harris 1968). Eggs and larvae are pelagic in surface waters. Larval duration has been estimated at 19-25 days (Pellizzari 2002). Larvae transform to juveniles at approximately 12 mm TL but may remain pelagic in open waters until at least 30 mm TL (Crossland 1981, Kingsford and Tricklebank 1991, Hickford and Schiel 2003). Larvae and juveniles form schools at the surface.

In the south-west region, the spawning period of *A. forsteri* extends from March to October (Thompson 1957a, 1957b). This spawning period has been inferred from gonad development across the region and by the timing of recruitment by 0+ fish to west coast estuaries (Chubb *et al.* 1981).

There is some uncertainty about the distribution of spawning in south-western Australia. The only documented observation of spawning in WA is from the West region, 20 km north of the mouth of the Swan Estuary (Chubb *et al.* 1981). There have been no documented observations of spawning in the South region, although there is indirect evidence to suggest spawning in this area. Fish with gonads in pre-spawning and spent condition have been observed in the South region, with a similar timing of gonad maturation to that on the west coast (Thomson 1957a, Lenanton 1977, Orr 2000). Also, a single larval *A. forsteri* (length 3.5 mm) has been reported entering Wilson Inlet on a flood tide (Neira and Potter 1992b). The small size of this larva suggests that it was only a few days old and was probably spawned locally. However, the time of capture (between mid-November and mid-January) is outside the known spawning period for the western stock, raising the possibility that this very small larva was misidentified. There is no evidence yet of spawning by *A. forsteri* in the South-east region, although small juveniles occur there.

The timing of recruitment by *A. forsteri* observed in DoF surveys since 1993 is consistent with an extended spawning period from March to October, although the duration of the spawning period apparently varies between regions. Fish <35 mm (estimated to be <3 months old) were caught in April-December in the West region, in

May-November in the South region and June-October in the South-east region (Figs. 5.6, 5.7, 5.8). This pattern suggested that the spawning period was longest in the West region and shortest in the South-east region.

Interestingly, the minimum length of juveniles in DoF samples varied between regions. The smallest individuals captured were 14 mm, 21 mm and 27 mm in the West, South and South-east regions, respectively (Figs. 5.6, 5.7, 5.8). These differences might reflect proximity to spawning locations, with the larger fish travelling a greater distance prior to settlement.

Recruitment

The average monthly catch rate of *A. forsteri* <50 mm (estimated to be <4 months old) at each site was used as an index of recruitment strength. Recruitment trends were examined at Mangles Bay, Warnbro Sound, Koombana Bay, Emu Point, and Poison Creek, are the sites where fish <50 mm has been most frequently captured by DoF.

At Mangles Bay, Warnbro Sound and Koombana Bay, the average monthly catch rate of fish <50 mm peaked each year in September-December (mostly October-November), with minor peaks in June-August also occurring in some years (Fig. 5.9). Peaks in both periods were clearly evident in 1996, 1998 and 2001 at Koombana Bay. At Emu Point, peaks in the monthly catch rate of fish <50 mm occurred in June-August and September-November, with peaks in each period being equally common and of a similar intensity. At Poison Creek, peaks occurred in June-August only.

In summary, the monthly catch rate of *A. forsteri* <50 mm at all sites formed a distinct peak in winter (June-August) and/or spring (September-December) each year. Fish <50 mm captured within these periods were estimated to have been spawned in autumn and winter, respectively. Thus, the majority of *A. forsteri* in south-western WA appear to fall into one of two distinct groups, either autumn-spawned or winter-spawned.

Most 0+ fish captured in the Perth region are winter-spawned. At Koombana Bay, most recruits are winter-spawned but a significant proportion of spring-spawned fish also occur. At Emu Point, recruits are an equal mixture of winter- and spring-spawned fish. At Poison Creek, recruits are almost exclusively spring-spawned. Therefore, there is a gradual change in the type of recruits along the south-west coast, from predominantly winter-spawned recruits in the West region to predominantly autumn-spawned in the South-east region.

In years/locations where pulses of winter and spring recruitment both occur, the length distribution of 0+ fish is bimodal. This effect is most evident in DoF samples in the West and South regions from August to December (Figs. 5.6, 5.7). A bimodal length distribution of 0+ *A. forsteri* has been previously been noted in the Swan, Peel-Harvey and Leschenault estuaries (Chubb *et al.* 1981, Lenanton *et al.* 1984, Potter *et al.* 2000).

The two pulses of recruitment in south-western Australia could be derived from multiple spawning events by a single stock. Alternatively, recruits could be derived from multiple breeding stocks, spawning at different times and possibly in different regions. Since female *A. forsteri* produce only one batch of eggs per season, the latter explanation is more likely. A possibility (related to the latter option) is that spawning occurs on the lower west coast where it is essentially continuous throughout autumn and winter, but variable rates of larval transport to each region lead to variations in monthly recruitment.

Recruitment patterns observed by DoF suggest that the Leeuwin Current has a major influence on the strength, timing and location of *A. forsteri* recruitment in south-western WA. In particular, the transport of recruits to the South and South-east regions appears to be dependent on the Leeuwin Current.

At Poison Creek, it is clear that recruitment by *A. forsteri* occurs in winter, which coincides with the period of Leeuwin Current flow along the south coast (Fig. 5.9). Thus, it is likely that recruits are transported to Poison Creek by the Leeuwin Current. At Poison Creek monthly catch rates of fish <50 mm since 1994 have been relatively low and patchy, making it difficult to detect with confidence trends in annual recruitment levels. Also, it is not possible to determine recruitment after 2005, when sampling at this site was limited to September to December and no longer included the winter recruitment period. However, the typically low catch rates at Poison Creek suggest a typically low supply of recruits (compared to Emu Point) which is consistent with the greater distance travelled by larvae from the presumed West coast spawning area.

At Emu Point, relatively high recruitment occurred from 1996 to 2000, during a period of relatively strong Leeuwin Current flow. The peak in annual recruitment at this site in 2000 coincided with one of the strongest Leeuwin Current flow years in the past 20 years (Figs. 3.1, 5.9). Negligible recruitment was observed at Emu Point from 2001 onwards. At Warnbro Sound and Koombana Bay, the relationship between annual recruitment and Leeuwin Current strength was unclear. At Mangles Bay, recruitment strength displayed an inverse relationship with Leeuwin Current strength. It must be noted that the power to determine annual recruitment strength was compromised at Koombana Bay and Emu Point after 2005, when sampling from May to August was discontinued and no longer included the winter recruitment period at these sites. However, the spring recruitment period was still included.

It is noteworthy that a previous survey, using similar methods to DoF, captured juveniles and adults of *A. forsteri* at inshore sites along the west coast, but only "subadults and adults" from seven inshore sites sampled along the south coast (Ayvazian and Hyndes 1995). The authors attributed this to the south coast sites being more wave-exposed. However, fish were sampled in this study during a period of very weak Leeuwin Current (1991-1992), and so lack of recruitment to these south-coast areas may actually have been responsible.

Juvenile growth and habitat use

Aldrichetta forsteri attain a maximum total length of about 40 cm and a maximum age of at least 7 years (Thomson 1957a-c, Curtis and Shima 2005). Females attain a larger maximum size than males. Growth is faster in the western stock, and western fish mature later and at larger sizes than eastern fish (Kailola *et al.* 1993). Western females and males mature at about 267 mm and 240 mm TL, respectively (Thomson 1957b).

In the south-west of WA, the growth rate of juvenile *A. forsteri* appears to vary considerable between regions. For example, the mean lengths of 0+ fish in May range from ~90 mm at Koombana Bay (this study), ~100 mm in the Blackwood River estuary, (Lenanton 1977), ~120 mm in marine waters of the Capes region (Lenanton 1982a), ~120 mm in the Perth area (this study) and 140-154 mm in the Swan Estuary (Chubb *et al.* 1981). Such differences in growth may reflect differences in the quality of juvenile nursery areas. However, further otolith-based studies of growth rates are required to confirm these apparent differences.

A study by Chubb *et al.* (1981) within the Swan Estuary provides the only detailed description of growth by *A. forsteri* in WA. In this estuary, fish reach a mean length of 161 mm TL at age 1 year and 297 mm at age 2 years (Chubb *et al.* 1981). However, 0+ fish in this estuary appear to grow faster than at locations (see above) and so it is not clear whether growth within the Swan Estuary is representative of growth at marine sites within the Perth region.

Juveniles recruit to both estuarine and marine nursery areas in the south-west region, but appear to avoid very wave-exposed sites (Lenanton 1982a). In the Perth region, 0+ fish (<150 mm) were captured at all seven of the DoF sampling sites (Fig. 5.10), suggesting that shallow waters at both sheltered and moderately wave-exposed sites are used as nurseries by this species. Only samples taken at Pinnaroo and Warnbro Sound also contained older individuals, including some fish that were likely to be mature. The presence of older fish at these two sites, which are moderately wave-exposed, suggests a movement towards more exposed sites with increasing size/age. At all West region sites, 0+ fish recruited during winter and formed a discrete length cohort that was evident in samples for 12 months following recruitment. A marked decline in the abundance of the cohort occurred after 12 months (i.e. in the following winter), when the modal length was approximately 125 mm (Fig. 5.6).

Overall, these patterns suggest that shallow waters at a wide range of inshore sites in the Perth region provide nursery areas for *A. forsteri*. Juveniles inhabit the shallow waters at these sites for the first 12 months of their life and then move to deeper water or to more exposed sites. Emigration from nursery sites by 1-year old fish coincides with the arrival of the next year class of recruits, thus avoiding competition.

These distributional patterns are consistent with those previously reported by Valesini *et al.* (2004), who captured small *A. forsteri* at sheltered and wave exposed coastal sites in the Perth region and found that the average size of fish increased with the level of wave-exposure. Distributional patterns in Perth coastal waters also mirror those observed in the Swan Estuary. Juvenile *A. forsteri* recruit to shallow banks in the lower-middle estuary and remain in these areas for the first year of life (i.e. until approximately June) (Chubb *et al.* 1981). Fish then move into deeper waters. They eventually move into marine waters at 2-3 years, at the onset of maturity (Chubb *et al.* 1981). The population in this estuary mainly comprises immature fish (age 0+, 1+ and some 2+).

Along with wave-exposure, the presence of aquatic vegetation appears to be another important factor influencing the distribution of juveniles. Although 0+ *A. forsteri* are often found at higher densities over bare sand than over vegetation (e.g. Connolly 1994, Valesini *et al.* 1997), they appear to benefit from nurseries with adjacent vegetation. At coastal sites along the lower west coast, the abundance of 0+ *A. forsteri* is positively correlated with the level of detached macrophytes, which appear to be an important source of shelter and food (especially amphipods) for juveniles (Lenanton 1982a, 1982b). The recruitment by 0+ fish in May/June occurs immediate before the winter/spring peak in the level of detached macrophytes in local surf zones and 0+ fish remain associated with detached macrophytes throughout summer on the west coast.

It appears that recruitment by *A. forsteri* is timed to allow newly settled fish to derive maximum benefit from the abundant food and shelter associated with seasonal detached macrophytes accumulations in surf zones on the west coast. This suggests that loss of marine vegetation adjacent to nurseries could negatively impact on local recruitment success by *A. forsteri* due to a reduced availability of food and shelter. The importance of vegetation to juveniles of this species was also suggested by the decline in juvenile abundance within the Peel-Harvey estuary following a decline in macroalgae after the opening of the Dawesville Cut (Young and Potter 2003a).

Future sampling

The methods historically employed by DoF, including sampling in this study, are effective in monitoring the annual abundance of 0+ *A. forsteri*. Juveniles recruit to coastal sites in winter and remain in shallow waters at these sites for approximately 12 months following settlement. Therefore, sampling of 0+ fish can potentially be conducted at any time except winter.

A sampling regime with multiple sites in the Perth region would be desirable for monitoring local recruitment. A comparison of annual recruitment patterns at Warnbro Sound and Mangles Bay suggests that the abundance of new recruits varies between sites (Fig. 5.9). Therefore, a recruitment index that averages trends across multiple sites may be more representative of overall bioregional recruitment than an index derived from a single site. Also, the inclusion of sheltered and moderately wave-exposed sites may help to overcome any potential effects associated with movement of fish between sites.

Aldrichetta forsteri has historically been very abundant in Perth coastal waters. It was the second-most abundant species in catches during a faunal survey of various inshore sites in Cockburn Sound in 1977-78 (Dybdahl 1979). Unfortunately, the findings of this survey can not be directly compared with DoF surveys because the seine net used in 1977-78 was much longer (210 m length) and of slightly larger mesh (9 mm in bunt) than that used by DoF since 1993. The area swept per haul in 1977-78 was approximately 7000 m^2 and would have included deeper waters than sampled by DoF. However, in future, the methods employed in 1977-78 could be replicated to provide a direct comparison of fish abundances.

Torquigener pleurogramma (Banded toadfish)

Significance

- This species is considered a nuisance by most recreational fishers. It can occur in high densities in shallow marine and estuarine waters where it is readily caught by line fishing, often outcompeting other fish for bait and preventing target species from being caught. It is poisonous to humans (although some fish species consume it).
- Blowfish are opportunistic feeders and consume a wide variety of benthic invertebrates, especially polychaetes, amphipods and bivalve molluscs (Potter *et al.* 1988). Large predatory fish, including tuna, are reported to consume blowfish.
- Anecdotal evidence suggests that *T. pleurogramma* population size on the West coast progressively increased after the 1970s. This species has apparently experienced large fluctuations in population size in the past, but the current high densities have been maintained over a much longer period than previously known fluctuations. This has sparked concerns that the higher densities of this species may now be permanent, possibly due to a climatic shift or to anthropogenic disturbance in the nearshore environment where this species lives. High densities of *T. pleurogramma* could reduce the abundance of prey species and the quality of recreational fishing in inshore areas.

Distribution

Torquigener pleurogramma are common in estuaries and protected coastal waters of southern Australia from Coral Bay, WA, to Adelaide, SA, and from Harvey Bay, Qld, to Narooma, NSW. They do not occur in Bass Strait or Tasmania but do occur around Lord Howe Island (Hutchins and Swainston 1986, Kuiter 1993). They form small to large schools, usually over sand (Kuiter 1993).

Torquigener pleurogramma comprises a single, genetically homogeneous population along the lower west coast (Schinzig 1992). Mixing between regions may occur during the dispersal of pelagic larvae or movement of adults in marine waters.

Torquigener pleurogramma is moderately abundant at many of the sites sampled by DoF since 1993. However, prior to 2005, catches of this species were often discarded and not recorded. All catches of *T. pleurogramma* have been consistently identified, counted and measured from September 2005 onwards. This report describes catches of *T. pleurogramma* by DoF since 2005.

Since September 2005, a total of 3,658 *T. pleurogramma* have been captured in marine waters. A further 265 *T. pleurogramma* were captured in Leschenault Inlet. (Fig. 2.1, Table 5.3). Overall, fish were caught at 15 inshore marine sites extending from Pinnaroo (West region) to Poison Creek (South-east region). The majority of DoF captures at marine sites occurred at Mangles Bay (68% of fish), Safety Bay (9%), Woodman Point (8%) and Koombana Bay (6%). The highest average catch rate occurred at Mangles Bay using the 61 m net (145 fish/day). Relatively average catch rates also occurred in Leschenault Inlet using the 61 m net (43 fish/day) and at Safety Bay and Woodman Point using the 21 m net (39 fish/day).

Overall, DoF catch rates since September 2005 indicate that *T. pleurogramma* has a widespread distribution along the lower west coast, where it is relatively abundant at many marine and estuarine sites. In contrast, catches on the southern coast of WA were low and infrequent. These findings are consistent with those of Ayvazian and Hyndes (1995), who found that *T. pleurogramma* was much less abundant at inshore sites along the south coast compared to the lower west coast.

Spawning and larval stage

During DoF sampling in the Perth region, fish <30 mm were observed from December to March (Fig. 5.11), which is consistent with the spawning period previously reported for this species. In the Perth region, spawning by *T. pleurogramma* occurs in shallow coastal water from October to January, peaking between November and January (Potter *et al.* 1988). There is no evidence of spawning within estuaries. Mature fish migrate from estuaries to adjacent marine waters prior to spawning. Adults may re-enter the estuary after spawning. Large adult schools have been observed in summer moving from estuary to ocean, and large numbers of dead *T. pleurogramma* have occasionally been observed along the coast in autumn, presumably dying after spawning (Hutchins and Thompson 1983).

Eggs of *T. pleurogramma* are demersal and larvae are pelagic (Leis and Carson-Ewart (2000). Transition from larva to pelagic juvenile occurs at 5-10 mm TL.

Recruitment

The minimum length of *T. pleurogramma* in DoF samples was 12 mm (caught at Challenger Beach in January). However, the majority of fish in samples were >40 mm suggesting that juveniles were either not present in shallow waters or were not typically retained by DoF sampling gear until this size.

The average monthly catch rate of fish <60 mm (estimated to be <12 months old) at Mangles Bay was used as an index of recruitment strength in the Perth region. The catch rate of fish <60 mm indicated no recruitment by 0+ fish to Mangles Bay in 2006 (Fig. 5.13). Fish <60 mm were also absent at other Perth sites in 2006, apart from 2 small fish caught at Warnbro Sound in March. Overall, there appears to have been negligible spawning (or recruitment failure following spawning) in summer 2005/06 in the Perth region. Highly variable annual recruitment appears to be characteristic of *T. pleurogramma* (Potter *et al.* 1988).

In contrast to the Perth region, where a mixture of juvenile (age 0+ and 1+) and adult (age 2+) fish were captured at each site (see below for description of growth), predominantly 2+ fish were captured in the Bunbury region. The minimum length of fish caught in the Bunbury region was >65 mm, (estimated age 1 year), and the majority of fish were >100 mm (age 2+ years) (Fig. 5.12). Previous surveys of inshore sites in Koombana Bay and within Leschenault Inlet have also yielded only 1+ fish (Potter *et al.* 1997). It is possible that neither Koombana Bay or Leschenault Inlet are nursery areas for *T. pleurogramma*. Alternatively, recruits to the Bunbury region may be derived from spawning to the north and migrate to this region during their first year.

Juvenile growth and habitat use

In the Swan Estuary, individuals reach maturity at the end of their 2nd year, at ~125 mm TL. *Torquigener pleurogramma* attains a maximum length of 230 mm TL and an age of at least 6 y (Potter *et al.* 1988).

The growth rate of 0+ *T. pleurogramma* appears to vary considerably between regions, even at relatively small spatial scales. Potter *et al.* (1988) estimated that juvenile *T. pleurogramma* typically recruited to the Swan Estuary at length 50-70 mm TL and age 7-9 months, and reached a length of 85-100 mm after 12 months. These fish experienced faster growth than those in adjacent marine waters, where fish reached approximately 74 mm at Rockingham and 65 mm at Jurien Bay/Dongara after 12 months (Potter *et al.* 1988).

The monthly length distribution of fish captured by DoF at various marine sites in the Perth region suggests fish attain 60-80 mm by 1 year, which is similar to the value reported above for Rockingham.

The proportion of juvenile and adult *T. pleurogramma* in samples collected by DoF varied between sites in the Perth region. No obvious preference for sheltered or wave-exposed habitats was evident in either age group, although the extremely high catch rates of juveniles at Mangles Bay suggest that this sheltered site is an important nursery for this species (Fig. 5.14). *T. pleurogramma* has previously been reported to be more abundance at sheltered inshore sites in the Perth region (Valesini *et al.* 2004).

At Mangles Bay, the catch rate of each age cohort declined during winter after reaching a modal length of 80 mm, at an estimated age of 18 months. This suggested migration of fish from this site, shortly before the onset of maturity at the end of their 2nd year.

Future sampling

Since 2005, DoF recruitment surveys have provided good baseline data for monitoring fluctuations in recruitment of *T. pleurogramma* in the Perth region. Mangles Bay has proven to be a particularly useful site for this purpose, due to consistent and relative high catches of juveniles.

In future, the annual recruitment index for *T. pleurogramma* derived from DoF surveys will allow an understanding of the environmental factors determining recruitment success in this species.

Arripis georgianus (Australian herring)

Significance

- Major commercial and recreational fishery target species.
- Juvenile *Arripis georgianus* consume a wide range of small invertebrates (Lenanton 1982b) while adults consume invertebrates and small fish, including garfish, pilchards and prawns (Kailola *et al.* 1993).
- *Arripis georgianus* are an abundant prey item for larger piscivores including fishery species (e.g. Australian salmon, kingfish and mulloway), seabirds and cetaceans.

Distribution

Arripis georgianus (Australian herring) are endemic to southern Australia. They inhabit continental shelf waters across southern Australia from the Gippslands Lakes (Vic) to Shark Bay (WA) (Kailola *et al.* 1993). They form schools along beaches, over seagrass/weed or near rocky reefs in coastal bays and estuaries.

Arripis georgianus across southern Australia essentially comprises a single breeding stock. Spawning by *A. georgianus* occurs in south-western WA from approximately Cervantes to Bremer Bay (Fairclough *et al.* 2000a). Eggs and larvae are dispersed from the spawning area southwards and eastwards with the Leeuwin Current. At maturity, fish from nursery areas in SA, Vic and eastern WA migrate back to south-west WA to spawn. Evidence from genetics, otolith microchemistry and tag/recaptures confirm that there is a high level of mixing between all regions across the range of this species (Ayvazian *et al.* 2004).

However, tagging also indicates that a significant proportion of fish in the West and South regions of WA do not migrate each year and are resident within their respective regions. Also, the extent of migration along the coast by pre-spawning fish and the extent of egg/larval dispersal is dependent on the strength of the Leeuwin Current. Fluctuations in current strength are probably the main determinant of recruitment strength in each region (Ayvazian *et al.* 2000). Successive years of weak Leeuwin Current are likely to lead to a concentration of breeding stock and juveniles on the lower west coast, with declining stock abundance on the south coast. Thus, the centre of distribution of this species is likely to vary among years.

Since DoF recruitment surveys began in 1993, a total of 18,582 *A. georgianus* have been captured during sampling with the 61 m net. None were captured with the 21 m net. Overall, these fish were caught at 22 inshore marine sites extending from Point Peron (West region) to Poison Creek (South-east region) (Fig. 2.1, Table 5.4). No fish were captured in Leschenault Inlet. The majority of DoF captures have occurred at Poison Creek (63% of fish) and Koombana Bay (26%). The highest average catch rates were also at these two sites (170 and 27 fish/day, respectively). The average catch rates at other sites were <10 fish/day (Table 5.4).

Sampling by DoF indicates that *A. georgianus* is widely distributed around the south-western coast of WA and juveniles of this species are relatively abundant in many inshore habitats.

Spawning and larval stage

Spawning by *A. georgianus* occurs on lower west coast and western-most part of the south coast of WA, but not in the South-east region (Fairclough *et al.* 2000a). In each area, spawning occurs over relatively short period from April to early June (Lenanton 1978, Fairclough *et al.* 2000a).

The eggs and larvae of *A. georgianus* are pelagic. To date, Fahlbusch (1995) has provided the only information about *A. georgianus* larval development and ecology. In this preliminary study, the transformation from larva to juvenile was found to occur between 12-27 mm SL. Pre-settlement *A. georgianus* (larvae or juveniles) were caught in offshore plankton samples at lengths ranging from 6-37.5 mm, with estimated ages ranging from 43-81 days.

The length of the planktonic larval phase experienced by new recruits probably varies significantly between regions. Modelling of ocean dispersal has suggested that eggs/larvae spawned on the lower west coast take approximately 60-80 days to reach the South-east region (Ayvazian *et al.* 2000). Samples of juvenile *A. georgianus* collected by DoF since 1993 indicated a significantly larger size at recruitment in the South-east region, compared to fish recruiting to the West region. The smallest *A. georgianus* in DoF samples collected since 1993 was 34 mm in the West region, 35 mm in the South region and 51 mm in the South-east region. This difference is consistent with a longer larval duration experienced by fish transported to the South-east region.

In DoF surveys, *A. georgianus* <45 mm (estimated age <3 months) were observed each month from May to September in the West region, and June to October in the South region (Figs. 5.15, 5.16, 5.17). This pattern of occurrence is consistent with a discrete spawning period from April to June.

Recruitment

Average monthly catch rates of fish <75 mm were used as an index of annual recruitment strength at each site. The monthly progression of length cohorts in DoF samples from each region suggested fish <75 mm were aged 4-7 months in the West and South regions and 4-8 months in the South-east region, assuming spawning in May (Figs. 5.15, 5.16, 5.17). Similarly, a previous study using otolith daily increments estimated that fish <75 mm were aged 140-200 days (Ayvazian *et al.* 2000).

Koombana Bay, Poison Creek and Emu Point were the sites that provided the most frequent catches and longest time-series of recruitment data for *A. georgianus.* Limited data from sites in the Perth region (not shown) suggested that recruitment at Koombana Bay also provided a reasonable index of recruitment strength in the Perth region.

Peaks in monthly catch rates in each region suggested relatively high overall recruitment in 1996, 1997 and 1998 (Fig. 5.18). In the West region, monthly catch rates at Koombana Bay suggested low recruitment in 2006 and negligible recruitment in 2007. The South and South-east regions also appeared to experience very low recruitment in 2007.

No sampling was undertaken from mid-2002 to mid-2005 and so recruitment strength in this period was unknown.

Juvenile growth and habitat use

Arripis georgianus attain a maximum length of 41cm TL, although sampling of WA fishery landings indicates that fish >300 mm are rare (Hutchins and Swainston 1986, Fairclough *et al.* 2000b). Similarly, the maximum age is at least 14 years, although fish aged >8 y are rare.

When all length data for *A. georgianus* collected by DoF since 1993 was combined (Figs. 5.15, 5.16, 5.17), the annual arrival of the 0+ age class and subsequent growth could be clearly followed over a 12-18 month period within each region. Patterns of growth were very similar to those previously described for juvenile *A. georgianus* growth by Fairclough *et al.* (2000b).

A comparison of the monthly length distribution of samples at Koombana Bay and Perth sites (pooled) suggests that growth did not vary significantly among sites in the West region (data not shown). However, there were marked differences in growth rates of 0+ fish between regions. By April (estimated age 10 month, assuming spawning in May), the modal length of the 0+ cohort was 140, 130 and 110 mm in the West, South and South-east regions, respectively (Figs. 5.15, 5.16, 5.17). Faster growth by juvenile *A. georgianus* in the west region, compared to the southern regions, during the first 18 months of life has previously been noted by Fairclough *et al.* (2000b).

The catch rate of each age class declined after July in each region, suggesting emigration from the extreme shallows sampled by DoF at each site after 12 months by a significant proportion of fish. However, occasional catches of older fish indicated that at least some fish continued to utilise shallow waters at ages of >12 months. An annual cohort of fish was evident in the South-east region until an estimated age of 23 months (length range 165-210 mm in May). In the West region, the pattern was less clear but an annual cohort was evident until an estimated age of 16 months (length range 160-190 mm in October) after which time it merged with larger fish. Larger fish present in samples in subsequent months could not be aged but were at least 2 years old. Overall, 0+ *A. georgianus* appear to recruit to inshore nursery areas and remain for at least 12 months. A significant proportion move away from the shallow waters sampled by DoF at each site, although some older fish continue to use these habitats up to at least age 2 years.

Maturing fish migrate from the South-east region to the South or West regions to spawn (Fairclough *et al.* 2000a). Therefore, all fish in DoF samples from the South-east region were presumed to be immature. The length at which 50% of male and female *A. georgianus* attain maturity is 179 and 197 mm, respectively (Fairclough *et al.* 2000a). Fish >197 mm TL were rare in DoF samples from the South-east region, representing only 0.5% of all *A. georgianus* captured in the region. Fish >197 mm TL represented a greater proportion of samples in the South (3.9%) and West (4.9%) regions.

In each region, the increase in modal length of the annual cohort suggested that fish typically reach maturity during their second year (Figs. 5.15, 5.16, 5.17). This is consistent with the finding of Fairclough *et al.* (2000a) that the average age at which 50% of individuals mature is 1.4/1.7 years for males/females (range 2-4 years). Differences in growth rate between regions suggest that the average age at maturity could be earlier for fish recruiting to the West region than for those recruiting to the South-east region.

Juvenile *A. georgianus* were present at four of the seven sampling sites in the Perth region, although only three fish was caught at Woodman Point (Fig. 5.19). *Arripis georgianus* was not caught at Safety Bay, Point Peron or Challenger Beach. Mainly adults (>180 mm) were present at Pinnaroo and Woodman Point and a mixture of adults and juveniles (<80 mm) were present at Warnbro Sound and Mangles Bay. The presence of juveniles at both sheltered (Mangles Bay) and wave-exposed (Warnbro Sound) sites suggests that the shallow waters of various types of habitat function as nurseries for this species.

The presence of aquatic vegetation appears to be an important factor influencing the distribution of juveniles. Although 0+ *A. georgianus* are often captured over bare sand, they appear to benefit from nurseries with adjacent vegetation. At coastal sites along the lower west coast, the abundance of 0+ *A. georgianus* is positively correlated with the level of detached macrophytes, which appear to be an important source of shelter and food (especially amphipods) for juveniles (Lenanton 1982a, 1982b). The recruitment by 0+ fish in May/June occurs immediate before the winter/spring peak in the level of detached macrophytes in local surf zones and 0+ fish remain associated with detached macrophytes throughout summer on the west coast.

Thus, it appears that recruitment by *A. georgianus* is timed to allow newly settled fish to derive maximum benefit from the abundant food and shelter associated with seasonal detached macrophytes accumulations in surf zones on the west coast. This suggests that loss of marine vegetation adjacent to nurseries could negatively impact on local recruitment success by *A. georgianus* due to a reduced availability of food and shelter.

Future Sampling

The beach seining methods employed by DoF are effective in sampling juvenile *A. georgianus* in inshore nursery areas throughout the first 12 months following recruitment.

The wide size range and relatively high average catch rates of *A. georgianus* at Warnbro Sound indicate that this is an appropriate site at which to monitor the abundance of 0+ fish of this species in the Perth region. However, the current DoF sampling program at Warnbro Sound is restricted to the months of September-October and January-March. Additional sampling, especially prior to September, would be desirable to monitor *A. georgianus* recruitment at this site.

Atherinomorus ogilbyi and Unidentified Atherinids (Hardyheads)

Significance

- Atherinids are among the most numerically abundant fish species in shallow marine and estuarine habitats of the lower west coast of WA, often occurring at extremely high densities.
- Atherinids are schooling fish that represent an abundant prey item for seabirds and piscivorous fish, including fishery target species (e.g. Hindell *et al.* 2000, Humphries *et al.* 1992).
- In shallow marine waters on the lower west coats of WA, atherinids comprise two main species - *Atherinomorus ogilbyi* and *Leptatherina presbyteroides.* Both species consume benthic and planktonic invertebrates, but *A. ogilbyi* consumes mainly benthic prey while *L. presbyteroides* consumes a high proportion of planktonic prey, thus avoiding competition (Prince *et al.* 1982).

Distribution

Multiple species of atherinids occur in shallow marine habitats in south-western Australia. However, the vast majority of atherinids in shallow marine habitats in south-western Australia (i.e. the types of marine habitats sampled by DoF) are *Atherinomorus ogilbyi* or *Leptatherina presbyteroides* (Ayvazian and Hyndes 1995, Valesini *et al.* 2004). A third species, *Atherina elongata*, occasionally occurs at low densities in marine waters, but is more common in estuaries. A recent study of inshore fish in the Perth region, using similar methods to DoF, reported that the composition of atherinids was *A. ogilbyi* 56.3%, *L. presbyteroides* 43.6% and *Atherina elongata* 0.1% (Valesini *et al.* 2004).

Atherinid species are morphologically similar and difficult to distinguish in the field. During DoF surveys, only large individuals of *A. ogilbyi* were specifically identified (*A. ogilbyi* attains a larger maximum size than other species and so larger fish can be distinguished on this basis). Other atherinids were not identified to species level, but it is likely that the majority of these "Unidentified Atherinids" captured in marine waters were either *L. presbyteroides* or small individuals of *A. ogilbyi.*

The majority of "Unidentified Atherinids" captured by DoF in Leschenault Inlet were likely to be either *L. presbyteroides* or *A. elongata*. A previous study in this estuary, using similar methods to DoF, reported the composition of atherinids was *L. presbyteroides* 62.0% , *A. elongata* 37.7% and *A. ogilbyi* 0.3% (Potter *et al.* 2000).

Atherinomorus ogilbyi occurs in coastal waters on the east coast of Australia in Qld and NSW and on the west coast of Australia, south of North West Cape (WA) (Hutchins and Swainston 1986). It occurs in marine waters and in the lower parts of estuaries (Prince and Potter 1983). Previous studies have reported that *A. ogilbyi* is widespread along the west coast, where it is relatively abundant in shallow marine sites, but absent at marine sites in the South and South-east regions (Prince and Potter 1983, Ayvazian and Hyndes 1995).

Leptatherina presbyteroides occurs in shallow protected coastal bays and estuaries of southern Australia, from Jervis Bay (NSW) to Geraldton (WA) including Tasmania

(Gomon *et al.* 1994). It is associated with seagrass and open sand/mud habitats. Previous studies have reported that *L. presbyteroides* is abundant and widespread in shallow, marine sites of the South, South-east and West regions (Ayvazian and Hyndes 1995).

The stock structure of atherinids in WA has not been examined, but given the lack of dispersal during the demersal egg phase, it is possible that there are multiple, semi-isolated populations of each species within each region.

Atherinids have historically been abundant at many of the sites sampled by DoF since 1993. However, prior to 2005, catches of these fish were often discarded and not recorded. All catches of atherinids have been consistently identified, counted and measured from September 2005 onwards. This report describes catches of atherinids by DoF since 2005.

Since September 2005, a total of 27,169 atherinids have been captured in marine waters, 30% of which were identified as *A. ogilbyi*. A further 8,971 Unidentified Atherinids were captured in Leschenault Inlet (Fig. 2.1, Table 5.5).

Atherinomorus ogilbyi was identified at 8 sites on the West region, from Pinnaroo to Koombana Bay. *Atherinomorus ogilbyi* was also identified at one site in the South region (Emu Point) and one site in the South-east region (Poison Creek). The captures at Poison Creek extend the eastward distribution of *A. ogilbyi* in southern WA, previously reported by Potter *et al.* (1986) as occurring eastwards to Flinders Bay. (Fig. 2.1, Table 5.5).

In marine waters, the majority of total atherinids (all species combined) were captured at Safety Bay (39% of fish), Mangles Bay (37%) and Challenger Beach (8%). An average daily catch rate of 594 and 249 fish/day was achieved at Mangles Bay and Challenger Beach, respectively, using the 61 m net while an average catch rate of 1336 fish/day was achieved at Safety Bay using the 21 m seine net. (Fig. 2.1, Table 5.5).

Atherinomorus ogilbyi comprised >50% of the total atherinid catch at Point Peron and Safety Bay and at least 30% at Challenger Beach. At the other marine sites (Mangles Bay, Warnbro Sound, Woodman Point, Pinnaroo), fish identified as *A. ogilbyi* comprised between 5 and 18% of the total atherinid catch at each site.

In Leschenault Inlet, average catch rates of total atherinids were generally higher than those in marine waters, ranging from 283 to 995 fish/day using the 21 m seine, and 690 fish/day using the 61 m seine net (Table 5.5).

Spawning and larval stage

Atherinids spawn demersal eggs with filaments that attach the eggs to sediment or algae (White *et al.* 1984). After hatching, larvae are neustonic (i.e. at the surface). The spatial patterns of recruitment to coastal nursery areas may be partly determined by wind-driven currents that are likely to strongly affect the distribution of neustonic larvae. Transformation from larva to juvenile is completed at about 18 mm TL.

The minimum length of *A. ogilbyi* in DoF samples taken since 2005 was 33 mm TL, which was observed at Warnbro Sound in February. On the West region, small (<40 mm) individuals of *A. ogilbyi* were first observed each year in February (Fig. 5.20). These fish were the smallest members of a broad size cohort of *A. ogilbyi* (approximate range 35-80 mm in February) that progressively increased in mean length until the following February. A pulse of annual recruitment by 0+ *A. ogilbyi* in February has previously been reported in Cockburn Sound and the nearby Swan Estuary (Prince and Potter 1983).

