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Status of southern garfish (*Hyporhamphus melanochir*) in Cockburn Sound, Western Australia

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Executive Summary

The status of the *Hyporhamphus melanochir* (southern garfish) stock in Cockburn Sound was assessed using a 'weight-of-evidence' approach. Cockburn Sound hosts the main commercial and recreational fisheries for this species in Western Australia (WA). The assessment incorporated all available information, including historical (1998-1999) and current (2010-2011) fishing mortality rates, yield per recruit, spawning biomass per recruit (i.e. spawning potential ratio (*SPR)*), historical and current catch composition (age/length/sex), long term catch and catch rate trends, and biological characteristics of the species.

Summary of biological and ecological information

H. melanochir is a temperate fish species that is harvested commercially and recreationally in nearshore and estuarine waters of the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) of WA, and in South Australia, Victoria and Tasmania. The maximum reported total length and age of *H. melanochir* are 49 cm and 10 years, respectively. Although this species grows rapidly and attains maturity at a relatively young age (~1 year), it has certain biological traits that make it inherently vulnerable to overfishing (i.e. small breeding stock sizes, low dispersal rate, low fecundity, and dependency on seagrass habitat).

Summary of weight-of-evidence assessment

The catch and catch rate trends in both sectors (commercial and recreational) suggest Cockburn Sound stock abundance has been declining gradually since the late 1990s and more rapidly after 2011. The decline is likely to be the result of the 'marine heatwave' event in 2011. The decline in *H. melanochir* abundance since the late 1990s, as indicated by catch rate trends, is consistent with other biological indicators (age structure, mortality rate estimates, per recruit analyses) that suggest declining stock status over the same period.

Commercial landings of *H. melanochir* in Cockburn Sound were sampled from mid-2009 to mid-2012 (the current study) and in 1998-1999 (a previous study). Recreational landings were also sampled in 2009-2012, with most data collected for this sector in 2011. Ages ranged from 0+ to 5+ years in 1998-1999 and from 0+ to 4+ years in 2009-2012. Between these periods, the modal age declined from 2+ to 1+ years, and the proportion of fish aged >2 years fell from 30% to less than 5%. The average length also declined between periods. Considering the maximum reported age of 10 years for *H. melanochir*, the age structure of the Cockburn Sound stock in 2009-2012 was heavily truncated.

The 2009-2012 age structure data revealed that the Cockburn Sound fisheries are currently strongly recruitment-dependent. *H. melanochir* recruit to both commercial and recreational fisheries in summer when aged ~1 year. The 1+ year class then dominates landings until the following summer, when they are replenished by the next 1+ year class. This characteristic makes the fisheries vulnerable to collapse in the event of a single year of poor recruitment. Recruitment failure associated with the unprecedented marine 'heatwave' event in 2011 is a likely explanation for the dramatic decline in catches after this year.

Fishing mortality *(F)* was estimated by two independent methods, using age structure data collected in 2010 and 2011. The majority of age data was collected before, or during, the marine 'heatwave' event in 2011 and so the age structure used to estimate *F* in this assessment was considered to be representative of the stock before any additional impacts of the 'heatwave'. The estimates of *F* in 2010-2011 were well above the limit reference point for *F*. The 95% confidence levels for *F* were entirely above the limit reference point. Fishing mortality in 2010-2011 was more than double that estimated in 1998-1999 for the stock. The values estimated for spawning potential ratio (*SPR*) in 2010-2011 were at or just below (*i.e.* close to breaching) the limit reference point for *SPR*. The current level of *F* on this stock carries a high risk to stock sustainability. Significant reductions in *F* (e.g. catch reductions) are required to reduce the sustainability risk to an acceptable level and to allow stock recovery.

Weight-of-evidence assessment

All lines of evidence are consistent with a high risk to the sustainability of the *H. melanochir* stock in Cockburn Sound at recent (post-2005) levels of catch and effort. The assessment identified that:

i) catch and catch rates are consistent with a large decline in stock abundance since the late 1990s,

ii) the average age and length of the catch has declined since 1998-1999 and current age structure is now truncated,

iii) the fishery is strongly recruitment-dependent (as a result of a truncated age structure) such that it is vulnerable to collapse after a single year of poor recruitment, and

iv) the current rate of fishing mortality is well above the limit reference point.

Future monitoring and assessment

The recreational catch of *H. melanochir* in Cockburn Sound is estimated to be larger than the commercial catch. The majority of recreationally harvested *H. melanochir* in Cockburn Sound (and the wider Perth metropolitan area generally) are taken by shore-based fishers. Thus, monitoring shore-based recreational catches and effort levels is important for effectively managing the impact of fishing on *H. melanochir* in Cockburn Sound. In the absence of cost-effective methods to monitor the total shore-based recreational sector, future stock assessments for *H. melanochir* will be reliant on commercial and/or fishery-independent sampling. In Cockburn Sound, commercial fishery sampling is currently more cost-effective than fishery-independent sampling. Frequent (e.g. every 2 years) age-based assessments of *H. melanochir* in Cockburn Sound are required to assess management actions taken to reduce the risks to sustainability identified for this stock.

1 Introduction

1.1 Background

Nearshore fish species such as southern garfish (*Hyporhamphus melanochir)*, Australian herring (*Arripis georgianus*), tailor (*Pomatomus saltatrix*) and whiting (Sillaginidae) have historically dominated shore-based and inshore boat-based landings by recreational and commercial fisheries in the West Coast Bioregion (WCB) of Western Australia (WA) (i.e. Kalbarri to Augusta, including the Perth Metropolitan Zone).

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

These low-level management approaches were the result of an earlier sustainability risk assignment of 'low' (e.g. Australian herring, sand whiting, yellow-eye mullet, sea mullet, skipjack trevally, southern garfish) or 'medium' (e.g. tailor, King George whiting) to many nearshore species (Prokop 1994). However, there are now many indications that the risk level and the status of the nearshore finfish resource within the WCB should be reviewed (Smith *et al.* 2013a, 2013b, Brown *et al.* 2014).

Serious concerns about the status of nearshore finfish resources within the WCB were raised in the late 2000s. At this time, declining trends in the catches and/or catch rates of Australian herring, garfish and tailor were evident, suggesting a decline in abundance of these popular fishery species. Results from a boat-based recreational fishing survey in 2005/06 revealed substantial declines in the annual catches of Australian herring (21% decline) and tailor (80% decline) since an earlier survey using similar methods in 1996/97 (Sumner *et al.* 2008). Concerns about the sustainability of nearshore species further increased in 2009 when management changes were introduced to ensure the ongoing sustainability of inshore demersal stocks. These measures, including an annual two-month closure to recreational fishing for demersal species, were designed to achieve a 50% reduction in catch by all sectors (Wise *et al.* 2007, Department of Fisheries 2008). In taking this action, it was recognised by the Department that an effort shift, with more recreational fishers targeting nearshore fish during the closed demersal season, was likely (Fisher *et al.* 2014). The increased targeting of nearshore fish would be additional to any increase due to the continuing human population growth in the Perth area and WA in general.

Concerns about the status of WCB nearshore finfish, especially Australian herring and tailor, from evidence of declining fishery catches and declining recruitment, combined with the likelihood of increased targeting within the WCB, highlighted the need for greater detail and precision of assessments to ensure the ongoing sustainable management of the nearshore finfish resource. In 2009 the Department of Fisheries gained funding from the WA Natural Resource Management (WANRM) to assess the status of Australian herring and tailor stocks, and provide preliminary assessments of the status of southern garfish and various whiting stocks in the WCB (and in the SCB where these species also occur). The WANRM-funded project was conducted from 2009/10 to 2012/13.

This document describes the assessment of the status of southern garfish in the WCB and SCB, and is the final report arising from the WANRM-funded project. Results of the assessments of Australian herring, tailor and whiting stocks have been previously published (Smith *et al.* 2013a, 2013b, Brown *et al.* 2014).

1.2 Resource assessment framework – finfish suites and indicator species

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

Within each Bioregion of WA, finfish resources are assigned to one of five ecological suites: estuarine, nearshore, inshore demersal, offshore demersal or pelagic. Indicator species for each suite have been identified using a risk-based approach, based on the vulnerability of the species/stock to fishing, as well as social, economic and cultural values (Department of Fisheries 2011). The collective status of the indicator species is used to indicate the status of an entire finfish suite. The following indicators have been selected to represent the nearshore finfish resources of the WCB: Australian herring, tailor, southern garfish, whitebait (*Hyperlophus vittatus*) and southern school whiting (*Sillago bassensis*).

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

The use of indicator species to manage the sustainability of an entire suite will vary in its application, depending on the characteristics of the suite. In the WCB, a precautionary management approach has been applied to demersal finfish resources whereby the indicator species with the poorest status determined the status of the entire inshore demersal suite (Wise *et al.* 2007). In the GCB, a more spatially explicit management approach to demersal finfish resources has been taken (Marriott *et al*. 2012). Due to the wide range of species with varying biological traits in the nearshore finfish suite of the WCB, and the diverse range of fisheries that target them, a spatially explicit management approach may also be appropriate.

1.3 Weight of evidence assessment

For all fisheries, a 'weight-of-evidence' approach to assess stock status is now considered to be best practice (Wise *et al.* 2007, Marriott *et al*. 2012). This approach increases the robustness of the assessment by considering all sources of data, thereby reducing uncertainty.

The weight-of-evidence approach allows all available biological, fishery-dependent and fishery-independent data to be considered, such as trends in catch, catch rate and recruitment, and other relevant biological, ecological and anthropogenic data (Wise *et al.* 2007, Marriott *et al*. 2012). This approach develops indicators that allow the performance of a stock to be assessed relative to management reference points. A range of management outcomes are possible - from broad, precautionary actions to very specific actions - depending on the precision of, and level of risk associated with, the estimate(s) of stock status and the inherent vulnerability of the species involved.

For the nearshore indicator species of the WCB, current data limitations prevent the development of integrated stock assessment models that could reliably estimate spawning stock biomass. However, a substantial amount of biological and fishery information is available for each stock and, using a weight-of-evidence approach, all of this information can be considered in each stock assessment.

The quanitative measures of stock status employed in a weight-of-evidence approach may be derived from one or more types of assessment. The Department considers five levels of assessment, which increase in the intensity of monitoring and complexity of analyses, from simple analyses of catch at the low end to complex integrated model assessments employing multiple data sources at the other end. The types of monitoring associated with each assessment level are:

Level 1: Catch data only.

Level 2: Level 1, plus fishery dependent effort data.

Level 3: Level 1 and/or 2, plus fishery dependent biological sampling of landed catch (e.g. average size, fishing mortality, etc estimated from representative samples).

Level 4: Level 1, 2 or 3, plus fishery-independent surveys of relative abundance, exploitation rate, recruitment or standardised fishery-dependent relative abundance data.

Level 5: Levels 1 to 3, and/or 4 integrated within a simulation, stock assessment model.

1.4 Objectives

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

Assessments of other nearshore indicator species (Australian herring, tailor and whiting) were presented in earlier reports (Smith *et al.* 2013a, 2013b, Brown *et al.* 2014). In this report, a Level 3 'weight-of-evidence' assessment of the status of the southern garfish stock in Cockburn Sound, which hosts the main Western Australian fishery for this species, is presented. A brief description of the other (smaller) WCB and SCB fisheries which capture southern garfish is also given.

Specific objectives:

- Determine catch and catch rate trends from commercial and recreational fishery data.
- Review, and estimate where required, key biological parameters (growth, reproduction, natural mortality) required to assess inherent vulnerability of key stocks including Cockburn Sound.
- Develop methods for collecting representative age samples in order to generate robust estimates of fishing mortality for the Cockburn Sound stock.
- Develop ageing methodologies
- Estimate fishing mortality for the Cockburn Sound stock and compare the current level with that estimatedfrom historical data sets (where available) to determine if the current status is unique or has occurred in the past.
- Recommend an ongoing monitoring regime for assessment of the Cockburn Sound

2 Biological synopsis

This section summarises the known biological characteristics of *Hyporhamphus melanochir* in Western Australia (WA). Information about the biology of this species in other regions is also provided for comparison. This section includes previously published information, plus the latest findings described in other sections of this report.

The biological parameters summarised in this section represent critical information required for a Level 3 (or higher) assessment of a *H. melanochir* stock. As described below, there is now a good understanding of the biological parameters for the Cockburn Sound stock (WA's largest *H. melanochir* fishery), and this achievement has enabled a Level 3 assessment of this stock (Section 7). The information about *H. melanochir* in Wilson Inlet (WA's second largest *H. melanochir* fishery) is still incomplete. Additional biological monitoring would be required to fill current knowledge gaps to enable a future Level 3 assessment of this stock.

2.1 Taxonomy

Subphylum - CEPHALOCHORDATA

Class - ACTINOPTERYGII

Order - BELONIFORMES

Family - HEMIRAMPHIDAE

Genus – *HYPORHAMPHUS*

The genus *Hyporhamphus* has a tropical/warm temperate circumglobal distribution. It contains 34 species, 8 within Australia (Gomon *et al.* 2008).

2.2 Garfish species in Western Australia

Eighteen species of garfish (family: Hemiramphidae) occur in Australia, with 11 of these occurring in WA (Collette 1974) (Table 2.1).

In the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) of WA, *Hyporhamphus melanochir* is the most common garfish species in commercial and recreational fishery landings, with small quantities of *Hemiramphus robustus* and *Hemiramphus regularis* also taken. In the northern areas (Gascoyne Coast Bioregion and North Coast Bioregion), the species composition of fishery landings is not well understood. The Shark Bay Beach Seine and Mesh Net Managed Fishery is the main commercial fishery for garfish in northern Bioregions. Limited monitoring of the catch suggests that the main species taken by this fishery are *Hemiramphus robustus* and *Hemiramphus quoyi* (Department of Fisheries, unpubl. data).

2.3 Distribution, habitat and diet

Hyporhamphus melanochir is distributed across southern Australia from Eden (southern NSW) to Lancelin (WA), including Tasmania (Gomon *et al.* 2008). It is a schooling species that occurs in shallow, coastal waters (<20 m) and is typically found near seagrass beds (Kailola *et al.* 1993). In WA, juveniles and adults also occur in the lower parts of estuarine basins but their distribution rarely extends into upper estuaries or rivers. *H. melanochir* is essentially a marine species that opportunistically uses the saline reaches of estuaries.

H. melanochir has a complex feeding pattern. Juveniles and adults can occur near the bottom or at the surface, depending on food availability. In South Australia (SA), *H. melanochir* have been observed to consume seagrass fronds during daylight but shift to consuming emergent benthic crustaceans, particularly amphipods, at night (Klumpp and Nichols 1983, Robertson and Klumpp 1983, Earl *et al.* 2011). It is likely that *H. melanochir* feeds preferentially on small crustaceans, which are more nutritious than seagrass, when these are available in the water column. Garfishes (Hemiramphidae) are one of only a few fish species known to include large quantities of seagrass in their diet (de los Santos 2012).

H. melanochir is considered ‘seagrass-dependent’ because seagrass forms a significant part of the diet of adults and their eggs (which are filamentous) require attachment to seagrass or macroalgae for successful development (see ‘Eggs and larvae’ below).

In Western Australia, the two main commercial fisheries for *H. melanochir* (in Cockburn Sound and Wilson Inlet) are located in areas of high seagrass biomass.

2.4 Stock structure

Given their shallow coastal distribution and limited potential for dispersal (due to biological characteristics described below), *H. melanochir* population structuring across the species range is likely to approximate a ‘stepping stone’ model (Kimura and Weiss 1964), where adjacent groups are more likely to exchange genes and be most similar, compared to more distant groups. Meristic and morphological characteristics across the species range (from southern WA to southern NSW) show a gradation/cline which is consistent with this model (Collette 1974).

Four major genetic groups of *H. melanochir* have been identified across the species range: i) WA waters, ii) ocean waters of western SA, iii) SA gulf waters and Victoria, and iv) Tasmania (Jones et al. 2002). Within WA, no significant genetic differences have been detected between fish on the west coast (sampled in Cockburn Sound) and on the south coast (sampled in Oyster Harbour) (Jones et al. 2002). However, the lack of genetic differentiation within these broad regional groups does not constitute evidence of a single breeding stock in each region because only a few migrants per generation would be required to maintain genetic homogeneity. Indeed, other evidence indicates that *H. melanochir* is characterised by complex population structuring, consisting of multiple, semi-discrete subpopulations within regions.

In SA, differences in otolith chemistry indicate that semi-discrete breeding populations of *H. melanochir* can be separated by distances of <60km (Steer *et al.* 2009a, 2010). These differences are evident in fish up to at least 2 years of age (i.e. until maturity). Minimal rates of egg and larval dispersal and juvenile/adult migration probably contribute to the maintenance of semi-discrete populations at very small spatial scales (Steer *et al.* 2009a, 2010, and see Sections below). It is not clear whether any of these subpopulations share a common source of recruitment, but at least some are thought to be self-sustaining (Steer *et al.* 2009b).

No studies of otolith chemistry have been conducted in WA. However, given the limited potential for dispersal and the evidence of population structuring in SA, it is likely that multiple, semi-discrete breeding stocks of *H. melanochir* occur within each Bioregion in WA. In WA, *H. melanochir* fisheries are mostly located in marine embayments (e.g. Cockburn Sound) or estuaries (e.g. Wilson Inlet). These sites are characterised by extensive areas of seagrass, which provide spawning and feeding habitat and would enable *H. melanochir* to complete its entire life cycle within these areas. Also, the semi-enclosed nature of these sites would encourage the local retention of fish. These factors suggest that each of the main *H. melanochir* fisheries in WA (i.e. Cockburn Sound, SCB ocean waters, Wilson Inlet) should be managed as discrete stocks.

2.5 Morphometrics

The relationships of i) total length versus fork length and ii) total length versus whole body weight were estimated in this study from pooled data collected from the WCB and SCB during 2009-2012 (see Section 3), as follows (also see Fig. 2.1) :

- $FL = (0.9452 \times TL) + 0.1954$ ($r^2 = 0.9978$, $n = 1719$, $p < 0.001$, sexes pooled)
- $W_{male} = 1.7688 \times 10^{-6} \times TL^{3.1458}$ ($r^2 = 0.9758$, $n = 1070$, $p < 0.001$)
- $W_{fem} = 1.6769 \times 10^{-6} \times TL^{3.1422}$ ($r^2 = 0.9687$, $n = 748$, $p < 0.001$)
- $W_{both} = 5.2724 \times 10^{-7} \times TL^{3.3520}$ ($r^2 = 0.9786$, $n = 1683$, $p < 0.001$)

where TL = total length in mm, FL = fork length in mm, W_{fem} = female whole body weight (in grams), W_{male} = male whole body weight, W_{both} = whole body weight (male and females pooled). Lengths are measured from the tip of the upper jaw.

Other studies have reported the size of *H. melanochir* in standard length (SL, in mm). This measurement is related to total length (TL) as follows :

$TL = 1.1423 \times SL + 0.7732$ ($r^2 = 0.995$, $n = 388$) (Jones *et al.* 2002)

2.6 Eggs and larvae

H. melanochir lays demersal eggs that are attached to seagrass or other aquatic macrophytes via filaments on the egg (Jordan *et al.* 1998, Jones *et al.* 2002). Ripe ova are transparent, filamentous and relatively large (up to 3 mm in diameter). Attachment to vegetation appears to be essential for egg survival (Jordan *et al.* 1998). Due to this demersal habit, there is typically no dispersal during the egg stage.