On the south coast, *A. ogilbyi* were infrequently observed in DoF samples, although some small fish (40-80 mm) were captured at Emu Point in January, September and October and at Poison Creek in April and September. These limited observations suggest similar monthly length distributions to those seen in the West region. All observations were consistent with the spring spawning period (October to January) previously reported for *A. ogilbyi* in the Perth region (Prince and Potter 1983).

The minimum length of Unidentified Atherinids in DoF samples taken since 2005 was 15 mm TL, which was observed at Point Peron in December. In the Perth region, these fish were likely to be *Leptatherina presbyteroides* or *Atherinomorus ogilbyi* (see discussion above). In the Perth region, small (15-20 mm) Unidentified Atherinids were observed in November, December and January (Fig. 5.21). The minimum length in samples then progressively increased from 24 mm in February to 35 mm in April. In May, the minimum size dropped to 29 mm, due to the presence of a small number of fish <40 mm in samples. The occurrence of small (<20 mm) fish in samples from November to January is consistent with the spring spawning periods previously reported for both *L. presbyteroides* (Sept-Dec) and *A. ogilbyi* (Oct-Jan) (Price and Potter 1983).

Interestingly, Prince and Potter (1983) observed a secondary spawning period by *L. presbyteroides* in April/May in the Swan Estuary, but concluded that this did not occur in marine waters. However, the presence of a few small (<40 mm) fish in DoF samples during May does suggest some additional spawning by this species in marine waters in autumn (perhaps March/April?).

Recruitment

Since the commencement of DoF recruitment surveys in 1993, the minimum lengths of Unidentified Atherinids and *A. ogilbyi* recorded in samples have been 15 and 25 mm TL, respectively (DoF unpubl. data). These values are similar to the minimum lengths of 17 and 21 mm TL for this species observed in another local study using similar methods (Valesini *et al.* 2004). Transformation by atherinids from larva to juvenile is completed at about 18 mm TL. This suggests that atherinids begin to recruit to shallow coastal sites in south-western Australia at the commencement of the juvenile stage.

Only a small number of *A. ogilbyi* were observed during DoF sampling in the South and South-east regions, presumably due a low abundance of this species on the southern coast. A previous study using similar methods failed to observe this species on the southern coast (Ayvazian and Hyndes 1995). The limited DoF data indicated that the monthly length compositions of *A. ogilbyi* populations in the South and

South-east regions were similar to that observed in the West region, suggesting that the timing of recruitment by *A. ogilbyi* is similar in all regions.

Juvenile growth and habitat use

When all length data for *A. ogilbyi* collected by DoF since 2005 was combined, the annual arrival of the 0+ age class and their subsequent growth could be tracked over a 12 month period. The 0+ recruits was first detected on the West region in February (length range 33-86 mm, modal length ~60-70 mm) (Fig. 5.20). The length range of the 0+ cohort expanded to 38-117 mm by October although the modal length was still 60-70 mm, suggesting slow growth over winter. The modal length of the 0+ cohort then progressively increased to 90-100 mm in December, 105-110 mm in January and approximately 120 mm in February, after which the cohort disappeared from samples.

This pattern of recruitment and growth is similar to that previously reported by Prince and Potter (1983) for *A. ogilbyi* in Cockburn Sound. They observed recruitment by the 0+ cohort of *A. ogilbyi* in February 1978 (length range 40-85 mm, mode 60-70 mm), which increased to a mode of 110-120 mm by December and finally merged in February with older fish >120 mm. In contrast to our data, Prince and Potter also observed a well-defined 1+ cohort (length range 120-190 mm) of *A. ogilbyi* in Cockburn Sound throughout the year. The larger seine net (length 210 m) used to capture fish in 1978 probably sampled deeper water and slightly further offshore than the 61 m net used by DoF. Larger fish may be present at DoF sites, but in deeper water beyond the zone sampled by DoF.

Atherinomorus ogilbyi reaches a maximum total length of 189 mm and a maximum age of about 2 years (Prince and Potter 1983, Potter *et al.* 1986). Individuals attain sexual maturity after about 1 year, at lengths >120 mm. Fish >120 mm were rare in DoF samples, suggesting that *A. ogilbyi* migrates away from the areas sampled by DoF at the onset of maturity.

Juvenile *A. ogilbyi* (<120 mm) were present at six of the seven sampling sites in the Perth region, including both sheltered (e.g. Mangles Bay) and moderately exposed (e.g. Warnbro Sound) sites (Fig. 5.22). A widespread distribution by *A. ogilbyi* across a range of inshore habitat types has previously also been noted by Valesini *et al.* (2004).

The only Perth site where juvenile *A. ogilbyi* were not caught was Pinnaroo. Fish caught at this site ranged from 108 to 170mm, and included the largest fish taken in DoF surveys. The occurrence of large fish at Pinnaroo, which was the most wave-exposed Perth site sampled by DoF, suggests that *A. ogilbyi* moves into more exposed habitats at maturity.

In summary, *A. ogilbyi* recruits to shallow coastal sites and remains in these nursery areas until the onset of maturity at approximately age 12 months and length 120 mm. The shallow waters of protected, or moderately wave-exposed, inshore sites in the Perth region provide potential nurseries for this species. Maturing individuals appear to emmigrate from the shallow waters of nursery sites, perhaps into slightly deeper waters at the same sites or perhaps to more wave-exposed sites elsewhere.

As discussed above, it is likely that a large proportion of Unidentified Atherinids sampled by DoF in the Perth region were *L. presbyteroides*. The monthly length distribution of Unidentified Atherinids in DoF samples was generally consistent with the modal lengths previously described for *L. presbyteroides* in Cockburn Sound of 40-50 mm in February, 50-60 mm in April/May and 70-80 mm in December (Prince and Potter 1983) (Fig. 5.21).

Leptatherina presbyteroides reaches a maximum total length of 110 mm and a maximum age of about 1 year (Prince and Potter 1983, Hutchins and Swainston 1986). Males and females mature at about 59 and 69 mm, respectively. Fish <69 mm comprised a high proportion of Unidentified Atherinids caught at six of the seven DoF sampling sites in the Perth region, including both sheltered and moderately wave-exposed habitats (Fig. 5.23). This suggests that each of these sites functioned as a nursery for *L. presbyteroides*. At Pinnaroo, which was the most wave-exposed Perth site sampled by DoF, the total abundance of Unidentified Atherinids was low and comprised a very small proportion of <69 mm fish. This distribution suggests a preference, especially by juveniles, for low energy sites. A strong preference by *L. presbyteroides* for sheltered sites was also observed by Valesini *et al.* (2004).

Future sampling

The high catch rates of small Atherinids during DoF surveys indicates that the shore-based seine netting method employed by DoF is reasonably effective in catching 0+ recruits of atherinids.

Monthly sampling during the warmer months at sheltered sites, such as Mangles Bay and Safety Bay, would be appropriate for monitoring annual recruitment of atherinid species in the Perth region.

***Hyperlophus vittatus* (Sandy sprat)**

Significance

- *Hyperlophus vittatus* is a schooling fish that represents an abundant prey item for seabirds and piscivorous fish.
- *Hyperlophus vittatus* is one of the four fish species that comprise the bulk of the diet of little penguins at Penguin Island. The majority of *H. vittatus* consumed by these penguins come from around Becher Point (near DoF sampling site at Warnbro Sound) (Lenanton *et al.* 2003). *Hyperlophus vittatus* is important in the diet of the penguins throughout the year (Klomp and Wooller 1998). The average size of fish consumed ranges from 43 to 76 mm TL, depending on the time of year. *Hyperlophus vittatus* at this size are juveniles and their availability presumably varies with annual recruitment strength.
- *Hyperlophus vittatus* is a commercial fishery target species.

Distribution and stock structure

Hyperlophus vittatus is a schooling species that is distributed across southern Australia from Kalbarri (WA) to Moreton Bay (Qld), excluding Tasmania (Gomon *et* *al.* 1994). Juveniles occur in estuaries and marine embayments, while adults occur in embayments and other coastal waters (Kailola *et al.* 1993).

Stock structure is unknown. In WA, the dispersal of pelagic larvae in coastal waters is probably sufficient to ensure genetic homogeneity within the West and South regions. However, slight differences in otolith morphology between regions suggest separation of populations (Gaughan *et al.* 1996). The habit of spawning within embayments (which tend to retain eggs/larvae) would limit mixing and could result in semi-discrete populations within regions.

Since DoF recruitment surveys began in 1993, a total of 110,739 *Hyperlophus vittatus* have been captured during sampling with the 61 m net. A further 883 have been captured with the 21 m net. Overall, these fish were caught at 15 inshore marine sites extending from Point Peron (West region) to Esperance (South-east region) (Fig. 2.1, Table 5.6). Some fish were also captured in the estuarine environment of Leschenault Inlet. The majority of DoF captures have occurred at Koombana Bay (52% of fish), Warnbro Sound (22%) and Pinnaroo (20%). The highest average catch rates by the 61 m net were also at these three sites (ranging from 152 to 327 fish/day). The highest average catch rates by the 21 m net were in Leschenault Inlet (Preston River site) (154 fish/day) (Table 5.6).

The *H. vittatus* observed in the South and South-east regions are significant because they represent the first observations of this species in marine waters along the southern WA coast. In WA, *H. vittatus* is largely restricted to the west coast and is considered rare on the southern coast (Ayvazian and Hyndes 1995, Gaughan *et al.* 1996). Previous observations of *H. vittatus* on the southern coast of WA are restricted to a few larvae caught entering Hardy, Wilson and Walpole-Nornalup Inlets and adults observed within Hardy Inlet (Lenanton 1977, Neira and Potter 1992a, 1992b, 1994).

In DoF surveys since 1993, *H. vittatus* were captured in the South region on 8 occasions and the South-east region on 1 occasion. The eastern-most catch of *H. vittatus* was at Esperance Town site in December 1998.

Spawning and larval stage

The eggs and larvae of *H. vittatus* are pelagic. Transformation from larva to juvenile occurs at 20-25 mm TL (Neira *et al.* 1998). Growth rates of *H. vittatus* larvae are relatively slow, reflecting the low temperatures experienced by larvae following spawning in winter. Growth is highly variable between regions, such that the ages of individuals 25 mm TL range between 80 to 120 days and individuals 30 mm TL range between 100 to 180 days (Gaughan *et al.* 1996).

On the lower west coast, *H. vittatus* spawns in nearshore marine waters, predominantly within 5 km of the coast, but not within estuaries. Spawning occurs at least as far south as Bunbury (Gaughan *et al.* 1996). *Hyperlophus vittatus* may spawn at any time of year on the west coast, but the majority of spawning occurs between May-September.

The distribution of eggs in coastal waters is very patchy and highly aggregated, suggesting that adults form multiple, localized spawning aggregations along the coast during the spawning season (Gaughan *et al.* 1996). Egg concentrations are higher in embayments (e.g. Warnbro Sound, Comet Bay, Cockburn Sound, Koombana Bay) suggesting that these areas are important spawning sites and/or that eggs tend to be retained in these areas.

The timing of spawning varies between embayments. For example, egg surveys in 1992 suggested peak egg production in June-September in Cockburn Sound, July-August in Warnbro Sound, June-July near Mandurah and April in Koombana Bay (Gaughan *et al.* 1996).

The timing of spawning may also vary between years within embayments. For example, eggs surveys in 1993 suggested peak egg production in November in Cockburn Sound, compared with June-September in the previous year (Gaughan *et al.* 1996).

Sampling by DoF since 1995 indicates that recruitment of *H. vittatus* at Koombana Bay consistently occurs in winter/spring each year, which suggests that spawning consistently occurs in autumn/winter near this site. The smallest individuals (<26 mm) were observed June-November and the average monthly catch rate of 0+ juveniles <40 mm consistently peaked between September and December each year (Figs. 5.24, 5.27). Previously, egg surveys have also indicated autumn/winter spawning by *H. vittatus* in the Bunbury region, with a peak in egg densities in April in Koombana Bay (Gaughan *et al.* 1996).

At DoF sampling sites within the Perth region, the timing of recruitment and spawning by *H. vittatus* was more variable than at Koombana Bay. At Pinnaroo, fish <26 mm were observed February-April and October-November, and peaks in the average monthly catch rate of fish <40 mm occurred in April and/or October-November each year (Figs. 5.25, 5.27). This pattern suggests spawning in winter, spring and summer.

Warnbro Sound, fish <26 mm were observed all months except March and May. Peaks in the average monthly catch rate of fish <40 mm occurred variously in January, June, August, October and/or November each year (Figs. 5.26, 5.27). This pattern suggests spawning throughout the year.

At Mangles Bay, no fish <26 mm were observed (the smallest was 27 mm, observed in December). A peak in the average monthly catch rate of fish <40 mm occurred between September and November each year at this site, suggesting spawning in winter/spring (Fig. 5.27).

Overall, patterns of monthly recruitment observed in DoF surveys since 1993 suggest that recruitment of *H. vittatus* to nearshore sites in the Perth region is variable, within and between sites, and that recruitment is potentially derived from spawning at any time of year. This contrasts with recruitment at Koombana Bay, where consistently occurs in winter-spring each year and recruits are derived from spawning in autumn/winter.

It is perhaps significant that recruitment to the northern-most Perth region site (Pinnaroo) in DoF surveys is apparently derived from spawning from winter to summer, whereas recruitment to the south at Koombana Bay is derived from spawning in autumn/winter. A mixture of recruitment derived from both northern and southern spawning events could explain why recruitment occurs throughout the year at Warnbro Sound.

Recruitment

Annual recruitment strength at selected sites on the West region was estimated from the monthly abundance of fish <40 mm TL in samples. At 40 mm, fish had an average age of 6 months (Gaughan *et al.* 1996).

Koombana Bay, Pinnaroo, Warnbro Sound and Mangles Bay were the sites that provided the most frequent catches and longest time-series of recruitment data for *H. vittatus.* Peaks in monthly catch rates suggest high annual recruitment at Warnbro Sound in 2000, 2001 and 2005, at Pinnaroo in 2000 and 2001, at Mangles Bay in 2000, and at Koombana Bay in 2001, 2005 and 2007 (Fig. 5.27).

Data from each Perth site were in agreement, suggesting similar trends in annual recruitment. Since the commencement of sampling in 1995, the highest levels of annual recruitment in the Perth region occurred in 2000 and 2001. No sampling was undertaken in 2003, 2004 or 2005 and so recruitment strength in these years was unknown.

Juvenile growth and habitat use

Hyperlophus vittatus attains a maximum total length of 130 mm and maximum age of 4 years (Kailola *et al.* 1993, Gaughan *et al.* 1996). Individuals mature after 1 year at approximately 70 mm TL (Gaughan *et al.* 1996). Juveniles remain within the same coastal area until maturity (Lenanton *et al.* 2003).

Observations at Koombana Bay suggest that new recruits of *Hyperlophus vittatus* remain in shallow waters for 12-18 months. At Koombana Bay, 0+ fish recruited in winter as a discrete length cohort which was evident in samples until the following winter (modal length ~65mm TL in August/September) (Fig. 5.24). Fish >80 mm were rarely caught, suggesting that fish migrate away shallow waters at this site at the onset of maturity.

Juvenile *H. vittatus* (<80 mm) were present at six of the seven sampling sites in the Perth region, although only 1 fish was caught at Safety Bay (Fig. 5.28). *Hyperlophus vittatus* was not caught was Point Peron. The presence of juveniles at both sheltered (e.g. Mangles Bay) and wave-exposed (e.g. Pinnaroo) sites suggests that various types of shallow habitats function as nurseries for this species.

Adults were only caught at Pinnaroo and Warnbro Sound, which were the most wave-exposed sites sampled by DoF in the Perth region. This suggests that *H. vittatus* may migrate to more exposed sites at the onset of maturity. Interestingly, catch rates of juveniles were also highest at these sites, suggesting higher recruitment at inshore sites in close proximity to spawning adults.

Average monthly samples of *H. vittatus* collected at Koombana Bay reveal the clear progression of an annual length cohort, which recruits in winter and increases to a modal length of approximately 65 mm by the following August/September (age 16 months, assuming spawning in April) (Fig. 5.24).

In the Perth region, a very extended spawning period produces a 0+ age cohort with an extremely wide range of lengths and multiple modes. Estimation of growth rates from progression of modes is difficult with this type of length distribution. Pooled data from all years of DoF sampling at Pinnaroo provides limited evidence of significantly faster growth in the Perth region compared with growth at Koombana Bay. At Pinnaroo, a distinct length cohort with a mode of ~32 mm is visible in January and appears to increase to a mode of 68-72 mm by April (Fig. 5.25). This cohort apparently attains a length of 65 mm by age 6-7 months (assuming spawning in Sept/Oct), which is more than twice the growth rate observed at Koombana Bay. Such a huge difference in juvenile growth rate is possible, given the wide range of larval growth rates reported for this species (Gaughan *et al.* 1996). However, further confirmation of juvenile growth rates, especially in the Perth region, is required.

In summary, juvenile *H. vittatus* recruit to shallow waters of protected and moderately wave-exposed coastal sites along the lower west coast and remains in these nursery areas until the onset of maturity at lengths ~70 mm. The onset of maturity, and thus the residence period in shallow waters, may vary according to growth rate. Limited data suggests that maturity is attained at approximately 16 months of age at Koombana Bay, but could be attained after only 6-7 months at Pinnaroo.

Maturing individuals appear to migrate from the shallow waters at protected sites to more wave-exposed sites.

Future sampling

While DoF recruitment surveys since 1993 have generated useful information about the annual recruitment patterns of *H. vittatus*, the methods employed in surveys are probably not optimal to monitor recruitment by this species. *Hyperlophus vittatus* is a schooling species that can occur in very high densities. As a result, catches are typically highly variable. Also, catches can be very large and often require subsampling in the field, which can reduce the precision of catch rate estimates. Future sampling for this species would ideally need to increase replication (i.e. >3 hauls per day) and minimise sample size (i.e. use a small net).

The smallest *H. vittatus* collected by DoF since 1993 was 13 mm, although fish below 22 mm were rare. A minimum length of 21 mm for this species was reported by another local study using similar methods (Valesini *et al.* 2004). Beach seining is therefore reasonably effective in capturing very small juveniles of *H. vittatus*, given that transformation from larva to juvenile occurs at 20-25 mm.

However, other methods, such as egg/larval surveys, may provide an equally reliable index of annual recruitment to the seine netting methods employed in this study.

Any type of sampling that aims to monitor the abundance of *H. vittatus* needs to be undertaken annually, due to the large fluctuation in annual recruitment that characterises this short-lived species. Sampling programs should include the spring recruitment period.

Catch rates of *H. vittatus* from Pinnaroo, Warnbro Sound and Mangles Bay suggested similar trends in annual recruitment. Thus, sampling at one or more of these sites is likely to yield a representative index of recruitment in the Perth region. Importantly, trends in annual recruitment at Koombana Bay differed to those observed in the Perth region. Thus, sampling at Koombana Bay is unlikely to provide a representative index of *H. vittatus* recruitment in the Perth region.

Spratelloides robustus **(Blue sprat)**

Significance

- Numerically abundant fish species in inshore waters on the lower west coast.
- Commercial fishery target species.
- Abundant prey item for seabirds and piscivorous fish. *Spratelloides robustus* is one of the four fish species that comprise the bulk of the diet of little penguins at Penguin Island (Klomp and Wooller 1998). *Spratelloides robustus* is seasonally important in the penguin diet, being mainly consumed during spring/summer. At this time, the average size of fish in the guts is 68 mm TL.
- Juevnile and adult *S. robustus* feed predominantly or exclusively on calanoid copepods (Schafer *et al.* 2002).

Distribution

Spratelloides robustus is distributed across southern Australia from the Dampier Archipelago, WA, to southern Queensland, including Tasmania (Hutchins and Swainston 1995). Juveniles and adults forms large schools in coastal bays and lower reaches of estuaries and are often found associated with shallow reefs. In south-western WA, *S. robustus* is very abundant in shallow coastal environments but relatively uncommon in estuaries (Lenanton 1982a).

Stock structure is unknown. In WA, the dispersal of pelagic larvae in coastal waters is probably sufficient to ensure genetic homogeneity within the west coast and south coast regions. However, the habit of spawning within embayments (which tend to retain larvae) and lack of dispersal by demersal eggs would limit mixing and could result in semi-discrete populations within regions.

Since DoF recruitment surveys began in 1993, a total of 109,674 *S. robustus* have been captured during sampling with the 61 m net. A further 21,408 have been captured with the 21 m net. Overall, these fish were caught at 20 inshore marine sites extending from Point Peron (West region) to Poison Creek (South-east region) (Fig. 2.1, Table 5.7). The majority of DoF captures have occurred at Pinnaroo (39% of fish), Warnbro Sound (29%), Woodman Point (16%) and Quindalup Beach (6%). The highest average catch rates by the 61 m net were at Woodman Point, Warnbro Sound and Pinnaroo (348-512 fish/day). The highest average catch rates by the 21 m net were at Woodman Point (5,153 fish/day) (Table 5.7).

DoF catch rates tended to be higher in the West region than in the South or South-east regions. This trend is in contrast to the findings of Ayvazian and Hyndes (1995) who, in a survey of 32 sheltered, surf zone sites, reported that *S. robustus* was typically more abundant on the southern coast than on the west coast.

Spawning and larval stage

Spratelloides robustus spawns over a very extended period during the warmer months of the year. Females spawn multiple batches of eggs every 1-2 days during this period (Rogers *et al.* 2003). *Spratelloides robustus* eggs are demersal and adhesive, while their larvae are pelagic (Neira *et al.* 1998). In SA, where *S. robustus* has been most intensively studied, spawning occurs in protected coastal bays and shallow marine embayments. The larvae remain in these embayments and do not disperse into offshore, shelf waters. In SA, larvae transform to juveniles after 30-40 days, at approximately 30 mm TL (Rogers *et al.* 2003).

In WA, published observations of larvae are restricted to those seen entering the mouths of estuaries in the West and South regions (Neira *et al.* 1992, Neira and Potter 1992b, Neira and Potter 1994, Young and Potter 2003b). These observations indicate that spawning takes place in marine waters in both the West and South regions of WA. There is no evidence yet of spawning in the South-east region.

The timing of spawning by *S. robustus* is apparently related to water temperature. In South Australia, spawning occurs from October to February, when water temperatures range from 19 to 26 ^{o}C (Rogers *et al.* 2003). On the central NSW coast, larvae have been caught from September to April, suggesting a longer spawning period possibly due to warmer temperatures (Neira *et al.* 1998). Trends in the abundance of larvae suggest a peak in spawning activity in central NSW in February-March (Neira *et al.* 1998).

The recruitment patterns of *S. robustus* observed by DoF indicate that in south-western WA this species also has an extended spawning period, peaking during spring/summer (see below).

The minimum lengths of *S. robustus* sampled by DoF in the West, South and South-east regions were 21, 24 and 41 mm TL, respectively (Figs. 5.29, 5.30). The significantly larger initial size of new recruits in the South-east region could be explained by a longer larval duration, during which time larvae grow to a larger size while they are being transported from a remote spawning location (possibly within the South region).

Recruitment

Recruitment patterns in the West region were estimated from the mean, monthly abundance of fish <40 mm TL in samples at Pinnaroo and Warnbro Sound. Fish <40 mm were estimated to be <3 months old (Rogers *et al.* 2003).

Fish <40 mm were caught in the West region during every month except July, suggesting spawning activity virtually all year (Fig. 5.29). However, monthly catch rates of fish <40 mm peaked strongly each year from January to April, suggesting that the main spawning period was spring/summer (Fig. 5.31).

In the South region, fish <40 mm were observed in January, April, June, September and December, suggesting an extended spawning period (Fig. 5.30). No fish <40 mm were observed in the South-east region – the smallest fish in this region (40-45 mm) were observed in January (Fig. 5.30).

Relative few fish <40 mm were caught along the southern coast. Instead, recruitment patterns in these regions were estimated from the mean, monthly abundance of fish <70 mm TL at Emu Point and Poison Creek. The monthly pattern of recruitment to the South and South-east regions was unclear but appeared to occur as two pulses per year, in summer and winter (Figs. 5.30, 5.31). Recruits in these pulses were estimated to have been spawned in spring and autumn, respectively.

Average monthly catch rates of fish <40 mm (or <70 mm) suggested relatively high annual recruitment at Pinnaroo in 2000/01 and 2001/02, at Warnbro Sound in 2000/01 and 2005/06, at Emu Point in 1999/2000 and 2000/01 and at Poison Creek in 1997/98 and 2000/01. Overall, trends in annual recruitment were inconsistent between sites, although all sites experienced strong recruitment in 2000/01.

Juvenile growth and habitat use

S. robustus attains maturity at approximately 66 mm TL after approximately 135 days (Rogers *et al.* 2003). The maximum reported length for this species is 100 mm (Hutchins and Swainston 1986), which is similar to the maximum lengths of 105 and 115 mm in DoF samples collected from the western and southern coasts, respectively.

The length structure of *S. robustus* in DoF samples indicated that fish in each region attain their maximum length after approximately 12 months. In each region, recruitment of 0+ fish occurred over an extended period, ending in autumn. The 0+ fish formed a wide, but discrete, annual length cohort. The modal length of this cohort progressively increased from winter until the following summer, after which time the cohort disappeared from samples (Figs. 5.29, 5.30). In each region, most 0+ fish attained maturity by the end of winter and attained their maximum size by the end of summer.

Overall, these growth patterns suggested the life span of *S. robustus* in south-western WA is up to 1 year. Similarly, the life span of *S. robustus* in SA appears to be <1 year (Rogers *et al.* 2003).

At DoF sampling sites in the Perth region, *S. robustus* >66 mm (i.e. mature fish) comprised a low proportion of total samples of this species (Fig. 5.32). This suggested that maturing fish move away from the shallow waters sampled by DoF into slightly deeper water to spawn.

The monthly length frequency distributions also suggested emmigration of maturing fish. In the West region, the modal length of the 0+ cohort remained at approximately 60 mm from May to September (Fig. 5.29). This may partly reflect slow growth during winter, but was probably also due to the emmigration of maturing fish from the shallow waters sampled by DoF. An increasing minimum length over this period, while the modal and maximum lengths remained constant, was consistent with emmigration of larger fish.

Spratelloides robustus was caught at 6 of the 7 inshore sites sampled by DoF in the Perth region (Fig. 5.32). No fish were captured at Point Peron. At each site except Safety Bay, samples comprised predominantly juveniles with a small proportion of adults. At Safety Bay, samples were collected in December, February, March and May and consistently contained only small juveniles. Safety Bay may be located close to a spawning area for *S. robustus.* Overall, juveniles occurred at both sheltered (e.g. Mangles Bay) and moderately wave-exposed (e.g. Warnbro Sound, Pinnaroo) sites, suggesting that a range of inshore habitat types in the Perth region provide nurseries for this species. The catch rates at Woodman Point were extremely high, suggesting that this may be an important local site for *S. robustus* (Table 5.7).

As a result of an extended spawning season, *S. robustus* within each year class are likely to experience variable growth rates, depending on the time of recruitment. For example, fish spawned in spring may grow more rapidly during their first 6 months of life due to warm temperatures in summer/autumn, compared to autumn-spawned recruits that may grow more slowly due to cooler temperatures in winter/spring. Such differences in growth could lead to differences in age-at-maturity and length of spawning period that, in turn, could lead to unequal contributions by spring- and autumn-spawned fish to total annual egg production.

Future sampling

The methods historically employed by DoF, including sampling in this study, are probably not optimal to monitor the annual abundance of *S. robustus. Spratelloides robustus* is a schooling species that can occur in very high densities. As a result, catches are typically extremely variable. Also, catches can be very large and often require subsampling in the field, which can reduce the precision of catch rate estimates. Future sampling for this species could be improved by increasing the frequency and replication (i.e. >3 hauls per day) and minimising sample sizes (i.e. use a small net). Alternative methods could also be investigated, e.g. ongoing DoF larval fish surveys in Cockburn Sound may provide an index of annual abundance.

Future sampling to monitor recruitment of this species in shallow nearshore sites would need to encompass late summer/autumn when the abundance of new recruits peaks.

Any type of sampling program that aimed to monitor stock abundance of *S. robustus* would need to operate annually, due to the 1-year life span of this species.

Hyporhamphus melanochir (Sea garfish)

Significance

- Commercial and recreational fishery target species. Cockburn Sound is WA's largest single *Hyporhamphus melanochir* fishery, comprising ~50% and 85% of recreational and commercial landings in the West region.
- *Hyporhamphus melanochir* is an indicator species used by DoF to monitor the Cockburn Sound fishery.
- *Hyporhamphus melanochir* is one of four fish species that comprise the bulk of the diet of little penguins (*Eudyptula minor*) at Penguin Island. The average size of *H. melanochir* consumed by penguins is 108mm TL (Klomp and Wooller 1998).

Distribution

Hyporhamphus melanochir are distributed across southern Australia from Eden (southern NSW) to Kalbarri (WA), including Tasmania (Kailola *et al.* 1993). It is a schooling species that typically occurs in shallow, coastal waters (<20 m) and is often found near seagrass beds (Kailola *et al.* 1993). Juveniles and adults of *H. melanochir* form schools that utilise the entire water column - they can occur near the bottom or at the surface, depending on food availability. In South Australia, *H. melanochir* have been observed to feed on seagrass near the bottom during the day and then migrate into surface waters to feed on planktonic invertebrates during the night (Robertson and Klumpp 1983, Klumpp and Nichols 1983). *Hyporhamphus melanochir* are one of the few fish species to include large quantities of seagrass in their diet.

In WA, juveniles and adults also occur in the lower parts of estuaries basins but their distribution does not extend into rivers (Lenanton 1982a, Potter and Hyndes 1994, Potter *et al.* 2000). *Hyporhamphus melanochir* is essentially a marine species that opportunistically uses the saline reaches of estuaries.

Genetic differences have been detected between *H. melanochir* caught in WA and those from the western waters of SA, but not between fish on the west coast (Cockburn Sound) and south coast (Princess Royal Harbour) of WA (Jones *et al.* 2002). This suggests that fish throughout south-western WA could be considered to be a single genetic stock. There is likely to be limited mixing between lower west coast and south coast populations due to minimal rates of egg and larval dispersal (see below). However, the extent of movement by juvenile and adult *H. melanochir* between regions is unknown.

Since DoF recruitment surveys began in 1993, a total of 3,550 *H. melanochir* have been captured during sampling with the 61m net. Only 4 have been captured with the 21 m net. Overall, these fish were caught at 11 inshore marine sites extending from Cervantes (West region) to Poison Creek (South-east region) (Fig. 2.1, Table 5.8). The majority of captures by this monitoring program have occurred at Koombana Bay (70% of fish), Poison Creek (9%), Emu Point (6%) and Pinaroo (5%). The highest average catch rates by the 61 m net were at Koombana Bay (14 fish/day) and Woodman Point (6 fish/day) (Table 5.8).

The widespread distribution of DoF catches and relatively low catch rates are consistent with previous studies, which also found *H. melanochir* at low densities at numerous inshore marine sites on the lower west coast and south coast (Lenanton 1982a, Ayvazian and Hyndes 1995).

Spawning and larval stage

Hyporhamphus melanochir is a multiple batch spawner with asynchronous spawning and a protracted spawning period over the warmer months (Jones *et al.* 2002). The length of the spawning period varies between regions, probably in response to temperature variations. The spawning season appears to be shorter at higher latitudes. Spawning occurs from October to February in Tasmania, and mainly from October to March elsewhere across southern Australia. In some regions of SA and WA, spawning has also been reported in September and April (Jones *et al.* 2002).

Spawning by *H. melanochir* occurs in shallow areas over seagrass or other vegetation. *Hyporhamphus melanochir* lays demersal eggs that are attached to seagrass or other aquatic macrophytes via filaments on the egg (Jordan *et al.* 1998). Thus there is typically no dispersal during the egg stage. Attachment to vegetation appears to be essential for egg survival (Jordan *et al.* 1998). An egg incubation period of 10-15 days has been estimated for *H. melanochir* at water temperatures of 20-26^{o}C (in SA) and 29 days at temperatures of 15-25 ^{o}C (in Tasmania) (Jones *et al.* 2002)

Hyporhamphus melanochir larvae hatch at an advanced stage (i.e. post-flexion) at a length of ~7 mm. They transform into juveniles at ~20 mm (Jones *et al.* 2002). Post-flexion larvae possess moderately developed fins and could potentially maintain their position in the vicinity of the spawning area. Thus, minimal dispersal from the spawning site may have occurred by the end of larval stage. Indeed, larvae have been found closely associated with seagrass beds in SA (Jones *et al.* 2002). Limited dispersal could be advantageous, given the dependence on aquatic vegeatation for food and reproduction at juvenile and adult stages. For the above reasons, it is likely that many small juveniles recruiting to inshore nursery areas are derived from local spawning activity.

In WA, there have been very few observations of larvae. This may partly be because *H. melanochir* larvae are neustonic (i.e. at the surface) and previous surveys of fish larvae in WA have sampled just below the surface. Also, previous surveys of fish larvae in WA have focused on estuaries. On the west coast, inshore marine waters are probably the main spawning area. In other states, this species spawns in coastal waters, usually near vegetation (Jordan *et al.* 1998, Jones *et al.* 2002). There is no evidence of spawning by *H. melanochir* in estuaries on the west coast. No larvae have been captured in the Peel-Harvey Estuary and only a single larvae has been taken in the Swan Estuary (Gaughan *et al.* 1990, Neira *et al.* 1992, Young and Potter 2003).

Interestingly, there is some evidence to suggest that *H. melanochir* spawns in Wilson Inlet on the south coast – commercial fishers have reported eggs attached to seagrass within the Inlet and larvae have been captured in the estuary basin and lower Denmark River (Neira and Potter 1992a).

Very limited information is available on the seasonality and distribution of spawning by *H. melanochir* in WA. Observations of spawning fish in WA have largely been restricted to Wilson Inlet (Jones *et al.* 2002), and it is not known whether reproductive patterns in this estuary are representative of populations elsewhere on the south coast. The timing and duration of the spawning period by *H. melanochir* on the west coast is yet to be described.

The recruitment patterns of juvenile *H. melanochir* observed during sampling by DoF since 1993 indicated a protracted spawning season over the warmer months for this species in both the West and South regions.

Fish <75 mm (estimated to be ~ 2 months old, Jones *et al.* 2002) were present in samples from December to April in the South region and from December to June in the West region (Figs. 5.33, 5.34, 5.35). No fish <75mm were observed in the South-east region.

Overall, the occurrence of fish <75 mm suggested a more extended spawning season in the Perth region (spring to autumn) than to the south at Koombana Bay or on the south coast (spring/summer). In the West region, fish <75 mm were observed in May and June at Pinnaroo only. At Koombana Bay, fish <75 mm were observed only from January to March and were never observed in May or June, despite a higher level of total sampling effort in these months at Koombana Bay than Pinnaroo. These patterns are consistent with previous suggestions of a longer (or later) spawning period by this species at lower latitudes (Jones *et al.* 2002).

The peaks in monthly catch rates of new recruits (see below) suggest peaks in spawning during early summer in the Perth region and during spring near Koombana Bay and along the south coast.

Recruitment

The minimum length of *H. melanochir* sampled by DoF was 35 mm and a minimum size of 27 mm was reported for this species in another local study (Valesini *et al.* 2004). However, the majority of juveniles taken by DoF were >60 mm. The catch rate of fish <100mm TL (estimated age <6 months) was used as an index of annual recruitment strength at each site.

At Koombana Bay, fish <100 mm were usually observed from January to April each year, with a peak in catch rate in February (Figs. 5.35, 5.36). The exception occurred in 2001/02, when fish <100 mm were observed in October and November only. In the Perth region, peaks in the monthly catch rates of fish <100 mm at Pinnaroo and Mangles Bay suggested that the main pulse of 0+ recruitment occurred between April and May (Figs. 5.33, 5.36).

Limited data also suggests a single, major pulse of annual recruitment in the South and South-east regions. The combined length data from these regions reveals a discrete cohort that is evident each month from April to October, with a steady increase in modal length from approximately 90 mm in April to 200 mm in October (Fig. 5.36). Backwards extrapolation of the growth of this cohort suggests a pulse of recruitment arriving in summer, although the exact time of arrival is difficult to estimate. The presence of a few small fish in December indicates that some recruitment occurs on the south coast in early summer.

Despite evidence of a single pulse of recruitment during early summer at Koombana Bay (derived from local spawning in spring), the length distribution of 0+ fish at this site in December was strongly bimodal (modes ~130, 200 mm), implying two pulses. The larger cohort was estimated to be approximately 12 months of age (see discussion of growth below) and so was probably spawned locally in spring. The smaller cohort was more likely to have been spawned in late summer and so may have been derived from spawning in the Perth region.

The catch rate of fish <100 mm at Koombana Bay suggested high 0+ recruitment in 1996/97, 1997/98 and 1999/00, and relatively low recruitment in 2000/01 and 2001/02. No recruitment was detected at Koombana Bay in 1995/96 or 1998/99. Catch rates of fish <100 mm in the Perth region suggested relatively high annual recruitment in 2000/01 and low recruitment in 2001/02 and 2007/08. No fish <100 mm were caught prior to 2000/01 in the Perth region.

No sampling was undertaken at Koombana Bay, Pinnaroo or Mangles Bay in 2002/03, 2003/04 or 2004/05. Also, in 2005/06 and 2006/07 (and in 2007/08 at Koombana Bay), sampling at each site was restricted to September-December. These months are unlikely to include the peak monthly catch rate of *H. melanochir* and so recruitment strength from 2002/03 to 2006/07 (and in 2007/08 at Koombana Bay) cannot be determined.

Juvenile growth and habitat use

Growth rates of *H. melanochir* vary between regions. For example, in Wilson Inlet (South coast), fish attain lengths of 184-264 mm TL after 12 months, whereas in SA fish attain an average length of 183 mm after 12 months and 210 mm at 15 months (Jones *et al.* 2002). Individuals attain maturity at 210-260 mm TL, depending on location (Jones *et al.* 2002). The maximum age and length attained by *H. melanochir* is 10 years and 52 cm TL, although the maximum size in WA commercial fishery landings is typically around 40cm TL (Kailola *et al.* 1993, Jones *et al.* 2002).

During sampling by DoF since 1993, the size range of all captured *H. melanochir* was 35-397 mm, indicating that the shallow waters sampled by DoF are utilised by all sizes of this species, including juveniles and adults. However, while adults evidently occur in shallow waters, the vast majority of *H. melanochir* caught by DoF and other studies of inshore areas have been juveniles. From 1993 to 2008, 90% of all fish caught were <190 mm (95% were <245 mm). Similarly, Lenanton (1982) reported that approximately 50% of all *H. melanochir* caught in seine net samples from inshore marine sites around the south-west region were age 0+ fish.

Observations at Koombana Bay suggest that new recruits may remain in shallow waters for up to 12 months. At Koombana Bay, 0+ fish recruited in January/February and were still evident in samples until the following December (length range 100-230 mm), after which time their abundance declined (Fig. 5.34). Older fish were also taken at Koombana Bay but at lower catch rates than 0+ fish, indicating that older fish occasional utilise shallow waters at this site.

The presence of 0+ fish in very shallow areas, with larger fish co-occurring at the same coastal sites but in slightly deeper water, is probably a typical pattern. This is illustrated by the fact that commercial fishers catch adult *H. melanochir* using beach-based netting methods at similar sites to those sampled by DoF. Longer nets than those used by DoF allow commercial fishers access to larger fish in deeper, offshore waters.

Estimating the growth rate of juvenile *H. melanochir* from the progression of modes in length frequency distributions is problematic. The protracted nature of spawning produces a 0+ age cohort with an extremely wide range of lengths and multiple modes. For example, in SA spawning can occur from September to April, resulting in an annual cohort of 0+ juveniles that ranges from 58-217 mm TL by the following November (Jones *et al.* 2002).

Inspection of monthly length cohorts from Koombana Bay reveals a similarly wide length range of 0+ fish to that seen in SA. By December, 0+ fish ranged from 100 to 230 mm, indictaing that recruits were derived from an extended spawning period during the previous spring/summer (Fig. 5.34).

Hyporhamphus melanochir was caught at 6 of the 7 inshore sites sampled by DoF in the Perth region, although a total of only 2 fish were caught at each of the Point Peron and Challenger Beach sites. No fish were caught at Safety Bay. Of the remaining sites, juveniles only were captured at Pinnaroo, adults only were taken at Woodman Point, while both adults and juveniles were captured at Mangles Bay and Warnbro Sound (Fig. 5.37). Notably, adults and juveniles both occurred at very sheltered (e.g. Mangles Bay) and moderately wave-exposed (e.g. Pinnaroo) sites, suggesting that a range of inshore habitat types are utilised at each life stage.

Cockburn Sound contains significant areas of seagrass, which is a spawning habitat for *H. melanochir*. Seagrass is also an important feeding habitat for juveniles and adults. It is likely that small juveniles occurring in this area are spawned locally, due to the low dispersal rates of eggs and larvae, and could then potentially complete their entire life cycle within this area. However, the rates of movement by older juveniles and adults in/out of the Perth region is unknown. More information about movement is required to determine whether *H. melanochir* in the Perth region (or within Cockburn sound) should be managed as a separate stock.

Future Sampling

Catch rates of *H. melanochir* in all local studies using a similar method to this study (i.e. shore-based seine netting during daylight) have typically been very low (e.g. Lenanton 1982, Potter *et al.* 2000, Ayvazian and Hyndes 1996, Valesini *et al.* 1997, Valesini *et al.* 2004).

Infrequent and low catches of *H. melanochir* juveniles have made it difficult to discern monthly or annual recruitment patterns at most inshore sites sampled in south-western WA. Since 1995, the average DoF catch rate of juveniles at Koombana has been relatively high, providing a reasonable measure of recruitment strength at this site. However, the strength and timing of annual recruitment differs substantially between sites along the west coast. Therefore, recruitment patterns at Koombana Bay are unlikely to be representative of recruitment in the Perth region.

Effective future monitoring of annual recruitment strength by 0+ *H. melanochir* in the Perth region, if using the seine netting methods of this study, would require local sampling and would need to include monthly sampling in late summer/autumn.

In the Perth region, higher catch rates and a greater size range in samples have been achieved by deploying seine nets at night, compared to the catches taken at the same sites during daylight (Valesini *et al.* 2004). This suggests net avoidance during the day and/or that additional fish migrate into shallow water at night. *Hyporhamphus melanochir* undergo a diurnal vertical migration, associated with a change in feeding behaviour, which may increase their catchability in shallow waters. In SA, schools of *H. melanochir* have been observed near the bottom feeding on seagrass/algae during the day, and then rising to the surface at night to feed on invertebrates (Robertson and Klumpp 1983). In future, catch rates of juvenile *H. melanochir* could potentially be increased at inshore sites by sampling at night. This would be feasible at a sheltered site such as Mangles Bay.

Pomatomus saltatrix (Tailor)

Significance

- Iconic recreational fishery target species on the lower west coast of WA
- There is currently concern about the sustainability of the lower west coast fishery due to high fishing pressure and poor recruitment. Breeding stock level is relatively low.
- Juvenile *Pomatomus saltatrix* consume small crustaceans, cephalopods and fish, while adults consume fish.

Distribution

Pomatomus saltatrix occurs in temperate and tropical waters of Australia, Africa, North America, South America and Europe. In Australia, it occurs in coastal waters of all Australian states except NT, from Fraser Island (Qld) to Onslow (WA) (Kailola *et al.* 1993). *Pomatomus saltatrix* is a schooling fish that is commonly found on beaches and off rocky headlands, but also inhabits shelf waters to a depth of 50 m. Adults and juveniles also occur in estuaries. In WA, *P. saltatrix* is more abundant on the west coast than along the southern coast.

Pomatomus saltatrix on the east and west coasts of Australia are genetically distinct stocks (Nurthen *et al.* 1992). In WA, fish within Shark Bay form a separate population to those on the lower west coast (Edmonds *et al.* 1999). The population structure of fish along the lower west is unclear.

Since DoF recruitment surveys began in 1993, a total of 2,111 *P. saltatrix* have been captured during sampling with the 61 m net. None were captured with the 21 m net. Overall, these fish were caught at 9 inshore marine sites extending across a wide range from Point Peron (West region) to Eucla (South-east region) (Fig. 2.1, Table 5.9). No fish were captured in Leschenault Inlet. The majority of DoF captures have occurred in the West region at Pinnaroo (50% of fish), Koombana Bay (42%) and Warnbro Sound (5%). The highest average catch rates were also at these three sites (7, 5 and 1 fish/day, respectively). The average catch rates at other sites were <1 fish/day (Table 5.9).

Low and infrequent catches of juvenile *P. saltatrix* along the southern coast during sampling by DoF and others (e.g. Ayvazian and Hyndes 1996) indicate that this species is relatively uncommon in southern regions.

Spawning and larval stage

The eggs and larvae of *P. saltatrix* are planktonic (Norcross *et al.* 1974). In *P. saltatrix* populations around the world, spawning occurs over an extended period during the warmer months, either in spring, summer and/or autumn, depending on the region (Juanes *et al.* 1996). Spawning occurs in continental shelf waters, typically within a temperature range of 18-26 °C (Juanes *et al.* 1996).

Spawning by *P. saltatrix* along the west coast is poorly understood, but there is some evidence to suggest spawning in spring around Geraldton, in summer around Perth and in autumn in the Capes region (Lenanton *et al.* 1996, DoF unpubl. data). Recruitment patterns of *P. saltatrix* to shallow water nursery sites (described below) suggest spring/summer spawning around Perth and autumn spawning in the Bunbury region. Variations in the timing of spawning along the west coast may result from regional temperature differences.

The development of *P. saltatrix* larvae in WA waters has not been described. However, on the Atlantic coast of the US, transition from larva to juvenile occurs after 18-25 d and 10-12 mm SL (Juanes *et al.* 1996). Juveniles remain pelagic for an additional 15-45 days before recruiting to estuarine and coastal nurseries at 30-80 mm TL.

Recruitment

The smallest *P. saltatrix* in DoF samples collected since 1993 was 24 mm TL, which was captured at Pinnaroo (Fig. 5.38). The minimum size at Koombana Bay was considerably larger at 38 mm. A high proportion of very small juveniles in samples from Pinnaroo (16% were <38 mm) could reflect closer proximity to a spawning site, compared to Koombana Bay.

The presence of *P. saltatrix* <100 mm (estimated age <3 months) provided an indictor of recent spawning. Fish <100 mm were captured during all months, suggesting spawning throughout the year along the west coast (Fig. 5.38). However, trends in monthly catch rates of fish <100 mm varied between sites, suggesting regional differences in seasonality of recruitment and perhaps also spawning. At Pinnaroo, catch rates peaked each year between December and May, with the exception of 1998 when an additional peak occurred in September (Fig. 5.39). At Koombana Bay, catch rates peaked each year between July-September, with some fish <100 mm also caught during summer in some years (Fig 5.39). These recruitment patterns suggest that *P. saltatrix* recruiting to Pinnaroo are mainly derived from extended spawning during spring/summer, whereas those recruiting to Koombana Bay are mainly spawned in autumn.

The catch rates of fish <100 mm suggested that annual recruitment at Koombana Bay was highest in 1998/99. High annual recruitment also occurred at Pinnaroo in 1998/99, due to an unusual pulse of recruitment in September (Fig. 5.39). The average length of these September recruits at Pinnaroo was >50 mm, which was larger than the typical size of new recruits at this site, but that similar to the typical size at Koombana Bay. In summary, the high annual recruitment experienced by Pinnaroo in 1998/99 may have been due to an influx of fish derived from winter-spawned in the Koombana Bay area, followed by an influx of fish derived from local spawning in spring/summer.

No sampling was undertaken from mid-2002 to mid-2005 and limited sampling was undertaken at each site from mid-2005 to mid-2007, so recruitment strength of *P. saltatrix* in these periods cannot be assessed. In 2007/08, catch rates of fish <100 mm suggest a moderate level of recruitment at Koombana Bay in 2007, but low recruitment at Pinnaroo (Fig. 5.39).

Juvenile growth and habitat use

Pomatomus saltatrix have been captured by DoF at three of the seven sites sampled in the Perth region (Fig. 5.40). All fish captured were juveniles (<300 mm). Only 2 fish were caught at Mangles Bay, despite frequent sampling at this site since 1999. The other two sites where *P. saltatrix* was caught were Pinnaroo Point and Warnbro Sound, which suggests a preference for moderately exposed habitats. A higher abundance of juvenile *P. saltatrix* at more wave-exposed inshore sites in the Perth region was also observed by Valesini *et al.* (2004).

Habitat selection by juvenile *P. saltatrix* is influenced by the availability of prey (i.e. small fish) and water temperature (Taylor *et al.* 2007). The preference for exposed sites in the Perth region may be due to these factors rather than wave energy levels.

Observations of juvenile *P. saltatrix* in the North America suggest a preferred temperature range of 16-24 °C. Growth rates of juvenile *P. saltatrix* <100 mm increase with increasing temperature up to 24 °C, beyond which growth rates decline (Buckel *et al.* 1995). The water temperature rarely exceeds 24 °C at Pinnaroo or Warnbro Sound.

The samples of juvenile *P. saltatrix* collected at Pinnaroo and Koombana Bay had a similar modal length each month, suggesting a short (<1 month) residence period and monthly replacement of juveniles in the shallow waters sampled by DoF. For this reason, growth could not be estimated from monthly progression of modal lengths in samples.

Juvenile growth has not been precisely measured in WA but is commonly 1-2.5 mm/day in other regions, and can reach rates up to 8.7% of body length per day (Juanes *et al.* 1996, Taylor *et al.* 2007). Overall, growth of *P. saltatrix* is very rapid compared to most other temperate fish species. Juvenile growth is also highly variable, mainly as a result of temperature variations (Taylor *et al.* 2007).

In the Perth region, *P. saltatrix* grow to a total length of about 250 mm after 18-22 months (Young *et al.* 1999). Maturity is attained by both sexes at 300-350 mm TL at an age of 2-3 years (Lenanton *et al.* 1996). Maximum reported size for this species is 120 cm although individuals >80 cm are rarely caught on the lower west coast of WA (Hutchins and Swainston 1986, DoF unpubl. data).

Future sampling

Pinnaroo and Koombana Bay are appropriate sites for monitoring monthly recruitment trends of *P. saltatrix* in the Perth and Bunbury regions, respectively. The timing of spawning and strength of larval recruitment appears to differ between these regions and so sampling in one region is unlikely to represent trends in the other. Adult *P. saltatrix* are fast swimming and migratory and so it is likely that older juveniles (above the size sampled by DoF) probably move between these regions. Recruits to the recreational fishery in the Perth region are probably derived from spawning in both areas and so sampling of juvenile *P. saltatrix* in local nurseries only would be inadequate to estimate total annual recruitment to the Perth fishery.

The standard monthly sampling regime currently employed by DoF at Koombana Bay and Pinnaroo (September-December at both sites) does not coincide with the peak recruitment periods for *P. saltatrix* at each site. Sampling would need to be extended to summer/autumn months at Pinnaroo and winter months at Koombana Bay to cover the peak recruitment periods.

High frequency (e.g. weekly) and replicated sampling at peak recruitment periods at key sites would be required to gain more information about fine-scale *P. saltatrix* recruitment patterns and growth rates in inshore nurseries.

Discussion

Species-based indicators

The DoF recruitment monitoring program has the potential to monitor annual recruitment by many inshore fish species within the Perth region. The program captures many fishery and non-fishery species and so can potentially provide a range of species-based indicators to monitor fishery and ecosystem status. The low impact methods employed by DoF are suitable for use in Marine Protected Areas and other environmentally-sensitive areas. Fish are released alive and there is negligible impact on habitats.

For some species, the existing DoF sampling schedule is adequate but, for other species, a higher sampling frequency and/or additional sampling sites within the Perth region would be desirable. There is scope within the program to modify/increase sampling effort to meet various monitoring objectives relating to particular species, if resources are made available. It may be more cost-effective to provide additional resources to this existing program than to implement new research to meet future management needs.

Our understanding of the biological characteristics and ecological requirements of most inshore species is surprisingly limited. Further information will be required to develop effective strategies for the sustainable management of these species and their habitats.

Community-based indicators

After archived data was collated, it was evident that captures of some 'low priority' species had not been recorded during DoF sampling in some years. Thus, archived data provided incomplete information about diversity and abundance in some sites/years. Hence, it was not possible to examine long-term trends in inshore fish communities in the Perth region.

In 2007/08, all captured species were fully recorded and so diversity, abundance and community composition at Perth sites could be described for this period. The abundance and diversity of fish species at each Perth site was relatively high in 2007/08. Also, the captured species encompassed a wide range of biological characteristics and trophic levels. For these reasons, it is likely that temporal and spatial trends in the composition of samples would reflect trends in the broader fish community at each site. The spatial and temporal trends in communities observed in 2007/08, which coincided with physical differences between sites and hydrological changes between months, suggested that the composition of fish communities does provide an integrated measure of environmental change in these inshore habitats.

In future, sampling by the DoF recruitment monitoring program will record all captured species and this ongoing fish community data has the potential to provide a low-cost index of general ecosystem ‘health’ in the inshore zone.

The composition of inshore fish communities in the Perth region has previously been described by Valesini *et al.* (2004). This independent study used the same shore-based seine netting methods as DoF and sampled at similar locations. The analytical approach described by Valesini *et al.* could be used to develop community-based indicators from future DoF data.

The value of inshore habitats in the Perth region

Many of the species examined in this report belong to stocks that range across the lower west and south coast. There is evidence to suggest that many inshore species spawn mainly, or exclusively, on the west coast. Therefore, a significant proportion of recruitment to the south coast is likely to be sourced from the west coast. Thus, the status of each breeding stock on the west coast is likely to affect the status of south coast inshore fish populations and fisheries.

The Leeuwin Current is a major factor determining recruitment strength of many inshore fish to both the west and south coasts. Long-term oceanographic and climatic changes which affect Leeuwin Current strength will determine spatial and temporal patterns of recruitment in both areas.

The larvae/early juveniles of many inshore fish species are resident in shallow, inshore nurseries habitats for 12 months after settlement. Therefore, any disturbance to nursery habitats, regardless of time of year, is likely to impact on 0+ individuals of each species.

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TABLES

Table 2.1. Total sampling effort (number of hauls using 61m and 21m seine nets) by the DoF recruitment monitoring program at sites in the West, South and South-east region, from 1993 to 2008.

REGION	SITE	No. of net hauls	% of total
WEST	Challenger Beach	27	0.78
	Dead Finish Anchorage	43	1.25
	Dunsborough Town Beach	33	0.96
	Hamelin Bay	45	1.31
	Koombana Bay	765	22.21
	Leschenault Inlet - Pelican Point	16	0.46
	Leschenault Inlet - Preston River	13	0.38
	Leschenault Inlet - Town Site	15	0.44
	Mangles Bay	251	7.29
	Pinnaroo	601	17.45
	Point Peron	13	0.38
	Point Walter	36	1.05
	Quindalup Beach	161	4.67
	Safety Bay	22	0.64
	Cervantes - Thirsty Point	119	3.46
	Toby's Inlet	57	1.66
	Warnbro Sound	434	12.60
	Woodman Point	20	0.58
WEST Total		**2,671**	**77.56**
SOUTH	Cheyne Beach	1	0.03
	Emu Point	274	7.96
	Horton Beach	54	1.57
	Shoal Bay	12	0.35
	Two Peoples Bay	57	1.66
SOUTH Total		**398**	**11.56**
SOUTH-EAST	Duke of Orleans	54	1.57
	Esperance Town Beach	57	1.66
	Eucla Jetty	6	0.17
	Eyre Bird Observatory	3	0.09
	Israelite Bay	6	0.17
	Noonaera Beach	6	0.17
	Poison Creek	234	6.79
	Red Rock Point	6	0.17
	Twilight Cove	3	0.09
SOUTH-EAST Total		**375**	**10.89**
Grand Total		**3,444**	**100**

Table 4.1. Total number of fish collected each month in 2007/08 at Perth sites. X - not sampled due to unfavourable environmental conditions. Sites in bold are those sampled as part of long-term DoF monitoring program. Other sites were sampled in 2007/8 specifically for this project. (*denotes sampling by 21 m seine net)

Year	Month	Challenger Beach	**Mangles Bay**	**Pinaroo**	Point Peron*	Safety Bay*	**Warnbro Sound**	Woodman Point*
2007	Sept	62	1299	X	144	409	112	263
	Oct	33	738	555	56	4568	172	101
	Nov	25	451	93	277	1434	449	116
	Dec	27	430	57	248	332	108	60
2008	Jan	962	1488	20517	X	547	252	19720
	Feb	1157	1028	518	X	1003	504	454
	Mar	438	2250	1909	X	4282	4184	N/A
	Apr	181	1654	X	X	X	X	306
	May	474	5964	X	X	2685	X	1671

Table 4.2. Contributions (%) by individual species to total catches at locations within the Perth region, sampled from September 2007 to May 2008 (bold – species contributing >1% to total catch at each site). (Site codes: CB- Challenger Beach; MB-Mangles Bay; P-Pinnaroo; PP-Point Peron; SB-Safety Bay; WS-Warnbro Sound and WP-Woodman Point).

		PERTH REGION SITES									
Common name	**Scientific Name**	**CB**	**MB**	**P**	**PP**	**SB**	**WS**	**WP**	Total	%	Fishery species
Sprat, Blue	*Spratelloides robustus*	**10.4**	0.2	**93.3**		**5.2**	**69.5**	**95.4**	48887	**56.5**	✓
Hardyhead - General	*Atherinidae sp.*	**46.8**	**56.7**	0.5	**36.5**	**33.6**	**5.5**	**1.9**	16365	**18.9**	
Hardyhead, Ogilby's	*Pranesus ogilbyi*	**20.1**	**6.8**	<0.1	**42.0**	**36.5**	**1.1**	0.1	7660	**8.9**	
Toadfish, Banded	*Torquigener pleurogramma*	**3.2**	**10.8**	0.2	**4.6**	2.1	**1.1**	**1.3**	2476	**2.9**	
Whiting, Western Trumpeter	*Sillago burrus*		**11.9**			0.2	0.1		1823	**2.1**	✓
Whiting, Southern School	*Sillago bassensis*	**5.4**	0.1	**2.7**	0.1	**5.1**	**1.1**	0.2	1740	**2.0**	✓
Whiting, School - General	*Sillago sp.*	1.0	<0.1	0.2		**7.8**	0.3	<0.1	1299	**1.5**	✓
Whiting, Western School	*Sillago vittata*	**6.1**	1.0	0.1	**1.5**	**4.6**	**2.6**	0.1	1255	**1.5**	✓
Sprat, Sandy	*Hyperlophus vittatus*	0.3	<0.1	**2.5**		<0.1	**7.0**	0.4	1089	**1.3**	✓
Whiting, Yellow-finned	*Sillago schomburgkii*		**2.4**	0.1	**1.8**	0.4	0.9	<0.1	521	0.6	✓
Mullet, Yellow eye	*Aldrichetta forsteri*	**3.6**	0.3		**1.7**	0.8	**1.4**	0.2	425	0.5	✓
Goby - General	*Gobiidae sp.*		**2.5**		0.4	0.2			418	0.5	
Goby, Long-Finned	*Favonigobius lateralis*		**2.0**		**2.8**	0.2			357	0.4	
Trumpeter, Six Lined	*Pelates sexlineatus*		**1.8**		0.1	0.3	0.1	<0.1	329	0.4	
Whiting - General	*Sillaginidae sp.*		0.1	0.1			**4.7**	<0.1	309	0.4	✓
Roach	*Gerres subfasciatus*		0.2			**1.2**	0.1		208	0.2	
Mullet, Sea	*Mugil cephalus*		0.3			**1.1**	0.1		203	0.2	✓
Gobbleguts	*Apogon rueppellii*		0.7		**1.7**	0.1	**1.1**		201	0.2	
Sandfish	*Lesueurina platycephala*	0.6		0.2	0.7	<0.1	**1.3**	0.1	167	0.2	
Toadfish, Prickly	*Contusus brevicaudus*	0.7	0.2	0.1	0.3	0.1	0.2	<0.1	105	0.1	
Garfish, Southern Sea	*Hyporhamphus melanochir*	0.1	0.5		0.3		0.1	0.1	103	0.1	✓
Whiting, King George	*Sillaginodes punctata*		0.2		**1.9**	0.3			86	0.1	✓
Flounder, Small-Toothed	*Pseudorhombus jenynsii*		0.2		0.1	<0.1	0.1		52	0.1	✓
Stinkfish, Goodlad's	*Callionymus goodladi*	0.6	<0.1	<0.1	0.1	0.1	0.2		51	0.1	
Flounder, Elongate	*Ammotretis elongatus*	0.7	0.1		0.3	<0.1	<0.1	<0.1	48	0.1	✓
Soldierfish	*Gymnapistes marmoratus*		0.2			<0.1	<0.1		33	<0.1	
Trumpeter, Sea	*Pelsartia humeralis*			<0.1			0.4	<0.1	31	<0.1	
Weed Whiting, Blue	*Haletta semifasciata*		0.1		0.1	<0.1	0.1		26	<0.1	
Flathead, Blue spotted	*Platycephalus speculator*	0.2		<0.1	0.1	<0.1	0.1		25	<0.1	✓
Anchovy, Australian	*Engraulis australis*							0.1	24	<0.1	✓
Salmon, Western Australian	*Arripis truttaceus*	<0.1	0.1			<0.1			22	<0.1	✓
Herring, Australian	*Arripis georgianus*		0.1	<0.1			0.1	<0.1	20	<0.1	✓
Leatherjackets - General	*Monacanthidae sp.*		<0.1		**1.8**	<0.1			17	<0.1	✓
Leatherjacket, Rough	*Scobinichthys granulatus*		0.1			<0.1	<0.1	<0.1	15	<0.1	
Butterfish, Western	*Pentapodus vitta*						0.2		14	<0.1	✓
Unknown Species	*Unknown Species*		<0.1	<0.1	0.4	<0.1		<0.1	14	<0.1	
Trevally (both species)	*P. dentex & P. wrighti*		0.1			<0.1	<0.1		13	<0.1	✓
Bream, Silver (Tarwhine)	*Rhabdosargus sarba*		0.1				0.1		11	<0.1	✓
Pipefish - General	*Syngnathidae sp.*		<0.1		0.3	<0.1		<0.1	11	<0.1	
Old Wife	*Enoplosus armatus*							<0.1	8	<0.1	
Dragonet, Fingered	*Dactylopus dactylopus*		<0.1				<0.1	<0.1	5	<0.1	
Flatheads - General	*Platycephalidae sp.*	0.1			0.3		<0.1		5	<0.1	✓
Goatfish, Bar-tailed	*Upeneus tragula*	<0.1	<0.1	<0.1					5	<0.1	
Flathead, Bar-tailed	*Platycephalus endrachtensis*	0.1	<0.1					<0.1	4	<0.1	✓
Weed Whiting - General	*Odacidae sp.*		<0.1						4	<0.1	
Goatfish - General	*Mullidae sp.*		<0.1	<0.1					3	<0.1	
Ray, Southern Fiddler	*Trygonorhina fasciata*		<0.1						3	<0.1	
Sole, Lemon Tongue	*Paraplagusia unicolor*	0.1		<0.1					3	<0.1	✓
Tailor	*Pomatomus saltatrix*			<0.1					3	<0.1	✓
Goatfish, Blue-spotted	*Upenichthys vlamingii*							<0.1	2	<0.1	
Leatherjacket, Prickly	*Chaetoderma penicilligera*		<0.1					<0.1	2	<0.1	
Leatherjacket, Toothbrush	*Acanthaluteres vittiger*		<0.1						2	<0.1	
Pipefish, Spotted	*Stigmatopora argus*						<0.1	<0.1	2	<0.1	
Ray, Southern Shovelnose	*Aptychotremata vincentiana*						<0.1		2	<0.1	
Weedfish, Southern-crested	*Cristiceps australis*		<0.1						2	<0.1	
Clingfish, Western Cleaner	*Cochleoceps bicolor*							<0.1	2	<0.1	
Cobbler	*Cnidoglanis macrocephalus*			<0.1					1	<0.1	✓
Flathead, Tassel-snouted	*Thysanophrys cirronasus*	<0.1							1	<0.1	
Grubfish, Wavy	*Parapercis haackei*	<0.1							1	<0.1	
Gurnard - General	*Triglidae sp.*	<0.1							1	<0.1	
Leatherjacket, Fan-bellied	*Monacanthus chinensis*		<0.1						1	<0.1	
Trevally, Skipjack	*Pseudocaranx dentex*		<0.1						1	<0.1	✓
Weed Whiting, Little	*Neoodax balteatus*		<0.1						1	<0.1	
Weedfish, Yellow-crested	*Cristiceps aurantiacus*							0.0	1	<0.1	
TOTAL number individuals caught		**3356**	**15094**	**23649**	**721**	**15239**	**5770**	**22689**	**86518**		
TOTAL number species caught		**23**	**46**	**22**	**24**	**32**	**35**	**30**	**64**		

TABLE 5.1. Total *Mugil cephalus* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Safety Bay	162	8	20.25
21m	West	Leschenault Inlet Pelican Point	42	3	14.00
21m	West	Leschenault Inlet Town Site	30	3	10.00
21m	West	Leschenault Inlet Preston River	1	2	0.50
21m	West	Point Peron	0	4	0.00
21m	West	Woodman Point	0	7	0.00
61m	West	Mangles Bay	3389	63	53.79
61m	West	Koombana Bay	973	176	5.53
61m	West	Leschenault Inlet	305	4	76.25
61m	West	Warnbro Sound	132	99	1.33
61m	West	Dunsborough Town Beach	83	11	7.55
61m	West	Pinnaroo	45	145	0.31
61m	West	Quindalup Beach	33	42	0.79
61m	West	Toby's Inlet	23	19	1.21
61m	West	Thirsty Point - Cervantes	17	38	0.45
61m	West	Point Walter	11	11	1.00
61m	West	Challenger Beach	0	9	0.00
61m	West	Dead Finish Anchorage	0	15	0.00
61m	West	Hamelin Bay	0	13	0.00
61m	West	Woodman Point	0	2	0.00
61m	South	Emu Point	426	74	5.76
61m	South	Shoal Bay	61	3	20.33
61m	South	Horton Beach	14	17	0.82
61m	South	Cheyne Beach	0	1	0.00
61m	South	Two Peoples Bay	0	19	0.00
61m	South East	Poison Creek	115	69	1.67
61m	South East	Esperance Town Beach	4	19	0.21
61m	South East	Israelite Bay	4	2	2.00
61m	South East	Duke of Orleans	0	18	0.00
61m	South East	Eucla Jetty	0	2	0.00
61m	South East	Eyre Bird Observatory	0	1	0.00
61m	South East	Noonaera Beach	0	2	0.00
61m	South East	Red Rock Point	0	2	0.00
61m	South East	Twilight Cove	0	1	0.00

TABLE 5.2. Total *Aldrichetta forsteri* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Leschenault Inlet Pelican Point	520	3	173.33
21m	West	Leschenault Inlet Town Site	140	3	46.67
21m	West	Safety Bay	128	8	16.00
21m	West	Leschenault Inlet Preston River	77	2	38.50
21m	West	Woodman Point	45	7	6.43
21m	West	Point Peron	12	4	3.00
61m	West	Koombana Bay	10554	176	59.97
61m	West	Pinnaroo	3973	145	27.40
61m	West	Warnbro Sound	3572	99	36.08
61m	West	Mangles Bay	1166	63	18.51
61m	West	Thirsty Point - Cervantes	469	38	12.34
61m	West	Leschenault Inlet	443	4	110.75
61m	West	Quindalup Beach	424	42	10.10
61m	West	Dunsborough Town Beach	188	11	17.09
61m	West	Point Walter	157	11	14.27
61m	West	Toby's Inlet	139	19	7.32
61m	West	Challenger Beach	121	9	13.44
61m	West	Dead Finish Anchorage	67	15	4.47
61m	West	Hamelin Bay	3	13	0.23
61m	West	Woodman Point	0	2	0.00
61m	South	Emu Point	5877	74	79.42
61m	South	Two Peoples Bay	316	19	16.63
61m	South	Horton Beach	163	17	9.59
61m	South	Shoal Bay	113	3	37.67
61m	South	Cheyne Beach	0	1	0.00
61m	South East	Poison Creek	3527	69	51.12
61m	South East	Esperance Town Beach	874	19	46.00
61m	South East	Eucla Jetty	347	2	173.50
61m	South East	Noonaera Beach	247	2	123.50
61m	South East	Duke of Orleans	179	18	9.94
61m	South East	Israelite Bay	171	2	85.50
61m	South East	Red Rock Point	28	2	14.00
61m	South East	Twilight Cove	12	1	12.00
61m	South East	Eyre Bird Observatory	8	1	8.00

TABLE 5.3. Total *Torquigener pleurogramma* catch, total effort and average catch rates at each site during the period 2005 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Leschenault Inlet Pelican Point	16	3	5.33
21m	West	Leschenault Inlet Preston River	0	2	0.00
21m	West	Leschenault Inlet Town Site	79	3	26.33
21m	West	Point Peron	33	4	8.25
21m	West	Safety Bay	314	8	39.25
21m	West	Woodman Point	278	7	39.71
61m	West	Mangles Bay	2473	17	145.47
61m	West	Koombana Bay	208	12	17.33
61m	West	Leschenault Inlet	170	4	42.50
61m	West	Warnbro Sound	166	19	8.74
61m	West	Challenger Beach	107	9	11.89
61m	West	Pinnaroo	42	12	3.50
61m	West	Woodman Point	7	2	3.50
61m	South	Cheyne Beach	0	1	0.00
61m	South	Emu Point	2	21	0.10
61m	South East	Poison Creek	28	15	1.87

TABLE 5.4. Total *Arripis georgianus* catch, total effort and average catch rates at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Leschenault Inlet Pelican Point	0	3	0.00
21m	West	Leschenault Inlet Preston River	0	2	0.00
21m	West	Leschenault Inlet Town Site	0	3	0.00
21m	West	Point Peron	0	4	0.00
21m	West	Safety Bay	0	8	0.00
21m	West	Woodman Point	0	7	0.00
61m	West	Koombana Bay	4831	176	27.45
61m	West	Warnbro Sound	720	99	7.27
61m	West	Thirsty Point - Cervantes	86	38	2.26
61m	West	Quindalup Beach	86	42	2.05
61m	West	Pinnaroo	83	145	0.57
61m	West	Dead Finish Anchorage	73	15	4.87
61m	West	Hamelin Bay	46	13	3.54
61m	West	Toby's Inlet	32	19	1.68
61m	West	Mangles Bay	23	63	0.37
61m	West	Dunsborough Town Beach	11	11	1.00
61m	West	Woodman Point	3	2	1.50
61m	West	Challenger Beach	0	9	0.00
61m	West	Leschenault Inlet	0	4	0.00
61m	West	Point Walter	0	11	0.00
61m	South	Emu Point	430	74	5.81
61m	South	Horton Beach	156	17	9.18
61m	South	Two Peoples Bay	62	19	3.26
61m	South	Cheyne Beach	0	1	0.00
61m	South	Shoal Bay	0	3	0.00
61m	South East	Poison Creek	11732	69	170.03
61m	South East	Duke of Orleans	99	18	5.50
61m	South East	Esperance Town Beach	84	19	4.42
61m	South East	Noonaera Beach	8	2	4.00
61m	South East	Red Rock Point	8	2	4.00
61m	South East	Eyre Bird Observatory	4	1	4.00
61m	South East	Israelite Bay	4	2	2.00
61m	South East	Eucla Jetty	1	2	0.50
61m	South East	Twilight Cove	0	1	0.00

TABLE 5.5. Total *Atherinomorus ogilbyi* and *Unidentified Atherinid* catch, total effort and average catch rates at each site during the period 2005 to 2008 (61 m net) and the period 2007 to 2008 (21 m net).