An egg incubation period of 10-15 days has been estimated for *H. melanochir* in water temperatures of 20-26 °C (in SA) and 29 days in temperatures of 15-25 °C (in Tasmania) (Jones *et al.* 2002). *H. melanochir* larvae hatch at an advanced stage (i.e. post-flexion) at a length of ~7 mm. They transform into juveniles at ~20 mm (Noel 2003). Larvae are typically found closely associated with seagrass beds (Jones *et al.* 2002). Post-flexion larvae possess moderately developed fins and can potentially maintain their position in the vicinity of the spawning area. Thus, minimal dispersal from the spawning site is likely to occur during the larval stage. Limited dispersal could be advantageous, given the dependence on aquatic vegetation for food and reproduction at juvenile and adult stages. Due to the limited dispersal of eggs and larvae, it is likely that small juveniles recruiting to inshore nursery areas are mostly derived from local spawning.

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 coastal, and previous surveys of fish larvae in WA have predominantly sampled sub-surface and/or offshore waters. During May 2005, sampling of ichthyoplankton at 65 sites along a cross-shelf transect (bottom depths 10-500 m) off Perth found *H. melanochir* larvae at the surface (0-1 m depth) but not immediately below the surface (~2 m depth). Larvae were restricted to waters in which the bottom depths ranged between 10-21 m (DoF, unpubl. data). Lack of observations during plankton surveys may also be partly due to net avoidance – larvae hatch at a late stage, with developed fins and swimming ability, and this may enable them to avoid capture.

It is unclear whether spawning by *H. melanochir* occurs in estuaries of the WCB. No larvae have been captured in the Peel-Harvey Estuary and only a single larva has been taken in the Swan-Canning Estuary (Gaughan *et al.* 1990, Neira *et al.* 1992, Young and Potter 2003). However, *H. melanochir* do appear to spawn in Wilson Inlet (SCB) as larvae have been captured and commercial fishers have reported eggs attached to seagrass within this estuary (Neira *et al.* 1992).

2.7 Fecundity

Hyporhamphus melanochir is a multiple batch spawner with asynchronous spawning over a protracted spawning period (Jones *et al.* 2002). Distinct groups of ova at different developmental stages and sizes are typically present in the ovaries of female *H. melanochir*, suggesting that individual females spawn multiple batches of eggs during the extended spawning season (Jones *et al.* 2002).

Batch fecundities ranging from 93 to 3884 have been reported for *H. melanochir* in the length range 22-40 cm TL (Jones *et al.* 2002). This is a low/medium level of fecundity, compared to other fish species (Patrick *et al.* 2010). Batch fecundity for *H. melanochir* increases with fish size. In past studies, depending on the sample examined, the relationship between batch fecundity and fish size was best described using either a linear, power or exponential curve. For example Jones *et al.* (2002) reported the following relationships at two sites (Tickera, Port Wakefield) in SA:

- $BF = 0.0023 \times SL^{4.021}$ ($r^2 = 0.6374$, $n = 60$, $p < 0.001$, Tickera)
- $BF = 15.84 \times W - 459.50$ ($r^2 = 0.7433$, $n = 60$, $p < 0.001$, Tickera)
- $BF = 0.0001 \times SL^{4.962}$ ($r^2 = 0.7268$, $n = 60$, $p < 0.001$, Port Wakefield)
- $\ln(BF) = 1.490 \times \ln(W) + 0.172$ ($r^2 = 0.6675$, $n = 60$, $p < 0.001$, Port Wakefield)

where BF = batch fecundity, SL = standard length in cm, W = ovary-free fish weight in grams.

Jones *et al.* (2002) measured batch fecundity in *H. melanochir* from the SCB of WA and found the following (relatively weak) relationships with body size:

- $BF = 102.30 \times SL - 1773.3$ ($r^2 = 0.2198$, $n = 52$, $p < 0.001$)

- BF = 6.67 x W – 390.05 ($r^2 = 0.1497$, $n = 52$, $p < 0.001$)

Fecundity has not been measured in any *H. melanochir* from the WCB of WA.

2.8 Spawning period

Monthly trends in gonad development (based on macroscopic gonad staging, GSI values and egg diameter distributions) and juvenile recruitment patterns indicate that spawning by *H. melanochir* in WA occurs over an extended period during the warmer months of the year (September-April), but with a peak in activity in spring/early summer (~December) (Jones *et al.* 2002, Section 4). Limited evidence suggests that the spawning period is slightly longer in the WCB than in the SCB (Section 4).

The timing of spawning in the SCB is similar to that observed in SA and Victoria (Jones *et al.* 2002). The spawning period in Tasmania (October to February) appears to be slightly shorter than in other regions, possibly in response to temperature differences. Overall, these patterns suggest a longer spawning period by this species at lower latitudes (or warmer temperatures) (Jones *et al.* 2002).

In some areas, the timing of spawning by *H. melanochir* may be size and/or age-dependent. Jones (1990) reported that larger fish (>27 cm standard length) spawned during spring, whereas smaller fish (<27 cm) spawned in summer in Baird Bay, SA. These smaller fish were mostly aged 2+ years and were spawning for the first time, while the larger fish were mostly 3+ or older and had probably spawned in previous years. In WA, there was no conspicuous difference in spawning times between large and small fish collected during 2009-2012 (Section 4).

2.9 Sex ratio

The sex ratio of *H. melanochir in* fishery landings is typically strongly skewed towards either males or females, depending on season and depth of capture. These variations reflect different behaviours of males and females during the spawning period. At this time, mature females typically form large schools in shallow (<5 m) waters while mature males are more widely dispersed and are found in deeper, offshore waters (Jones *et al.* 2002).

In SA, schooling fish in shallow waters were estimated to comprise 92% females, while non-schooling fish in deeper water comprise 84% males during the reproductive season in November-April (Jones *et al.* 2002). The majority of commercial fishery landings in SA are taken in this period by haul nets, which are deployed in shallow (<5 m) waters. Consequently, commercial fishery landings in SA are strongly dominated by females (Fowler *et al.* 2008). A small proportion of commercial landings in SA are taken by 'dab nets' in deeper, offshore waters and these landings are typically dominated by males. Similarly, *H. melanochir* sampled by gill nets in the deeper waters of Baird Bay, SA, were predominantly male (Jones 1990).

In WA fisheries, the sex ratio of landings also varies according to depth and season. For example, in Cockburn Sound, commercial landings are taken in deeper waters (>5 m). These landings comprise 80-90% males in the spawning period and ~50% males during the non-spawning period (Section 5). In contrast, commercial landings in Wilson Inlet are taken in shallow waters (<5 m). These landings comprise 90-100% females in the spawning period and 50-60% females during the non-spawning period (Jones *et al.* 2002). Since the timing of commercial landings in Cockburn Sound (mainly February-June) and Wilson Inlet (June-October) overlaps with the spawning period, the total annual catch in Cockburn Sound is dominated by males while the total annual catch in Wilson Inlet is dominated by females.

The sex ratio of landings during the non-spawning season is approximately 50:50, suggesting that the sex ratio in each *H. melanochir* population is probably equal.

2.10 Length at maturity

During 2009-2012, the smallest mature male observed in the WCB was 218 mm TL and the smallest mature female was 229 mm TL. In the SCB, the smallest mature male and female was 205 mm and 211 mm TL, respectively.

Within each Bioregion, males and females attained maturity at similar sizes (Section 4). However, individuals attained maturity at a significantly larger size in the SCB. In the WCB, the length at which 50% (L_{50}) and 95% (L_{95}) of individuals attained maturity was estimated to be 228 mm and 279 mm TL, respectively (Table 2.2). In the SCB, the L_{50} and L_{95} were estimated to be 243 mm and 307 mm, respectively.

Previously, an L_{50} of 261 mm TL was estimated for female *H. melanochir* in WA (Jones *et al.* 2002), based on pooled samples of fish collected in 1998-1999 from various locations in the SCB and WCB. However, ~80% of these fish were collected from the SCB (and ~70% from Wilson Inlet) and so this estimate essentially represented the size at maturity in the SCB (Table 7.2).

The L_{50} value for the SCB estimated in 2009-2012 was lower than that estimated in 1998-1999 (243 mm versus 261 mm), suggesting that the average size at which maturity is attained may have declined in this region.

As experienced by numerous other exploited fish stocks around the world (Sharp and Hendry 2009), the length at maturity of *H. melanochir* in SA appears to have declined in response to a high fishing mortality rate. In SA, the L_{50} of 215 mm TL in the 1990s was substantially lower than the L_{50} of 248-259 mm TL (calculated from a reported length of 21-22 cm SL) in the 1950s (Ling 1958, Jones *et al.* 2002). This change was interpreted as a consequence of a significant increase in fishing mortality (Fowler *et al.* 2008). Adding weight to this interpretation is the findings of Jones (1990) who sampled a population of *H. melanochir* in SA in the 1980s that was subject to negligible levels of fishing and observed an L_{50} similar to that observed in the 1950s (i.e. 21-22 cm SL).

2.11 Age at maturity

Previously Jones *et al.* (2002) estimated the age at which 50% of *H. melanochir* attain maturity (A_{50}) in WA. This estimate (A_{50}=19 months) was based on a pooled sample of fish (females only) collected from various locations in the SCB and WCB in 1998-1999. However, since ~80% of these fish were collected from the SCB (and ~70% from Wilson Inlet), this A_{50} estimate essentially reflected the age at which *H. melanochir* matures in the

SCB, not the WCB. Age at maturity in the WCB was not specifically estimated in 1998-1999 due to low a sample size (Jones *et al.* 2002).

The A_{50} of 19.0 months in the SCB was similar to values estimated for other *H. melanochir* populations in SA (A_{50} = 17.5 months) and Victoria (A_{50} = 19.3 months) during 1998-1999 (Jones *et al.* 2002).

In 2009-2012, the estimates of A_{50} for female and male *H. melanochir* in the WCB were less than 12 months (Section 4). Although an A_{50} estimate was not available from the WCB in 1998-1999, the shape of the growth curve in 1998-1999 (Fig. 2.2) suggests that maturity could have been attained later (perhaps during the 2nd year of life) at this time (assuming L_{50} = 228 mm in both periods).

2.12 Maximum age and length

H. melanochir is reported to attain a maximum length of approximately 490 mm TL (Gomon *et al.* 2008). The maximum observed age is 10 years (Jones 1990, Jones *et al.* 2002). In SA, the maximum reported age is 10 years for males and 8 years for females (Jones 1990) and in Tasmania it is 7 years for males and 8 years for females (Jordan *et al.* 1998).

In WA, the largest fish collected in the SCB and WCB during recent sampling in 2009-2012 were 410 mm (female, from Wilson Inlet) and 386 mm (female, from Perth), respectively. The largest male was 373 mm (from Perth). During previous sampling in 1998-1999, the largest fish collected in the SCB and WCB were 425 mm (female, from Wilson Inlet) and 381 mm (female, from Perth), respectively (Jones *et al.* 2002, DoF unpubl. data).

In 2009-2012, the oldest fish collected in the WCB was aged 5 y (one male from Cockburn Sound). The oldest females were aged 4 y (one fish from Perth, one fish from Mandurah). In 1998-1999, the oldest female collected was 5 y in the WCB and 10 y in the SCB (from Wilson Inlet). The oldest males in each Bioregion were aged 4 y.

2.13 Growth characteristics

In *H. melanochir* populations throughout Australia, female *H. melanochir* typically attain a greater length-at-age than males (Ling 1958, Jones 1990, Jones *et al.* 2002, Fowler *et al.* 2008) (Table 2.3).

Using length-at-age data collected in 1998-1999, Jones *et al.* (2002) fitted von Bertalanffy growth curves for *H. melanochir* in WA and reported that the male and female growth curves differed significantly in the SCB, but not in the WCB (Table 2.4, Fig. 2.3). In the SCB, female *H. melanochir* typically attained greater lengths than males at corresponding ages. The fish examined by Jones *et al.* (2002) were collected from various locations within each Bioregion, with approximately half of the SCB fish from Wilson Inlet and half of the WCB fish from Cockburn Sound.

In 2009-2012, von Bertalanffy growth curves were fitted to length-at-age data for fish collected from the WCB (mainly from Cockburn Sound) (Section 6). The growth curves for the two sexes differed significantly, with females typically attaining greater lengths than males at corresponding ages (Table 2.5, also see Section 3). SCB fish were not aged, and so growth parameters were not estimated for this region in 2009-2012.

A comparison of the growth curves for *H. melanochir* in the WCB in 1998-1999 versus 2009-2012 suggests that fish were growing more rapidly during their first year of life in 2009-2012, compared with 1998-1999 (Fig. 7.3).

2.14 Mortality

Jones (1990) sampled the age structure of a population of *H. melanochir* in SA that was subject to negligible levels of fishing and estimated an instantaneous rate of natural mortality (M) of 0.53 y^{-1} for males and 0.36 y^{-1} for females, using catch curve analysis. These rates are equivalent to an annual rate of survival (S) of 59% and 70%, respectively (where $S = e^{-M}$).

Natural mortality has also been estimated by the empirical regression equation method of Hoenig (1983, equation using data from all taxa) :

$$log_e M = 1.44 - 0.982\ log_e t_{max}$$

where t_{max} is the maximum age (in years) attained by the stock. At a maximum age of 10 y, natural mortality for *H. melanochir* is estimated to be 0.44 y^{-1} (equivalent to S = 64%). This value (for both sexes pooled) is consistent with the 'direct' mortality estimates calculated by Jones (1990) for females and males.

In 1998-1999, an instantaneous rate of total mortality (Z) of 0.90 y^{-1} was estimated for *H. melanochir* in the WCB (Jones *et al.* 2002, using the mortality estimator of Chapman and Robson (1960) data for sexes pooled). This is equivalent to an annual rate of survival (S) of 41%.

During 2010-2011, an average Z value of 1.57 (data for sexes pooled) was estimated for *H. melanochir* in the WCB using the method of Chapman and Robson (1960), and a similar estimate was derived applying linear catch curve analysis (see Ricker, 1975) (Section 6). This rate is equivalent to S = 21%. Hence, total annual survivorship of *H. melanochir* in the WCB is estimated to have declined from 41% in 1998-1999 to 21% in 2010-2011. During 2010-2011, average Z values of 1.40 for WCB females (S = 25%) and 1.66 for WCB males (S = 19%) were estimated.

In 1998-1999, a Z value of 0.98 y^{-1} was estimated for *H. melanochir* in the SCB, equivalent to S = 37% (Jones *et al.* 2002, data for sexes pooled). Z was not estimated in the SCB in 2010-2011.

Given that $Z = M + F$, where F refers to the instantaneous rate of fishing mortality, if M = 0.44 y^{-1}, then F in 1998-1999 was 0.46 y^{-1} in the WCB and 0.54 y^{-1} in the SCB (sexes pooled). In 2010-2011, F in the WCB was estimated to be 1.13 y^{-1} for sexes pooled, 0.96 y^{-1} for females and 1.22 y^{-1} for males.

In 1998-1999, Z for *H. melanochir* populations in Gulf St Vincent and Spencer Gulf in SA was estimated to be 2.15 and 1.77 y^{-1} (indicating F values of 1.71 and 1.33 y^{-1}) (Jones *et al.* 2002). These levels of mortality were subsequently concluded to be unsustainable for these populations. At the time of writing, fishery catch levels in these areas were yet to recover after declining sharply in 2002/03. Furthermore, these SA populations displayed strong age and length truncation, and exploitable biomass and egg production were well below acceptable limits (Steer *et al.* 2012).

Table 2.1. Species of garfish recorded in Western Australia. ([1] Allen and Swainston 1988; [2] Hutchins and Swainston 1986; [3] Collette 1974; [4] www.fishbase.org)

Species	Common name	Distribution in WA	Max. total length (cm)	Notes
Hyporhamphus melanochir	Southern garfish	Lancelin southwards [2]	52	
Euleptorhamphus viridis	Longfin garfish	Albany northwards [1, 2]	60	Coastal & offshore; mostly tropical; distinctive appearance (ribbon-like body & wing-like pectoral fins)
Hyporhamphus regularis (western subspecies)	River garfish	Bunbury to Kalbarri [2]	38	Estuarine
Hemirhamphus robustus	Three-by-two garfish	Geographe Bay northwards [1]	48	Mostly tropical
Arramphus sclerolepis	Snubnose garfish	Carnarvon northwards [1]	38	Mostly estuarine; distinctive appearance (short lower jaw)
Hyporhamphus affinis	Tropical garfish	Shark Bay northwards [1]	25	Coastal
Hyporhamphus quoyi	Longtail garfish	Shark Bay northwards [1]	34	Coastal
Hyporhamphus dussumieri	Slender garfish	Shark Bay northwards [3, 4]	38	
Hyporhamphus neglectissimus	Neglected garfish	Broome northwards [3]	15	
Zenarchopterus buffonis	Northern river garfish	Port Hedland northwards [1]	13	Coastal & estuarine
Hemirhamphus far	Blackbarred garfish	Dampier Archipelago northwards [1]	35	Coastal

Table 2.2. Logistic parameters describing the total lengths (mm) at which 50% and 95% of individuals of *Hyporhamphus melanochir* in the WCB and SCB attain maturity (i.e. L_{50} and L_{95}, respectively), estimated from data collected in 2009-2012. 95% confidence limits are presented in brackets. *n* = number of fish sampled.

Bioregion	Sex	L_{50}	L_{95}	*n*	Sampling period
WCB	Both	225 (221-230)	281 (275 - 287)	1242	2009-2012 (Section 3)
SCB	Both	243 (237 - 251)	307 (291 - 326)	656	2009-2012 (Section 3)
SCB	Female only	261 n/a	n/a n/a	420	1998-1999 (Jones *et al.* 2002)

Table 2.3. Estimates of von Bertalanffy growth parameters for *Hyporhamphus melanochir* sampled from a lightly fished population in Baird Bay in South Australia in 1984/85 (Jones 1990). Numbers in brackets denote standard errors. SL = standard length.

Sex	L_∞ (SL, cm)	k (y^{-1})	t_0 (y)
Female	38.7 (±0.6)	0.540 (±0.044)	0.30 (±0.08)
Male	36.7 (±0.4)	0.507 (±0.032)	0.12 (±0.08)

Table 2.4. Estimates of von Bertalanffy growth parameters for *Hyporhamphus melanochir* sampled from the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) of WA in 1998-1999 (Jones *et al.* 2002). Numbers in brackets denote standard errors. *n* = number of fish sampled. SL = standard length.

Location	Sex	$L_{\infty,}$ (SL, mm)	k (m^{-1})	t_0 (m)	*n*
WCB (WA)	Female	307 (±9)	0. 054 (±0.006)	-4.5 (±0.7)	114
	Male	300 (±13)	0.050 (±0.007)	-5.1 (±0.9)	89
	Both	303 (±8)	0.053 (±0.005)	-4.7 (±0.5)	203
SCB (WA)	Female	349 (±13)	0.040 (±0.007)	-9.5 (±0.7)	188
	Male	296 (±11)	0.094 (±0.027)	2.4 (±2.9)	61
	Both	342 (±10)	0.043 (±0.007)	-7.6 (±2.8)	249

Table 2.5. Estimates of von Bertalanffy growth parameters for *Hyporhamphus melanochir* sampled from the West Coast Bioregion (WCB) in 2009-2012 (Section 4). 95% confidence limits are provided in brackets. *n* = number of fish sampled. TL = total length.