Net type	Region	Site	E(no. days)*	Hardyhead, Ogilby's	Hardyheads - General	Total	cpue (ogilby)	cpue (total)
21m	West	Leschenault Inlet Pelican Point	3	0	2660	2660	0.00	886.67
21m	West	Leschenault Inlet Preston River	2	0	566	566	0.00	283.00
21m	West	Leschenault Inlet Town Site	3	0	2984	2984	0.00	994.67
21m	West	Point Peron	4	303	263	566	75.75	141.50
21m	West	Safety Bay	8	5569	5120	10689	696.13	1336.13
21m	West	Woodman Point	7	13	239	252	1.86	36.00
61m	West	Challenger Beach	9	674	1569	2243	74.89	249.22
61m	West	Koombana Bay	12	5	242	247	0.42	20.58
61m	West	Leschenault Inlet	4	45	2716	2761	11.25	690.25
61m	West	Mangles Bay	17	1165	8935	10100	68.53	594.12
61m	West	Pinnaroo	12	27	123	150	2.25	12.50
61m	West	Warnbro Sound	19	110	743	853	5.79	44.89
61m	West	Woodman Point	2	0	188	188	0.00	94.00
61m	South	Cheyne Beach	1	0	0	0	0.00	0.00
61m	South	Emu Point	21	153	1690	1843	7.29	87.76
61m	South East	Poison Creek	15	38	0	38	2.53	2.53

TABLE 5.6. Total *Hyperlophus vittatus* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	Mean cpue (n/day)
21m	West	Leschenault Inlet Town Site	342	3	114.00
21m	West	Leschenault Inlet Preston River	307	2	153.50
21m	West	Leschenault Inlet Pelican Point	149	3	49.67
21m	West	Woodman Point	84	7	12.00
21m	West	Safety Bay	1	8	0.13
21m	West	Point Peron	0	4	0.00
61m	West	Koombana Bay	57521	176	326.82
61m	West	Warnbro Sound	24751	99	250.01
61m	West	Pinnaroo	22102	145	152.43
61m	West	Mangles Bay	3524	63	55.94
61m	West	Dead Finish Anchorage	1868	15	124.53
61m	West	Toby's Inlet	521	19	27.42
61m	West	Thirsty Point - Cervantes	165	38	4.34
61m	West	Dunsborough Town Beach	26	11	2.36
61m	West	Quindalup Beach	11	42	0.26
61m	West	Challenger Beach	9	9	1.00
61m	West	Hamelin Bay	0	13	0.00
61m	West	Point Walter	0	11	0.00
61m	West	Leschenault Inlet	0	4	0.00
61m	West	Woodman Point	0	2	0.00
61m	South	Emu Point	193	74	2.61
61m	South	Horton Beach	45	17	2.65
61m	South	Two Peoples Bay	0	19	0.00
61m	South	Shoal Bay	0	3	0.00
61m	South	Cheyne Beach	0	1	0.00
61m	South East	Esperance Town Beach	3	19	0.16
61m	South East	Poison Creek	0	69	0.00
61m	South East	Duke of Orleans	0	18	0.00
61m	South East	Eucla Jetty	0	2	0.00
61m	South East	Israelite Bay	0	2	0.00
61m	South East	Noonaera Beach	0	2	0.00
61m	South East	Red Rock Point	0	2	0.00
61m	South East	Eyre Bird Observatory	0	1	0.00
61m	South East	Twilight Cove	0	1	0.00

TABLE 5.7. Total *Spratelloides robustus* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total Blue sprat catch 95-08	Total sampling dates	cpue (n/day)
21m	West	Leschenault Inlet Pelican Point	0	7	0.00
21m	West	Leschenault Inlet Preston River	0	8	99.50
21m	West	Leschenault Inlet Town Site	0	3	0.00
21m	West	Point Peron	0	2	0.00
21m	West	Safety Bay	796	3	265.33
21m	West	Woodman Point	20612	4	5153.00
61m	West	Pinnaroo	50850	146	348.29
61m	West	Warnbro Sound	38439	99	388.27
61m	West	Quindalup Beach	7508	42	178.76
61m	West	Dead Finish Anchorage	1376	15	91.73
61m	West	Woodman Point	1024	2	512.00
61m	West	Koombana Bay	604	176	3.43
61m	West	Challenger Beach	349	9	38.78
61m	West	Thirsty Point - Cervantes	310	40	7.75
61m	West	Hamelin Bay	191	15	12.73
61m	West	Mangles Bay	189	63	3.00
61m	West	Toby's Inlet	56	19	2.95
61m	West	Dunsborough Town Beach	41	11	3.73
61m	West	Leschenault Inlet	0	4	0.00
61m	West	Point Walter	0	12	0.00
61m	South	Two Peoples Bay	4133	19	217.53
61m	South	Emu Point	3005	74	40.61
61m	South	Horton Beach	158	18	8.78
61m	South	Cheyne Beach	0	1	0.00
61m	South	Shoal Bay	0	3	0.00
61m	South East	Duke of Orleans	746	18	41.44
61m	South East	Poison Creek	694	69	10.06
61m	South East	Esperance Town Beach	1	19	0.05
61m	South East	Eucla Jetty	0	2	0.00
61m	South East	Eyre Bird Observatory	0	1	0.00
61m	South East	Israelite Bay	0	2	0.00
61m	South East	Noonaera Beach	0	2	0.00
61m	South East	Red Rock Point	0	2	0.00
61m	South East	Twilight Cove	0	1	0.00

TABLE 5.8. Total *Hyporhamphus melanochir* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

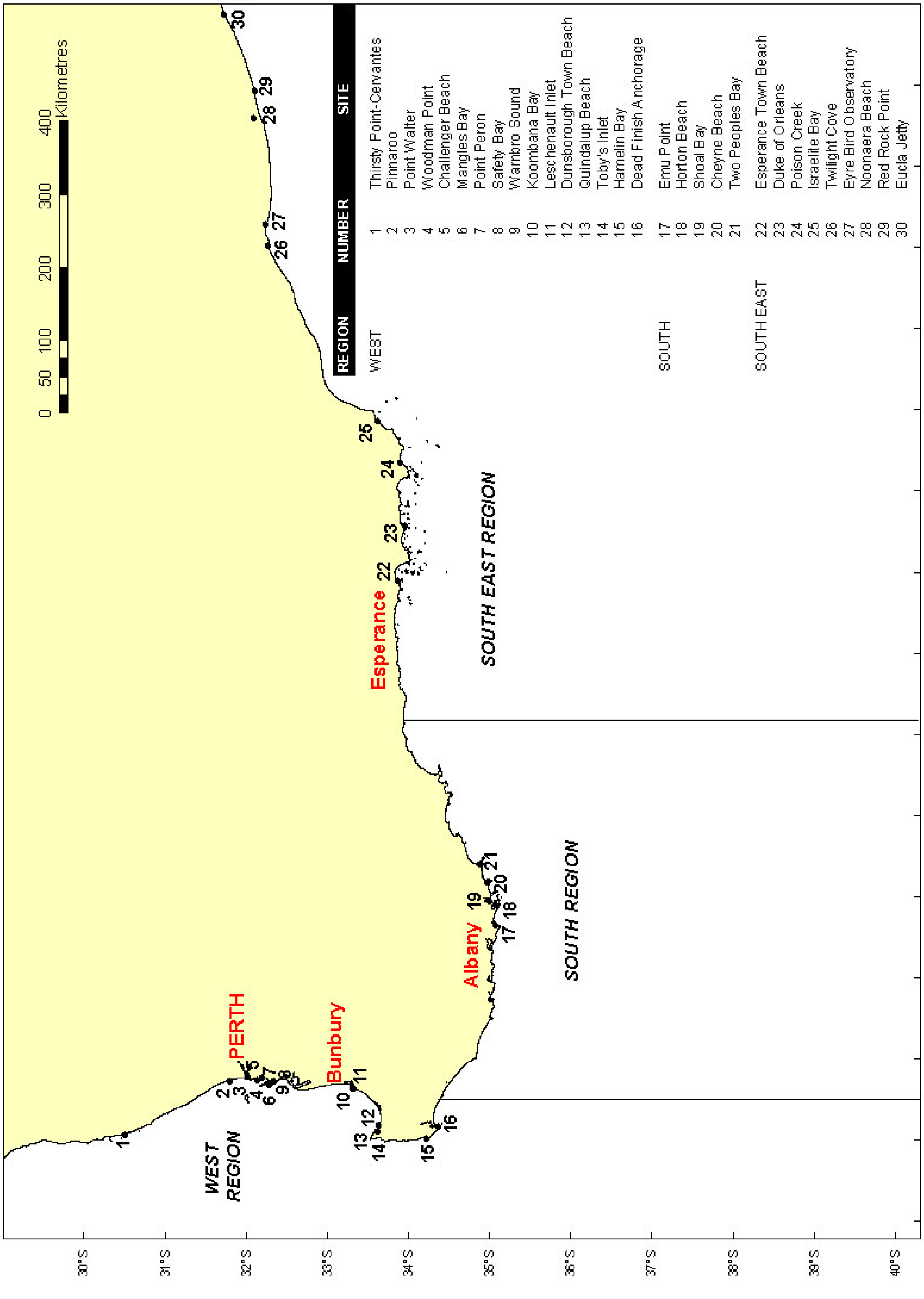
Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Point Peron	2	4	0.50
21m	West	Woodman Point	2	7	0.29
21m	West	Leschenault Inlet Pelican Point	0	3	0.00
21m	West	Leschenault Inlet Preston River	0	2	0.00
21m	West	Leschenault Inlet Town Site	0	3	0.00
21m	West	Safety Bay	0	8	0.00
61m	West	Koombana Bay	2499	176	14.20
61m	West	Pinnaroo	191	145	1.32
61m	West	Warnbro Sound	174	99	1.76
61m	West	Mangles Bay	144	63	2.29
61m	West	Woodman Point	12	2	6.00
61m	West	Thirsty Point - Cervantes	10	38	0.26
61m	West	Challenger Beach	3	9	0.33
61m	West	Dead Finish Anchorage	0	15	0.00
61m	West	Dunsborough Town Beach	0	11	0.00
61m	West	Hamelin Bay	0	13	0.00
61m	West	Leschenault Inlet	0	4	0.00
61m	West	Point Walter	0	11	0.00
61m	West	Quindalup Beach	0	42	0.00
61m	West	Toby's Inlet	0	19	0.00
61m	South	Emu Point	202	74	2.73
61m	South	Horton Beach	8	17	0.47
61m	South	Cheyne Beach	0	1	0.00
61m	South	Shoal Bay	0	3	0.00
61m	South	Two Peoples Bay	0	19	0.00
61m	South East	Poison Creek	306	69	4.43
61m	South East	Israelite Bay	1	2	0.50
61m	South East	Duke of Orleans	0	18	0.00
61m	South East	Esperance Town Beach	0	19	0.00
61m	South East	Eucla Jetty	0	2	0.00
61m	South East	Eyre Bird Observatory	0	1	0.00
61m	South East	Noonaera Beach	0	2	0.00
61m	South East	Red Rock Point	0	2	0.00
61m	South East	Twilight Cove	0	1	0.00

TABLE 5.9. Total *Pomatomus saltatrix* catch, total effort and average catch rate at each site during the period 1993 to 2008 (61 m and 21 m nets only).

Net type	Region	Site	Total no. caught	Total sampling dates	cpue (n/day)
21m	West	Leschenault Inlet Pelican Point	0	3	0.00
21m	West	Leschenault Inlet Preston River	0	2	0.00
21m	West	Leschenault Inlet Town Site	0	3	0.00
21m	West	Point Peron	0	4	0.00
21m	West	Safety Bay	0	8	0.00
21m	West	Woodman Point	0	7	0.00
61m	West	Pinnaroo	1049	145	7.23
61m	West	Koombana Bay	897	176	5.10
61m	West	Warnbro Sound	115	99	1.16
61m	West	Thirsty Point - Cervantes	32	38	0.84
61m	West	Quindalup Beach	6	42	0.14
61m	West	Toby's Inlet	5	19	0.26
61m	West	Mangles Bay	2	63	0.03
61m	West	Challenger Beach	0	9	0.00
61m	West	Dead Finish Anchorage	0	15	0.00
61m	West	Dunsborough Town Beach	0	11	0.00
61m	West	Hamelin Bay	0	13	0.00
61m	West	Leschenault Inlet	0	4	0.00
61m	West	Point Walter	0	11	0.00
61m	West	Woodman Point	0	2	0.00
61m	South	Emu Point	4	74	0.05
61m	South	Cheyne Beach	0	1	0.00
61m	South	Horton Beach	0	17	0.00
61m	South	Shoal Bay	0	3	0.00
61m	South	Two Peoples Bay	0	19	0.00
61m	South East	Eucla Jetty	1	2	0.50
61m	South East	Duke of Orleans	0	18	0.00
61m	South East	Esperance Town Beach	0	19	0.00
61m	South East	Eyre Bird Observatory	0	1	0.00
61m	South East	Israelite Bay	0	2	0.00
61m	South East	Noonaera Beach	0	2	0.00
61m	South East	Poison Creek	0	69	0.00
61m	South East	Red Rock Point	0	2	0.00
61m	South East	Twilight Cove	0	1	0.00

FIGURES

Figure 2.1. Location of all regions and sites sampled by the DoF recruitment monitoring program, 1993 to 2008.



REGION	NUMBER	SITE
WEST	1	Thirsty Point-Cervantes
	2	Pinnaroo
	3	Point Walter
	4	Woodman Point
	5	Challenger Beach
	6	Mangles Bay
	7	Point Peron
	8	Safety Bay
	9	Warnbro Sound
	10	Koombana Bay
	11	Leschenault Inlet
	12	Dunsborough Town Beach
	13	Quindalup Beach
	14	Toby's Inlet
	15	Hamelin Bay
	16	Dead Finish Anchorage
SOUTH	17	Emu Point
	18	Horton Beach
	19	Shoal Bay
	20	Cheyne Beach
	21	Two Peoples Bay
SOUTH EAST	22	Esperance Town Beach
	23	Duke of Orleans
	24	Poison Creek
	25	Israelite Bay
	26	Twilight Cove
	27	Eyre Bird Observatory
	28	Noonaera Beach
	29	Red Rock Point
	30	Eucla Jetty

Figure 2.2. Location of sites sampled by the DoF recruitment monitoring program in the Perth region in 2007/08.

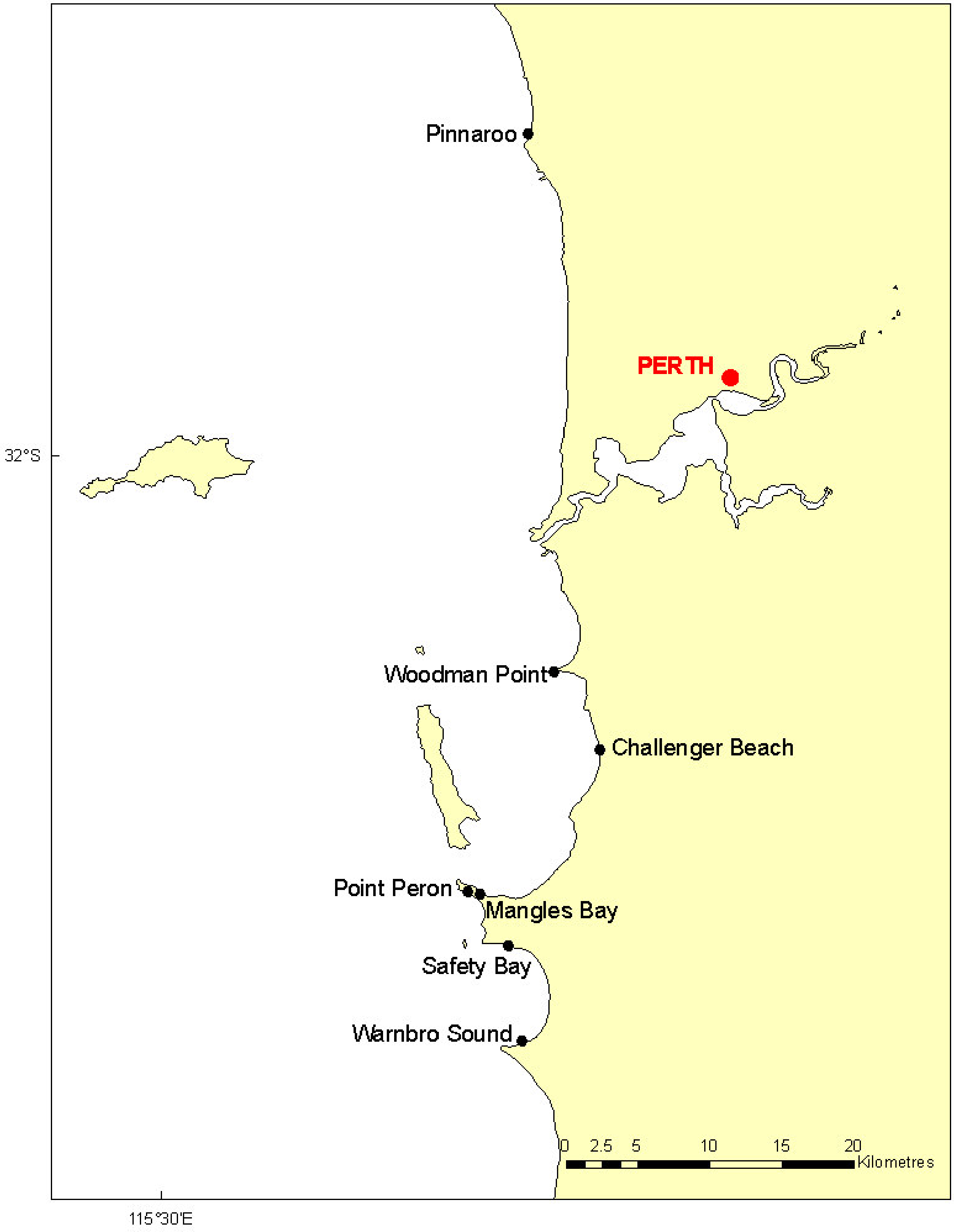


Figure 3.1 Average annual sea level at Fremantle (Source: National Tidal Centre) and average annual average Southern Oscillation Index from 1990 to 2007 (Source: Bureau of Meteorology), (averaged from monthly values).

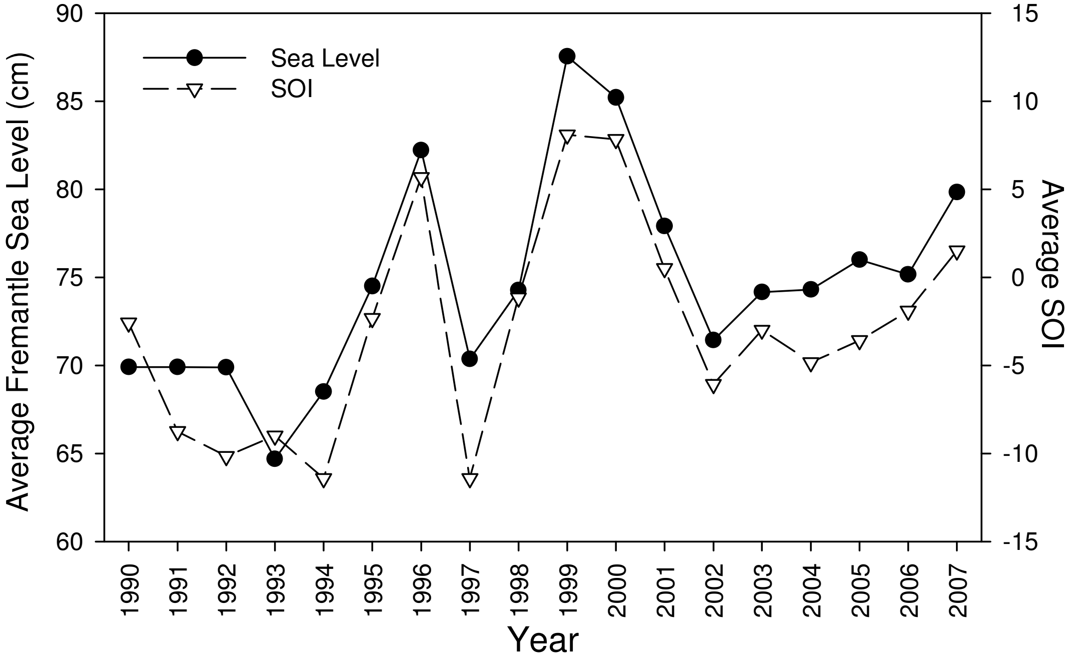


Figure 3.2. Mean monthly temperature and salinity at inshore sites within the Perth region sampled by DoF. **a)** average temperature at Warnbro Sound, Pinnaroo and Mangles Bay from 1995 and 2008 and **b)** temperature at Warnbro Sound, Pinnaroo and Mangles Bay in 2007/08; **c)** temperature at Challenger Beach, Woodman Point, Point Peron and Safety Bay in 2007/08; **d)** salinity at Warnbro Sound, Pinnaroo and Mangles Bay from 1995 and 2008; **e)** salinity at Warnbro Sound, Pinnaroo and Mangles Bay in 2007/08; **f)** salinity at Challenger Beach, Woodman Point, Point Peron and Safety Bay in 2007/08.

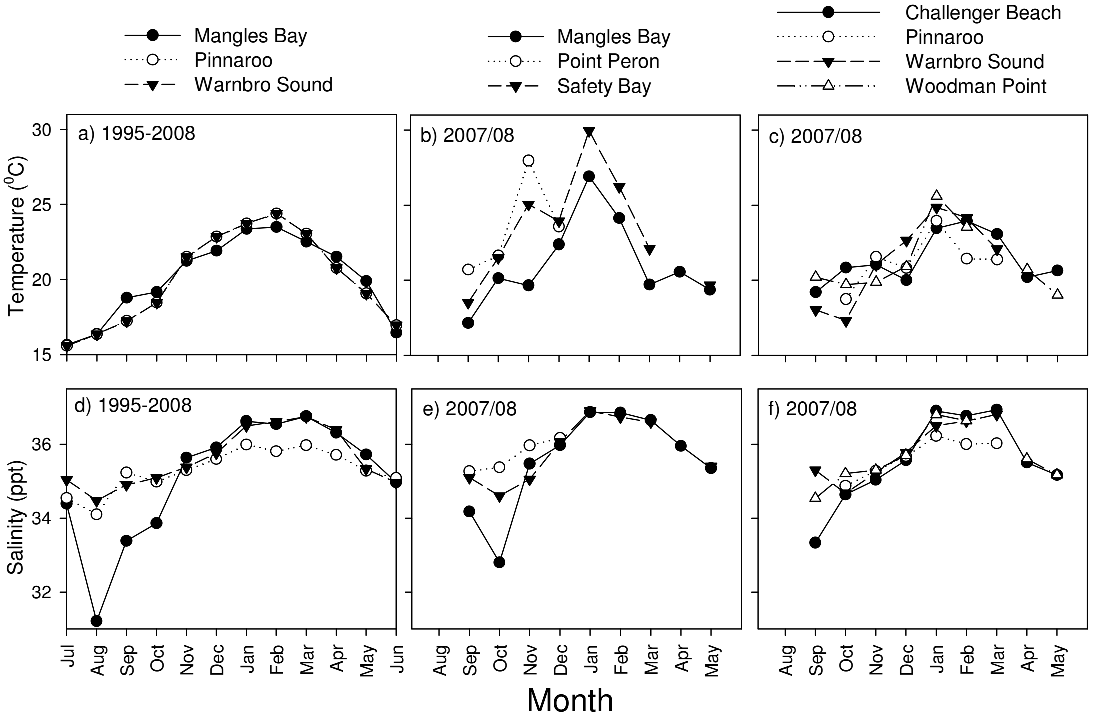


Figure 4.1. Mean (± s.d.) of **a)** number of species, **b)** Shannon-Weiner diversity index, **c)** number of individuals and **d)** number of individuals (excluding *Spratelloides robustus*), per month at sites within the Perth region, sampled September 2007 to May 2008. (MB-Mangles Bay, WS-Warnbro Sound, SB-Safety Bay, PP-Point Peron, WP-Woodman Point, CB-Challenger Beach, P-Pinnaroo)

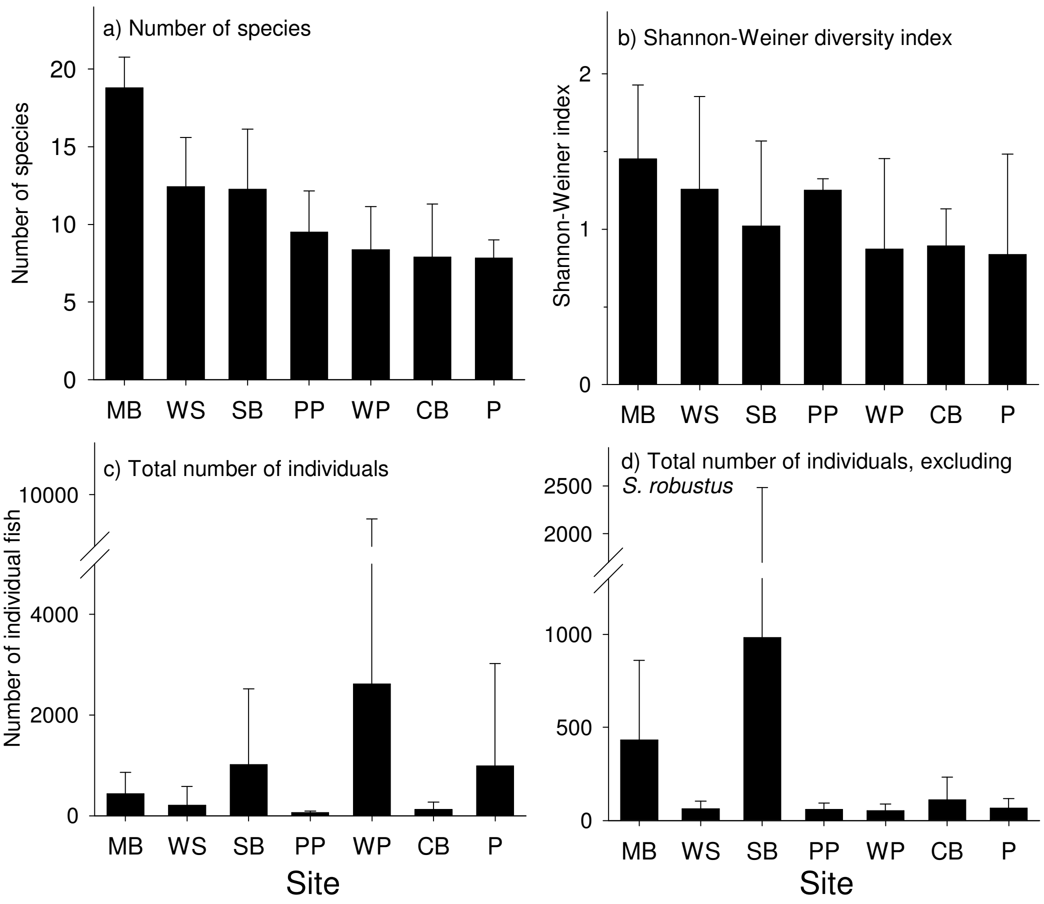


Figure 4.2. Two dimensional non-metric MDS plots of similarities between the composition of fish communities at inshore sites within the Perth region sampled monthly by **a)** 61 m seine net and **b)** 21 m seine net, from September 2007 to May 2008.

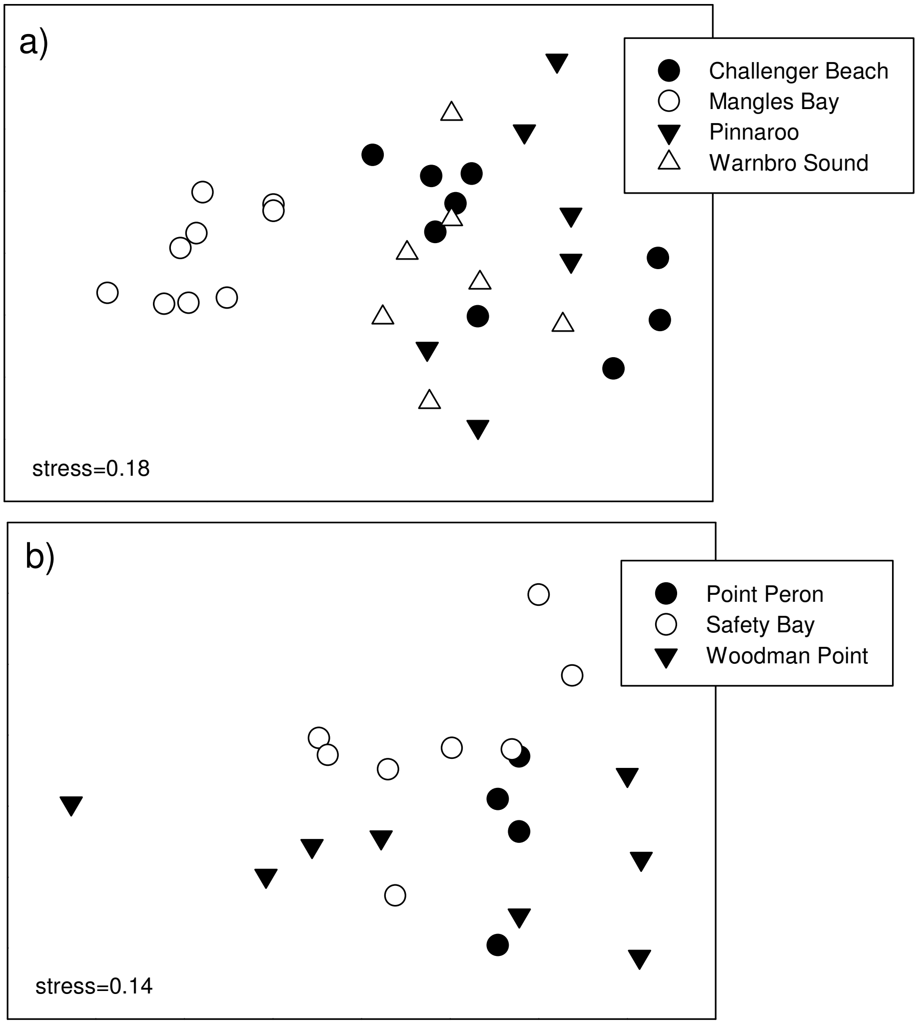


Figure 4.3. Two dimensional MDS plots of Bray-Curtis similarities between monthly samples of inshore fish from sites in the Perth region, sampled from September 2007 to May 2008 (1=January, 2=February, etc). (Point Peron not shown due to only 4 samples being taken at this sites)

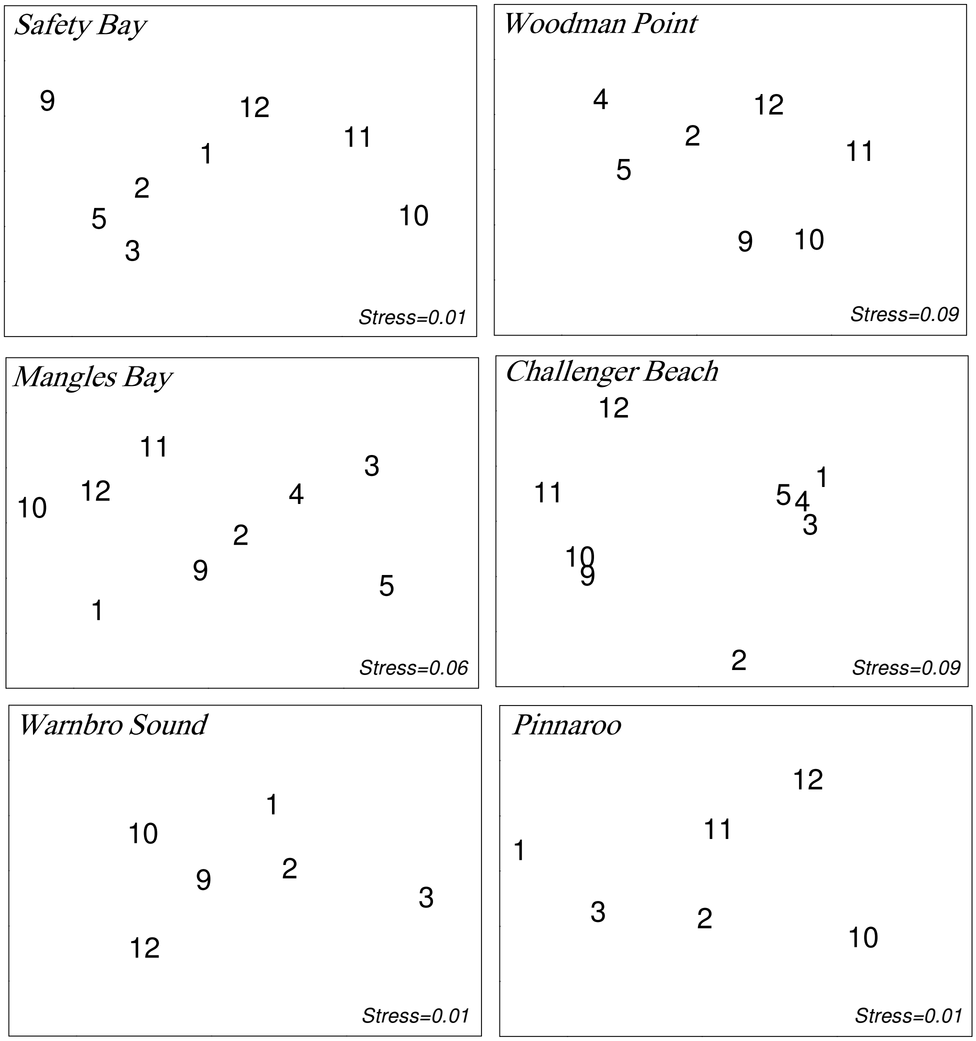


Figure 4.4. Two dimensional MDS plots of Bray-Curtis similarities between monthly samples of inshore fish from all sites in the Perth region, sampled from September 2007 to May 2008. Filled circles = samples collected September-December; Open circles = samples collected January-May.

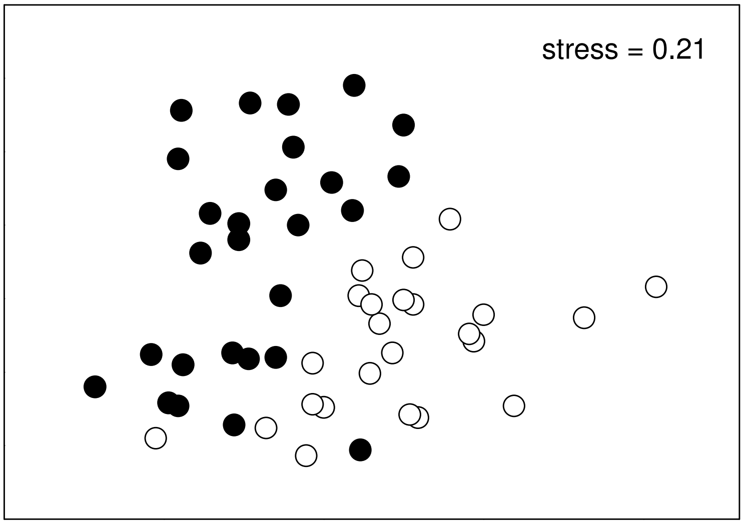


Figure 4.5. Monthly mean (± s.d.) salinity versus water temperature during sampling of inshore fish from all sites in the Perth region, sampled from September 2007 to May 2008.