Sex	L_∞ (TL, mm)	k (y^{-1})	t_0 (y)	n
Both	316 (312 - 321)	1.24 (1.14 - 1.34)	-0.33 (-0.40 - -0.27)	1271
Male	304 (300 - 309)	1.40 (1.27 - 1.53)	-0.27 (-0.33 - 0.23)	841
Female	332 (326 - 340)	1.25 (1.13 - 1.40)	-0.26 (-0.32 - 0.21)	413

Table 2.6. Estimates of the instantaneous rates of total mortality (*Z*, y^{-1}) and fishing mortality (*F*, y^{-1}), and annual rates of survivorship (*S*) for *Hyporhamphus melanochir* populations in WA. A rate of natural mortality, *M*, of 0.44 y^{-1} is assumed for each population.

Bioregion	Sampling period	Sex	*Z*	*F*	*S*	Source
WCB	1998-1999	Both	0.90	0.46	41%	Jones *et al.* 2002
	2009-2012	Both	1.57	1.13	21%	Section 3
		Female	1.44	0.96	25%	
		Male	1.66	1.22	19%	
SCB	1998-1999	Both	0.98	0.54	37%	Jones *et al.* 2002

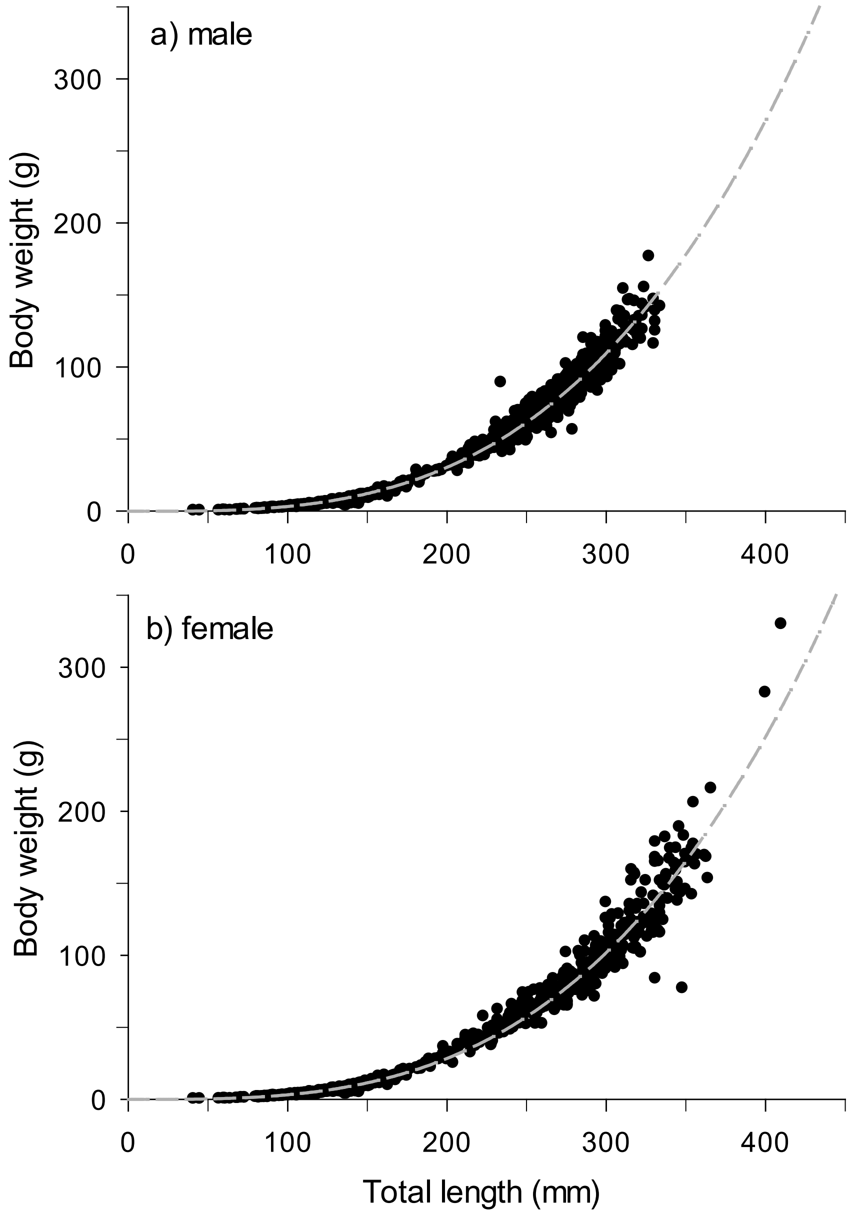

Figure 2.1. **Relationship between total length (TL) and whole body weight (W) of a) male and b) female *Hyporhamphus melanochir* collected from west coast and south coast waters of WA in 1998-1999 and 2009-2012. Fitted lines: FL = $W_{male} = 1.7688 \times 10^{-6} \times TL^{3.1458}$ ($r^2 = 0.9758$, $n = 1070$, $p < 0.001$) and $W_{female} = 1.6769 \times 10^{-6} \times TL^{3.1422}$ ($r^2 = 0.9687$, $n = 748$, $p < 0.001$).**

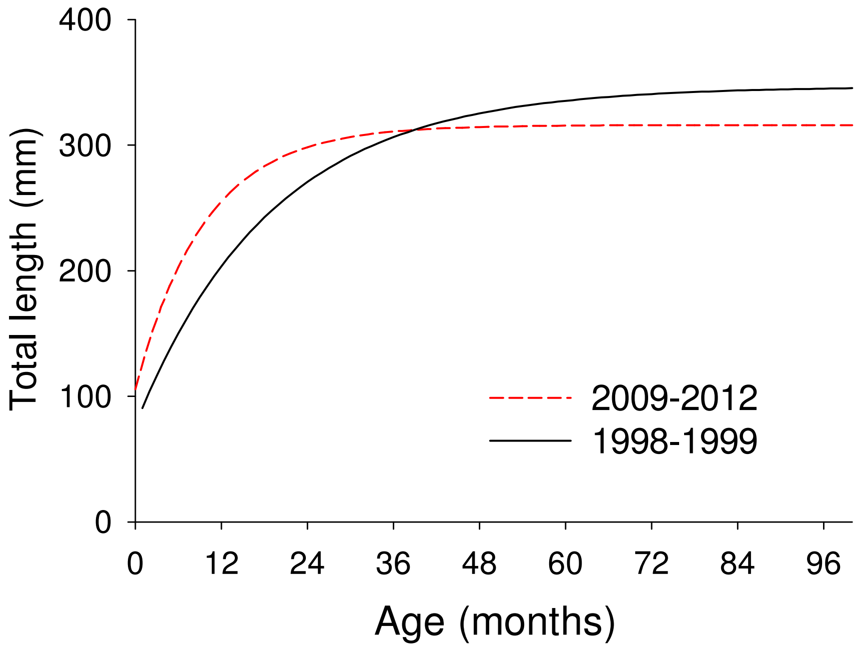

Figure 2.2. **Comparison of von Bertalanffy growth curves for *Hyporhamphus melanochir* in the West Coast Bioregion (WCB) (sexes combined), estimated from samples collected in 1998-1999 (Jones *et al.* 2002) and in 2009-2012 (Section 3).**

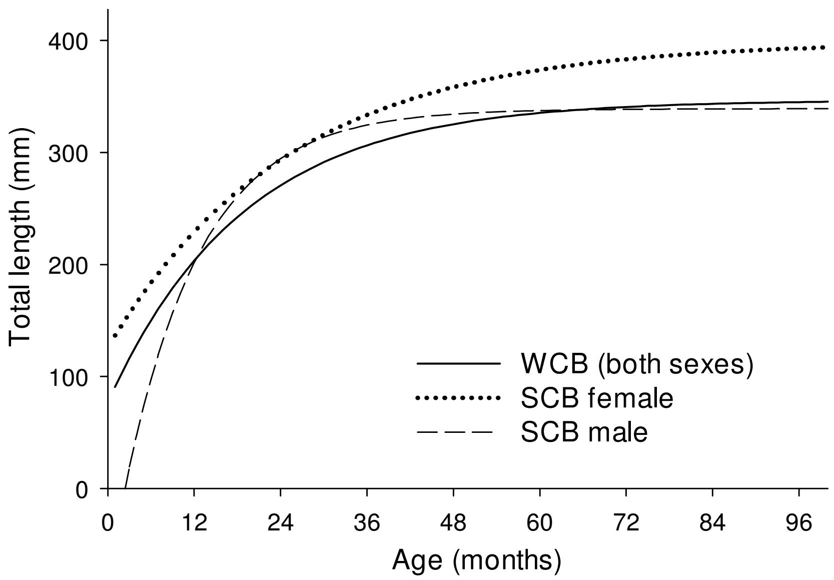

Figure 2.3. **von Bertalanffy growth curves for *Hyporhamphus melanochir* in the West Coast Bioregion (WCB) (sexes combined) and South Coast Bioregion (SCB) (males and females separately), estimated from samples collected in 1998-1999 (Jones *et al.* 2002).**

3 Biology of *Hyporhamphus melanochir* in WA

Summary

- Growth and reproductive parameters were estimated for *H. melanochir* in the WCB, based on biological data collected in 2009-2012. Results were compared with previously reported parameters estimated from data collected in the WCB in 1998-1999. Limited data from the SCB was also examined.
- Across southern Australia (the species range), the maximum reported total length and age of *H. melanochir* are 49 cm and 10 y, respectively.
- In 2009-2013, the largest fish collected in the SCB and WCB were 410 mm (female, from Wilson Inlet) and 386 mm (female, from Perth), respectively. The oldest fish in the WCB was aged 5 y. Fish from the SCB were not aged in 2009-2013.
- In 1998-1999, the largest fish collected in the SCB and WCB were 425 mm (female, from Wilson Inlet) and 381 mm (female, from Perth), respectively. In 1998-1999, the oldest fish was 5 y in the WCB and 10 y in the SCB.
- Data from both sampling periods indicate that the growth patterns of *H. melanochir* differ between sexes and Bioregions. Females typically attain greater lengths at age than males. Fish in the SCB typically attain a greater length-at-age than those in the WCB.
- In WA, *H. melanochir* spawns over an extended period during the warmer months (spring, summer, autumn), but with a peak in activity in spring/early summer (November/December). The spawning period is slightly longer in the WCB than in the SCB.
- *H. melanochir* typically attain maturity at a smaller size in the WCB compared to the SCB. In 2009-2013, the estimated total lengths at which 50% (L_{50}) and 95% (L_{95}) of individuals in the WCB attained maturity were 225 mm and 281 mm, respectively. The L_{50} and L_{95} in the SCB were 242 mm and 311 mm, respectively. The sizes at which males and females attained maturity was similar within each Bioregion.
- In 2009-2013, the majority of females and males in the WCB attained sexual maturity during their first year of life. Fish from the SCB were not aged in 2009-2013 (outside the scope of this study) and so age at maturity was not determined for that Bioregion.

3.1 Introduction

In WA, *Hyporhamphus melanochir* is distributed from Lancelin southwards (Gomon *et al.* 2008). Fishery landings of this species in WA are highly localised. In the WCB, the vast majority of fishery landings are taken in the Perth metropolitan area, particularly within Cockburn Sound which is a shallow (<20 m) marine embayment in the southern metropolitan area (Section 4). It is a popular location for shore and boat-based recreational fishing and it also hosts a commercial fishery (the *Cockburn Sound (Fish Net) Managed Fishery*). Cockburn Sound produces >80% of total commercial landings and >50% of total recreational landings of *Hyporhamphus melanochir* in the WCB each year (Section 4).

As there is evidence to suggest that *H. melanochir* in Cockburn Sound is a largely self-replenishing population (Section 2), this population is managed as a discrete stock. A relatively rudimentary 'Level 2' assessment (i.e. monitoring catch rate trends) has previously been used to determine the status of this stock (Smith *et al.* 2013a). Recently, catch rates have declined, raising concerns about stock sustainability (Section 4). A more rigorous assessment of the status of *H. melanochir* in Cockburn Sound is therefore now warranted, and this requires additional information regarding key biological characteristics of the stock.

Estimates for some important biological parameters (e.g. growth parameters) for *H. melanochir* in WA were previously published by Jones *et al.* (2002). However, these estimates were based on data collected predominantly from the SCB, rather than in Cockburn Sound in the WCB. Since the characteristics of *H. melanochir* are known to vary spatially (Section 2), the biological parameters for SCB populations of this species cannot be assumed to apply in Cockburn Sound.

Additionally, since the biological characteristics of a species may also vary temporally (e.g. Cottingham *et al.* 2014), the parameters for SCB populations observed in 1998-1999 by Jones *et al.* (2002) should be re-evaluated.

Objectives of this Section:

- Implement a dedicated sampling program to collect biological information about *H. melanochir* in the WCB, particularly in Cockburn Sound.
- Determine the key biological characteristics of the stock of *H. melanochir* in Cockburn Sound, including i) growth pattern, ii) spawning period, and iii) age- and size-at-maturity for *H. melanochir*.
- Determine the same key biological characteristics for *H. melanochir* in the SCB from existing data, where available.

3.2 Methods

3.2.1 Fishery-independent sampling

Annual beach seine net sampling of juvenile fish was commenced by DoF in 1993 to monitor recruitment levels for a wide range of fish species at numerous sites across south-western WA (Ayvazian *et al*. 2000). A more restricted annual sampling regime targeting a subset of key nearshore fishery species has been employed since mid-2005 (Gaughan *et al.* 2006). Six sites are each sampled from September to April. The number of months sampled each year varies between sites, ranging from 4 to 7 months per site. The timing of sampling at each site is designed to maximize the catch rates of the target species (Gaughan *et al.* 2006). Since mid-2005, sampling has occurred at 3 sites within the Metropolitan Zone (Pinnaroo Point, Mangles Bay, Warnbro Sound – all located in Perth), 1 site within the South-west Zone (Koombana Bay - located in Bunbury), 1 site in the South Zone (Emu Point – located in Albany) and 1 site in the South-east Zone (Poison Creek – east of Esperance).

A full description of the beach seine netting methodology used to collect juvenile fish can be found in Ayvazian *et al*. (2000) and Gaughan *et al*. (2006). Briefly, netting was conducted in the morning, commencing approximately 2 hours after sunrise. Fish were collected using a beach seine net (total length 60.6 m, height 2.0 m), composed of two wings of length 29.1 m (22 mm stretched mesh) and a bunt of length 2.4 m (8 mm mesh). The net was deployed from a small dinghy rowed in an arc from/to the beach. The area swept by the net was estimated to be 592 m^2 per haul. Both ends of the net were hauled back onto the beach, where the catch was sorted. At all sites, the area swept by the net was predominantly bare sand, sometimes interspersed with small patches of drifting or fixed vegetation (seagrass or algae).

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

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

To obtain older juveniles of *H. melanochir* (length range 130-230 mm TL) that were poorly represented in both fishery-independent seine net samples and in fishery landings, additional fishery-independent sampling was undertaken using scoop netting. Scoop netting was used in Cockburn Sound on three nights in 2011 (3 March, 9 March, 4 April) to collect a total of 174 fish. Fish were netted after being attracted to the surface by a spotlight.

3.2.2 Sampling of fishery landings

From September 2009 to January 2012, a random sample of 30-60 *H. melanochir* (whole fish) was obtained from commercial landings by the *Cockburn Sound (Fish Net) Managed Fishery* each month. Landings were not available in some months, resulting in a total of 20 months being sampled over this 30-month period. A total of 928 fish were collected. All commercial landings were taken by a surface haul net (260 m length x 18 m depth) consisting of panels of 50 mm (2 inch) and 37 mm mesh (1.5 inch) in the wings and 25 mm (1 inch) in the bunt.

From September 2009 to June 2012, samples of *H. melanochir* (either whole fish or filleted frames) caught using line fishing methods in the WCB were donated by recreational fishers. These donations were obtained via the “Send Us Your Skeletons” project, which is an ongoing fish frame collection program targeted towards recreational fishers. A total of 314 fish were obtained from recreational fishers over this 34-month period (Table 3.1). The number of fish collected per month ranged from 0 to 79 over this period. Donated fish were mainly caught in the Perth region.

Sampling in the SCB was opportunistic during 2009-2013. A relatively small number of fish were collected from recreational and commercial fishers this area (Table 3.1).

For simplicity, the sampling periods in the WCB and SCB are both referred to as ‘2009-2013’ below.

3.2.3 Laboratory

In the laboratory, the whole body weight (to nearest 0.01 g), the total length (to nearest mm, from the tip of upper jaw to the tip of the caudal fin) and fork length (to nearest mm, from the tip of the upper jaw to the fork of the caudal fin) was measured for each fish. Sagittal otoliths were removed from each fish, dried, weighed (to nearest 0.00001 gram) and stored in labelled paper envelopes.

Gonads were removed, sexed and weighed (to nearest 0.01 gram). A developmental stage was assigned to each gonad based on the macroscopic criteria of Ling (1958), as follows:

Female:

Stage 1 - Immature virgin. Ovaries small and thread-like, extending about one-third of the length of the body cavity. Sometimes only just visible; and it is almost always impossible to distinguish the sex. No ova visible.

Stage 2 - Immature virgin. Ovaries distinguishable as such. Small and thin, about 2 mm in diameter, occupying same space as stage 1 in the body cavity. White in colour or translucent; individual ova not visible.

Stage 3 - Maturing virgin or recovering or resting mature (spent,) fish. Ovaries about 3 mm in diameter, extending half way along length of body cavity. A blood-vessel runs along dorsolateral surface of gonads, with smaller ones ramifying over the more posterior region. Small white ova to be seen in translucent ovaries.

Stage 4 - Maturation continuing. Ovaries about same relative length as in stage 3 but twice as thick. Blood-vessels larger. Ova plainly visible, having a diameter of about 1 mm.

Stage 5 - Maturation still in progress. Ovaries about 8 mm in diameter, extending some three-quarters of the way along length of body cavity. Blood vessels ramifying over the ovaries are reduced, but the main dorsolateral ones still large. The ova appear to be clearing and are about 1.5 mm in diameter.

Stage 6 - Ripe ova, but not yet running. Ovaries lie along the entire length of the body cavity and have become much swollen to about 20 mm diameter. Only the large lateral blood-vessels obvious. Ripe ova 3 mm in diameter appear as a clear, yellow-green, jelly-like mass and are quite firmly packed, the ovary being fairly turgid. There is no sign of the genital pore being open. Smaller ova constitute a second group; diameter about 1.5 mm.

Stage 7 - Running ripe. Ova shed through genital pore when slight pressure is applied to the abdomen. If some ova have been extruded the ovaries will be limp and flaccid, with the remaining large ripe ova lying free in the lumen. Blood-vessels running along the side of each ovary are still very big and clearly defined.

Stage 8 - Spent ovary. May or may not be bloodshot, but very limp and shrunken. Tunica tough and leathery, unlike easily ruptured ovarian wall of ripe stage. Blood begins to appear at the posterior end where the ramifying vessels were obvious in the earlier stages. Only a few residual large ova remain, but many "medium-sized" ones of the next smallest group still visible.

Male:

Stage 1 - Immature virgin. As in stage 1 of the females: sex indistinguishable; gonad is thread-like, about one-third the length of the gut space.

Stage 2 - Immature virgin. Sex just recognisable. Testis a little thicker than in stage 1, and of noticeable "brittle" structure as distinct from the somewhat elastic ovary; still extending about a third of the way from the anal end of gut cavity; coloured yellowish cream.

Stage 3 - Maturing virgin or recovering or resting spent adult. Cream in colour and displaying a triangular cross section about 2 mm across. Same relative length as earlier stages.

Stage 4 - Maturing (though easily confused with spent). Colour brownish pink. About 3 mm in cross section, extending half way along the body cavity. Posterior end more tubular and white.

Stage 5 - Mature, but milt not yet running. Pale pink in colour, and swollen to about 25 mm across, extending half way along the body cavity. Triangular shape still obvious. Tubules visible as a tightly coiled mass. Pink colour gives way to white at posterior end, where milt is accumulating. A median blood-vessel visible in posterior region and giving off branches to each testis.

Stage 6 - Running ripe. Testes even more swollen. Very soft, and pale pink in colour with black spots on surface. Strap-like in general shape, with tubules plainly visible in the body of the organs. Genital pore open and white milt exuded by the application of slight pressure on the abdomen.

Stage 7 - Spent. Much reduced in size and showing signs of blood, which colours the testis a dull reddish brown.

3.2.4 Otoliths and age estimation

Opaque zones form annually within the sagittal otoliths of *H. melanochir* (Jones *et al.* 2002, DoF in prep.). Sagittal otoliths to be aged were embedded in resin and sectioned. Briefly, one sagitta per fish was embedded in clear polyester (epoxy) resin. One transverse section (220 µm thick) was then taken through the otolith primordium using a low-speed Buehler-Isomet diamond saw. The section was mounted on a glass slide with casting resin. Sectioned otoliths were examined under reflected light against a black background using a dissecting microscope. Otolith structures were interpreted using protocols for *H. melanochir* described by Jones *et al.* (2002), and in DoF (in prep.).

An average birthdate of 1 January was assigned to all fish, based on the timing of spawning indicated by gonad development. Spawning by *H. melanochir* occurs over an extended period during the warmer months each year (see Results). While 1 January was selected to represent the middle of the spawning period, the actual birthdates of individual fish may occur several months before or after this date each year. Hence, the assigned age of fish (based on an average birthdate of 1 January) may under- or over-estimate the actual age by several months.

In this study, otoliths from the WCB and SCB were collected, but only those from the WCB were aged. SCB otoliths were stored and could be examined in future if required.

3.2.5 Analysis of length and weight data

The relationships of i) total length versus fork length and ii) total length versus whole body weight were determined by regression analysis (see Section 2 for regression equations). These relationships, which were estimated from data collected in the WCB and SCB in 2009-2013 (years and Bioregions pooled), were used to estimate total length or body weight, respectively, when the values of these variables were unavailable.

3.2.6 Growth

The patterns of growth of male and female *H. melanochir* in the WCB (but not SCB due to insufficient data) were determined based on length-at-age data collected during 2009-2013. Growth was described by fitting the von Bertalanffy growth model (von Bertalanffy 1938) to length-at-age data for each sex, using non-linear, least-squares regression, employing Solver in Microsoft Excel. The von Bertalanffy growth equation is

$$L_t = L_\infty\{1 - exp[-k(t - t_0)]\}$$

where L_t is the estimated length (TL, mm) of fish at age t (y), L_∞ is the asymptotic length (mm), *i.e.* the mean length the fish would reach if they were to grow indefinitely, k is the growth coefficient (y^{-1}), which describes the rate at which L_∞ is approached, t_0 is the hypothetical age (y) at which the fish have a length of zero, and *t* is the estimated age (y).

Since few small (<200 mm TL) *H. melanochir* were collected from the commercial or recreational sector, data from smaller (90-180 mm) fish collected using fishery independent methods were included when fitting the growth curve. These small fish were mostly juveniles that could not be sexed macroscopically, so the length-at-age data for these fish were added randomly, but in equal proportions, to the female and male data sets to which growth curves were fitted. 95% confidence limits for the equation parameters were derived by randomly resampling (with replacement) and analysing the length-at-age data to create 200 bootstrap estimates of growth parameters. The 95% CL were calculated as the 2.5 and 97.5 percentiles of the bootstrap parameter estimates.

3.2.7 Timing of reproduction

The gonadosomatic index (GSI) for each fish was calculated as gonad weight (g) divided by the whole body weight (g).

To determine the spawning period of *H. melanochir*, samples collected during 2009-2013 in the WCB were pooled. Similarly, samples collected during 2009-2013 in the SCB were pooled. Gonads at stage 1 and 2 were omitted and then the monthly proportions of gonads at stages 3 to 8 were plotted for each sex in each Bioregion. The presence of stages 5/6 (male) and 6/7 (female) were used to indicate the spawning period. Peaks in mean monthly GSI values were also used to indicate the timing of spawning in each Bioregion. Mean monthly GSIs were calculated from individual GSI values of all stage 3-8 gonads collected in that month (stage 1 gonads were omitted).

When estimating size at maturity, females at macroscopic gonad stages 3-8 and males at stage 3-7 were classified as 'mature'. Given that there is evidence of at least some spawning activity by *H. melanochir* during each month (see Results), data from all months were included in the analysis. The equation describing the probability, ρ, that a female or a male *H. melanochir* of length L is mature is

$$\rho = 1/\{1 + \exp[-\ln(19)(L - L_{50})(L_{95} - L_{50})]\}$$

where L_{50} and L_{95} are the estimated lengths at which 50 and 95% of the individuals, respectively, would be expected to be mature. A logistic regression analysis based on the above equation was undertaken using maximum likelihood estimation using SOLVER in Microsoft Excel. The log-likelihood, λ, was calculated as

$$\lambda = \sum_j \{X_j ln\rho_j + (1 - X_j) ln(1 - \rho_j)\}$$

where the *j*th fish was represented by *X*=0 if it was immature and *X* =1 if it was mature. The data were randomly resampled and analysed to create 200 sets of bootstrap estimates of the parameters of the logistic equation. The point estimates and 95% CLs of the parameters were taken as the median and 2.5 and 97.5 percentiles, respectively, of the corresponding predicted values resulting from this resampling analysis.

Initially, a logistic curve was fitted in the same manner as described above to the age-at-maturity data in an attempt to provide estimates for the ages at which 50% and 95% of *H. melanochir* mature. However, the curve provided a relatively poor fit to the data reflecting, the very young age at which individuals attain maturity (less than 12 months) and the limited data available for 0+ fish. Therefore, fish were instead grouped by year class and the percentage of mature individuals in each year class calculated.

3.3 Results

3.3.1 Spawning period

In the WCB, monthly mean GSI values for males and females during 2009-2013 were elevated from August to April, suggesting an extended reproductive period (Fig. 3.1a). Both sexes displayed a pronounced GSI peak in November/December, suggesting that reproductive activity peaked in these months.

The presence of advanced macroscopic gonads (stages 5-6 in males and stages 6-7 in females) over multiple months also suggested an extended spawning period in the WCB (Fig. 3.2). These data suggested spawning during all months, but with the majority of spawning activity occurring in the warmer months (September to April).

In the SCB, limited data was obtained during 2009-2013 to assess monthly patterns in reproductive activity in this region. Elevated GSI values in December suggested spawning in these months, similar to the timing of peak spawning in the WCB (Fig. 3.1b). The presence of advanced macroscopic gonads (stages 5-6 in males and stages 6-7 in females) suggested spawning during December, January and February in the SCB (Fig. 3.3). Overall, these data indicate an extended spawning period during the warmer months in the SCB, similar to the timing of spawning in the WCB.

The exception to this pattern was the high mean GSI value for females in the SCB during May (no data available for males in May) (Fig. 3.1b). Females sampled in this month were collected from Wilson Inlet during 2011. In autumn 2011, mean monthly air temperature in the SCB was well above average, and rainfall was well below average (Australian Bureau of Meteorology website). Therefore, atypically high water temperatures could have induced spawning in Wilson Inlet in May 2011. Previous sampling in 1998-1999 did not find evidence of spawning during May in Wilson Inlet (Jones *et al.* 2002).

In 1998-1999, female gonads collected from the SCB (Wilson Inlet) indicated spawning from September to February, based on the presence of stage 6 and 7 female gonads, with the highest prevalence of these stages from September to December (Jones *et al.* 2002). In 1998-1999, egg diameter was also used to infer the spawning period in the SCB (Jones *et al.* 2002). Mean egg diameter was elevated from September to March, including a peak in September/October. Mean egg diameter was lowest during May-August.

The recruitment patterns of juvenile *H. melanochir* observed during annual beach seine net sampling by DoF since 1995 also indicate a protracted spawning season over the warmer months for this species in both the WCB and SCB. Although this sampling program was not designed to monitor juvenile *H. melanochir* (the 8 mm mesh in the seine net is too large to effectively retain small garfish), a substantial number of juvenile *H. melanochir* have been captured. When pooled across years, the monthly length frequency data from this program provides a good indication of the timing of spawning in each Bioregion.

Fish <75 mm (assumed to be <3 months old) were present in samples from December to June in the WCB and from December to April in the SCB (Figs. 3.4 and 3.5). These recruitment patterns suggest a more extended spawning season in the WCB (spring, summer and autumn) than in the SCB (spring and summer). This is consistent with the timing of spawning suggested by gonad development.

3.3.2 Length-at-maturity

During 2009-2013, the smallest mature male (i.e. at macroscopic gonad stages 5-7) observed in the WCB was 218 mm TL. The smallest mature female (stages 6-8) in the WCB was 229 mm TL. In the SCB, the smallest mature male and female was 205 mm and 211 mm TL, respectively.

The logistic regressions describing the probabilities of maturity of fish at a given length were not significantly different for females and males collected in the WCB during 2009-2012 (likelihood ratio test, $p > 0.05$) or in the SCB during 2009-2013 (likelihood ratio test, $p > 0.05$). Therefore, data from both sexes were pooled. Logistic regressions for the WCB and SCB (data for sexes pooled) were significantly different (likelihood ratio test, $p < 0.001$). Individuals attained maturity at a significantly larger size in the SCB.

Thus, L_{50} and L_{95} in the WCB were 225 mm and 281 mm, respectively (Table 3.2, Fig. 3.6a) which were substantially lower than the values of 242 mm and 311 mm, respectively, for the SCB (Table 3.2, Fig. 3.6b).

3.3.3 Age-at maturity

In the WCB during 2009-2013, 19% of females and 55% of males sampled at age 0+ years were mature (Fig. 3.7). At age 1+, 92% of females and 82% of males were mature and at age 3+ years, virtually all fish were mature. This demonstrates that the majority of female and male *H. melanochir* in the WCB attain sexual maturity during their first year. Note that *H. melanochir* collected from the SCB in 2009-2013 were not aged and so age-at-maturity was not determined.

3.3.4 Growth

Female and male *H. melanochir* collected in the WCB during 2009-2013 exhibited different growth patterns (Fig. 3.8). Females attained a higher maximum length (L_∞) compared to males (Tables 3.3 and 3.4). L_∞ was estimated to be 332 mm for females and 304 mm for males (Table 3.3).

Growth by both sexes was rapid in the first year of life. At age 1 year, females and males reached an average of 264 and 252 mm TL, respectively (Table 3.4). Individuals of both sexes approached their maximum length after 2 years. At age 2 years, females and males reached an average of 313 and 291 mm TL, respectively.

H. melanochir collected from the SCB in 2009-2013 were not aged and so their growth patterns were not determined.

The largest fish collected in the SCB and WCB were 410 mm (female, from Wilson Inlet) and 386 mm (female, from Perth), respectively. The largest male collected was 373 mm (from Perth).

The oldest fish collected in the WCB were aged 5 y (one male and one fish of unknown sex, both from Cockburn Sound). The oldest females were aged 4 y (one fish from Perth, one fish from Mandurah).

3.4 Discussion

3.4.1 Spawning period

All available evidence, including monthly trends in gonad and egg development, and the timing of recruitment by small (<75mm) juveniles, suggests that spawning by *H. melanochir* in both the WCB and SCB occurs over an extended period during the warmer months (spring, summer, autumn), but with a strong peak in activity in spring/early summer (November/December). The spawning period is slightly longer in the WCB.

The timing of spawning in the SCB is similar to that observed in SA and Victoria (Jones *et al*. 2002). The spawning period appears to be slightly shorter in Tasmania (October to February) than in other regions, possibly in response to temperature differences. Overall, the observations in WA and other states suggest the spawning period of this species is longer at lower latitudes (or warmer temperatures). A more protracted spawning period at lower latitudes has also been observed in other temperate species in south-western Australia, e.g. *Sillago bassensis* (southern school whiting) (Brown *et al*. 2013), *Pseudocaranx dentex* (silver trevally) (Farmer *et al*. 2005) and *Pagrus auratus* (snapper) (Wakefield 2006).

In some areas, the timing of spawning may be size- and/or age-dependent. Jones (1990) reported that larger fish (>27 cm standard length) spawned during spring, whereas smaller fish (<27 cm) spawned in summer in Baird Bay, SA. These smaller fish were mostly aged 2+ and were spawning for the first time, while the larger fish were mostly 3+ or older and had probably spawned in previous years. In WA, there was no observed difference in spawning times between large and small fish collected during 2009-2013.

3.4.2 Length at maturity

H. melanochir typically attain maturity at a smaller size in the WCB compared to the SCB. In 2009-2013, the estimated total lengths at which 50% (L_{50}) and 95% (L_{95}) of both sexes of *H. melanochir* attained maturity in the WCB were 225 mm and 281 mm, respectively. The L_{50} and L_{95} for *H. melanochir* in the SCB were 242 mm and 311 mm, respectively.

Previously, a slightly higher L_{50} of 261 mm TL was reported for female *H. melanochir* in WA (Jones *et al.* 2002). This estimate was based on pooled samples (n = 851) collected in 1998-1999 from various locations in the SCB and WCB. However, ~70% of these fish were collected from the SCB (and ~50% from Wilson Inlet) and so this estimate mostly reflected the size at maturity in the SCB.

In a previous study of *H. melanochir* in SA, it was concluded that the length-at-maturity had declined in response to high fishing pressure (Fowler *et al.* 2008). In this case, the L_{50} had declined from about 248-259 mm TL (~ 21-22 cm SL) in the 1950s to 215 mm TL by the 1990s (Ling 1958, Jones *et al.* 2002). In contrast, during the 1980s, Jones (1990) sampled a population of *H. melanochir* in SA that was subject to negligible levels of fishing and reported a length-at-first maturity similar to that observed in the 1950s (*i.e.* 21-22 cm SL).

3.4.3 Age at maturity

The age at maturity (*i.e.* A_{50}) for *H. melanochir* in various regions of southern Australia was previously estimated by Jones *et al.* (2002), who reported that 50% of females in WA, SA and Victoria attain maturity at 19.0, 17.5 and 19.3 months, respectively. However, the fish collected from WA by Jones *et al.* were mainly obtained from Wilson Inlet (SCB) and hence the value cited for WA related to the SCB, not the WCB.

Sampling of *H. melanochir* in the WCB in 2009-2013 indicated that the majority of females and males attained sexual maturity during their first year of life. Assuming a birth date in spring/summer, the majority of individuals would therefore reach maturity and be ready to spawn by the following spring/summer, at an age of approximately 12 months. This indicates substantially earlier maturation in the WCB compared to *H. melanochir* populations elsewhere.

3.4.4 Growth and longevity

Female and male *H. melanochir* collected in the WCB, during 2009-2013 exhibited different growth patterns, with females typically attaining a greater mean asymptotic length than males. Females reach a greater average size-at-age than males in most other *H. melanochir* populations across southern Australia, including the SCB of WA (Ling 1958, Jones 1990, Jones *et al.* 2002, Fowler *et al.* 2008).

Using data collected in 1998-1999, von Bertalanffy growth parameters for *H. melanochir* in WA were estimated by Jones *et al.* (2002), who concluded that male and female growth curves were not significantly different in the WCB (see Chapter 2 for more detail). The fish examined by Jones *et al.* (2002) were collected from various locations within the WCB, with approximately half of the fish from Cockburn Sound. The non-significant difference between male and female growth parameters in 1998-1999 may have been a consequence of the relatively small sample sizes (89 males and 114 females) examined by Jones *et al.* (2002).

H. melanochir is reported to attain a maximum length of approximately 49 cm TL (Gomon *et al.* 2008). In 2009-2013, the largest fish collected in the SCB and WCB were 410 mm (female, from Wilson Inlet) and 386 mm (female, from Perth), respectively. During previous sampling in 1998-1999, the largest fish collected in the SCB and WCB were 425 mm (female, from Wilson Inlet) and 381 mm (female, from Perth), respectively (Jones *et al.* 2002, DoF unpubl. data). In 2009-2013, the oldest fish collected in the WCB was aged 5 y. Fish collected from the SCB in 2009-2013 were not aged. In 1998-1999, the oldest fish collected was 5 y in the WCB and 10 y in the SCB (Jones *et al.* 2002).

Despite a larger number of fish being sampled from the WCB, the largest *H. melanochir* in both 1998-1999 and 2009-2013 sampling periods were collected from the SCB. This is consistent with differences in growth between Bioregions, with individuals in the SCB typically attaining greater lengths at age (Jones *et al.* 2002).

The maximum observed age of *H. melanochir* is 10 years, which has been observed in SA and WA (Jones 1990, Jones *et al.* 2002).

3.4.5 Conclusion

The findings of this study are consistent with other studies of *H. melanochir*, which indicate that the biological characteristics of this species are variable between regions, probably as a consequence of different environmental factors affecting growth and development. For this reason, it is important to determine the biological parameters specific to each *H. melanochir* stock when assessing stock status.

In WA, the growth and reproductive characteristics of *H. melanochir* evidently differ between the WCB and SCB, which is unsurprising given the substantial differences in environmental conditions between these regions. The results of this study, in combination with the results of previous studies, suggest that WCB *H. melanochir* typically grow more rapidly, mature earlier, attain smaller sizes at corresponding ages and spawn over a longer period than those in the SCB.

This study successfully estimated the pattern of growth, age and size at maturity and spawning period for *H. melanochir* in Cockburn Sound, which hosts the main *H. melanochir* fishery in the WCB. This key biological information can now be used to provide a more rigorous and informed assessment of the status of this popular fishery. Previously published biological parameters for *H. melanochir* in 'Western Australia' (Jones *et al.* 2002) were estimated from fish sampled predominantly within the SCB, and so were not applicable to Cockburn Sound.

Table 3.1. Number of male, female and juvenile *Hyporhamphus melanochir* collected per month in each Bioregion of WA from commercial fishers, recreational fishers and fishery-independent sampling ('research') during 2009-2013 in the West Coast Bioregion (WCB) and in the South Coast Bioregion (SCB).