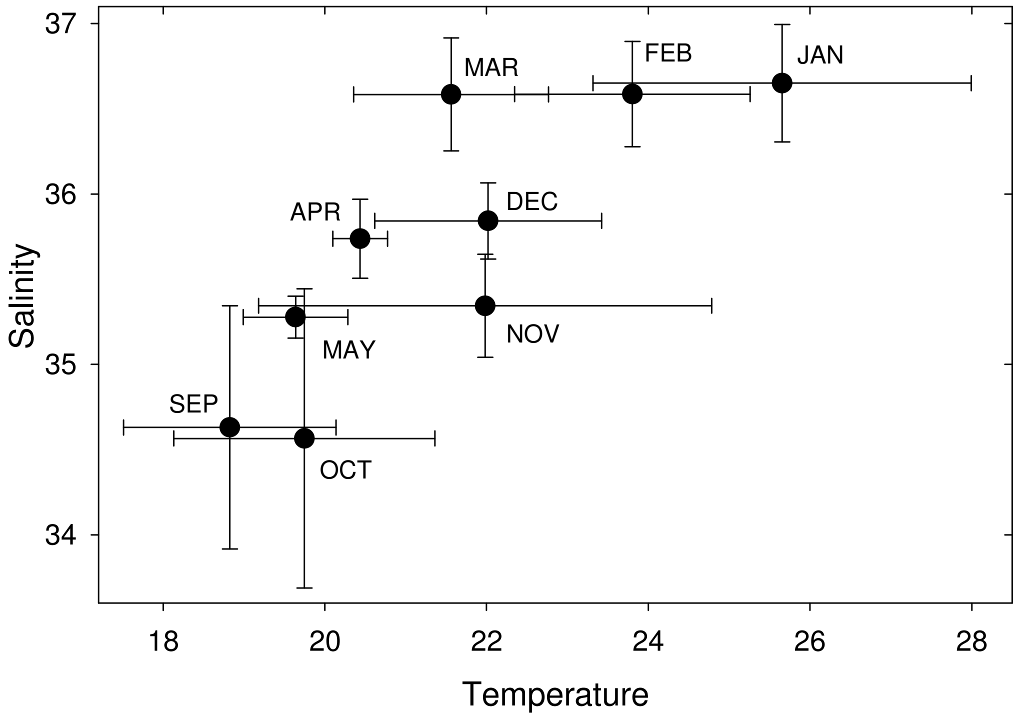


Figure 5.1. Monthly length frequency distributions of *Mugil cephalus* in the West region, summed from all samples taken 1993 to 2008.

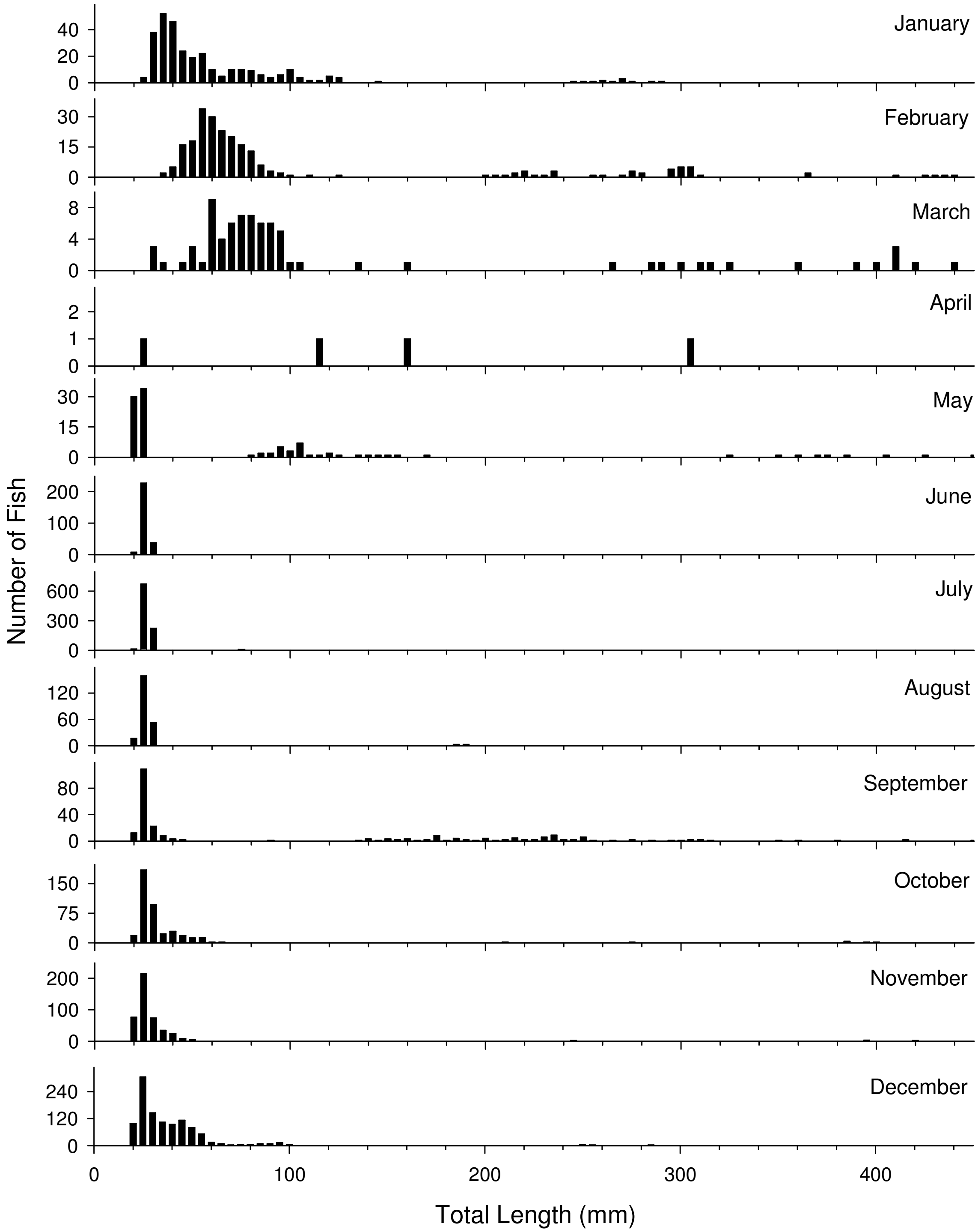


Figure 5.2. Monthly length frequency distributions of *Mugil cephalus* in the South region, summed from all samples taken 1993 to 2008.

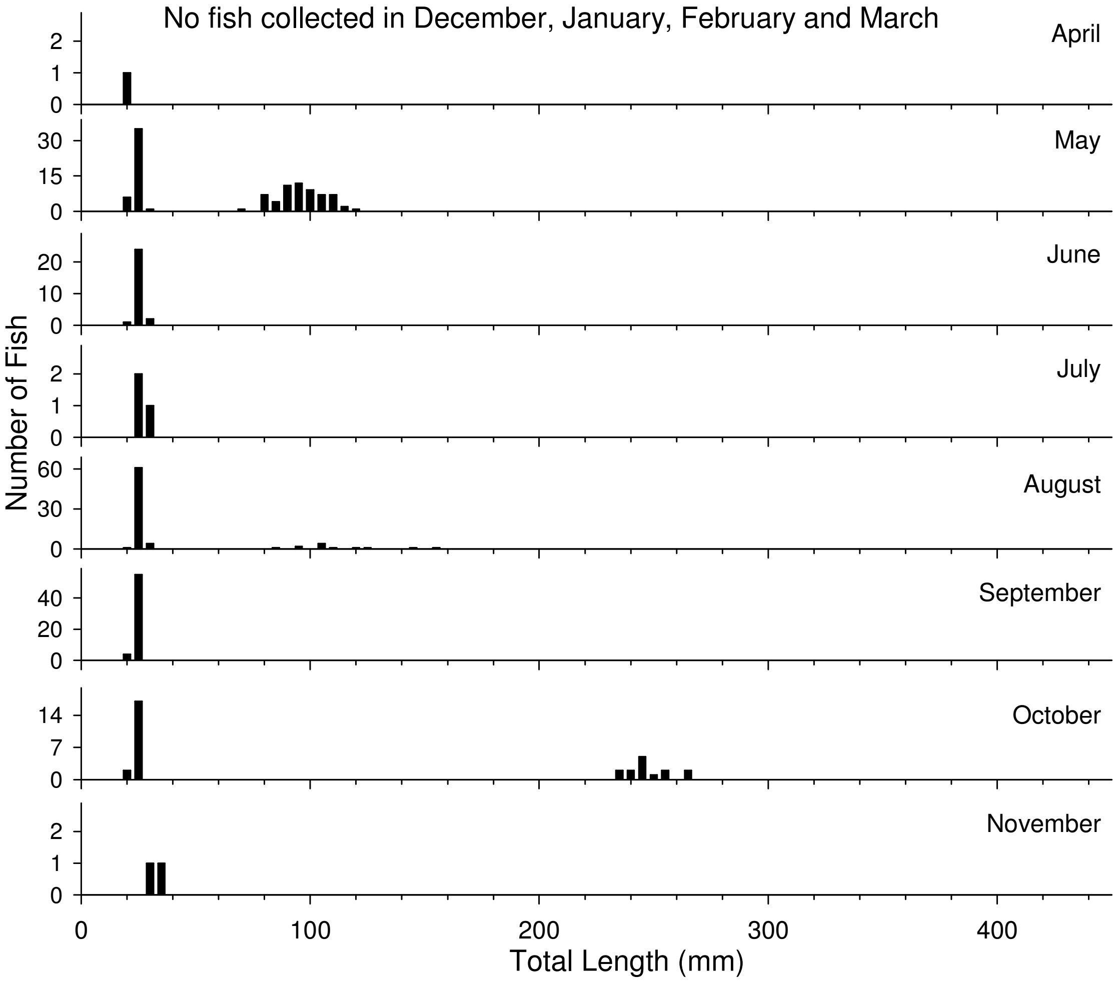


Figure 5.3. Monthly length frequency distributions of *Mugil cephalus* in the South East region, summed from all samples taken 1993 to 2008.

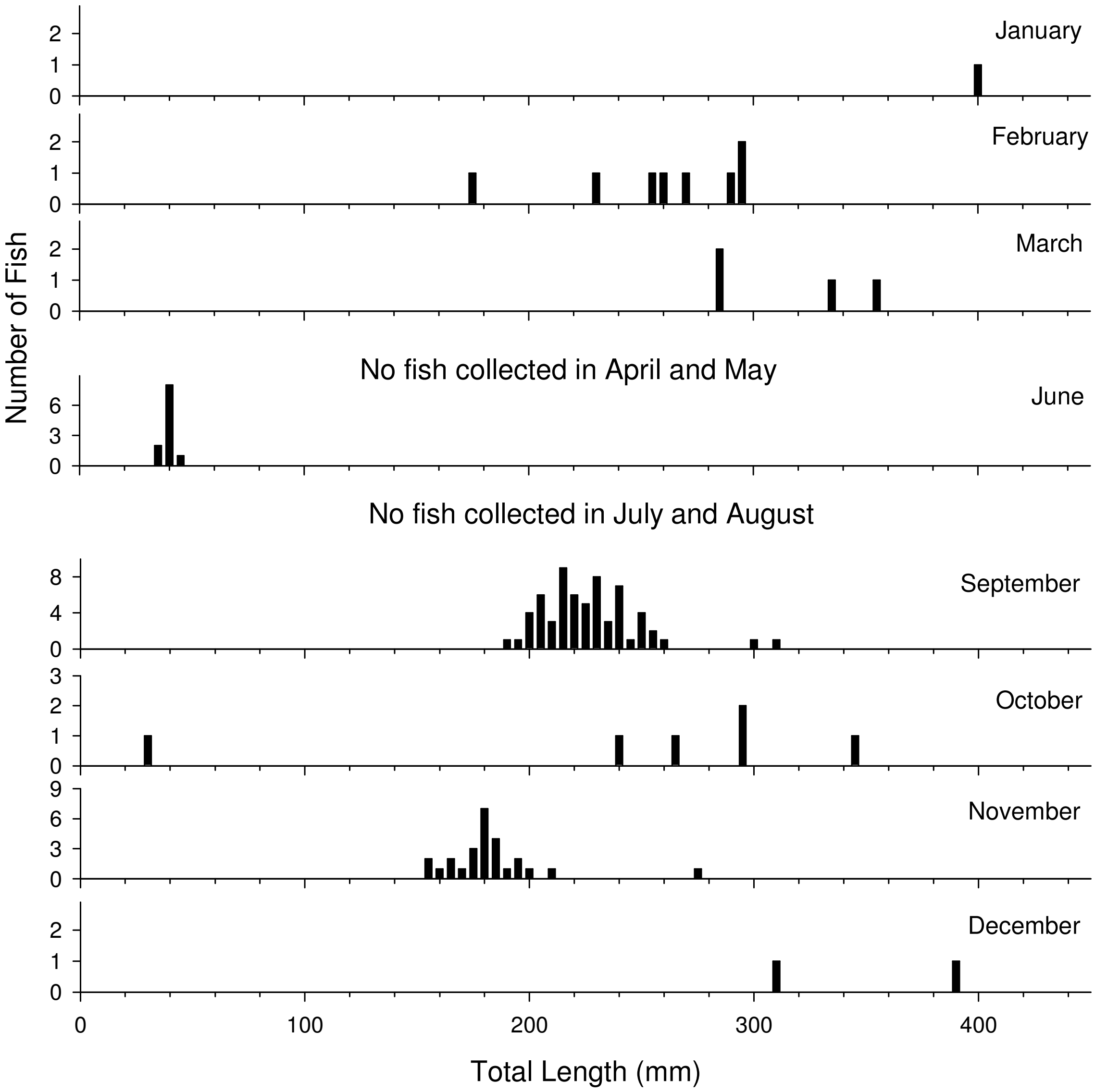


Figure 5.4a-d. Mean monthly catch rates (fish per haul) of *Mugil cephalus* <40 mm TL at **a)** Mangles Bay, **b)** Warnbro Sound, **c)** Koombana Bay and **d)** Emu Point, from 1996 to 2008 (blank – no sample taken).

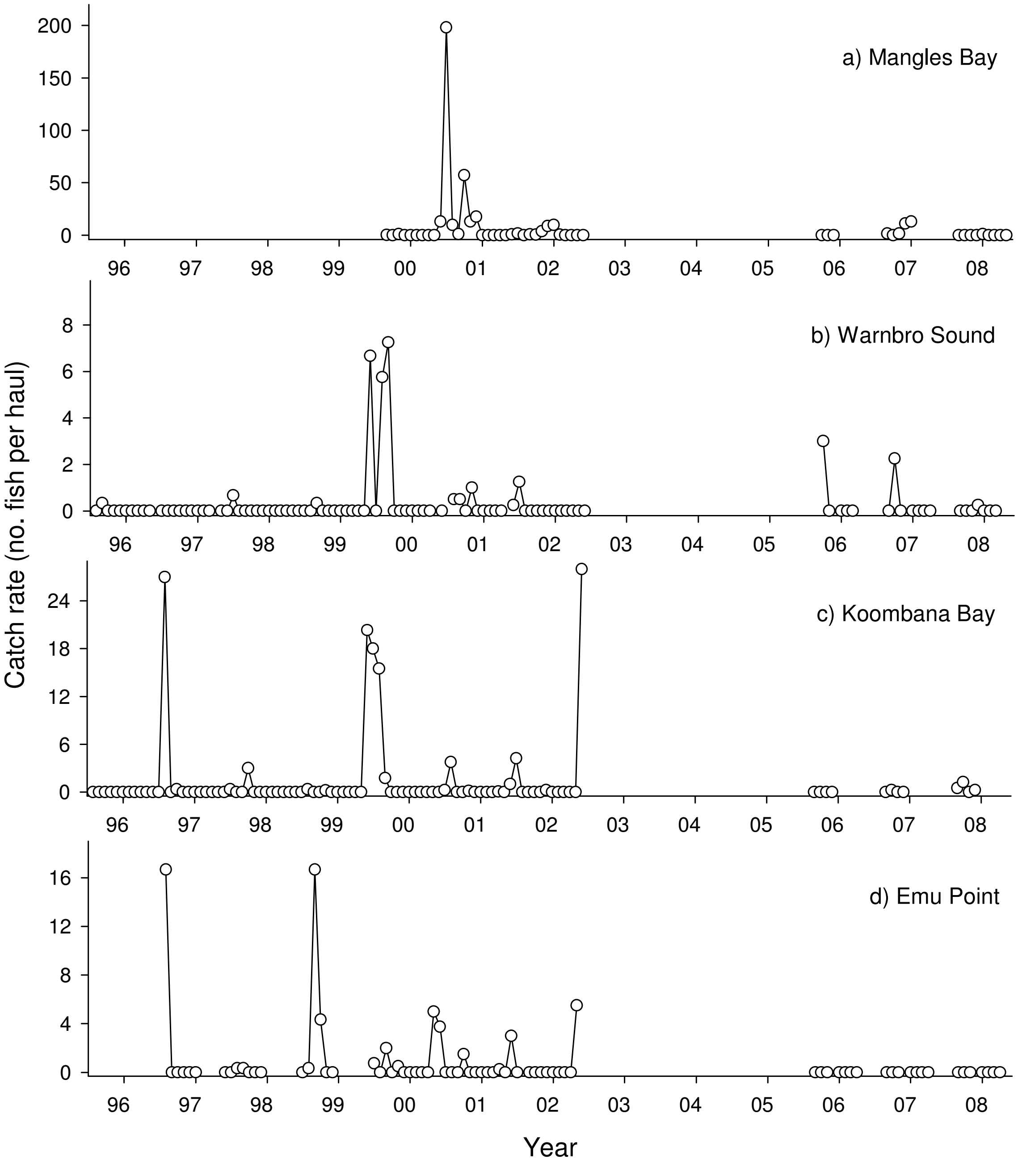


Figure 5.5. Length frequency distributions of total *Mugil cephalus* captured at sites in the Perth region, summed from all samples taken 1993 to 2008.

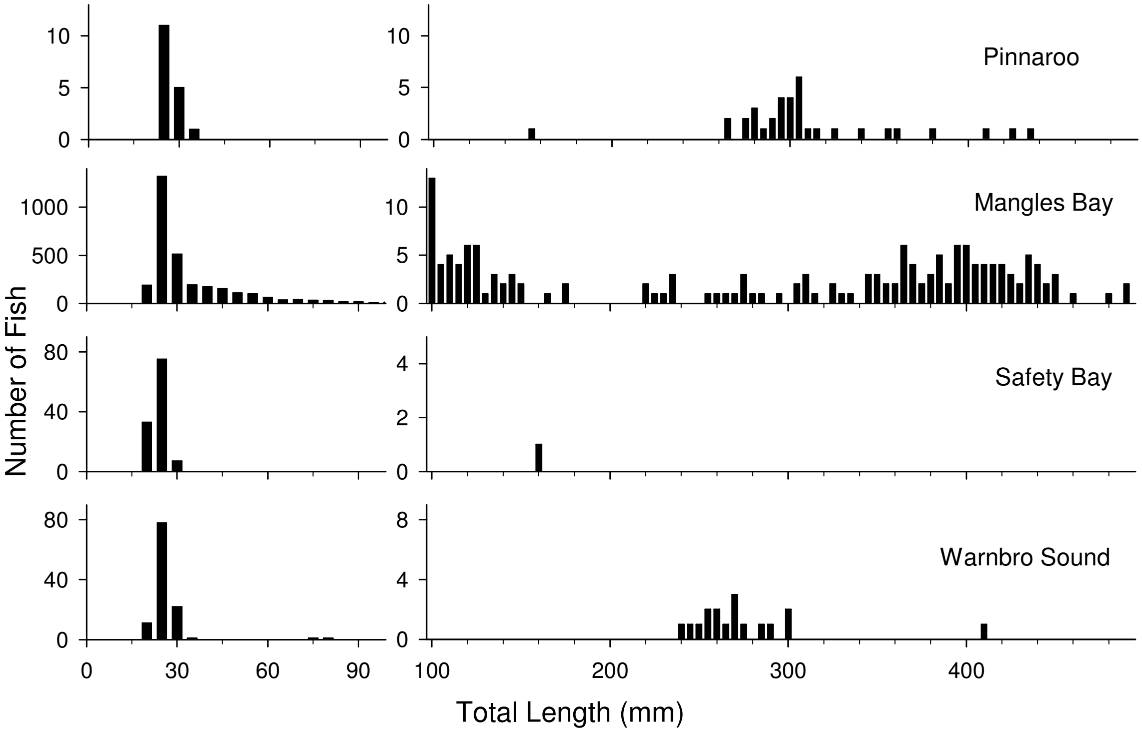


Figure 5.6. Monthly length frequency distributions of *Aldrichetta forsteri* in the West region, summed from all samples taken 1993 to 2008.

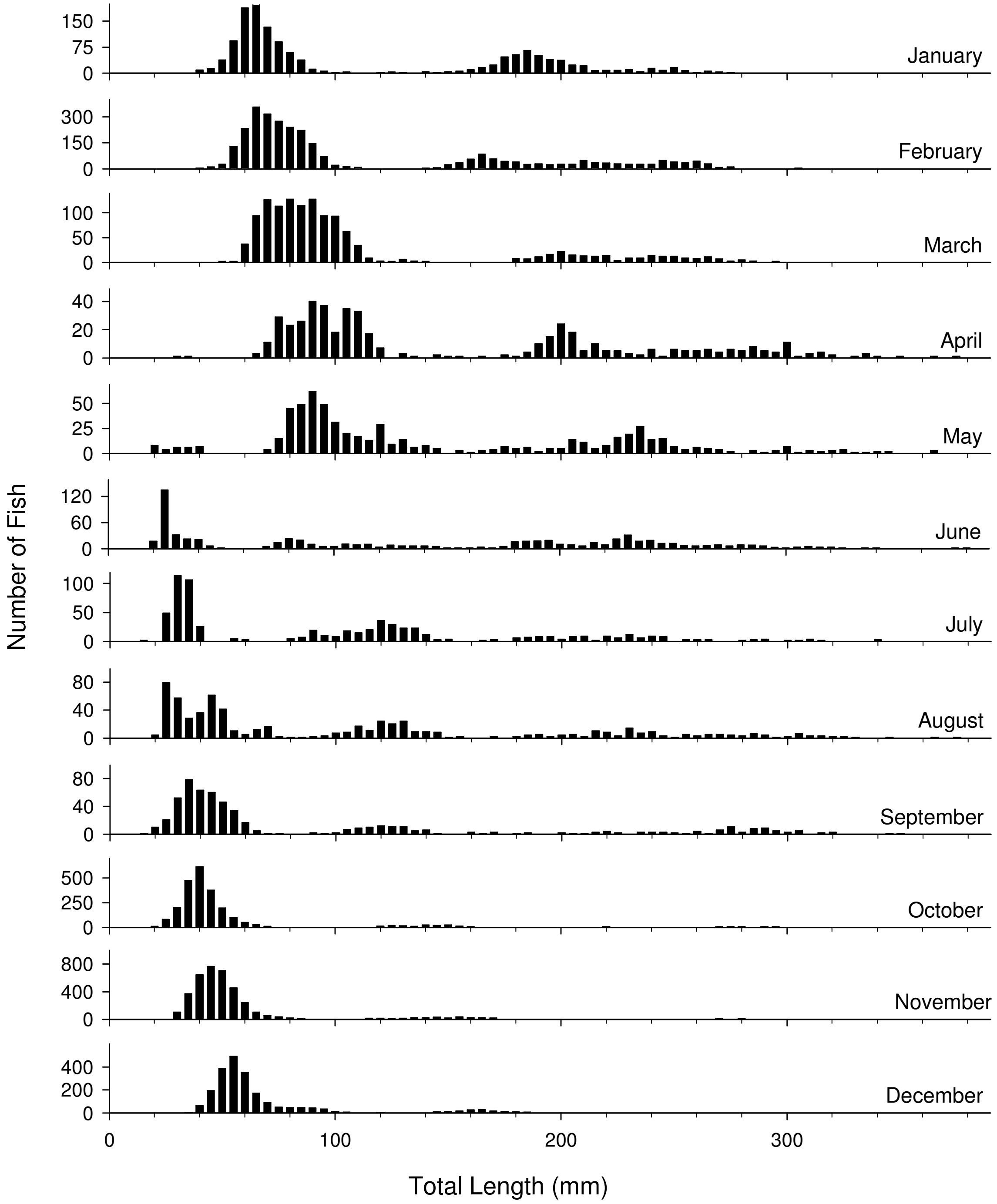


Figure 5.7. Monthly length frequency distributions of *Aldrichetta forsteri* in the South region, summed from all samples taken 1993 to 2008.

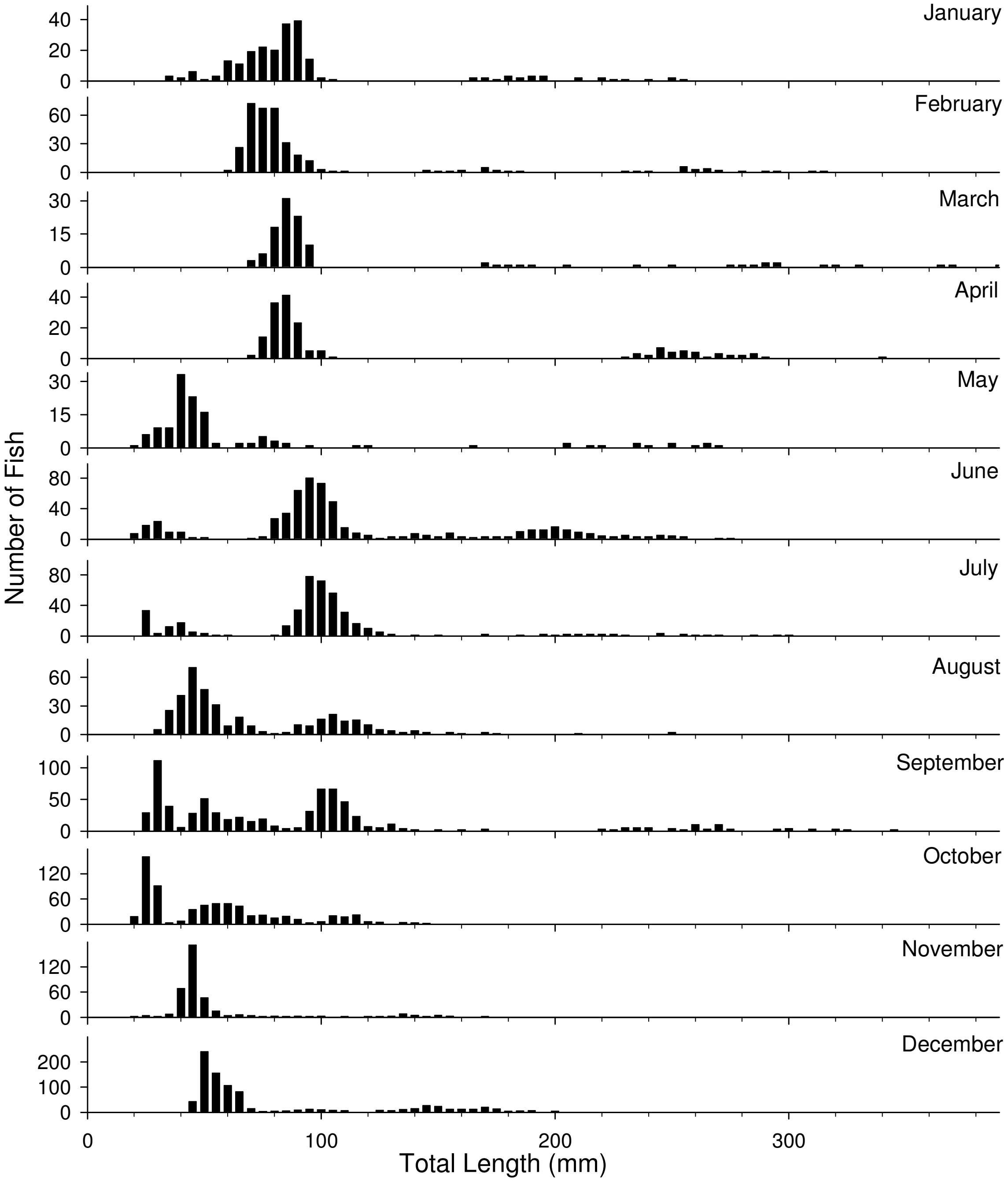


Figure 5.8. Monthly length frequency distributions of *Aldrichetta forsteri* in the South East region, summed from all samples taken 1993 to 2008.

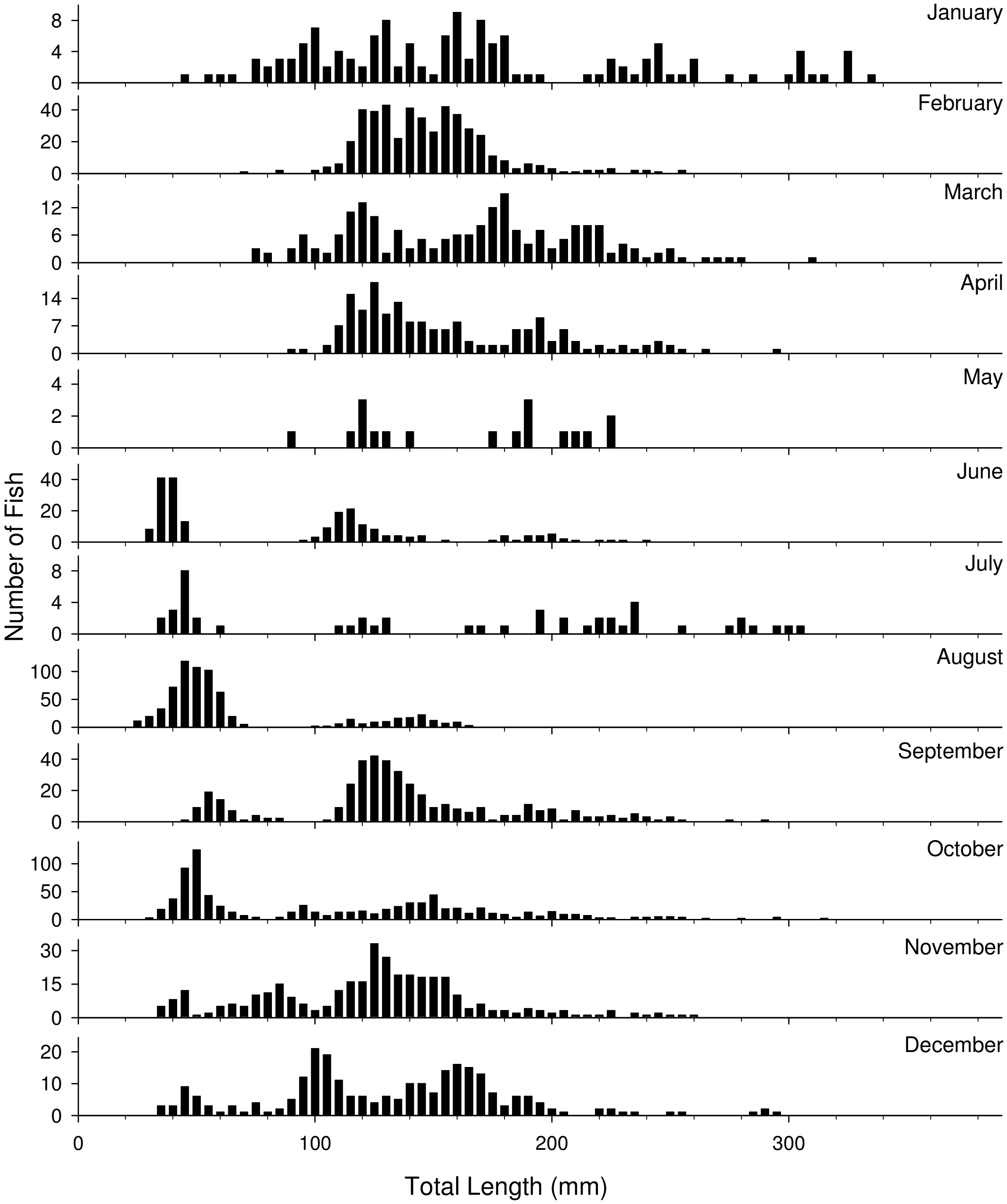


Figure 5.9a-e. Mean monthly catch rates (fish per haul) of *Aldrichetta forsteri* <50 mm TL at **a)** Mangles Bay, **b)** Warnbro Sound, **c)** Koombana Bay, **d)** Emu Point and **e)** Poison Creek, from 1996 to 2008 (blank – no sample taken).

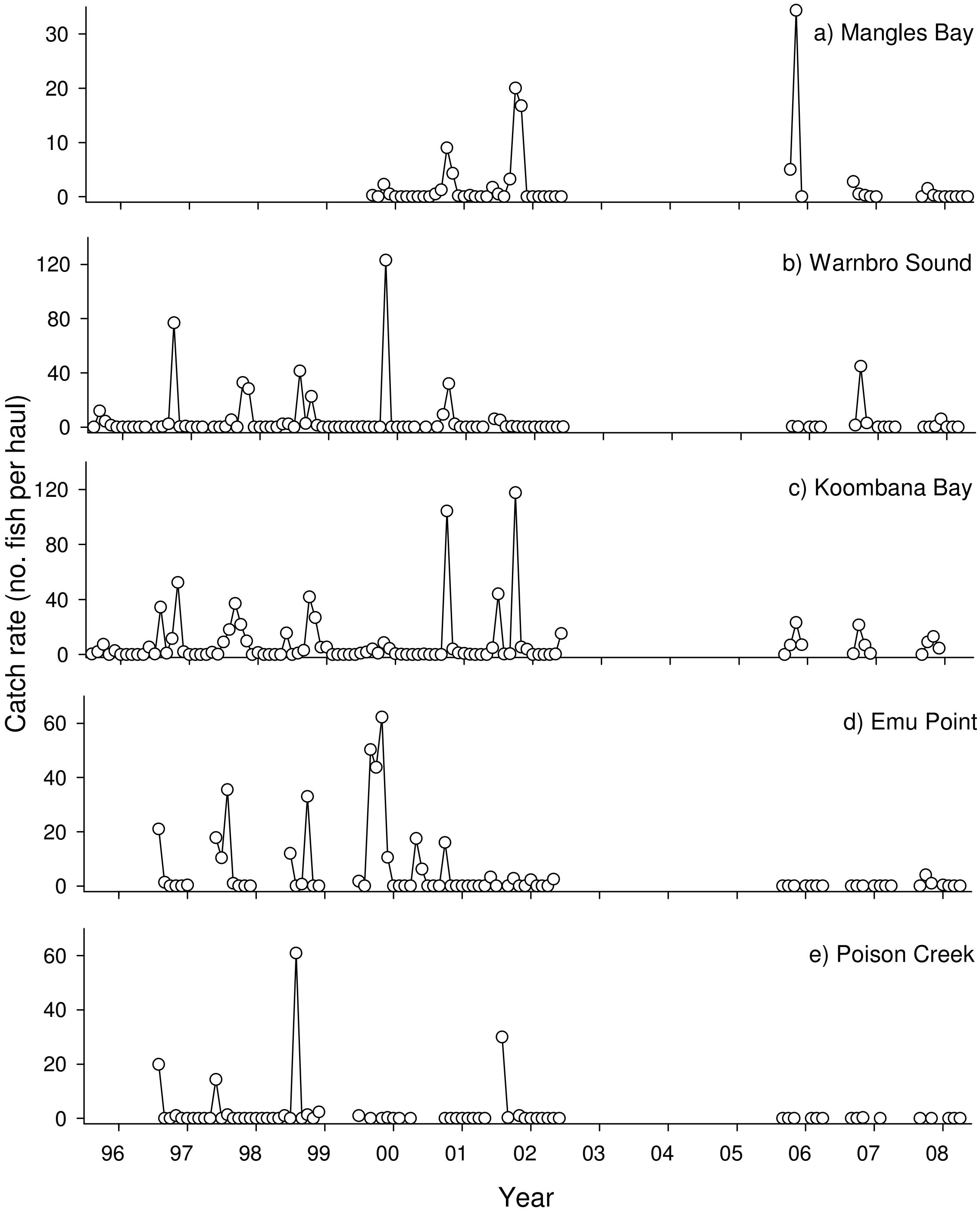


Figure 5.10. Length frequency distributions of *Aldrichetta forsteri* at sites in the Perth region, summed from all samples taken 1993 to 2008.