Source	Sex	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
WCB Commercial	Juvenile/unknown	2	3				20	2	10				1
	Female	22	17	29	15	48	30	27	42		2	12	13
	Male	93	70	61	27	33	35	45	58		28	85	98
WCB Recreational	Juvenile/unknown	3	3	21	28			3	4	8		1	
	Female	2	9	35	15	5	1	5	4	15	1	5	1
	Male	1	12	56	9	5	2	2	17	19		22	
WCB Research	Juvenile/unknown	18	7	111	38					1			1
	Female	19	4	8	30								
	Male	1	4	12	19								
SCB Commercial	Juvenile/unknown	3	2					1					
	Female	34	32					2	11	1			10
	Male	20	48					1	19	1			13
SCB Recreational	Juvenile/unknown			4		2							
	Female			6		5			3			3	1
	Male			8					2				1
SCB Research	Juvenile/unknown			8	123						13	6	
	Female			1	11							4	
	Male				7							2	

Table 3.2. Estimates of logistic parameters (L_{50} and L_{95}) used to describe the relationship between probability of maturity with fish length for *Hyporhamphus melanochir* in the WCB and SCB, estimated from sampling in 2009-2013. 95% confidence limits for the logistic parameters are presented in brackets. *n* refers to sample size.

Bioregion	Sex	L_{50}	L_{95}	*n*
WCB	Both	225 (221 - 230)	281 (275 - 287)	1242
	Male	223 (217 - 229)	283 (277 - 290)	745
	Female	225 (219 - 232)	277 (267 - 285)	497
SCB	Both	241.6 (235 - 250)	311 (293 - 339)	541
	Male	250 (238 - 270)	323 (289 - 374)	226
	Female	235 (227 - 243)	300 (278 - 323)	225

Table 3.3. von Bertalanffy growth parameters estimated for *Hyporhamphus melanochir* sampled in the West Coast Bioregion (WCB) in 2009-2013. 95% confidence limits for the growth parameters are presented in brackets. *n* refers to sample size.

Sex	k (y^{-1})	L_∞ (TL, in mm)	t_0 (y)	n
Both	1.24 (1.14 - 1.34)	316 (312 - 321)	-0.33 (-0.40 - -0.27)	1271
Male	1.40 (1.27 - 1.53)	304 (300 - 309)	-0.27 (-0.33 - -0.23)	841
Female	1.25 (1.13 - 1.40)	332 (326 - 340)	-0.26 (-0.32 - -0.21)	413

Table 3.4. Mean length-at-age for *Hyporhamphus melanochir* sampled in the West Coast Bioregion (WCB) in 2009-2013, estimated from von Bertalanffy growth parameters for females, males and sexes pooled.

	Mean length-at-age (TL, mm)		
Age (years)	**Female**	**Male**	**Both**
1	264	252	255
2	313	291	298
3	327	301	311
4	331	303	315
5	332	304	316

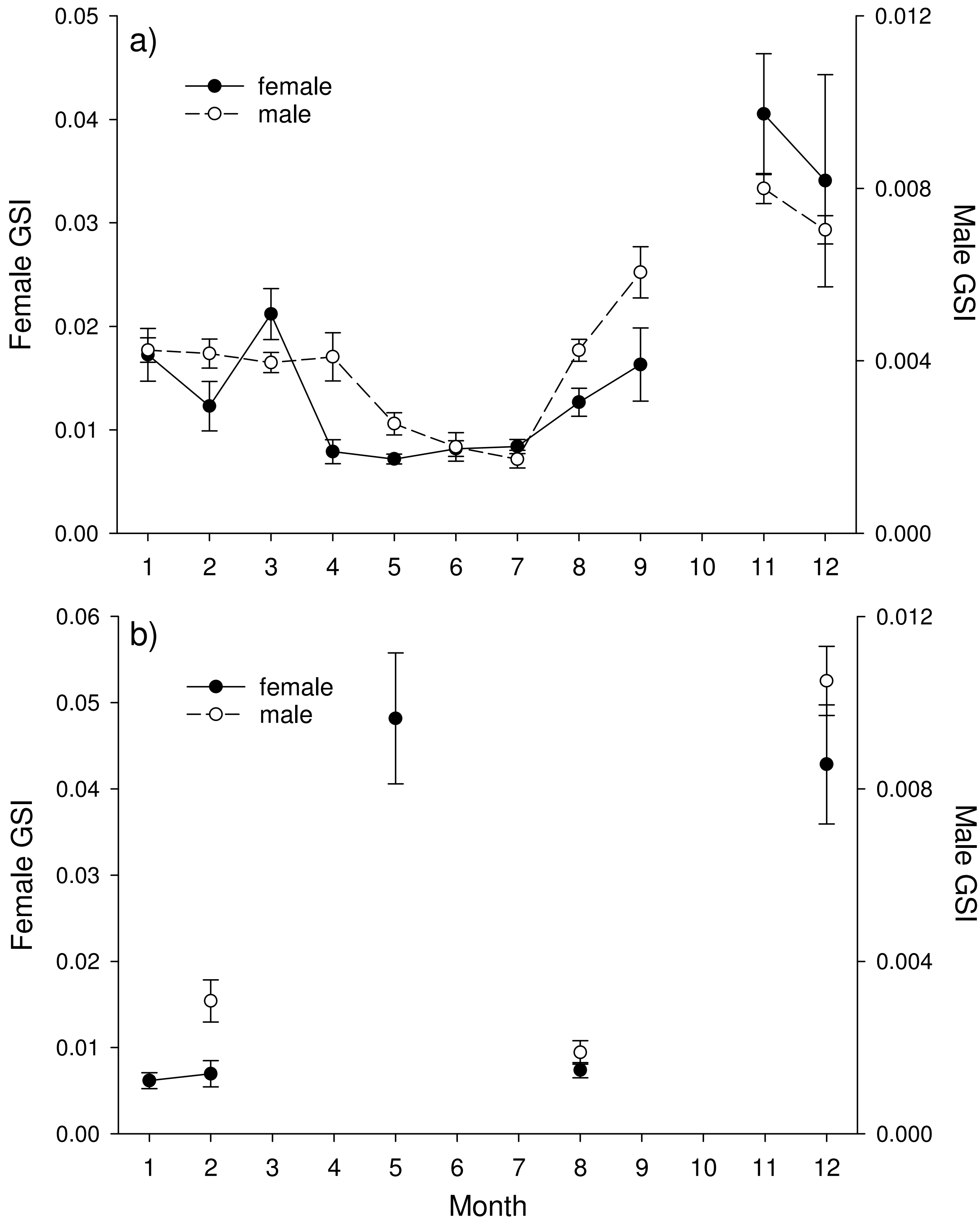

Figure 3.1. **Monthly mean (± s.e.) GSI values for male and female *Hyporhamphus melanochir* collected in the a) West Coast Bioregion and b) South Coast Bioregion in 2009-2013. (Month 1 = January, 2 = February, etc.) (blank – value not shown, less than 5 fish sampled during the month).**

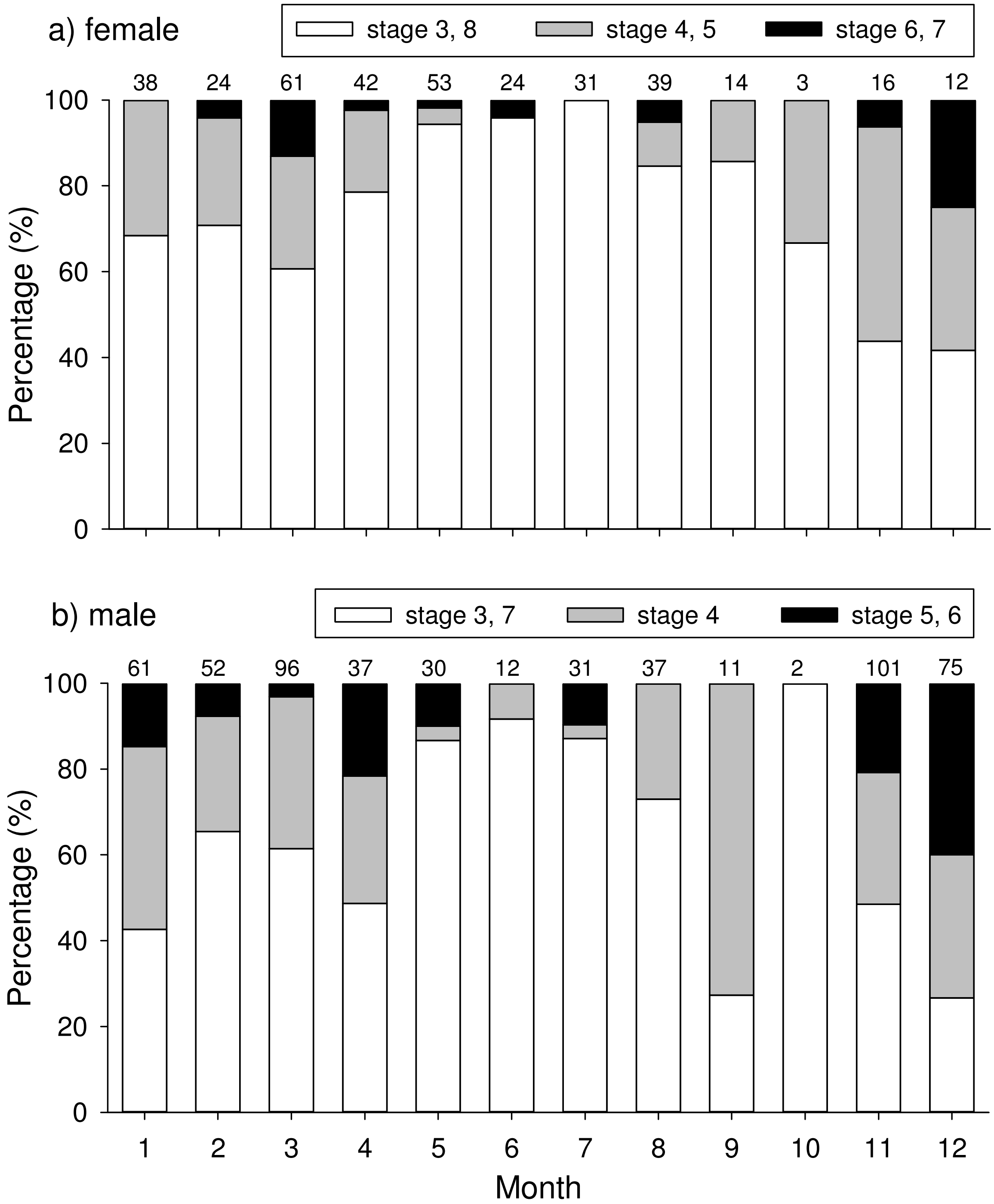

Figure 3.2. **Monthly percentage of gonads at each macroscopic stage in a) female and b) male *Hyporhamphus melanochir* collected in the West Coast Bioregion, 2009-2013. Sample size shown above each bar. (Month 1 = January, 2 = February, etc.).**

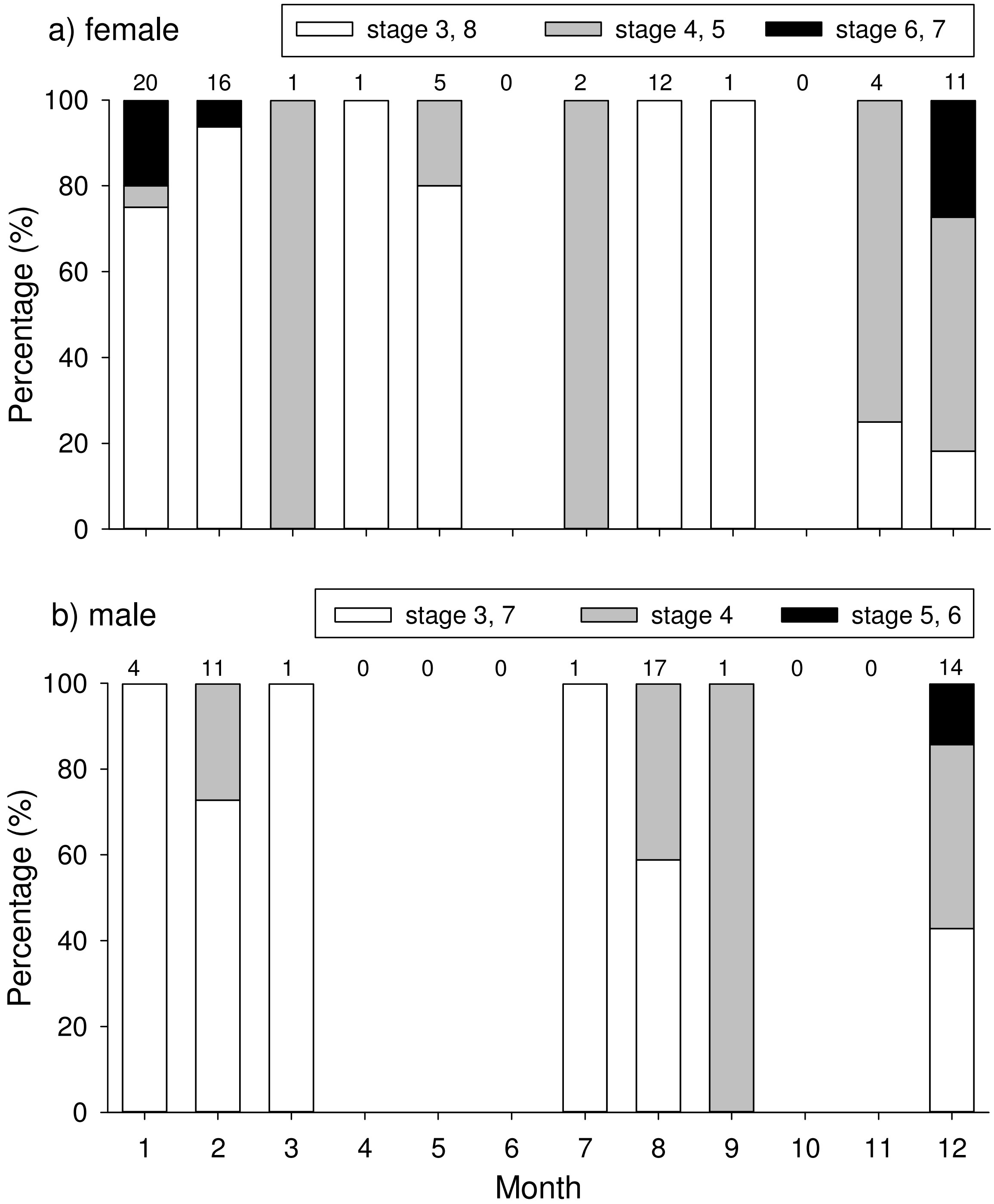

Figure 3.3. **Monthly percentage of gonads at each macroscopic stage in a) female and b) male *Hyporhamphus melanochir* collected in the South Coast Bioregion, 2009-2013. Sample size shown above each bar. (Month 1 = January, 2 = February, etc).**

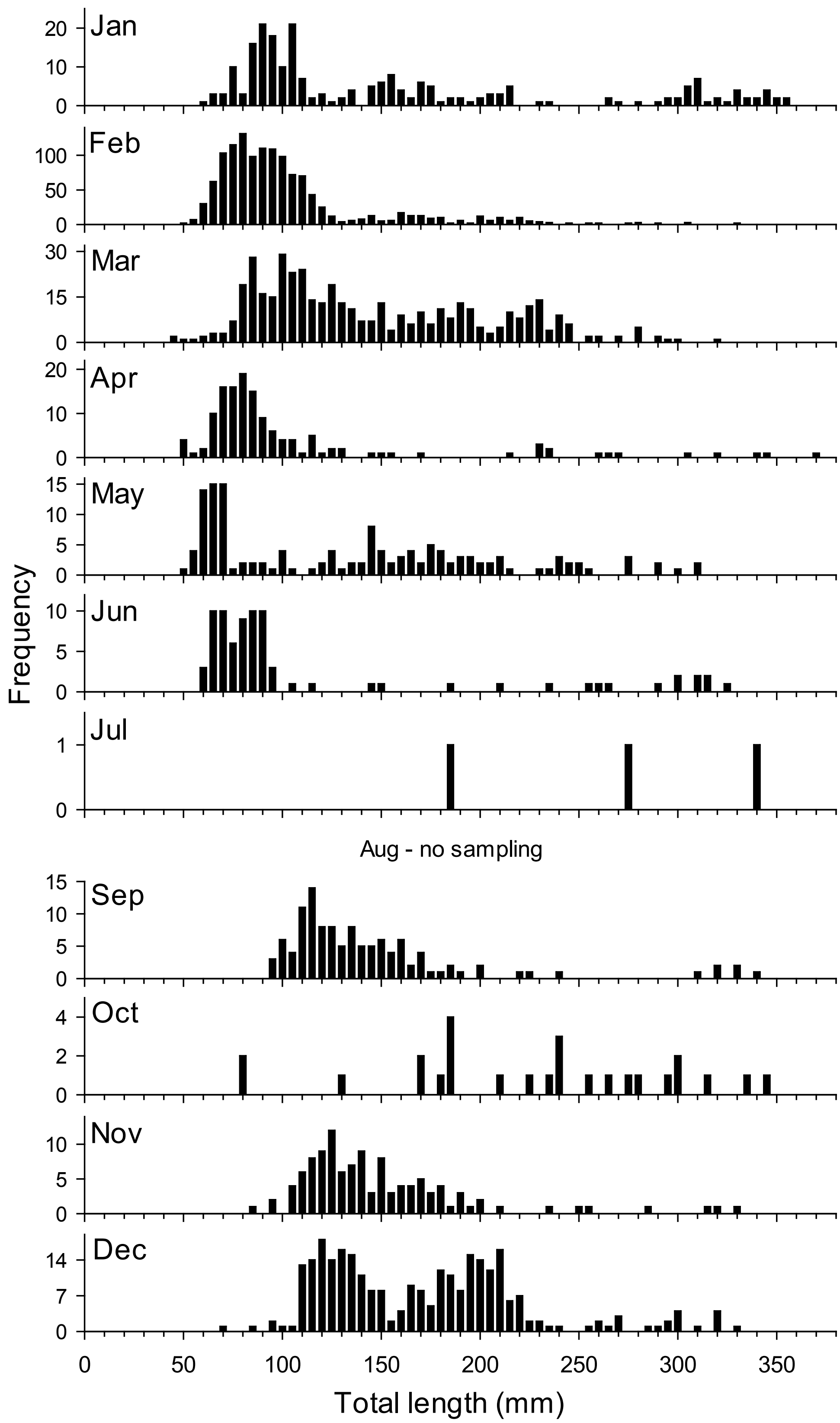

Figure 3.4. **Monthly length frequency distributions for *Hyporhamphus melanochir* collected by beach seining at various sites within the West Coast Bioregion, 1995/96 to 2011/12 (years pooled).**

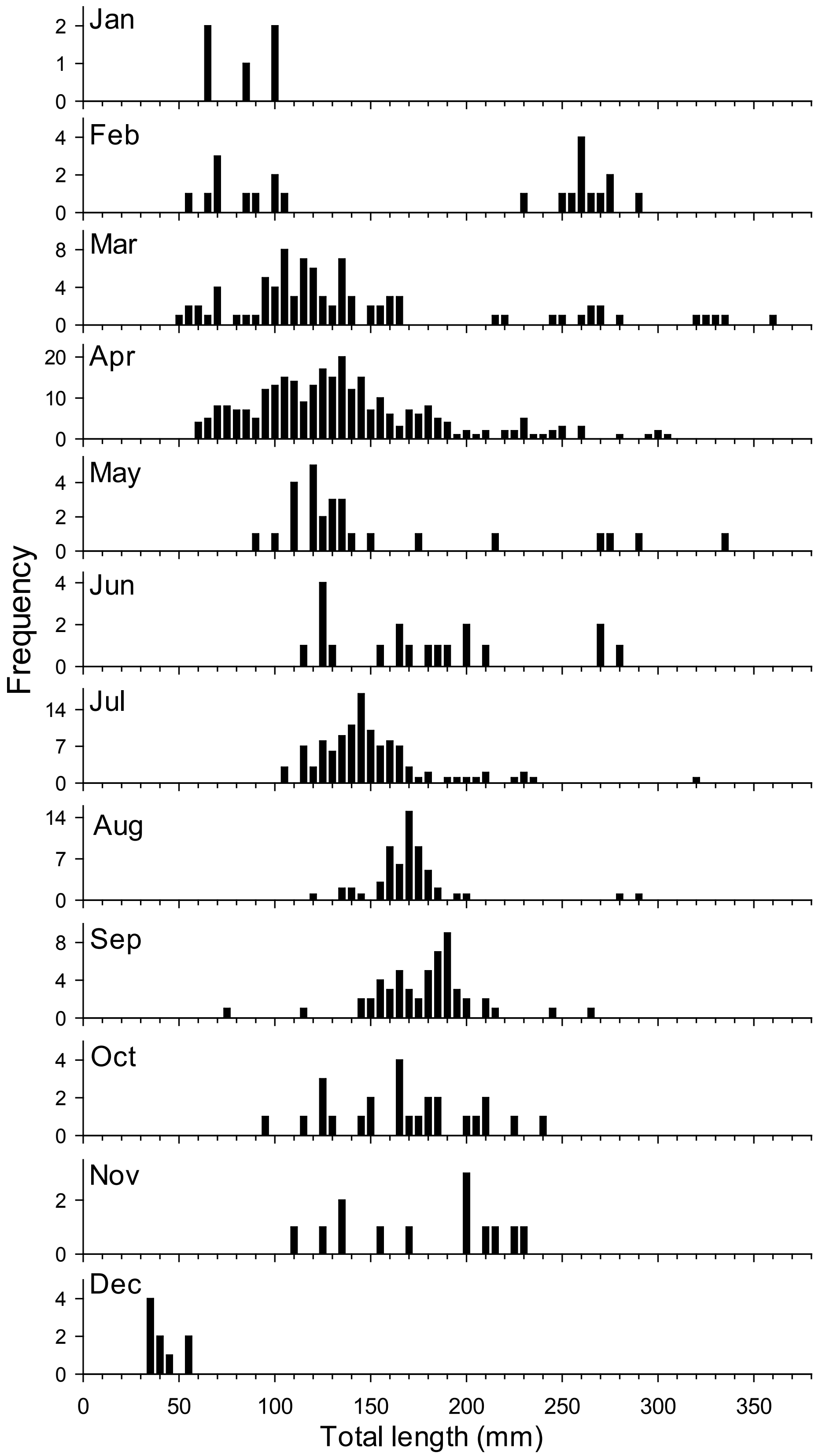

Figure 3.5. Monthly length frequency distributions for *Hyporhamphus melanochir* collected by beach seining at various sites within the South Coast Bioregion, 1995/96 to 2011/12 (years pooled).

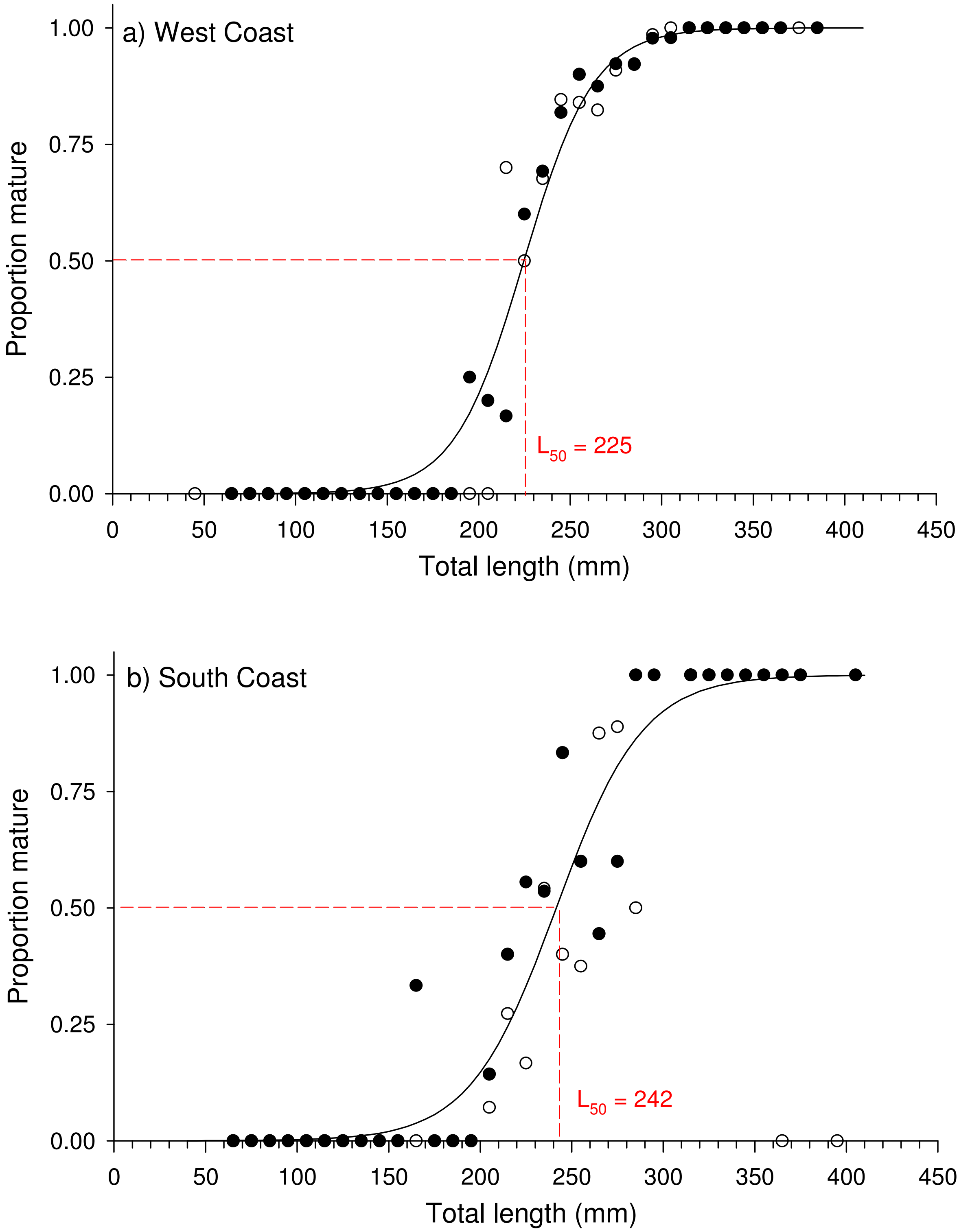

Figure 3.6. Proportion of mature individuals within each 10 mm size class for male and female *Hyporhamphus melanochir* collected in the a) West Coast Bioregion and b) South Coast Bioregion, 2009-2013. The line represents a logistic curve fitted to the pooled maturity data for the two sexes. L_{50} is the estimated length at which 50% of individuals attain maturity.

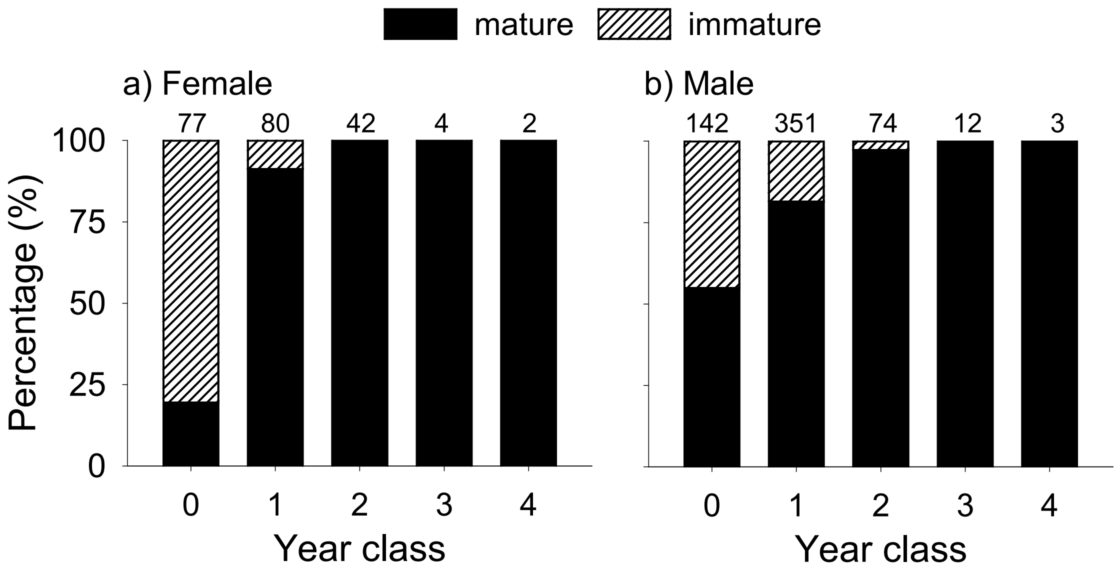

Figure 3.7. **Percentage of mature individuals within each year class for a) female and b) male *Hyporhamphus melanochir* collected in the West Coast Bioregion, 2009-2013. Sample size shown above each bar.**

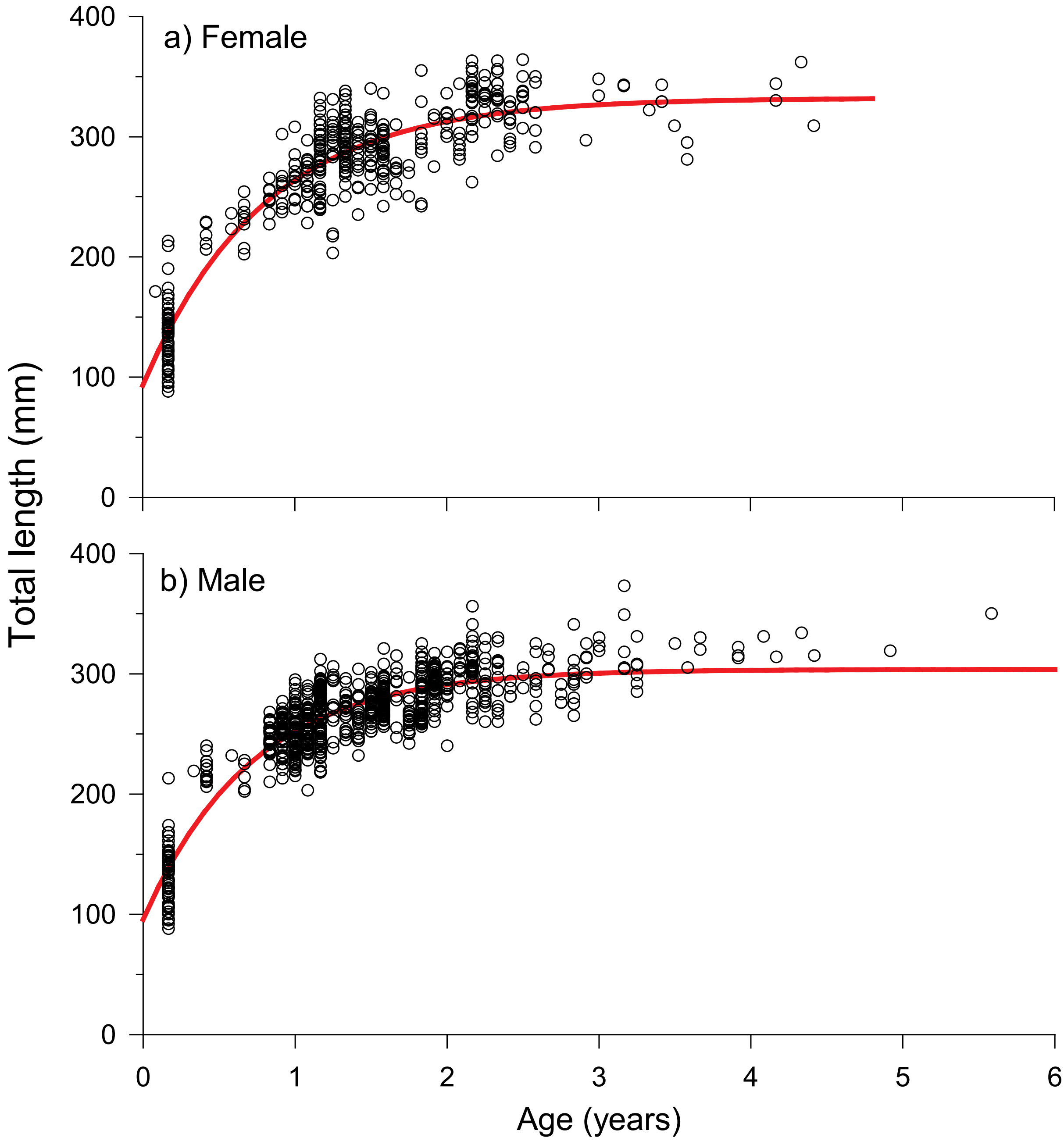

Figure 3.8. von Bertalanffy growth curves fitted to the total lengths (mm) at age (y) for a) female and b) male *Hyporhamphus melanochir* collected during 2009-2013 in the West Coast Bioregion (WCB).

4 Fishery catch and effort

Summary

- *Hyporhamphus melanochir* is harvested commercially and recreationally in nearshore and estuarine waters of the WCB and SCB of WA. The catch and catch rate of *H. melanochir* in all fisheries in WA appears to be highly seasonal, with monthly trends determined by the spawning-related movements of adult fish.
- Cockburn Sound is the largest commercial fishery for *H. melanochir* in WA, typically producing about half of the state commercial catch, and the majority (>80%) of WCB commercial landings each year. Wilson Inlet currently produces the majority (>50%) of SCB commercial landings.
- Over the past decade, the annual commercial catch in the WCB has typically ranged from 10 to 20 t per year. However, the catch declined rapidly after 2011, reaching only 4 t in 2013.
- The vast majority of the recreational catch of *H. melanochir* in WA is taken in the WCB. The exact recreational catch level is uncertain due to lack of information about the shore-based catch, but the recreational share is believed to comprise the largest component of the total catch (commercial plus recreational) in the WCB. Limited data suggests that the recreational share of *H. melanochir* landings in the WCB in recent years is 60-65%, with approximately half of this taken in Cockburn Sound.
- All catch and catch rate indicators from both sectors (commercial and recreational) suggest a major decline in abundance of *H. melanochir* in Cockburn Sound (and probably the broader Perth area) since the late 1990s. In Cockburn Sound, catches and catch rates suggest stock abundance has been declining gradually since 1995 and rapidly since 2011. These indicators suggest a very substantial (70-90%) reduction in abundance, reaching historically low levels in 2013 and 2014.
- The decline in *H. melanochir* abundance in Cockburn Sound indicated by catch rate trends is consistent with other biological indicators (see Section 6) that suggest worsening stock status over the same period.
- Given that the majority of *H. melanochir* harvested in the WCB are taken recreationally, mainly by shore-based fishers, it will be necessary to obtain more information about shore-based recreational landings (catch level, distribution and composition) to effectively manage the impact of fishing on *H. melanochir* stocks in the WCB, including in Cockburn Sound.
- Since 2005/06, individual daily catches of *H. melanochir* (including discarded fish) reported by volunteer logbook fishers in the WCB have ranged from 0 to 11. This suggests that the current recreational daily bag limit of 30 fish is rarely attained and is not constraining total recreational catches.
- Although catch rate trends suggest that the abundance of *H. melanochir* in Wilson Inlet has been stable to date, the increasing commercial catch trend is of some concern given

the vulnerability to overfishing that *H. melanochir* has displayed elsewhere. Higher levels of monitoring of this stock would need to be undertaken to determine whether the current catch level is sustainable.

4.1 Introduction

Hyporhamphus melanochir is an important commercial and recreational fishery species within temperate waters of WA. It is a small, but relatively valuable, component of the nearshore commercial catch in the West Coast and South Coast Bioregions, fetching a wholesale price of up to $10 per kilogram in 2013 (DoF unpub. data). *H. melanochir* is also among the ten most popular (i.e. numerically abundant) finfish species caught by shore- and boat-based recreational fishers in both Bioregions (Henry and Lyle 2003, Sumner *et al.* 2008, Smallwood *et al.* 2012, Ryan *et al.* 2013).

Despite the overall importance of *H. melanochir* to nearshore fisheries in temperate WA, the characteristics of the individual fisheries that target this species, and their catch and effort trends, are poorly understood. This type of information is fundamental to understanding the status of local exploited stocks of this species and to developing effective management.

Given the complex stock structuring exhibited by *H. melanochir*, with semi-discrete populations separated by small distances (< 60km, Steer *et al.* 2010, 2011), it is important to identify the location of fishery landings of this species to identify risks to particular stocks due to localised exploitation. Once identified, 'high risk' stocks can then provide a focus for future management. At a minimum, catch and effort data in 'high risk' stocks should be monitored closely since catch rate trends may provide a cost-effective indicator of stock abundance.

Objectives of this Section:

- Describe the spatial and temporal distribution of commercial and recreational fishery landings of *H. melanochir* in Western Australia.
- Based on the distribution of landings, identify 'high risk' stocks of *H. melanochir* and evaluate the potential of local fishery catch and effort data to provide an index of relative abundance for these stocks.
- Describe trends in *H. melanochir* abundance in 'high risk' stocks as suggested by fishery catch rates.

4.2 Methods

4.2.1 Fisheries management

The *Cockburn Sound (Fish Net) Managed Fishery* operates in Cockburn Sound and adjacent waters in the Perth region, covering an area of ~190 km^2 (Fig. 4.3). The number of licensees in this fishery was reduced (via voluntary licence buy-back scheme) to a single licence in 2003 and subsequent years. In addition to this licensee, a small number of other commercial fishers are permitted by Conditions attached to their fishing boat licences to net fish within Cockburn Sound. However, in practice, negligible quantities of *H. melanochir* are taken by these fishers.

The *Cockburn Sound (Fish Net) Management Plan 1995* specifies that all garfish must be captured with a 'garfish net'. This net is effectively a surface haul net (deployed to/from a boat) and is defined in the Plan as 260 m length x 18 m depth, consisting of panels of 50 mm (2 inch) and 37 mm mesh (1.5 inch) in the wings and 25 mm (1 inch) in the bunt.[1]

The *South Coast Estuarine Managed Fishery* operates in 13 estuaries in the SCB, including Wilson Inlet. In practice all 13 estuaries are not fished each year. In this fishery, *H. melanochir* are taken by haul nets (deployed to/from a boat) and by gill nets (described as 'set nets' in the Management Plan). The *South Coast Estuarine Management Plan 2005* specifies that gill nets used in this fishery have a minimum mesh size of 57 mm, which is too large to effectively retain garfish. Therefore, a subclause of the Plan specifies that gill nets with a minimum mesh size of 44 mm are permitted from the 1st of June to the 1st of November each year. The maximum length of net(s) with this mesh size deployed per licensee must be less than 400 m. These nets must be set in waters >2m deep, with a maximum net depth of 50 meshes.