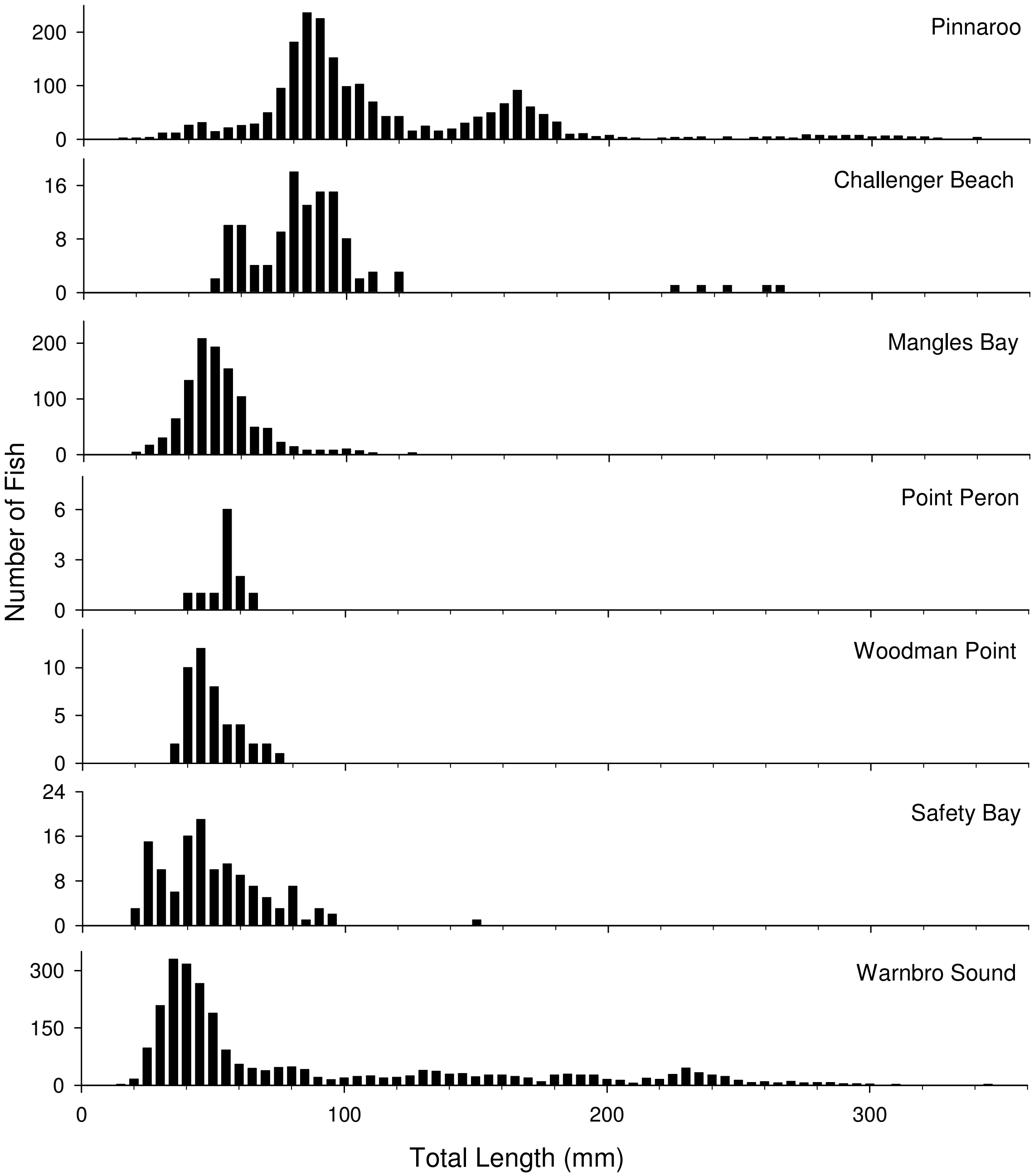


Figure 5.11. Monthly length frequency distributions of *Torquigener pleurogramma* at sites within the Perth region, summed from all samples taken mid-2005 to mid-2008.

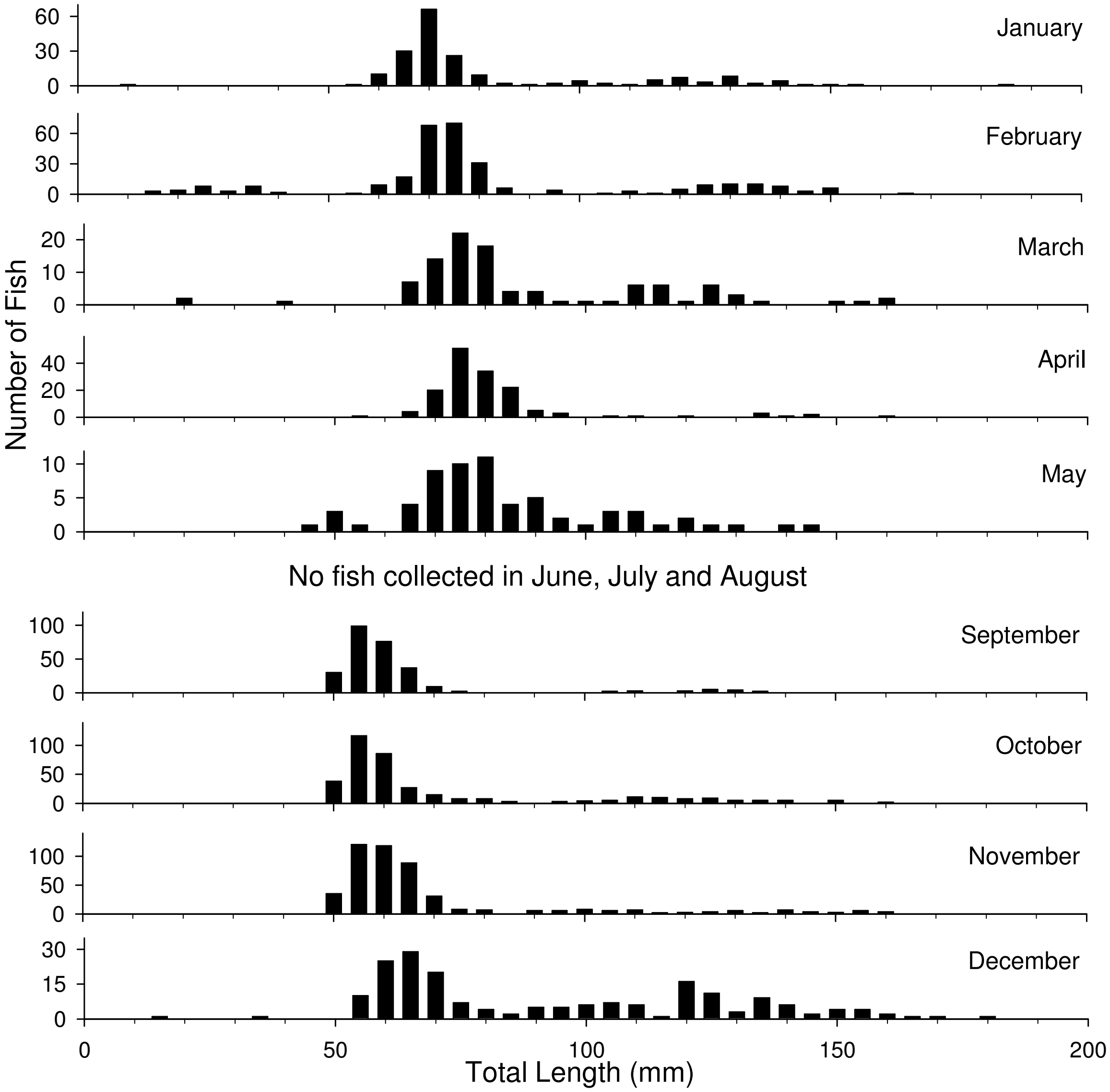


Figure 5.12. Monthly length frequency distributions of *Torquigener pleurogramma* at sites within the Bunbury region from September to December, summed from all samples taken mid-2005 to mid-2008.

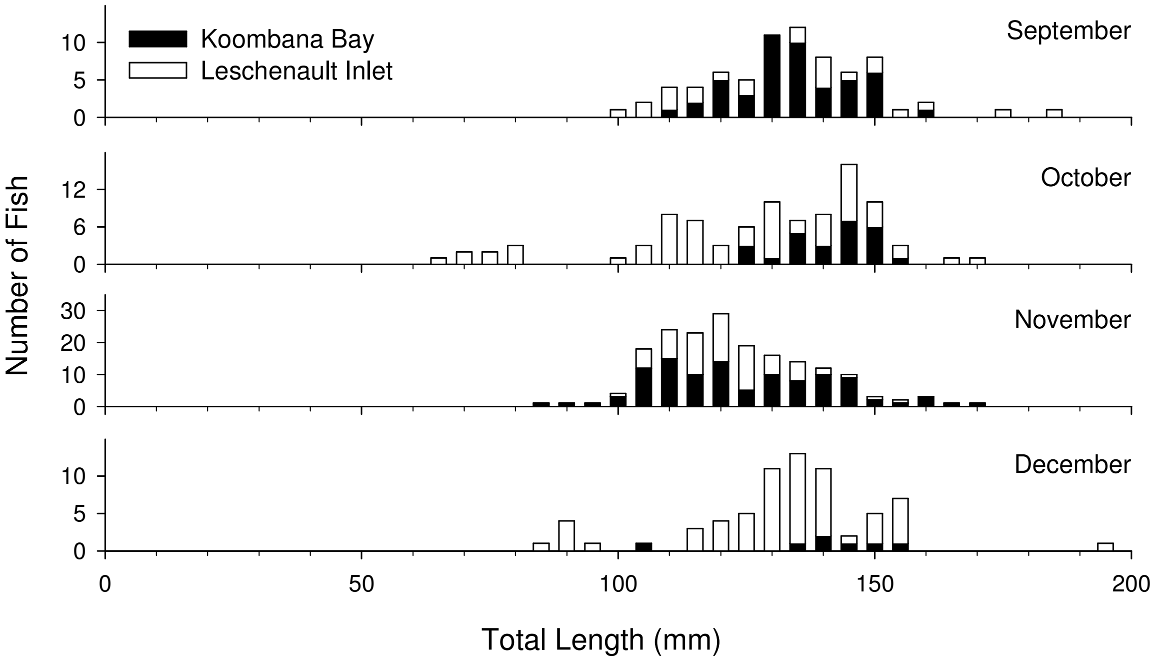


Figure 5.13. Mean monthly catch rates (fish per haul) of *Torquigener pleurogramma* <60 mm TL at Mangles Bay from October 2005 to May 2008.

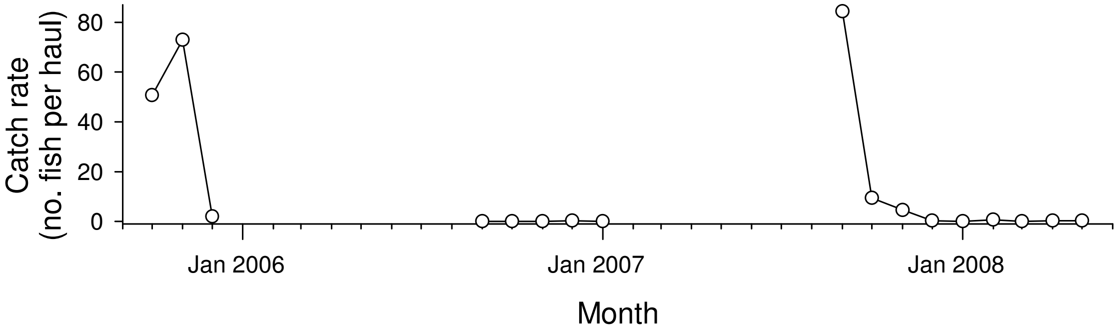

Catch rate
(no. fish per haul)
0
20
40
60
80
Jan 2006
Jan 2007
Jan 2008
Month

Figure 5.14. Length frequency distributions of *Torquigener pleurogramma* at sites in the Perth region, summed from all samples taken October 2005 to May 2008.

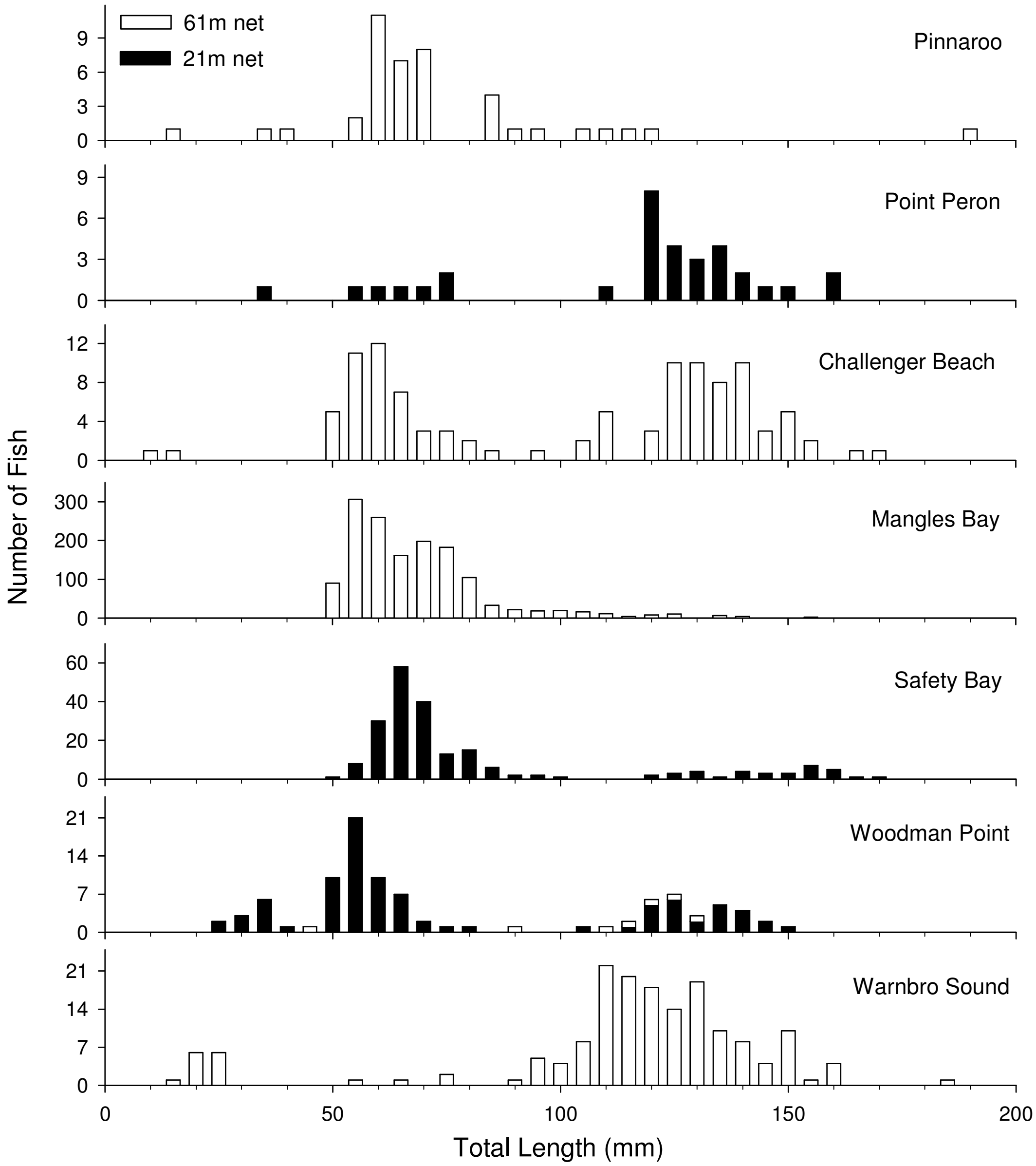


Figure 5.15. Monthly length frequency distributions of *Arripis georgianus* in the West region, summed from all samples taken 1993 to 2008.

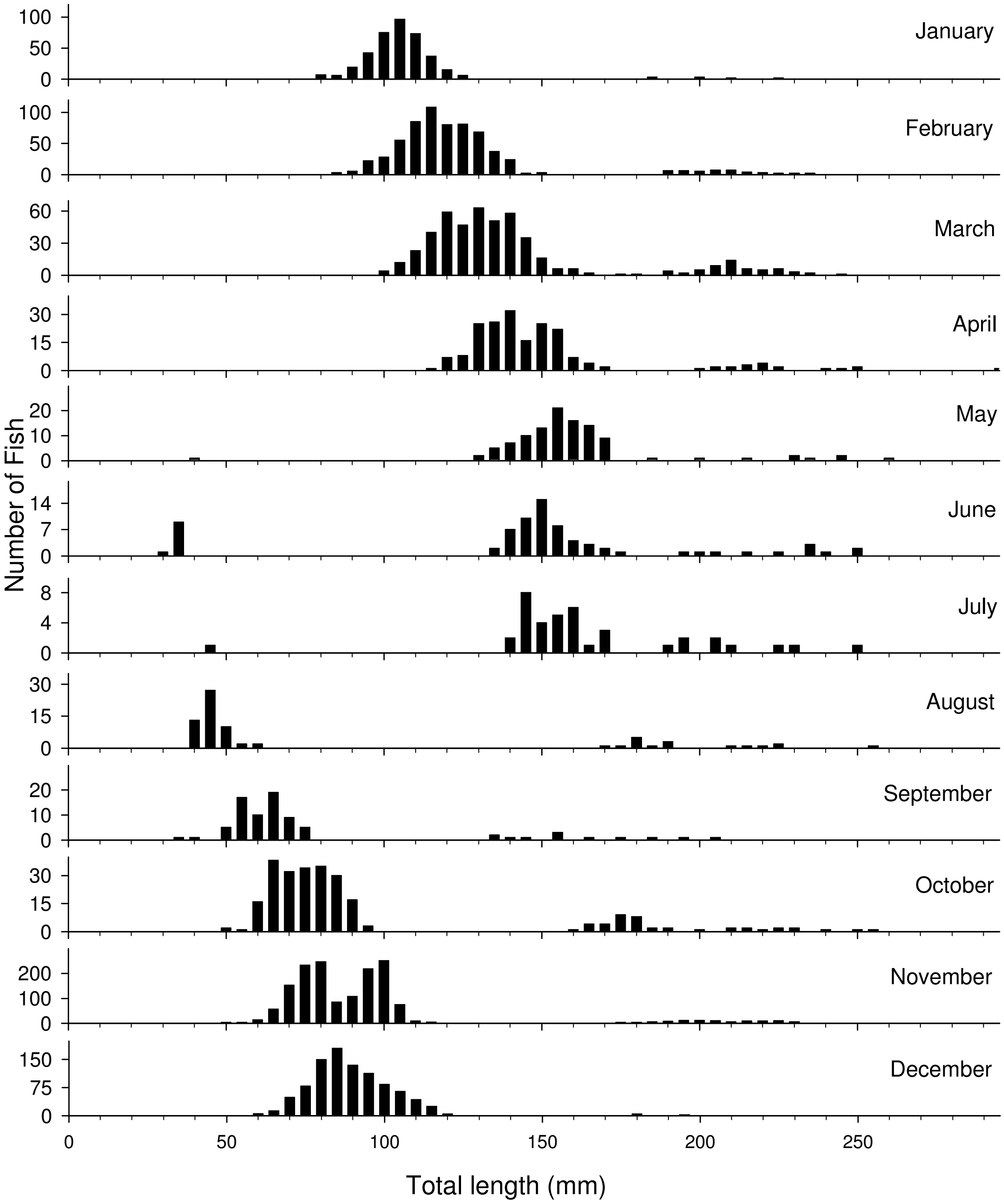


Figure 5.16. Monthly length frequency distributions of *Arripis georgianus* in the South region, summed from all samples taken 1993 to 2008.

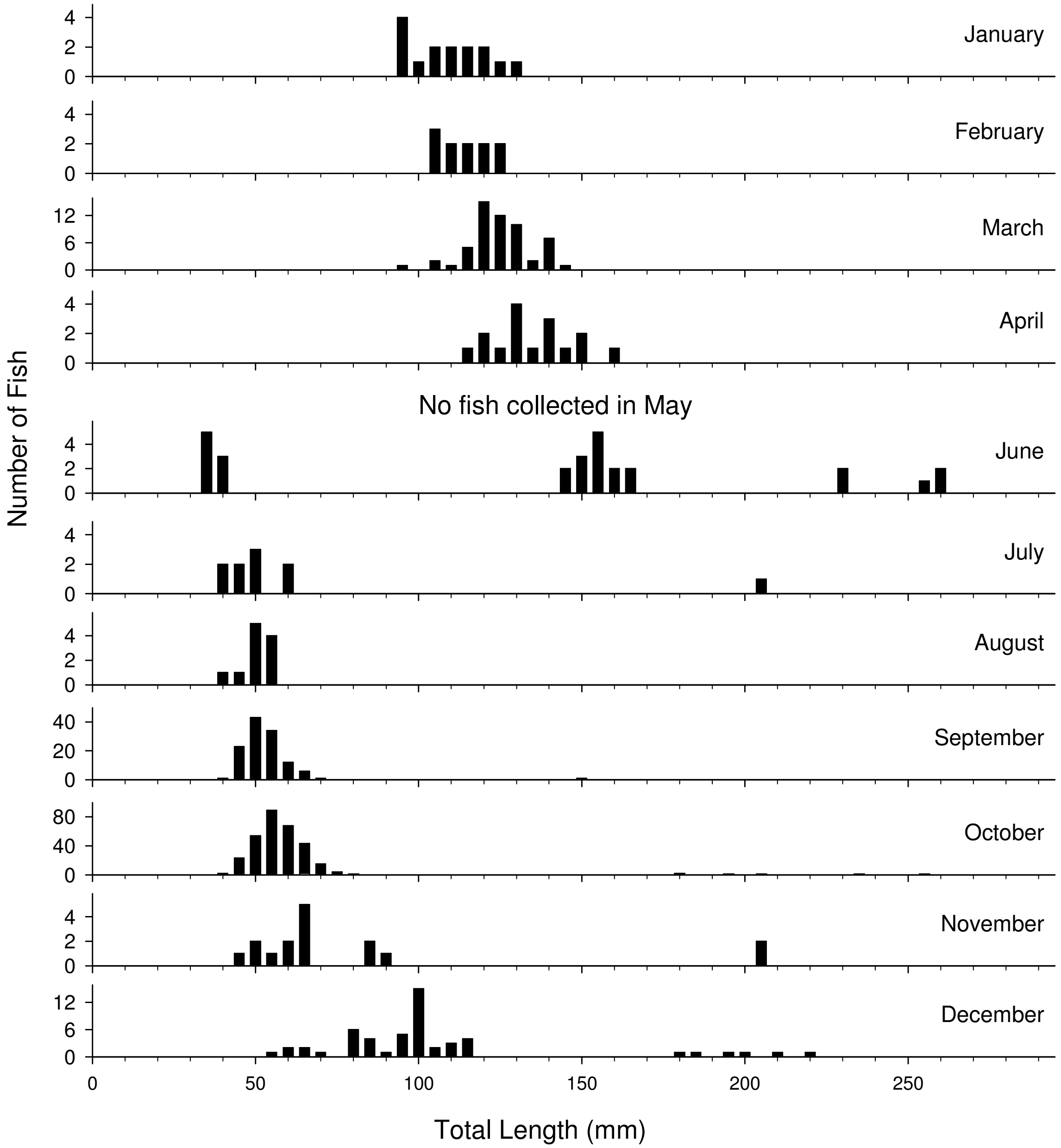


Figure 5.17. Monthly length frequency distributions of *Arripis georgianus* in the South East region, summed from all samples taken 1993 to 2008.

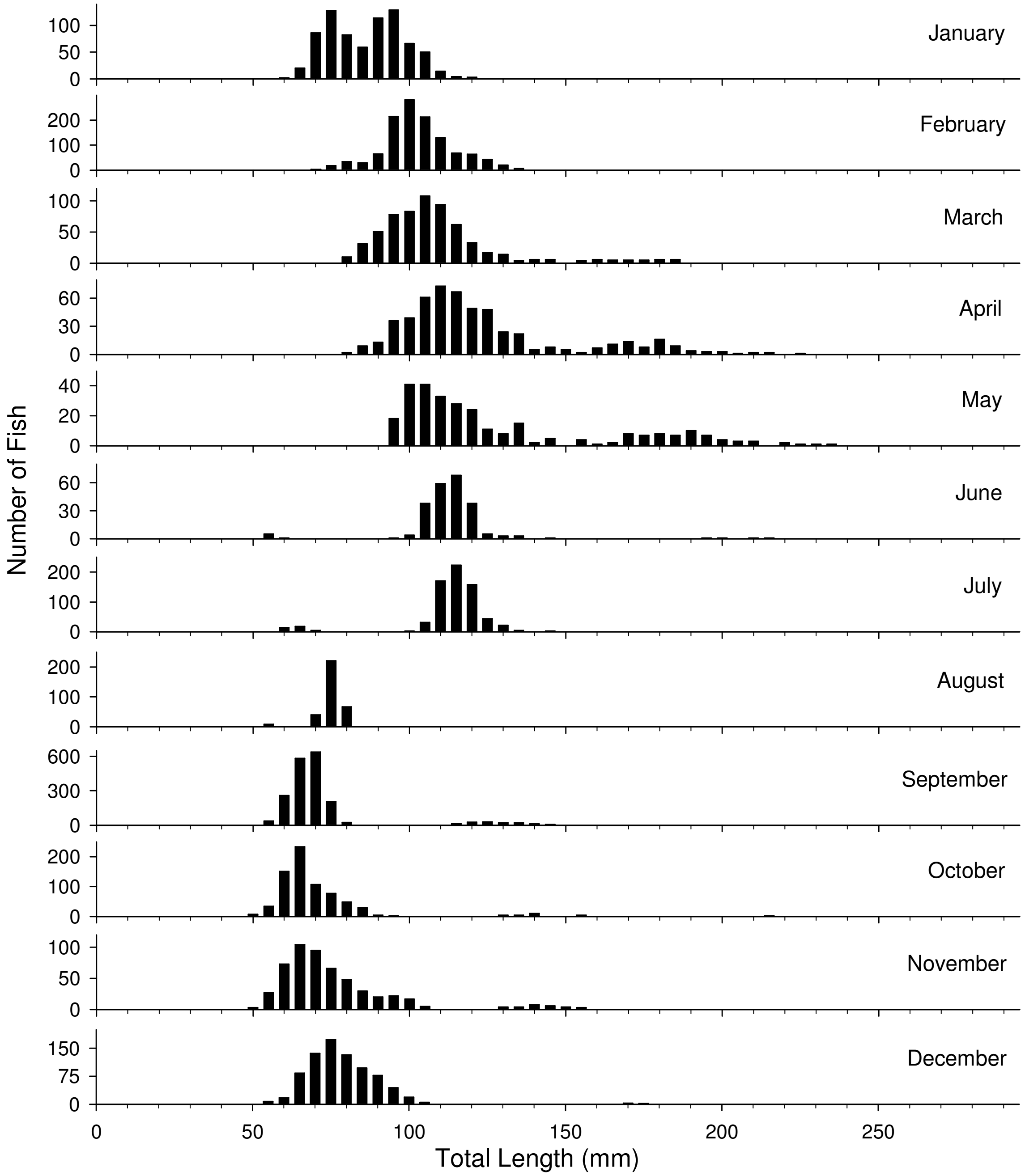


Figure 5.18. Mean monthly catch rates (fish per haul) of *Arripis georgianus* <75 mm TL at **a)** Koombana Bay, **b)** Emu Point and **c)** Poison Creek, from 1993 to 2008 (blank – no sample taken).

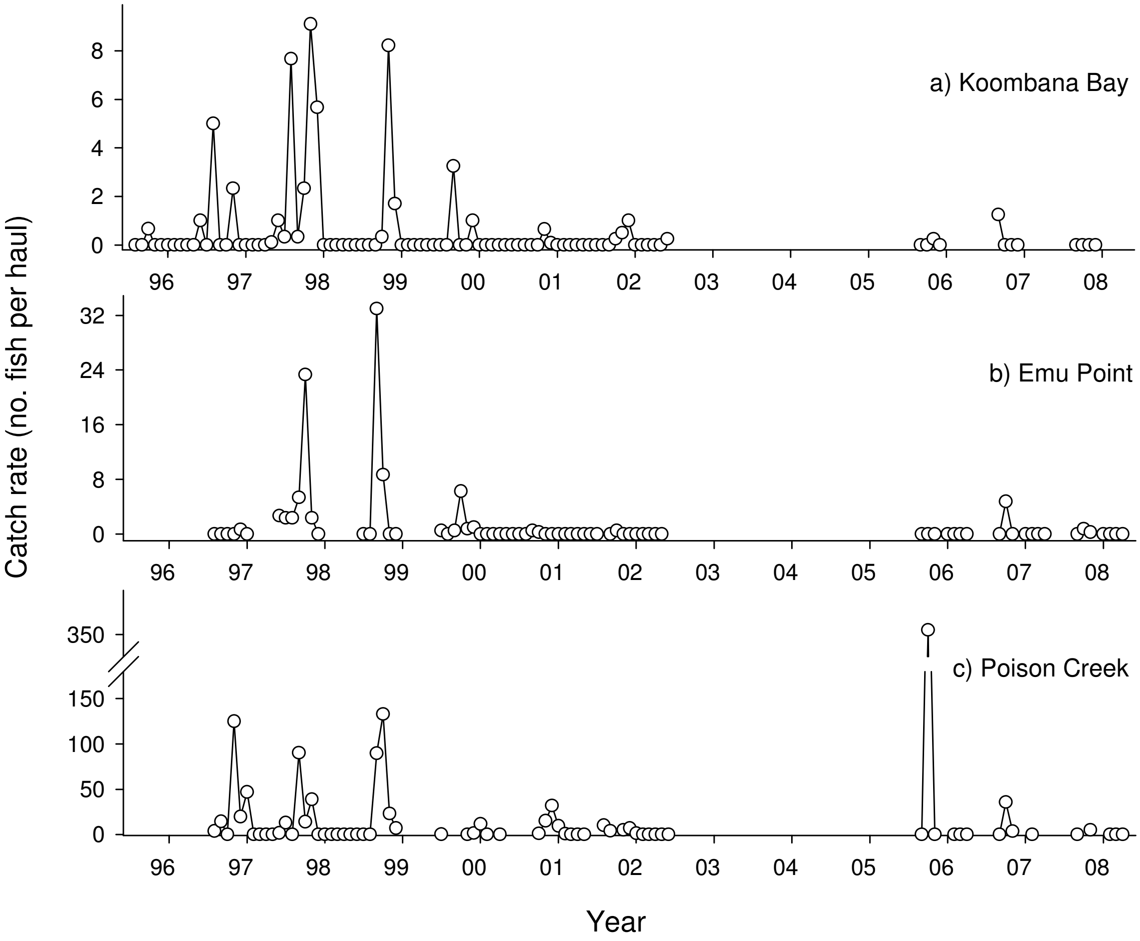


Figure 5.19. Length frequency distributions of *Arripis georgianus* at sites in the Perth region, summed from all samples taken 1993 to 2008.

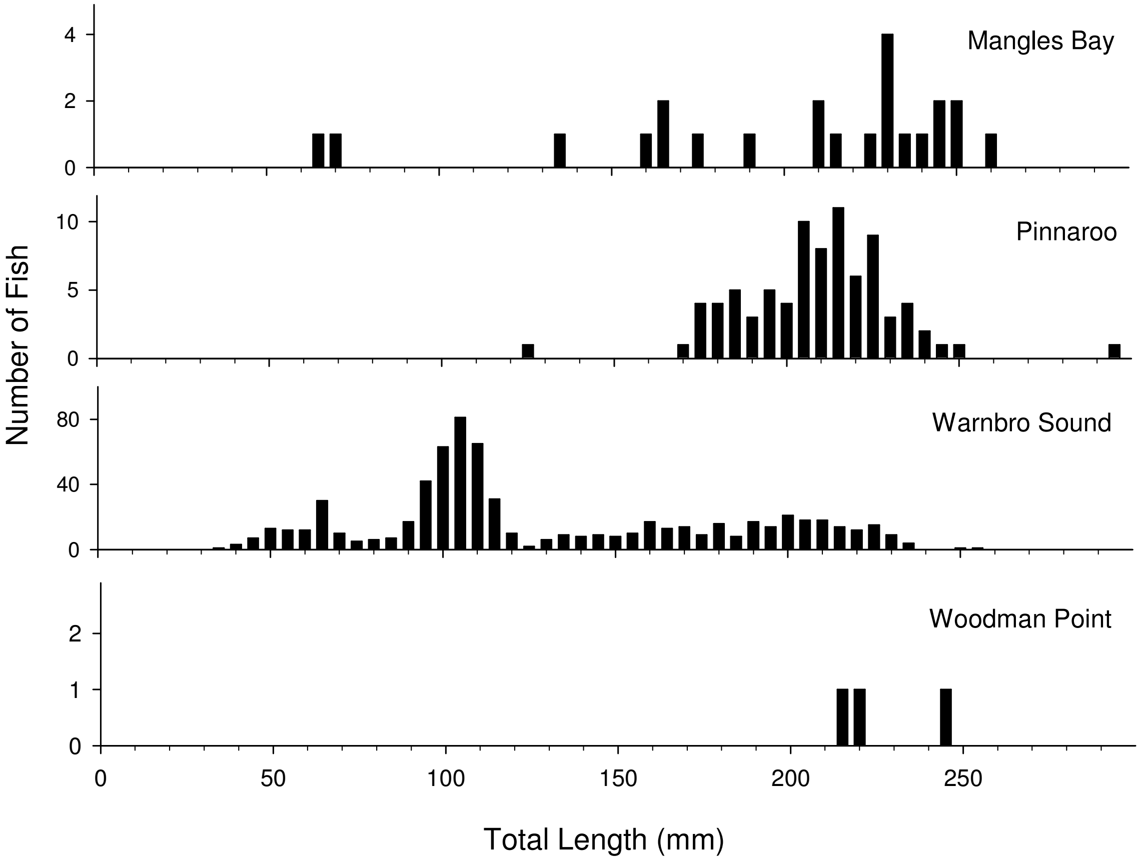


Figure 5.20. Monthly length frequency distributions of *Atherinomorus ogilbyi* in the West region, summed from all samples taken 2005 to 2008.

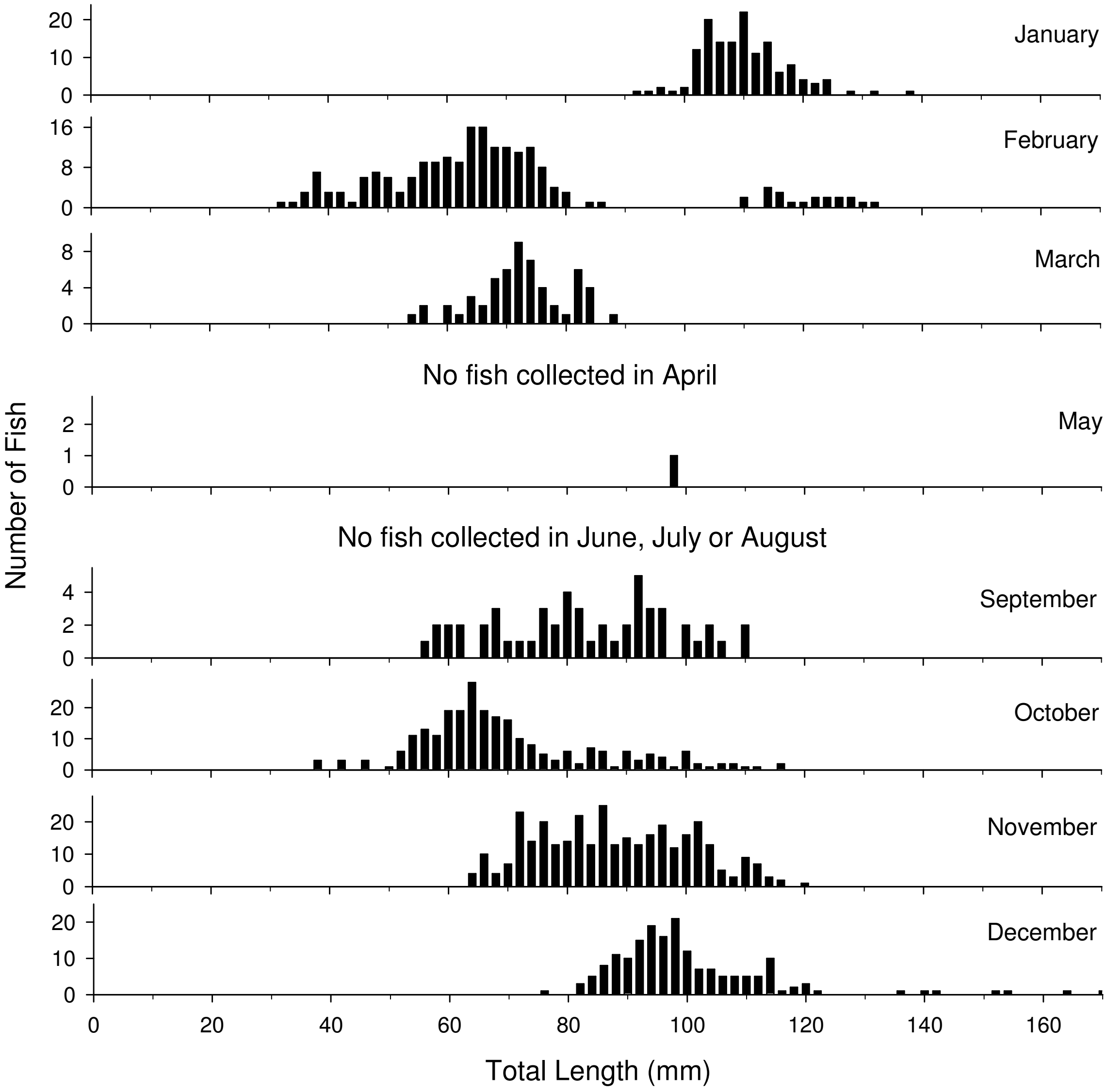


Figure 5.21. Monthly length frequency distributions of *Unidentified Atherinids* in the West region, summed from all samples taken 2005 to 2008.