The vast majority of *H. melanochir* landings by the *South Coast Estuarine Managed Fishery* occur in Wilson Inlet.

From 1975 to 1991, a legal minimum length of 230 mm TL for *H. melanochir* applied to recreational and commercial fishers in WA. In June 1991, the legal minimum length for recreational fishers was removed (i.e. there has been no minimum length for recreational fishers since June 1991) and garfish species were placed in a 'low risk' finfish category. A mixed species recreational bag limit of 40 applied to this group until October 2009. In October 2009, this limit was reduced to 30 in the WCB, but remained at 40 in the SCB. In February 2013, a state-wide mixed species daily bag limit of 30 'nearshore/estuarine' finfish (including garfish) was implemented.

The legal minimum length of 230 mm TL for *H. melanochir* taken by commercial fishers was removed in May 2011. There is currently no legal minimum length for *H. melanochir* taken by commercial fishers.

4.2.2 Sources of commercial catch data

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

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

[1] At the time of writing, all commercial landings of garfish taken in Cockburn Sound were incorrectly recorded in the Department of Fisheries catch and effort database (CAES) as being taken by 'gill nets'.

Prior to 1990, the compulsory monthly catch and effort returns submitted by all WA commercial netting fisheries, which includes all *H. melanochir* fisheries, provided limited detail about the netting methods used. Hence, landings reported prior to 1990 cannot always be accurately assigned to particular methods. For example, the returns did not distinguish between various types of haul nets (e.g. beach seine versus haul net). After 1990, the format of monthly returns issued by DoF was altered to provide more detailed information about catches by each of these methods.

New compulsory monthly catch and effort returns introduced after 1990 were also accompanied by the introduction of additional CAES reporting blocks and so more detail about the location of catches is available after 1990. For example, a specific block number was assigned to Geographe Bay and various individual estuaries (Fig. 4.1).

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

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

4.2.3 Calculation of commercial catch-per-unit-effort (CPUE)

Catches of finfish are reported in compulsory monthly returns as the total weight (kg) of each species captured by each fishing method (haul net, gill net, etc) during the month. Monthly fishing effort is reported in 'block days' (Bdays), which is the total number of days spent using a particular method within a particular CAES reporting block. The area of a CAES block is typically 1 x 1 degree (60 x 60 nautical miles) (Fig. 4.1).

Due to the multi-species nature of most commercial netting fisheries and the monthly aggregation of data reported by fishers, it is often not possible to determine precisely the effort spent specifically targeting *H. melanochir* by a particular method. In multi-species fisheries, a single method can be used to target *H. melanochir* and several other species within a single month. In the absence of daily or 'shot-by-shot' catch and effort information, the target species and the effort directed towards a particular species cannot be ascertained[2].

The problem of the lack of knowledge of targeted effort can be partly overcome by restricting the calculation of catch rates to times/areas where *H. melanochir* contributes a relatively large proportion of the total catch of all species. This increases the likelihood that reported effort was actually spent targeting *H. melanochir*.

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

In this Section, annual CPUE was calculated for various commercial fisheries that have historically captured the majority of *H. melanochir* landings in WA. For each fishery, annual CPUE was calculated as the total annual catch (C) by the fishery, divided by the total annual effort (E) by the fishery. Specific definitions of total catch and total effort are outlined below for each fishery. In this Section, commercial 'catch' refers to live weight of landed fish.

Cockburn Sound CPUE

In Cockburn Sound, commercial fishers have historically targeted *H. melanochir* during all months (although the catch is usually seasonal, peaking in autumn). The majority of pre-1990 landings were recorded as taken by ‘gill nets’. However, more recent landings are known to have been mainly taken by ‘garfish nets’. It is not possible to distinguish between catches of *H. melanochir* by gill nets and garfish nets in historical DoF records because the code ‘GN’ was used for both gill net and garfish net. Annual trends in gill/garfish netting catch and effort in Cockburn Sound changed markedly after 1996 in response to the restructuring of the gill net fishery to exclude targeting of crabs. Most of the *H. melanochir* catch after this time can be assigned to garfish netting. Annual catch and effort by garfish netting can therefore be calculated with a much greater degree of confidence from 1996 onwards.

Since 2003, the *H. melanochir* landings in Cockburn Sound have been exclusively taken by a single vessel. This vessel also reported the vast majority of *H. melanochir* landings in the previous decade (65 - 85% of the total *H. melanochir* catch in Cockburn Sound was taken by this vessel each year). In addition to fishing activity within Cockburn Sound (CAES block 9600), this vessel reports a small amount of *H. melanochir* catch and effort in the adjacent CAES block (3115) each year (Fig. 4.1). The catch rate of *H. melanochir* by this vessel was calculated from the catch and effort reported in both blocks. The annual CPUE of garfish in Cockburn Sound was determined from the catch and effort reported by this single vessel, calculated as CPUE = C/E , where;

C = sum of H. melanochir catches by garfish netting in CAES blocks 9600 and 3115. All months included.

E = sum of Bdays by garfish netting in CAES blocks 9600 and 3115. All months included.

South Coast Bioregion ocean waters CPUE:

Relatively small quantities of *H. melanochir* are taken each year by beach seine nets on ocean beaches in the SCB, mainly around Albany. *H. melanochir* are traditionally captured by beach fishers in May-September. The annual CPUE of *H. melanochir* on ocean beaches of the SCB was determined from the catch and effort reported by beach-based fishers, calculated as CPUE = C/E , where;

C = sum of H. melanochir catches by haul and seine nets in all ocean CAES blocks in the South Coast Bioregion, reported from May-Sept, inclusive.

E = sum of Bdays by haul and seine nets in all ocean CAES blocks in the South Coast Bioregion, reported from May-Sept, inclusive.

4.2.4 Recreational fishery catch and effort

The total state-wide catch and effort of recreational fishers was estimated in 2000/01 during the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003). In the WCB, the catch (numbers of fish) and effort of recreational fishers was estimated by DoF during 12-month surveys of boat-based recreational fishing in 1996/97, 2005/06, 2008/09, 2009/10 and 2011/12 and a 3-month survey of shore-based recreational fishing in April-June 2010[3]. The length composition of the retained catch of selected species (including *H. melanochir*) was estimated during DoF surveys.

Details of the DoF boat-based surveys from 1996/97 to 2009/10 are given by Sumner *et al.* (2008). Briefly, boat-based fishers were interviewed at various boat ramps between Kalbarri and Augusta. Catch information was obtained using the bus route method between ramps within districts, with completed trip information obtained at the time of the interview. Estimates of total catch and effort in the Bioregion were calculated using weightings derived from the distribution of effort observed in the survey. Details of the DoF statewide boat-based survey in 2011/12 are given by Ryan *et al.* (2013). Briefly, this survey used the 'Recreational Fishing from Boat Licence' (RFBL) as the basis for sampling fishers and used an integrated system of the following survey methods: (i) off-site Phone Surveys (encompassing an initial Screening Survey, 12 month Phone-Diary Survey, followed by post-enumeration "Wash-Up"/Attitudinal, Non-Intending Fisher and Benchmark Surveys), ii) on-site Boat-Ramp Surveys (including a state-wide Biological Survey and a Perth metropolitan Validation Survey), and (iii) a remote Camera Survey.

Details of the shore-based survey are given by Smallwood *et al.* (2011a, 2011b). Briefly, catch information was obtained in April–June 2010 by roving creel surveys and interviews of incomplete trips. Shore-based fishers were interviewed in the Perth area (Ocean Reef to Woodmans Point). There were 1,194 incomplete trip interviews with fishing parties during the study. An individual was randomly selected from each fishing party to answer questions on behalf of all people in the group.

Each of the above surveys employed different techniques to estimate catch and are not directly comparable. Artifacts of the various survey methods may have contributed to the differences in catch estimates, in addition to any changes in the availability of fish.

The conversion of recreational catch estimates from *number* to *weight* of fish is problematic. The estimated average weight per retained individual of *H. melanochir* ranges from approximately 70 to 165 grams, depending on the survey (see Section 3 for size composition in various surveys). For example, the average weight of retained fish was estimated to be 138 grams during the April–June 2010 shore-based survey and 104 grams during the 2011/12 boat-based survey. The wide range of estimated weights may partly reflect actual spatial and temporal variations in average fish size. However, variations in estimated weight may also be a consequence of unrepresentative sampling during some surveys. In this Section, an average weight of 120 g per fish has been assumed for all surveys when calculating catch weights.

[3] Another 3-month survey of shore-based fishing was conducted April-June 2014, but results were not available at the time of writing.

Voluntary recreational logbooks

A voluntary recreational fisher logbook program (part of the DoF Research Angler Program (RAP)) commenced in 2005 and is ongoing. Participants in the RAP logbook scheme include shore- and boat-based recreational fishers in the WCB and SCB.

Recreational logbook fishers were asked to record fishing date, location, start and finish times of each fishing session, number and name of each captured species, whether fish were retained or released and the total length (TL) of each fish to the nearest millimetre.

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

For the purpose of this analysis, the 'Perth area' was defined as logbook reporting blocks BN56-BN64, BO56-B064, BP56-BP64, BQ56-BQ64 and BR56-BR64 (Fig. 5.2). Shore-based catch and effort at Rottnest Island was excluded.

H. melanochir are usually identified correctly by logbook fishers in the Perth area. Some non-specific "garfish" landings were recorded in logbooks. These were assumed to be *H. melanochir* because the only other species of garfish likely to be taken by shore-based recreational fishers in the Perth area is *Hemirhamphus robustus* (three-by-two garfish*).* *Hyporhamphus robustus* is distinct in appearance and is uncommon in Perth fishery landings (~5% of all garfish species landings) compared to *H. melanochir*.

To examine average monthly trends in logbook data, the catch (C_{month}), effort (E_{month}) and catch rate ($CPUE_{month} = C_{month} / E_{month}$) was calculated for each month over the period 2005/06 to 2011/12. Data from 2012/13 and 2013/14 were excluded due to very low levels of reported catch in these years.

To remove the effect of annual variation, monthly values of C_{month} and E_{month} within each year were standardised by dividing by the sum of monthly values for that year. An average standardised value was then calculated for each month over the period 2005/06 to 2011/12.

The average annual catch rate (CPUE) of *H. melanochir* by shore-based logbook fishers operating in ocean waters of the Perth area was calculated from 2005 until 2014. Only partial data were available (i.e. zero catch and/or effort reported in some months) for 2005 and 2014. Catch and effort in October and November was excluded from the calculation of CPUE due to the very low catch levels in these months. $CPUE = C / E$, where

C = total catch of H. melanochir, including retained and released fish, reported in all months, excluding October and November.

E = total number of hours fished, including fishing trips resulting in non-garfish catches and nil catch, reported in all months, excluding October and November.

4.3 Results

4.3.1 Total commercial catch by Bioregion

H. melanochir is targeted by commercial fisheries in the SCB and WCB. This is the main species of garfish taken commercially in these Bioregions. Prior to 1990, river garfish (*Hyporhamphus regularis*) was also occasionally reported (Fig. 4.4). However, *H. regularis* is not known to occur in the SCB, and so SCB landings recorded as 'river garfish' were probably *H. melanochir*. In the WCB, 'river garfish' was mainly recorded in Cockburn Sound and the Leschenault and Peel-Harvey estuaries. Although *H. regularis* does occur in these areas it is likely that many of these landings were also *H. melanochir*. The other garfish species occurring in the WCB (i.e. *Hemirhamphus robustus* and *Euleptorhamphus viridis*) are infrequently found in commercial landings.

Since 2000, the total state catch of *H. melanochir* has ranged from 38 t (in 2004) to 11 t (in 2012). Cockburn Sound produced approximately 50% (range 20-70% per year) of all commercial landings of *H. melanochir* in WA over this period.

From 1976 to 2013, total annual landings of *H. melanochir* in the SCB ranged from 4 t (in 2001) to 35 t (in 1992), and followed a stable (i.e. non-directional) long-term trend over this period (Fig. 4.4). In the last 5 years (2009-2013), SCB total annual landings ranged from 5 to 13 t.

Over the past decade (2004-2013), SCB landings of *H. melanochir* were mainly taken in coastal waters (53% by weight of SCB catch, mainly taken in CAES block 3418) and in Wilson Inlet (42%), with minor quantities in other estuaries (5%) (Fig. 4.5a). The landings in coastal waters were predominantly by beach seine nets (97% of catch by weight in this location), landings in Wilson Inlet were predominantly by gill nets (90%) and in other estuaries were predominantly by haul nets[4] (89%). Since 2011, the majority of SCB landings were taken in Wilson Inlet (Fig. 4.5a). This change was due to the combined effects of a decrease in ocean landings and an increase in Wilson Inlet landings.

From 1976 to 2013, total annual landings of *H. melanochir* in the WCB ranged from 4 t (in 1978, 1983 and 2013) and 44 t (in 1999) (Fig. 4.4). After the early 1980s, annual landings increased steadily until the peak was reached in 1999. This increase was due to an expansion of the Cockburn Sound *H. melanochir* fishery, which increased from <1 t in 1980 (comprising 8% of WCB landings) to 37 t in 1999 (84% of WCB landings). Since 1991, Cockburn Sound (i.e. CAES block 9600) has contributed 82% (range 70-96% per year) of WCB landings. In the last 5 years (2009-2013), WCB total annual landings ranged from 4 to 19 t.

Over the past decade (2004-2013), *H. melanochir* landings in the WCB were taken in Cockburn Sound (82% of WCB landings), in Geographe Bay (CAES blocks 9601, 3315, 33151) (8%), coastal waters near Augusta (block 3415) (5%) and in waters adjacent to Cockburn Sound (CAES block 3115) (5%) (Fig. 4.5b). Over this period, all landings in Geographe Bay and Augusta were taken by beach seine nets, and all landings in Cockburn Sound and adjacent waters by 'garfish net'.

[4] A 'beach seine net' is deployed to/from the shore, whereas a 'haul net' is deployed to/from a boat.

4.3.2 Wilson Inlet commercial fishery

Wilson Inlet is a small (48 km^2) estuary that is seasonally open to the sea (typically during winter/spring). Consequently, the *H. melanochir* population in this estuary has very limited connectivity with populations in adjacent ocean waters. Given this limited connectivity and the low dispersal potential of the species due to its biological characteristics (see Section 2), Wilson Inlet is assumed to host a discrete, self-sustaining breeding stock of *H. melanochir*. There is evidence that breeding occurs in this estuary - fish possessing developed and spent gonads have been collected from this estuary and *H. melanochir* eggs attached to seagrass have been reported by commercial fishers (see Section 3).

From 1976 to 2013, total annual landings of *H. melanochir* in Wilson Inlet ranged from 0-2 t (prior to 1988) to 10 t (in 2013) (Fig. 4.5a). From 1988 to 2013 there was an increasing trend in landings. In all periods, the majority of *H. melanochir* were taken by gill nets.

H. melanochir landings by gill nets in Wilson Inlet are highly seasonal, mainly occurring June-October. In the past decade (2004-2013), 94% of fish landed by gill nets were taken during June-October. During these months gill nets with small mesh (minimum mesh size 44 mm) are permitted in this fishery. In other months, larger mesh (minimum 57 mm), which is less effective at retaining *H. melanochir*, is required.

The primary target species in Wilson Inlet is cobbler (*Cnidoglanis macrocephalus*), which typically comprises 50-60% by weight of the annual catch, with the remainder comprising numerous secondary target species. *H. melanochir* are mainly caught in June-October when landings of cobbler are lowest (Fig 4.6). Hence, the timing of the *H. melanochir* catch in Wilson Inlet does not indicate a seasonal availability of this species, but rather is determined by management arrangements and the availability of other species.

Small quantities of *H. melanochir* are also taken in Wilson Inlet by haul nets. These landings are mainly during the warmer months, which demonstrates the availability of *H. melanochir* at this time (Fig. 4.6). Haul netted fish are typically landed in better condition than gill netted fish, fetching a higher price. However, haul netting is more labour intensive (usually a team of 2 required, lengthy retrieval time, etc.) than gill netting (single operator, rapid retrieval, etc.) and so is less favoured in this fishery.

Due to the multi-species nature of the fishery in Wilson Inlet and the monthly reporting of catch and effort (effort, in days, is reported as a monthly total), it is not possible to determine the level of effort spent specifically targeting *H. melanochir*. During June-October, *H. melanochir* typically comprise 0-30% of gill net landings by each fisher, implying that the majority of their gill netting effort is spent targeting other species. Since effort specifically directed towards *H. melanochir* cannot be quantified, CPUE for this species cannot be determined in this fishery.

Although specific effort is not known, other data suggest that the level of targeting of *H. melanochir* by this fishery has increased since 1990. From 1990 to 2013, the number of vessels reporting garfish landings in Wilson Inlet remained relatively stable, between 6 to 12 (Fig. 4.7a). However, when expressed as a proportion of the total number of vessels active in this estuary per year, the number of vessels reporting *H. melanochir* increased from ~50% to

~80%. Over the same period, the annual catch of *H. melanochir* increased from 1 t to 10 t, representing an increase from 1% to 9% of the total annual finfish catch of the Wilson Inlet fishery (Fig. 4.7b).

The increased targeting of *H. melanochir* may have been in response to the increasing value of this species. The wholesale price of *H. melanochir* has increased at a slightly faster rate than the price of the other main target species (i.e. cobbler, black bream, sea mullet) in the Wilson Inlet fishery (Fig. 5.8). In recent years, the price of *H. melanochir* has been similar or higher than the price of these other species.

4.3.3 South Coast Bioregion ocean beach commercial fishery

From 1976 to 2013, annual landings of *H. melanochir* in ocean waters of the SCB ranged from 1 t (in 2000) to 33 t (in 1992) (Fig. 4.5a). These landings were mainly taken in coastal waters east of Albany (i.e. CAES block 3418).

Landings of *H. melanochir* in ocean waters of the SCB are highly seasonal, mainly occurring during May-September each year (Fig. 4.9). The timing of the catch partly reflects availability (P. Benson. commercial fisher, pers. comm.) but also reflects the timing of other activities by the beach-based net fishers in this region. In particular, these fishers traditionally target *Arripis truttaceus* (western Australian salmon) and *A. georgianus* (Australian herring) during their 'spawning run' in March-April and also target salmon during their 'back run' in August-October.

Due to the multi-species nature of the SCB beach-based netting fishery and the monthly reporting of catch and effort (effort, in days, is reported as a monthly total), it is not possible to precisely determine the level of effort expended on targeting *H. melanochir*. The level of haul net and beach seine effort reported during May-September each year, when *H. melanochir* comprises a relatively high proportion of the catch, provides the best available measure of targeted effort by beach-based net fishers.

Since 1995, the average catch rate of *H. melanochir* by beach-based net fishers during May-September fluctuated between 6 and 101 kg per day (Fig. 4.10a). The highest catch rates occurred in more recent years. However, this trend is unlikely to reflect an increase in abundance of *H. melanochir*, but rather, is likely to be a consequence of reduced catch and effort associated with the main target species (A. *truttaceus* and *A. georgianus*), due to declines in the abundance and marketability of those species. In recent years, *H. melanochir* comprised a higher proportion of the beach-based netting catch during May-September, mainly due to declines in landings of the other target species (Fig. 4.10b).