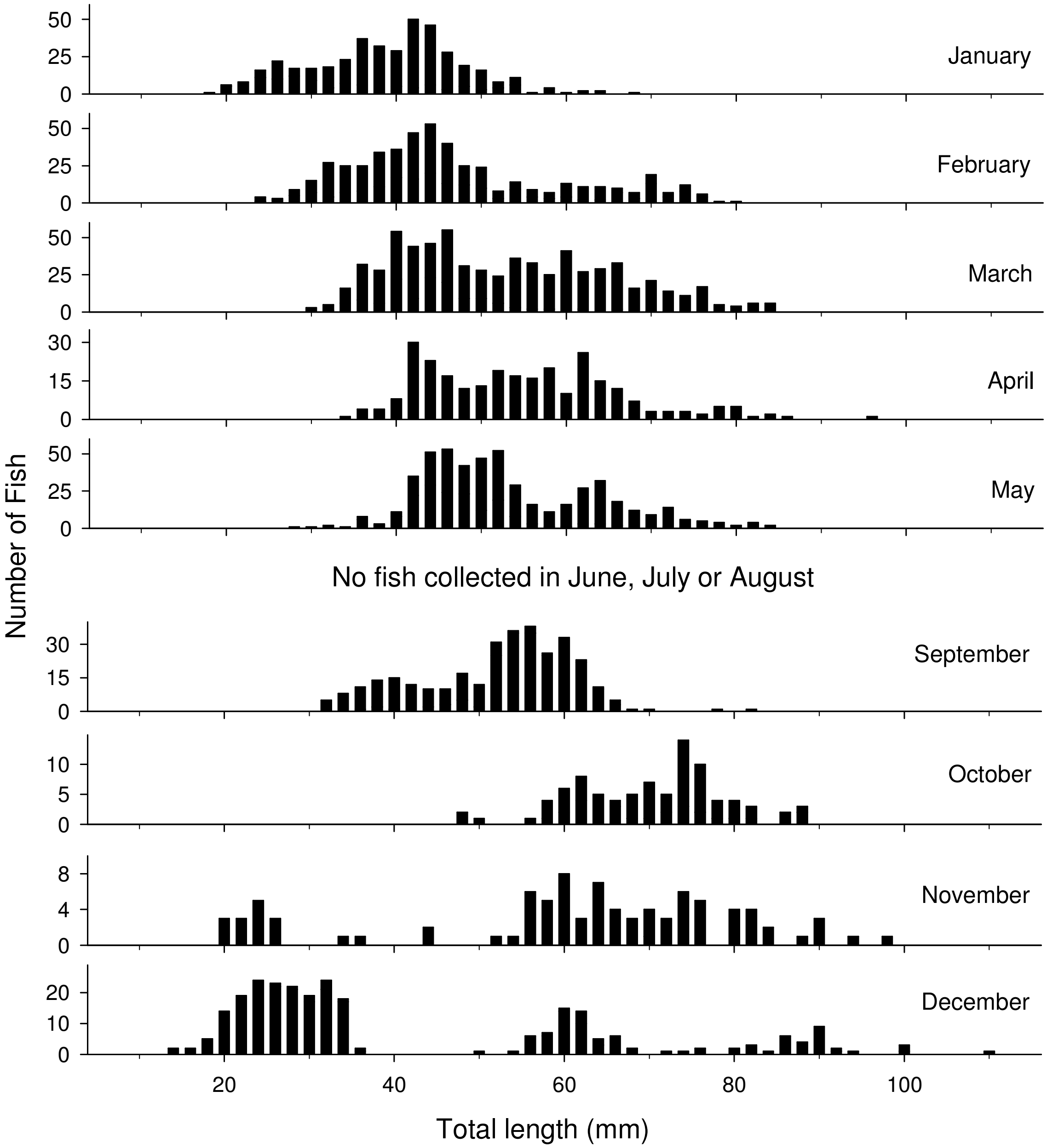


Figure 5.22. Length frequency distributions of *Atherinomorus ogilbyi* in the Perth region, summed from all samples taken 2005 to 2008.

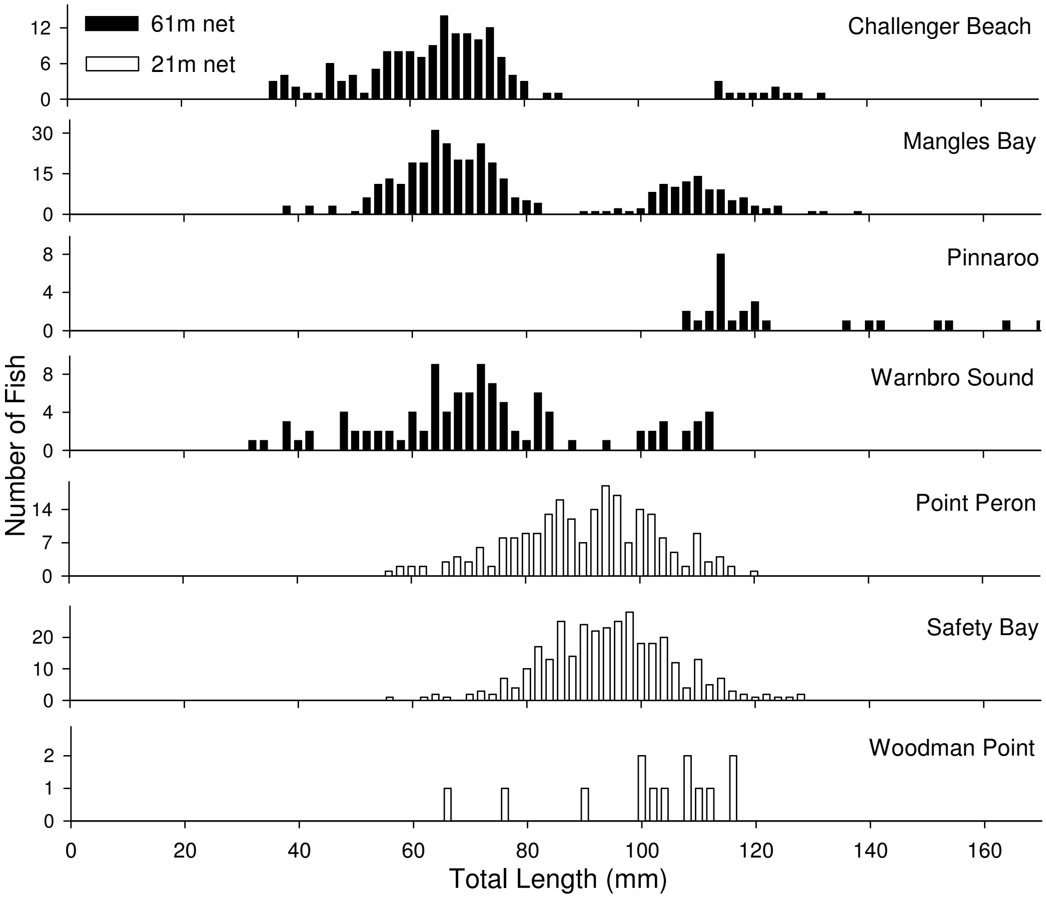


Figure 5.23. Length frequency distributions of *Unidentified Atherinids* at sites in the Perth region, summed from all samples taken 2005 to 2008.

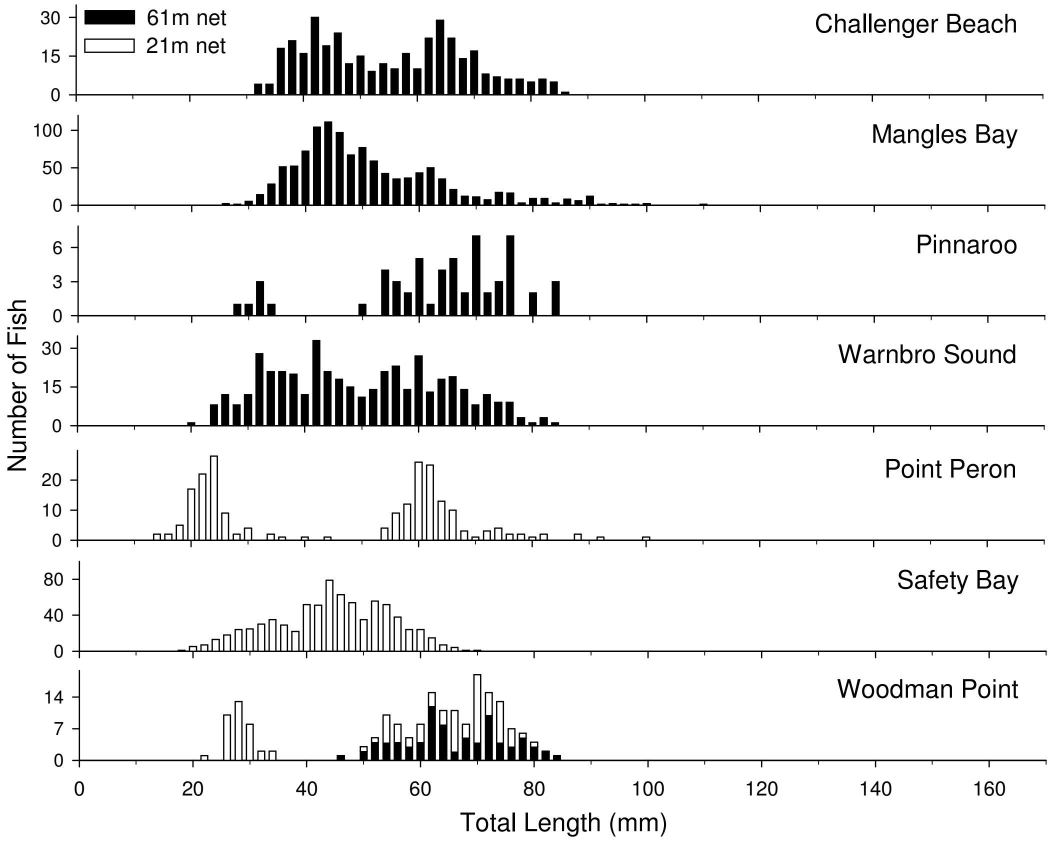


Figure 5.24. Monthly length frequency distributions of *Hyperlophus vittatus* at Koombana Bay, summed from all samples taken 1993 to 2008.

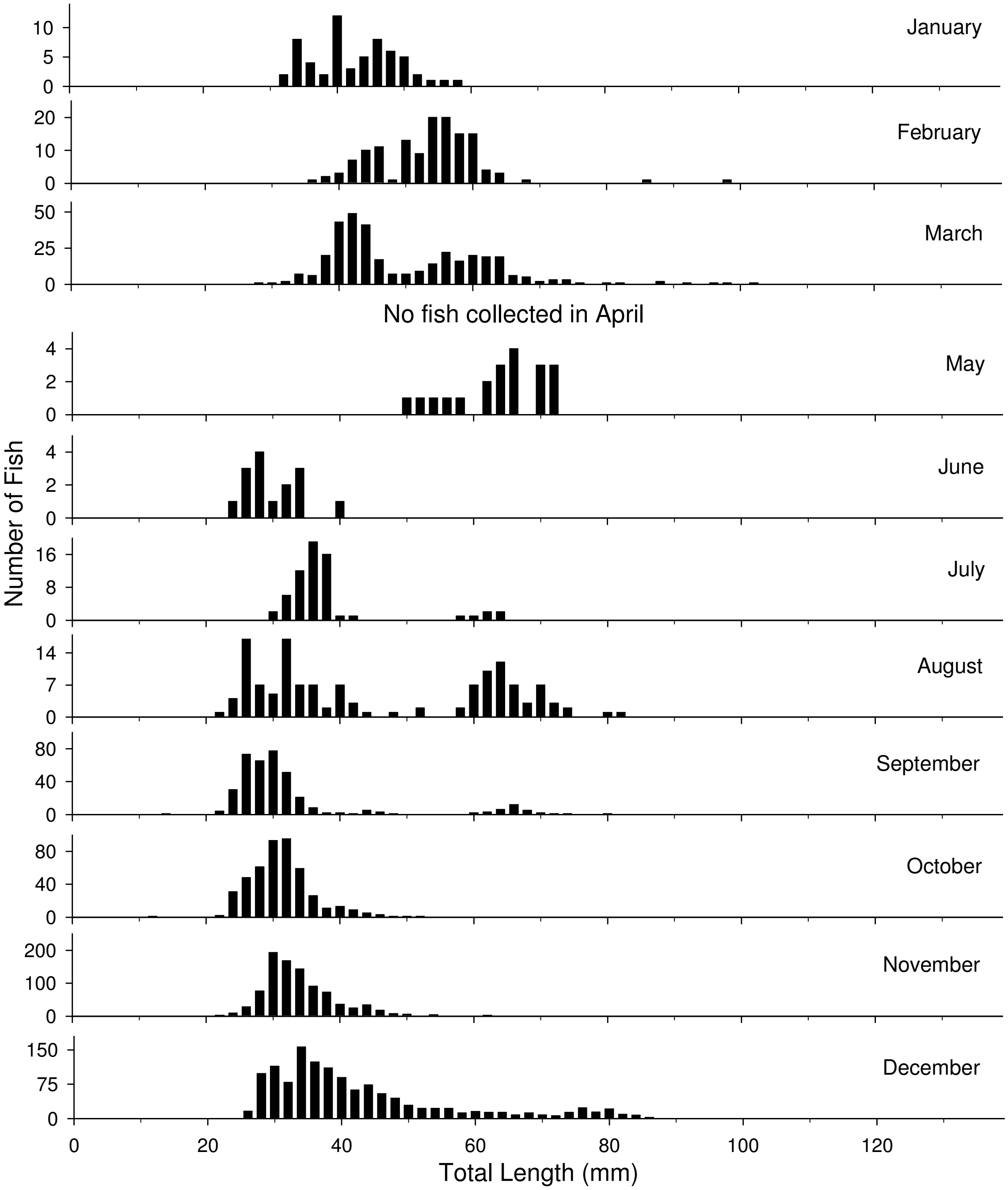


Figure 5.25. Monthly length frequency distributions of *Hyperlophus vittatus* at Pinnaroo, summed from all samples taken 1993 to 2008.

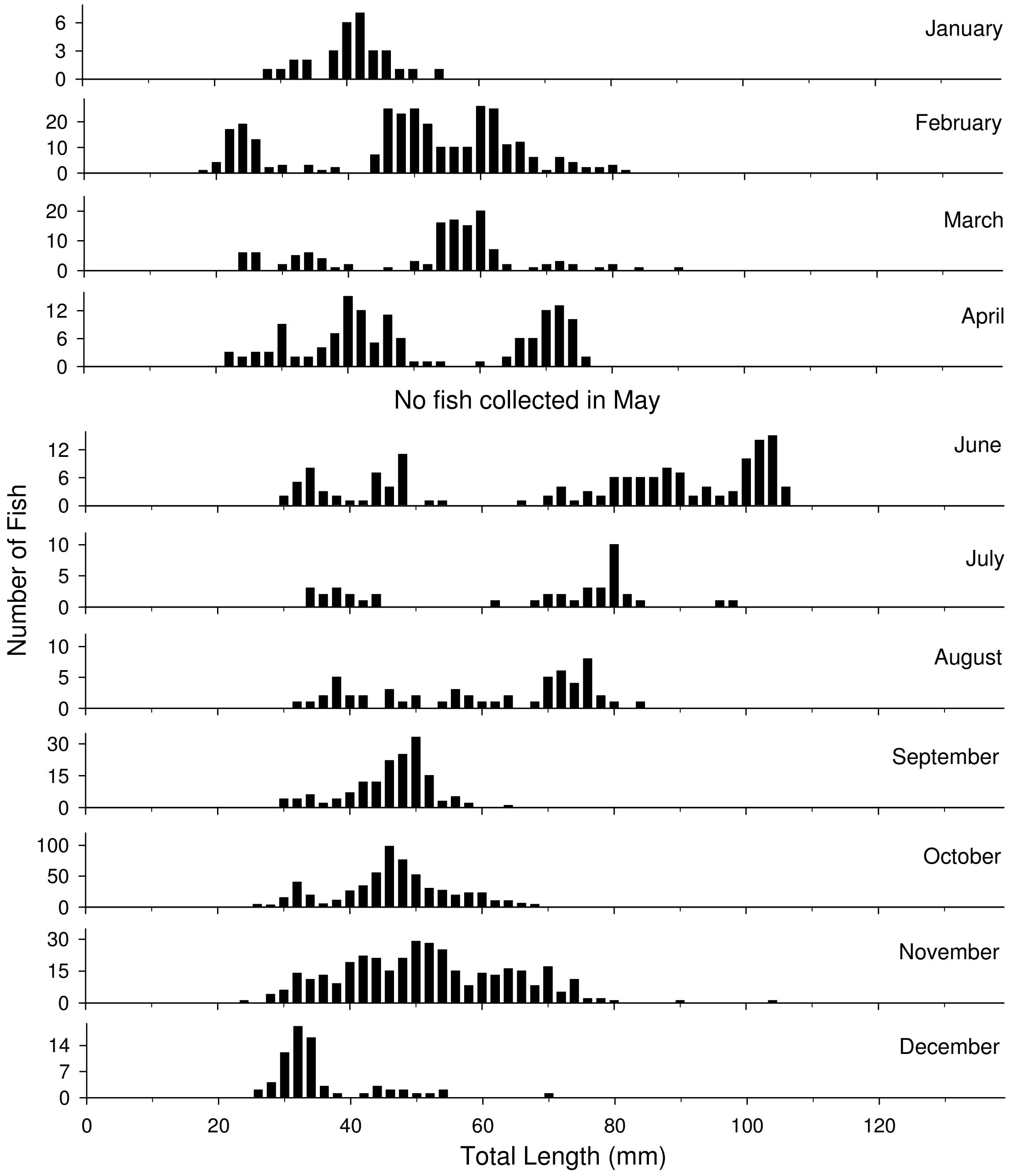


Figure 5.26. Monthly length frequency distributions of *Hyperlophus vittatus* at Warnbro Sound, summed from all samples taken 1993 to 2008.

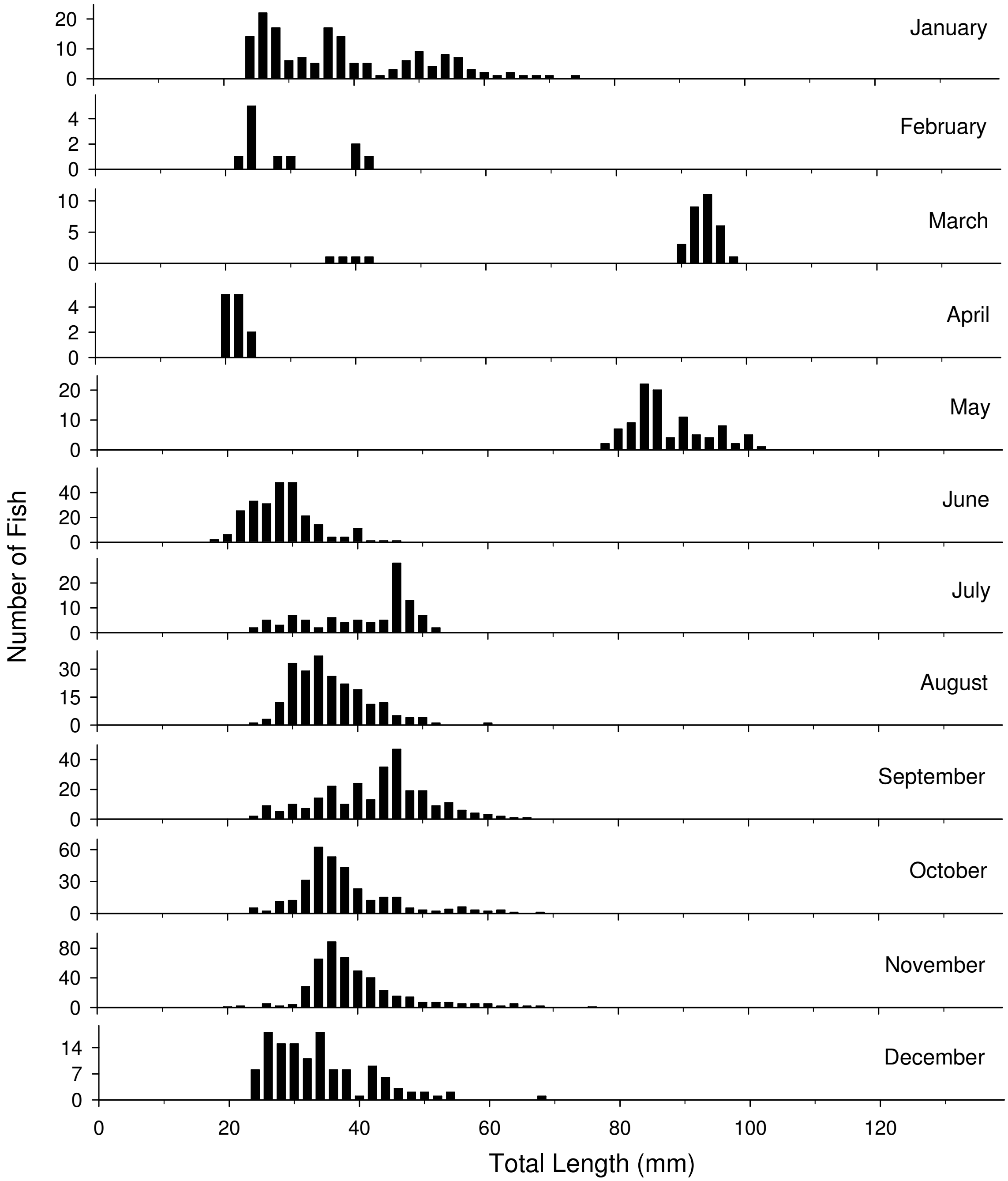


Figure 5.27a-d. Mean monthly catch rates (fish per haul) of *Hyperlophus vittatus* <40 mm at **a)** Pinnaroo, **b)** Mangles Bay, **c)** Warnbro Sound and **d)** Koombana Bay, from 1993 to 2008 (blank – no sample taken).

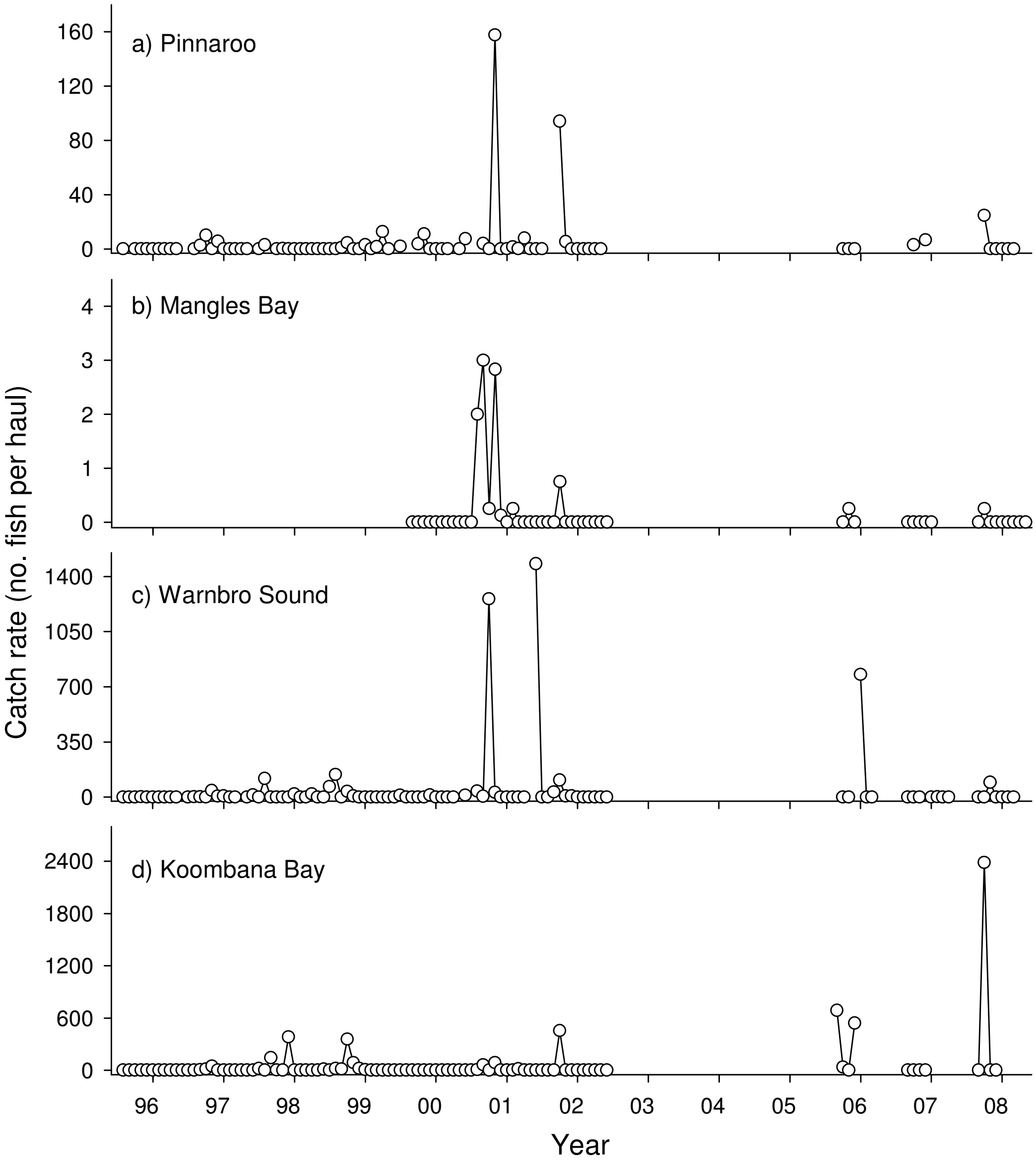


Figure 5.28. Length frequency distributions of *Hyperlophus vittatus* at sites in the Perth region, summed from all samples taken 1993 to 2008.

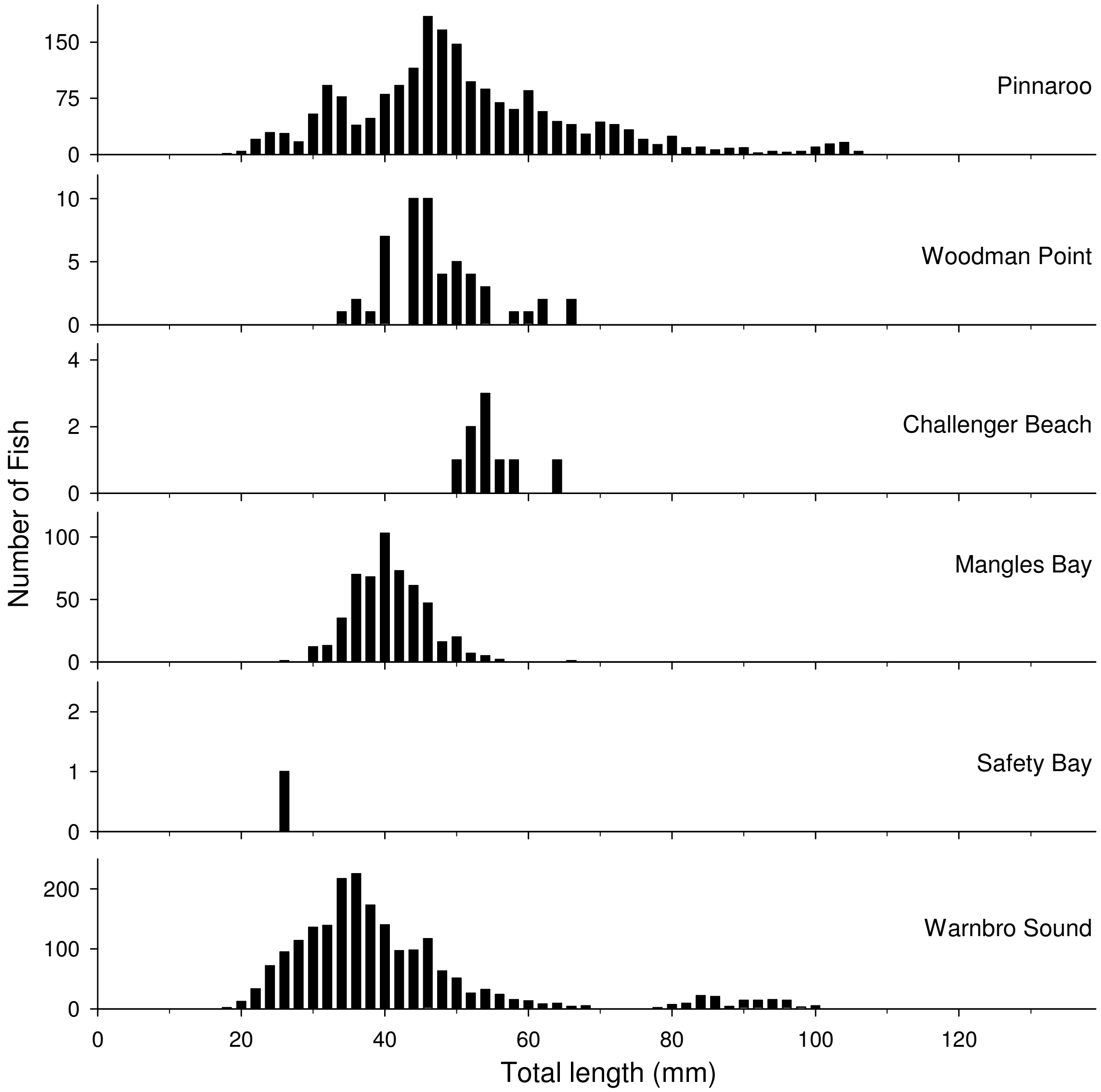


Figure 5.29. Monthly length frequency distributions of *Spratelloides robustus* in the West region, summed from all samples taken 1993 to 2008.

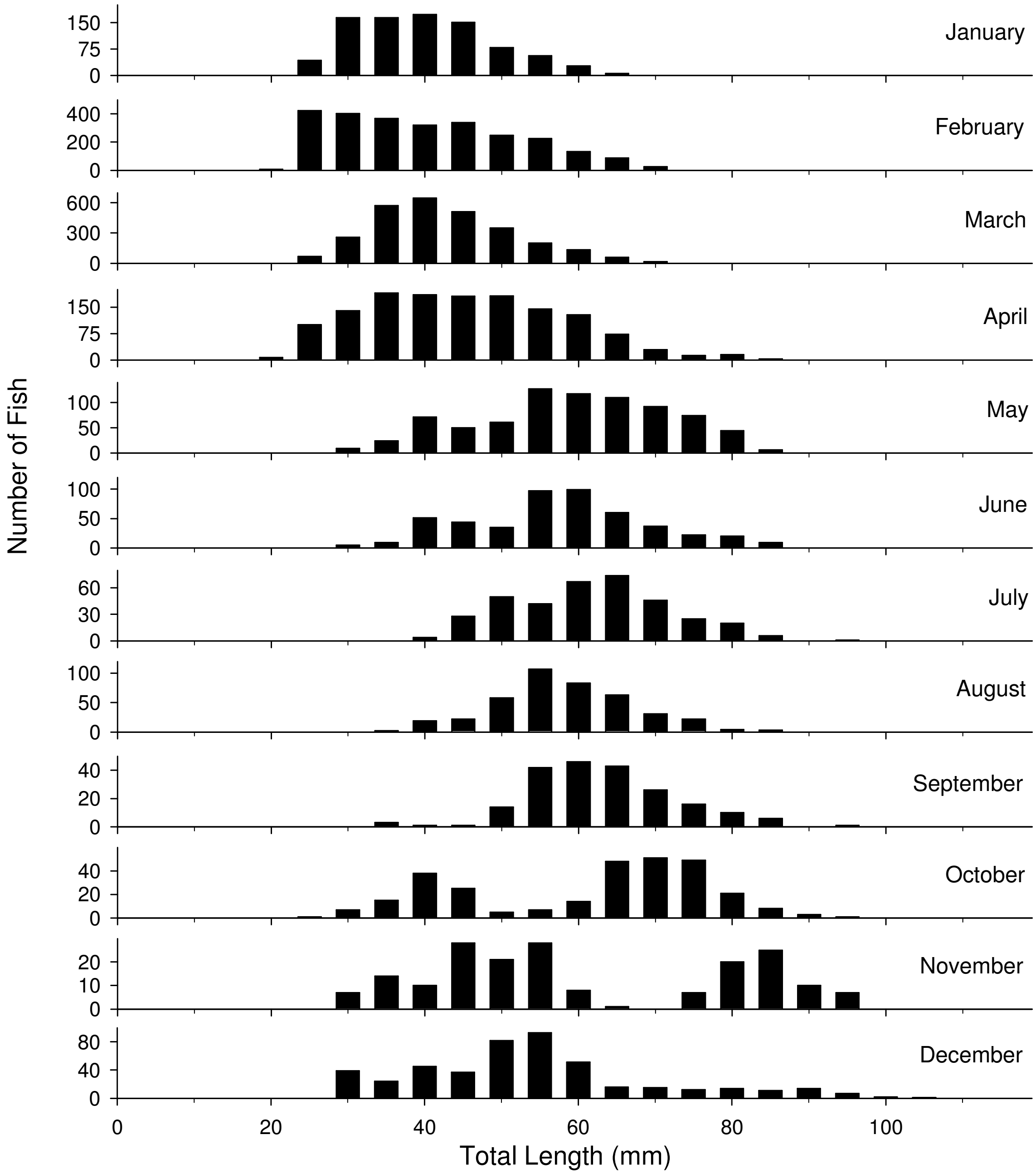


Figure 5.30. Monthly length frequency distributions of *Spratelloides robustus* in the South and South East regions, summed from all samples taken 1993 to 2008.

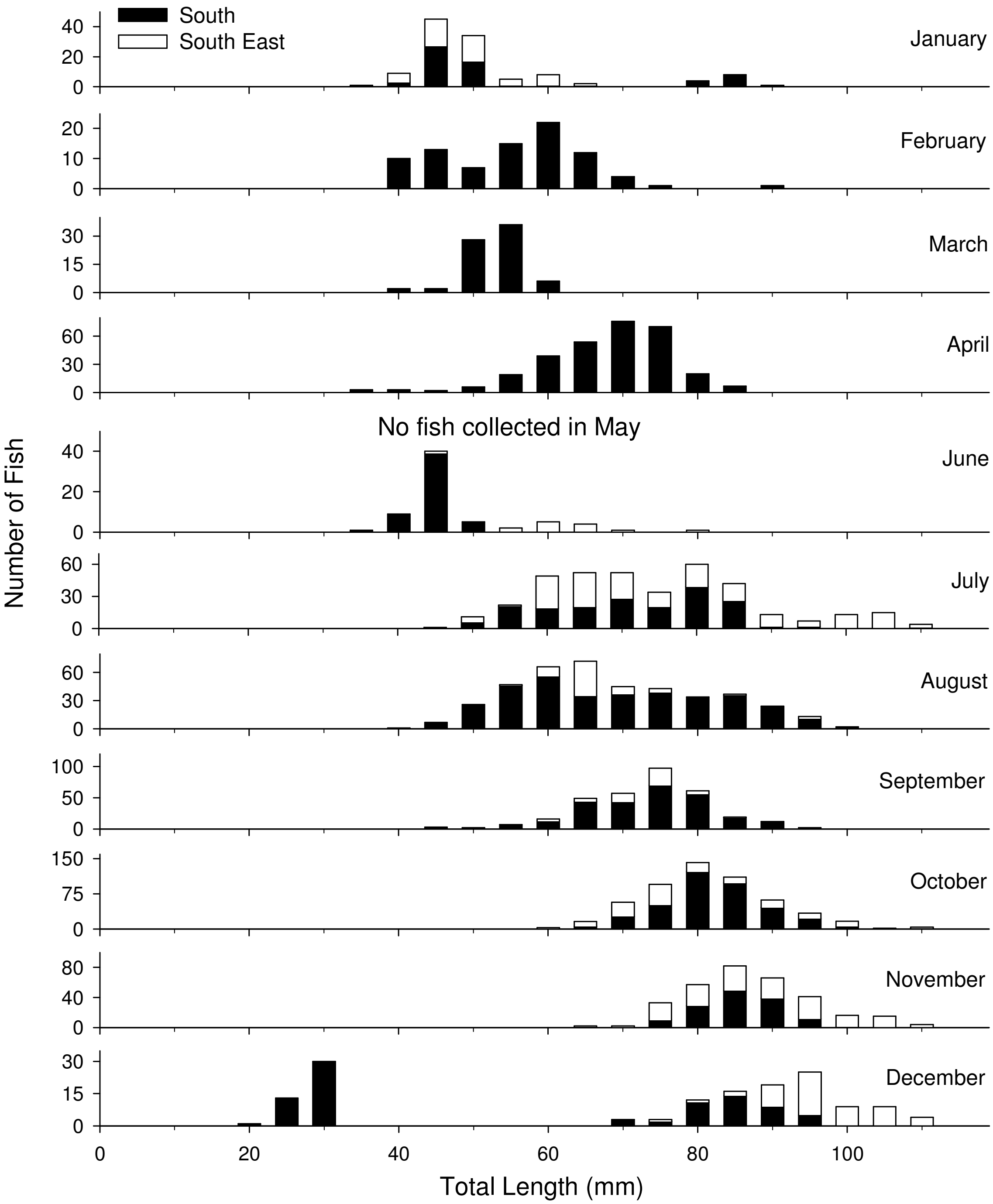


Figure 5.31. Mean monthly catch rates (fish per haul) of *Spratelloides robustus* <40 mm TL at **a)** Pinnaroo and **b)** Warnbro Sound, and <70 mm TL at **c)** Emu Point and **d)** Poison Creek, from 1993 to 2008.

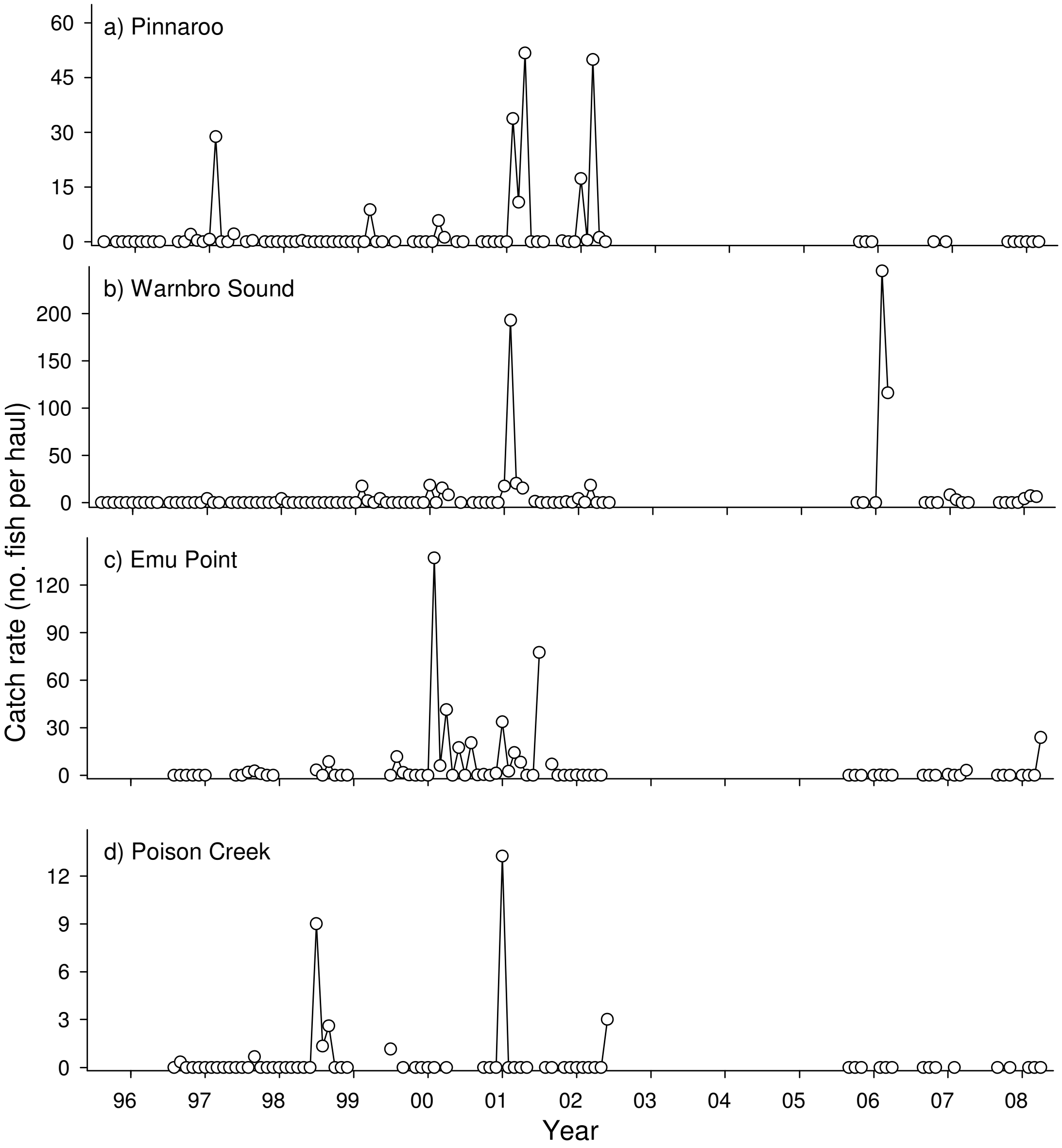


Figure 5.32. Length frequency distributions of *Spratelloides robustus* at sites in the Perth region, summed from all samples taken 1993 to 2008.

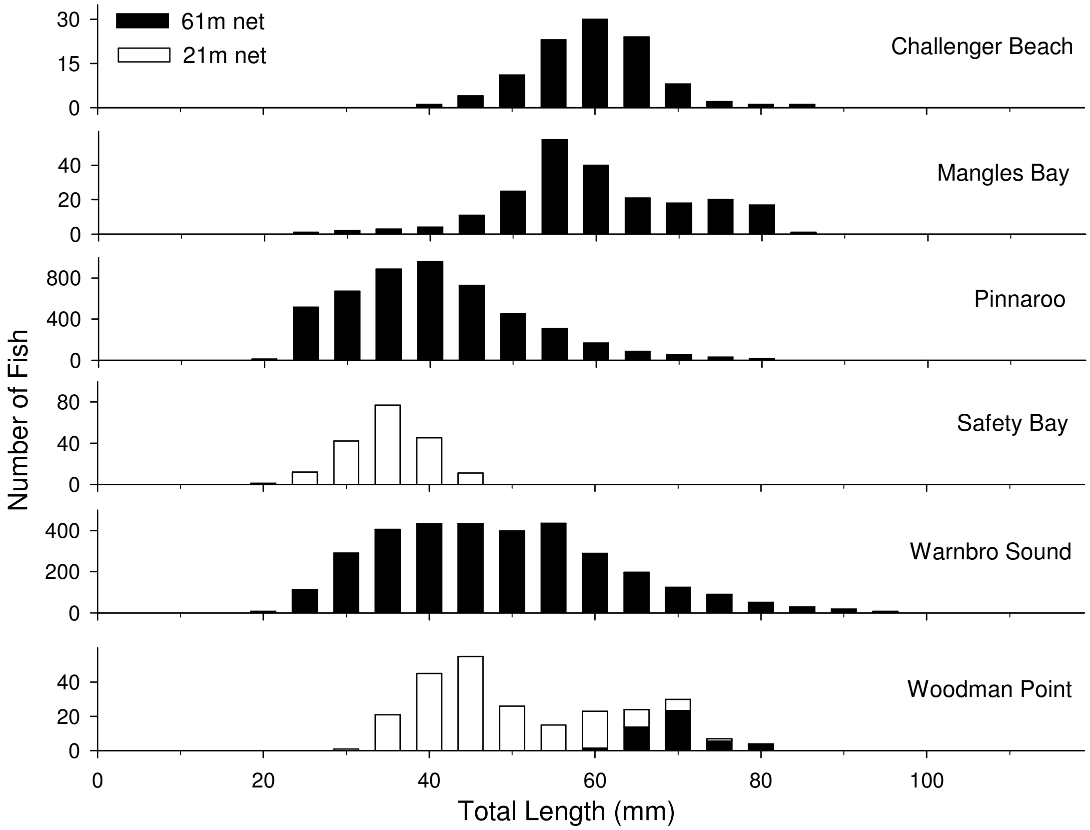


Figure 5.33. Monthly length frequency distributions of *Hyporhamphus melanochir* in the West region, summed from all samples taken 1993 to 2008.

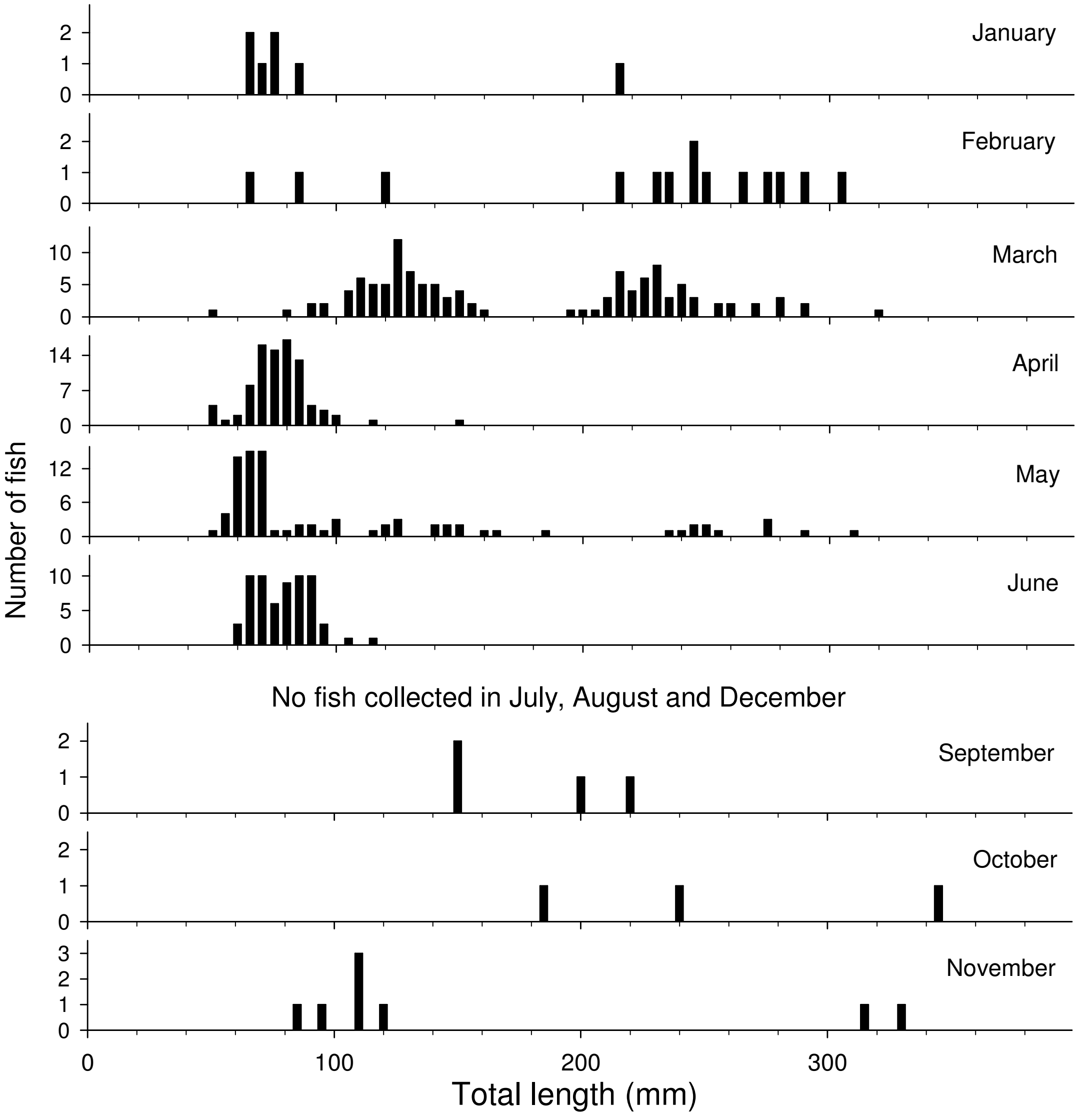


Figure 5.34. Monthly length frequency distributions of *Hyporhamphus melanochir* at Koombana Bay, summed from all samples taken 1993 to 2008.

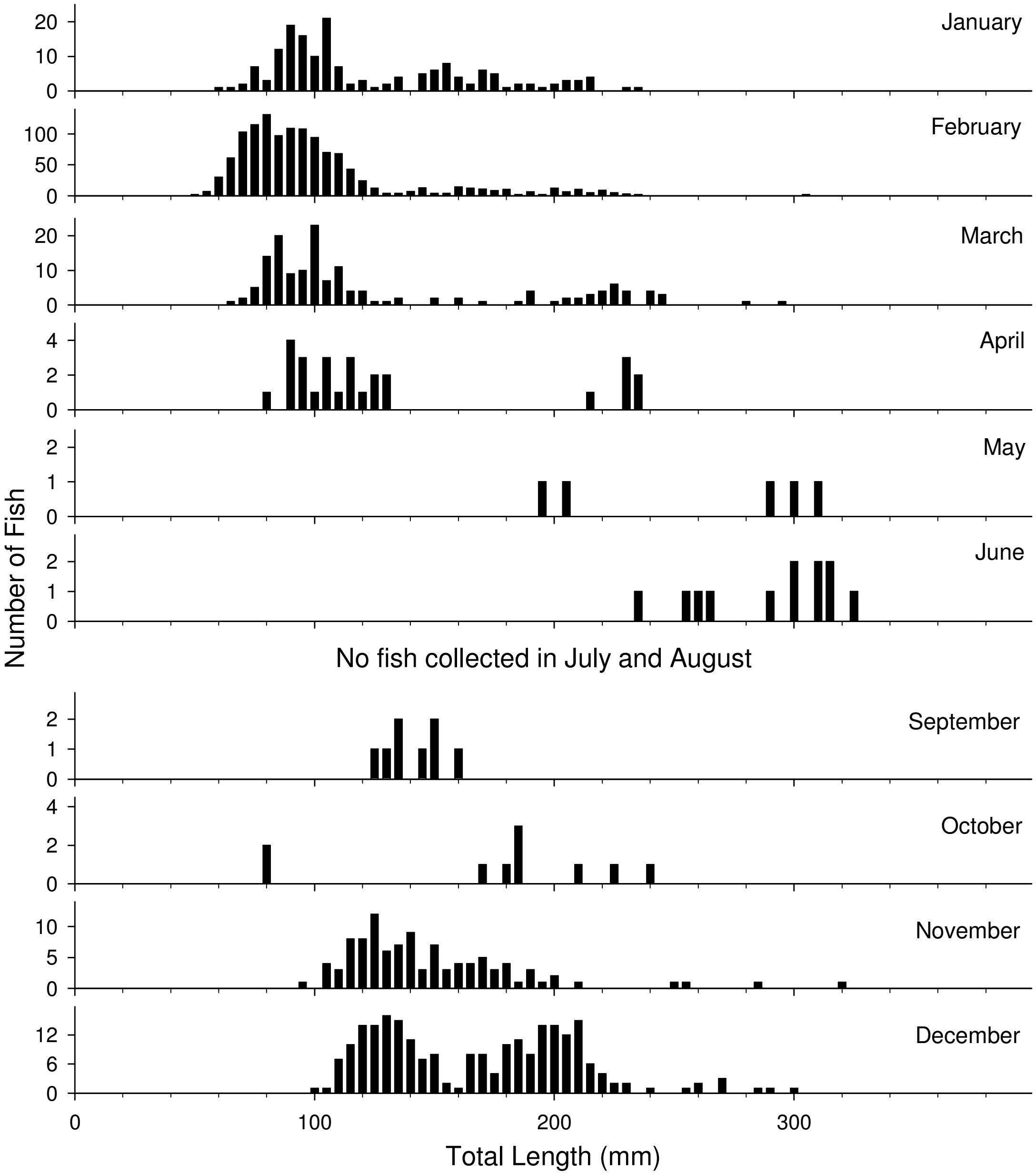


Figure 5.35. Monthly length frequency distributions of *Hyporhamphus melanochir* in the South and South East regions, summed from all samples taken 1993 to 2008.

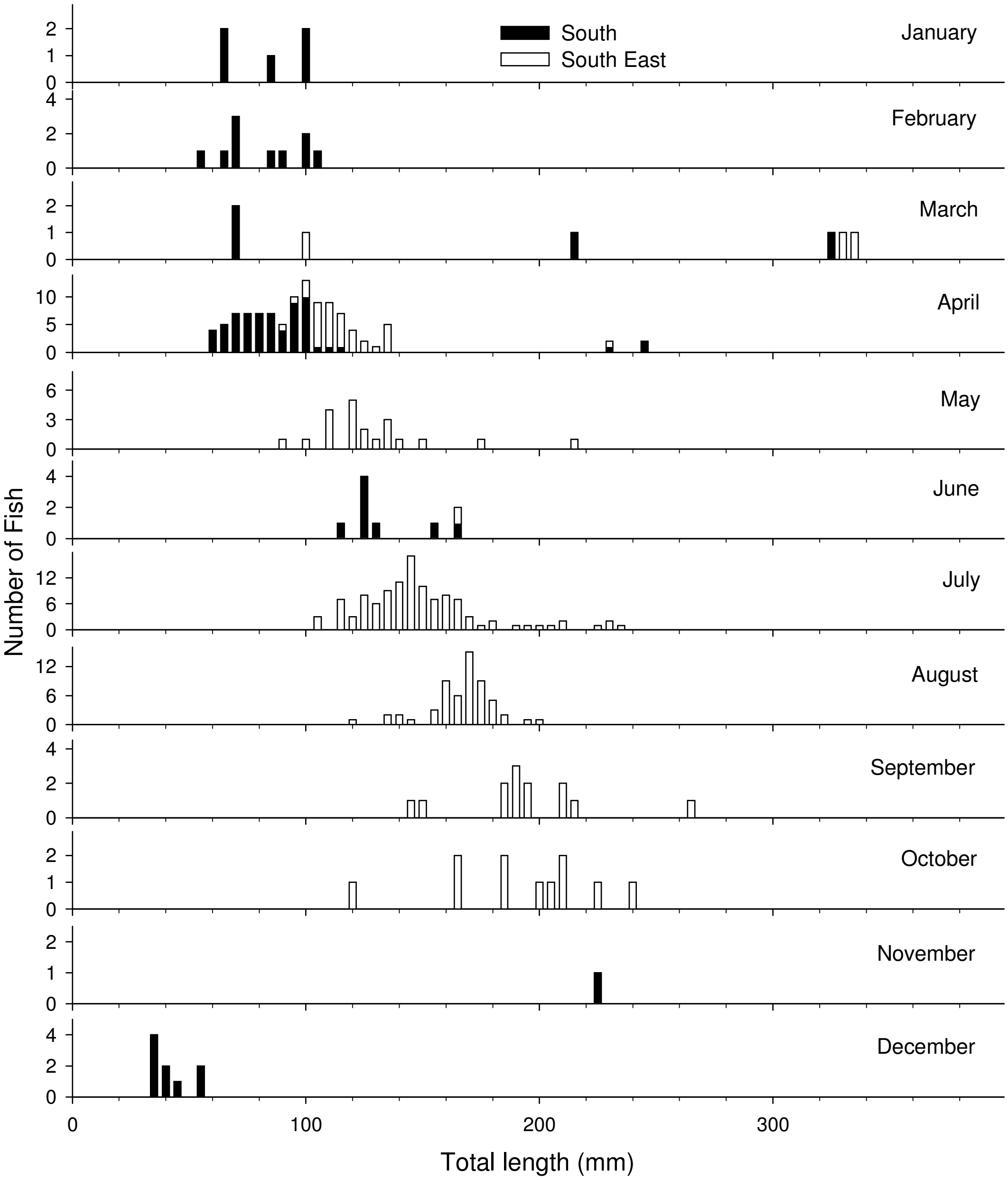


Figure 5.36a-c. Mean monthly catch rates (fish per haul) of *Hyporhamphus melanochir* <100 mm at **a)** Pinnaroo, **b)** Mangles Bay and **c)** Koombana Bay, from 1993 to 2008 (blank – no sample taken).

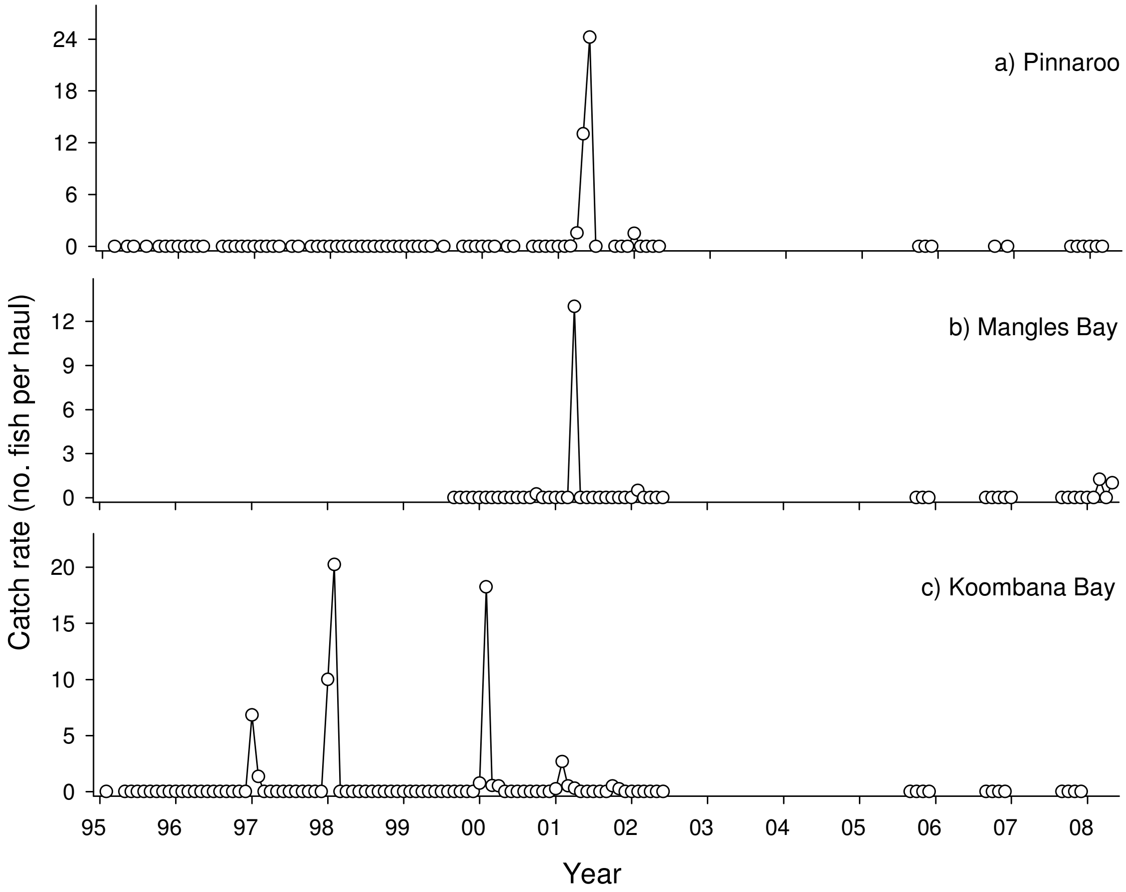


Figure 5.37. Length frequency distributions of *Hyporhamphus melanochir* at sites in the Perth region, summed from all samples taken 1993 to 2008.

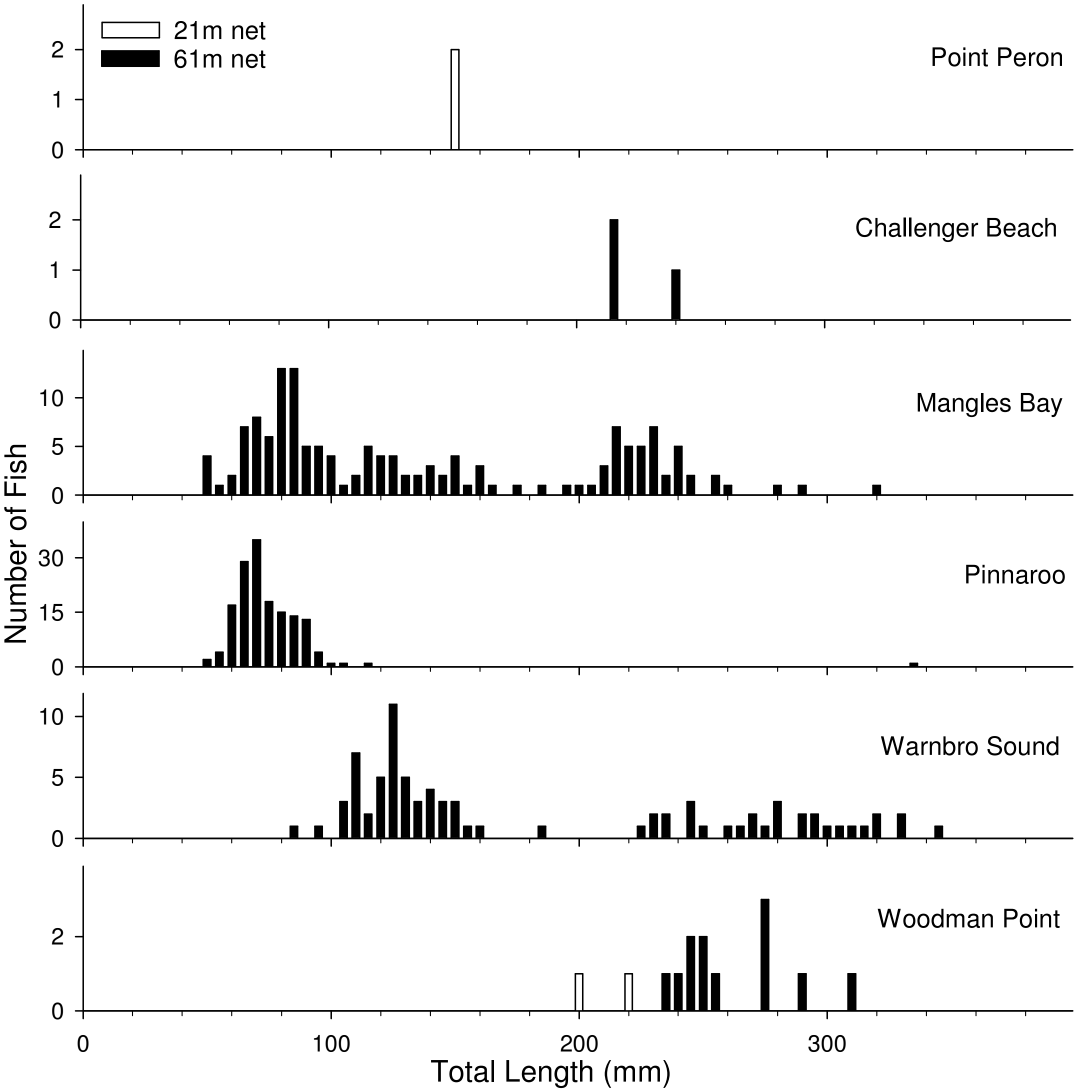


Figure 5.38. Monthly length frequency distributions of *Pomatomus saltatrix* at Pinnaroo and Koombana Bay, summed from all samples taken 1993 to 2008.

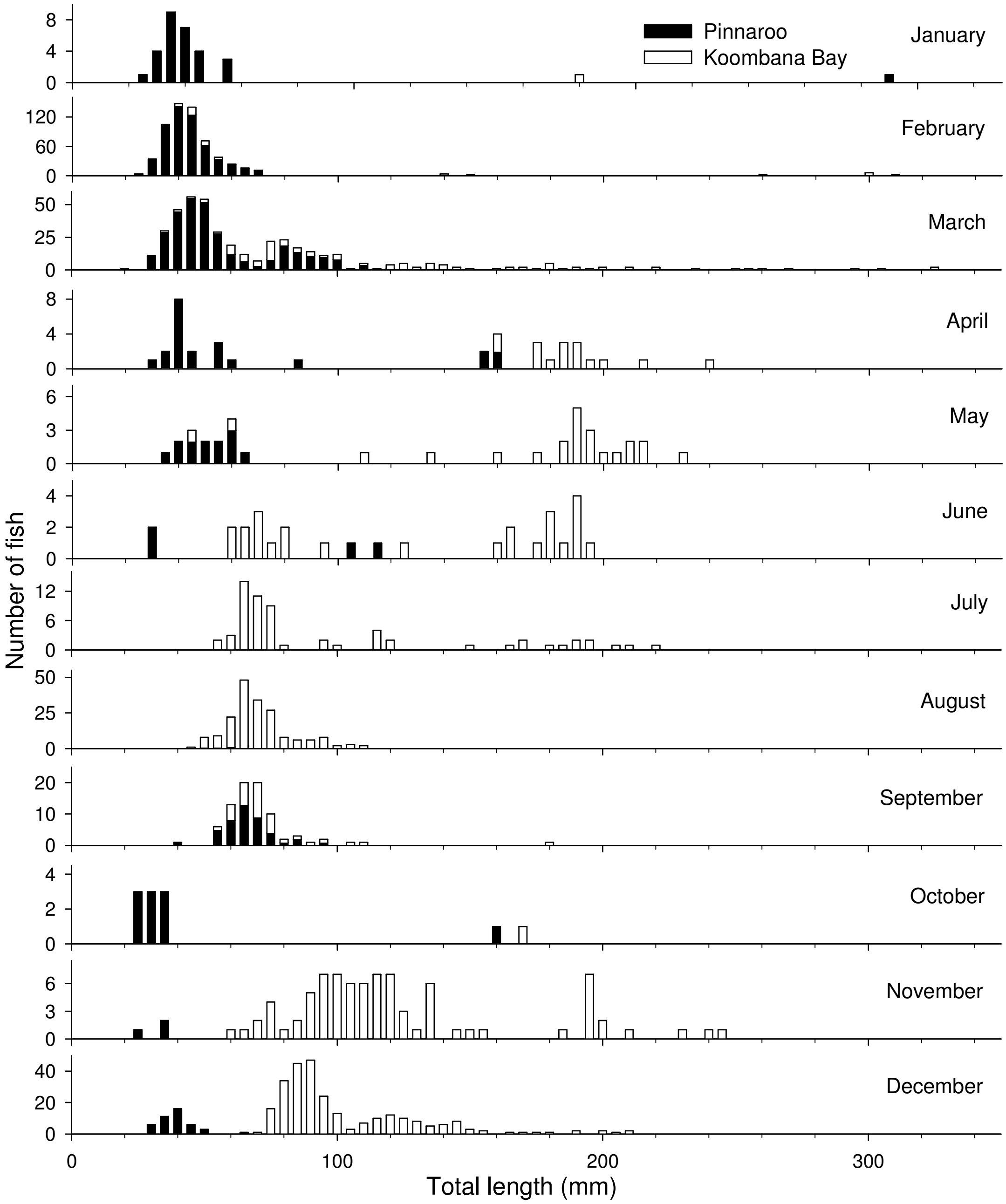


Figure 5.39a-b. Mean monthly catch rates (fish per haul) of *Pomatomus saltatrix* <100 mm at **a)** Koombana Bay and **b)** Pinnaroo, from 1993 to 2008 (blank – no sample taken).

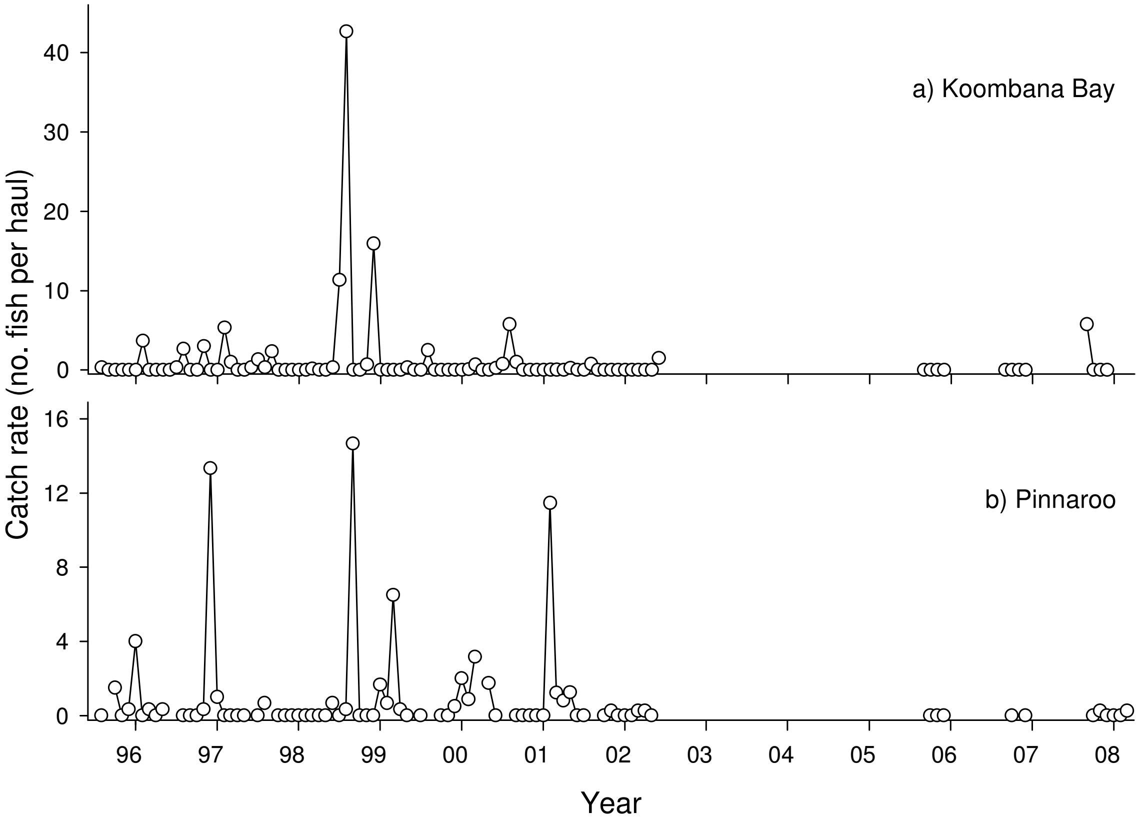


Figure 5.40. Length frequency distributions of *Pomatomus saltatrix* at sites in the Perth region, summed from all samples taken 1993 to 2008.