4.3.4 Cockburn Sound commercial fishery

H. melanochir is taken commercially in Cockburn Sound (CAES block 9600, formerly part of 3315) by the *Cockburn Sound (Fish Net) Managed Fishery*. This fishery had 6 licensees in the early 1990s, but this number was reduced via a Voluntary Fishery Adjustment Scheme (VFAS, i.e. license buy-backs) to just one licensee in 2003 and subsequent years. *H. melanochir* and *A. georgianus* have consistently been the main species targeted by this licensee, comprising 55% and 38%, respectively, of the total finfish catch taken by netting methods since 1995.

Historically, commercial landings of *H. melanochir* in the Perth/Mandurah area, including the main fishing area of Cockburn Sound, have been highly seasonal, reaching a maximum during March-May and a minimum during November-December each year (Figs. 4.11a and 4.12). Historical landings of *H. melanochir* in other areas of the WCB have also been seasonal, although the timing differs to Cockburn Sound. In Geographe Bay landings peaked in October-December, while estuarine landings peaked over an extended period from October to May (Fig. 4.11b and 4.11c).

Whilst commercial landings of *H. melanochir* have declined over time in most areas of the WCB, mainly due to reductions in fishing effort (area closures, license buy-backs, etc.), the catch of *H. melanochir* in Cockburn Sound has been relatively stable, reflecting continuous targeting of this species since the late 1980s (Fig 4.5b). Hence, the catch rate of the *Cockburn Sound (Fish Net) Managed Fishery* currently provides the best available index of *H. melanochir* availability in the WCB.

The annual commercial catch of *H. melanochir* in Cockburn Sound in the late 1970s was low (<2 t per year) (Fig. 4.5b). Landings gradually increased after this time, reaching an historical peak of 38 t in 1999. Landings then gradually declined to reach 10-15 t per year during the period 2006-2011. The catch declined sharply from 15 t in 2011 to 6 t in 2012, and then 3 t in 2013 (Fig. 4.5b). These annual catch trends (increasing and decreasing) partly reflect trends in annual commercial effort in Cockburn Sound.

Due to the multi-species nature of the catch in the Cockburn Sound fishery and the monthly reporting of catch and effort (effort, in days, is reported as a monthly total), it is not possible to precisely determine the level of effort expended on targeting *H. melanochir*. However, since *H. melanochir* comprised 38-83% of the total catch per year (and 55% overall) from 1995 and 2011, this implies that a substantial proportion of the annual effort was directed towards *H. melanochir*.

From 1995 to 2013, the annual total effort reported by the main vessel in this fishery increased slightly while the annual catch and average catch rate of *H. melanochir* by the vessel followed a declining trend (Fig. 4.13a). Over this period, the total annual catch weight (including all species) by this vessel was stable, but the proportion of *H. melanochir* in the total annual catch declined (Fig. 4.13b). The catch, catch rate and proportion each declined more sharply after 2011, reaching historically low levels in 2013. From 2010 to 2013, the annual catch of *H. melanochir* by this vessel declined by 77%, and the annual catch rate by 76%.

4.3.5 West Coast Bioregion recreational fishery

The current recreational catch of *H. melanochir* in WA is unknown. The only survey of the state-wide catch, including shore- and boat-based catches, was in 2000/01 during a national phone diary survey (Henry and Lyle 2003). In 2000/01, the total retained recreational catch of *H. melanochir* in WA was estimated to be 230,503 fish (27.7 t), with 92% (25.6 t) taken in the WCB and the remaining 8% (2.1 t) taken in the SCB (Table 4.4). Within the WCB, 59% of the catch was taken by shore-based ocean fishers, 34% by boat-based ocean fishers and the remainder (6%) by estuary fishers (either shore or boat-based) (Table 4.1). In 2000/01, 80% of the total WCB recreational catch of *H. melanochir* was taken in the Perth metropolitan area. The most popular recreational area was Cockburn Sound (area equivalent to Cockburn Sound commercial fishery zone), where 53% of the total WCB recreational catch was taken.

The current catch of *H. melanochir* by shore-based fishers, who are still thought to take the largest share of recreational landings within the WCB, is not known. A pilot survey of this sector was conducted during April-June 2010 in the Perth region and estimated a retained catch of 56,987 (6.8 t) (Smallwood *et al.* 2012) (Table 4.2). During this survey, *H. melanochir* was the second most commonly retained species (after *Arripis georgianus*), with an average catch rate of 0.27 fish per angler hour (retained fish only; 0.29 fish per angler hour with the inclusion of released fish). In 2003, a 12-month survey of shore-based fishers at Rottnest Island estimated a total catch of 3,847 fish (<1 t) and an average catch rate of 0.088 fish per angler hour (0.095 with the inclusion of released fish) during the survey (Smallwood *et al.* 2006). *H. melanochir* was the second most commonly retained species (after *A. georgianus*) during this survey.

A second survey of shore-based recreational fishing in the Perth region was conducted in April-June 2014. The final results of this survey were not available at the time of writing. Preliminary estimates of the retained *H. melanochir* catch and catch rate during this survey was <4,500 fish and 0.03 fish/hour (C. Smallwood, unpubl. data). These preliminary values represent substantial declines in recreational catch and catch rate since the previous survey in 2010. The decline in catch rate implies a ~90% reduction in availability of *H. melanochir* between 2010 and 2014.

Since the current spatial and temporal distribution of the *H. melanochir* recreational catch is not known, the results of these spatially limited surveys cannot be ‘scaled up’ to precisely estimate the total annual recreational catch within the WCB. However, it is reasonable to assume that the total annual WCB shore-based catch in 2009/10 was higher than that estimated for the 3-month Perth survey in 2010. The shore-based catch in April-June 2010 (56,987 fish) was approximately twice the entire annual WCB boat-based catch in 2009/10 (28,186 fish) (Table 4.3). This suggests that the shore-based share of *H. melanochir* recreational landings in the WCB was more than 66% in 2009/10.

Estimates of annual landings of *H. melanochir* by boat-based recreational fishers in the WCB are available from surveys conducted by DoF in 1996/97, 2005/06, 2008/09, 2009/10 and 2011/12 (Sumner *et al.* 2008, DoF in prep., DoF unpubl. data), as well as the 2000/01 national survey (Henry and Lyle 2003). These surveys indicate that the boat-based catch in the WCB has declined since 1996/97 (Table 4.3). Retained landings of *H. melanochir* were estimated to be 58,506 fish (7.0 t) in 1996/97 but only 16,168 fish (2.4 t) in 2011/12, representing a 72% reduction in catch.

The majority (~70%) of *H. melanochir* taken by boat-based fishers in the WCB are caught in autumn (Sumner and Williamson 1999, Ryan *et al.* 2013).

Unlike earlier boat-based surveys, which were restricted to the WCB, the 2011/12 survey was state-wide and estimated that 84% of boat-based landings of *H. melanochir* were caught in the WCB, with the remainder in the SCB.

Since *H. melanochir* is one of many species captured by boat-based fishers and comprised a relatively small proportion of the total boat-based catch during each survey, the effort spent specifically targeting *H. melanochir* could not be estimated. Therefore, the catch rate of this species in each survey period could not be determined.

Release rate by recreational fishers

H. melanochir released by recreational fishers have been estimated to comprise between 1 and 20% of total captures, depending on the survey (Table 4.4). Voluntary logbook fishers who captured garfish in the WCB reported average release rates of 4% and 13% for shore- and boat-based fishers, respectively, during the period 2005/06 – 2011/12.

WCB daily recreational catch and bag limit

From 2005/06 to 2011/12, the number of *H. melanochir* caught per day ranged between 0 and 11 for shore-based logbook fishers and 0 and 8 for boat-based logbook fishers in the WCB (Fig. 4.14). These daily catch levels included discarded fish. Daily catch levels of *H. melanochir* reported by logbook fishers were well below the daily bag limit (30 or 40 fish, depending on year) for this species in the WCB, which suggests that the daily bag limit is rarely attained. It is unclear whether the number of *H. melanochir* caught per day by logbook fishers is representative of the daily catch level of other recreational fishers.

WCB voluntary logbook CPUE

From 2005 to 2014, average monthly catch rates of *H. melanochir* reported by shore-based recreational logbook fishers in the Perth area were strongly seasonal, typically being highest in February-September and lowest in October-November (Fig. 4.15).

Over this period, relatively small numbers of *H. melanochir* were captured by logbooks fishers each year. About 100 fish per year were usually reported, with the exception of 2011 when over 300 fish were reported. Most fish were captured near the mouth of the Swan River or at Cottesloe Beach (blocks BQ60 and BR61), which are among the most popular locations for shore-based recreational fishing in Perth.

From 2005 to 2014, the average annual catch rate of *H. melanochir* reported by shore-based logbook fishers in the Perth area steadily declined, reaching zero in 2013 and 2014 (Fig. 4.16).

4.4 Discussion

In WA, *H. melanochir* is found in the WCB and the SCB (from Lancelin southwards) and is targeted by commercial and recreational fishers across this range. The majority of both commercial and recreational landings each year are from the WCB. Cockburn Sound is the main fishing area, producing the majority of commercial landings (>80%) and the majority of recreational landings (>50%) in the WCB. The recreational catch of *H. melanochir* in WA is not precisely known due to the lack of information about shore-based fishing. However, sufficient data are available to indicate that the recreational catch share is larger than the commercial share within the WCB. Within the WCB recreational sector, the shore-based catch is estimated to comprise at least 66% of the total catch.

In the SCB, the majority of commercial landings are currently reported from Wilson Inlet and the remainder from ocean waters around Albany. The total recreational catch of *H. melanochir* in the SCB is not precisely known but the available data suggest that it is very low compared to the commercial catch.

The main targeted populations of *H. melanochir* in WA (Cockburn Sound, Wilson Inlet, SCB ocean) are assumed to be separate breeding stocks. There has been little research to specifically examine the stock structure of *H. melanochir* in WA (but see Collette 1974, Jones *et al.* 2002). However, given the limited dispersal capabilities of this species, and the large spatial separation between the Bioregions, it is assumed that the WCB and SCB host separate breeding stocks. Furthermore, *H. melanochir* appear to spawn within Wilson Inlet, which is separated from the ocean by a sand bar for much of the year, and so are able to maintain a self-sustaining population within this estuary. Thus, the two main fisheries in WA - Cockburn Sound and Wilson Inlet - almost certainly target separate breeding stocks.

A large body of evidence is available to assist in determining the current status of the Cockburn Sound stock, including a long period of reliable catch and effort data from the commercial fishery. Trends in commercial catch rates are believed to provide a good indication of abundance for this stock, and these trends suggest a substantial decline in stock abundance over the past decade. A substantial decline in the availability of *H. melanochir* over this period has also been reported by the main operator in the Cockburn Sound Fish Net Fishery. The decline in abundance is consistent with biological indicators (length/age structure and mortality rate) which suggest worsening stock status over this period (see Section 6).

The commercial catch and catch rate of *H. melanochir* in Cockburn Sound have been declining gradually since 1995 and more rapidly since 2011. Both reached historically low levels in 2013. Between 2010 and 2013, the commercial catch declined by 77%, and the catch rate by 76%.

Catch and effort data from the recreational fishery in Cockburn Sound (or from the broader Perth recreational fishery) are more limited than the commercial data. However, where available, recreational catches and catch rates suggest a similar declining trend in *H. melanochir* abundance over the past decade to that indicated by the commercial data (Fig. 4.17). In particular:

- the shore-based catch rate of *H. melanochir* in the Perth area reported in voluntary recreational logbooks declined steadily from 2005 to 2013, reaching zero in 2013 and 2014;
- the catch rate of *H. melanochir* by shore-based recreational fishers in the Perth region during autumn (April-June) is estimated to have declined by approximately 90% between 2010 and 2014; and
- in the WCB, the retained catch of *H. melanochir* by boat-based recreational fishers (much of which is taken in the Perth area) is estimated to have declined by 72% between 1996/97 and 2011/12, with much of this decline apparently occurring between 1996/97 and 2005/06.

In the absence of a robust index of abundance for *H. melanochir* in the WCB boat-based recreational fishery, it is uncertain whether the decline in catch reflected a decline in abundance between 1996/07 and 2011/12, or a shift in targeting by boat-based fishers towards other species. However, while the *H. melanochir* catch declined by about 70% between surveys in 1996/97 and 2005/06, the total WCB boat-based effort increased by about 35% over the same period (DoF, unpubl. data). Hence, a large shift in targeting away from *H. melanochir* would be required to explain this decline in boat-based catch, and so the more likely explanation is a decline in abundance.

Changes in the recreational possession limit for *H. melanochir* are not likely to be responsible for the decline in the boat-based catch. A reduction in the recreational bag limit for this species in the WCB occurred in October 2009 (from 40 to 30 fish, as part of a mixed bag of 'low risk' species). However, daily catches reported by recreational fishers in voluntary logbooks indicate that a daily catch of 30 fish is rarely attained (Fig. 4.14). Furthermore, the pronounced decline in catch observed between 2000/01 and 2005/06 occurred prior to the change in bag limit.

The reasons for the apparent stock decline in Cockburn Sound are not known although fishing pressure and unfavourable environmental factors are both likely to have contributed. The sharp drop in abundance in 2011 coincided with an unprecedented 'heatwave' event along the west coast of WA in February/March of 2011 (Pearce *et al.* 2011, Pearce and Feng 2011, Caputi *et al.* 2014). During this event, sea surface temperatures were up to 5 °C above average and the Leeuwin Current flowed at record-strength. This event resulted in significant shifts in the structure of coastal ecosystems in the WCB (Wernberg *et al.* 2013). In Cockburn Sound, temperatures in bottom waters were 2-4 °C above average and dissolved oxygen levels were ~2 mg/l below average (Rose *et al.* 2011). Atypically warm summer temperatures occurred again in 2012 and 2013 along the west coast, including in Cockburn Sound (Caputi *et al.* 2014).

Since Cockburn Sound is near the northern edge of the *H. melanochir* range, the average summer temperatures in this area are presumably at the maximum level tolerable for this species. Any sustained increase in temperature above the long term average is likely to be unfavourable to *H. melanochir* in Cockburn Sound and may result in reduced growth or condition, leading to higher mortality or lower reproductive output. The recent 'heatwave' is part of a longer term trend of gradually increasing sea surface temperatures around south-western Australia over the past 5 decades (Pearce and Feng 2007). This may be causing a slow decline in environmental quality for *H. melanochir* in Cockburn Sound and contributing to the gradual decline in abundance.

Apart from the direct effects of high temperatures on growth and condition, *H. melanochir* may have also been indirectly impacted by the loss of habitat or food associated with warmer conditions. Limited monitoring of seagrass (*Posidonia* spp.) shoot density at shallow (<5 m) sites in Cockburn Sound suggests a gradual decline since 2003 (when monitoring commenced), including a sharp decline after the 2011 'heatwave' (CSMC 2013, Caputi *et al.* 2014). *H. melanochir* is dependent on seagrass for reproduction, feeding and shelter, and individuals are associated with seagrass habitat at all life history stages (see Section 2).

Therefore, any loss of seagrass in Cockburn Sound is expected to have multiple negative impacts on the local *H. melanochir* stock. Any recent loss of seagrass would be in addition to the massive loss that occurred historically. An estimated 80% of the original seagrass area in Cockburn Sound was lost between 1954 and 1978 (Cambridge and McComb 1984).

Unfavourable environmental conditions are likely to have exacerbated the impact of fishing pressure on the *H. melanochir* stock in Cockburn Sound. Although the total annual catch of this stock is unclear due to lack of data about recreational landings, the total rate of mortality from all types of fishing ('*F*') can still be estimated. The rate of *F* in recent years has been unsustainable for this stock (see Section 6). Interestingly, the total level of annual catch and effort (commercial plus recreational) impacting on this stock has probably declined slightly over the past 1-2 decades (because commercial catch/effort has declined), but *F* may actually have been increasing over this period if the stock size was declining due to poor recruitment due to environmental factors.

The development of more sustainable management of *H. melanochir* in Cockburn Sound is presently hindered by a lack of information about the shore-based recreational fishery, which takes the largest individual share of the catch. Although an accurate estimate of the recreational catch in the WCB is not available, it is still evident from the limited data that i) the shore-based recreational catch is substantially larger than the boat-based recreational catch and ii) the total recreational catch is greater than the total commercial catch. Information about the quantity, timing, spatial distribution and composition of the shore-based recreational catch is needed to fully understand the impact of this sector on *H. melanochir* in Cockburn Sound and to effectively manage this impact.

The most recent multi-sector (i.e. shore- and boat-based) survey of recreational fishing in the WCB was in 2000/01. Since then only partial surveys that were focused on a single sector, area, or time period have been conducted. It is possible to estimate total annual recreational catch from these limited surveys by 'scaling up' the partial catch estimate, assuming the catch proportions observed in 2000/01 or other surveys. Other assumptions (e.g. average fish weight) also need to be applied. Using this approach, the recreational share of total *H. melanochir* landings in the WCB in recent years is estimated to be 60-65% (Fig. 4.18), with approximately half of this taken in Cockburn Sound. Almost all of the WCB commercial catch, which comprises the remaining 35-40% share, is harvested in Cockburn Sound.

Due to the number of assumptions required to estimate it, the current total annual recreational catch of *H. melanochir* within Cockburn Sound (or in the WCB) is uncertain. A comprehensive 12-month, Bioregion-wide survey of the shore-based recreational fishery would reduce this uncertainty. However, a cost-effective methodology will need to be developed to enable this type of survey (Smallwood *et al.* 2011a, 2011b).

Future surveys should aim to quantify the number of *H. melanochir* released/discarded by recreational fishers. Previous estimates of released fish range from 1 to 20% of total captures of this species, depending of the survey. The mortality rate of released *H. melanochir* is not known but is assumed to be high as the post-release mortality of a closely-related species, *Hyporhamphus australis*, was estimated to be 49.2% after capture by recreational line fishing (Butcher *et al.* 2010). The main source of this mortality was scale loss due to handling by dry hands. On the basis of this evidence, approximately half of all released *H. melanochir* are assumed to die after release.

When assessing the impact of the shore-based recreational fishery on the *H. melanochir* stock within Cockburn Sound, the quantity and composition of the catch during spring/early summer (i.e. the *H. melanochir* spawning period) is of particular interest. Mature females aggregate in shallow water (< 5m) to deposit their eggs at this time. Evidence from *H. melanochir* fisheries in WA and elsewhere indicate that landings in shallow water are dominated by females during the spawning period, comprising almost 100% of catches in some cases (Jones *et al.* 2002, also see Sections 2 and 5). There have been no recent surveys of shore-based recreational fishing during spring/early summer and so the levels of catch and effort for such fishing are not known. Data reported in voluntary logbooks in Perth suggest the shore-based catch rate of *H. melanochir* is low in spring/early summer, but if total shore-based recreational effort is high then the catch level at this time could still be significant. Detailed information about the shore-based recreational fishery during spring/early summer (including catch, effort and catch composition) is required to understand the full impact of the recreational sector on the *H. melanochir* stock within Cockburn Sound and to formulate effective management of this fishery.

The spawning behavior of *H. melanochir* appears to strongly influence the monthly catch level and composition in the main commercial fisheries in the WCB. Historically, landings in Cockburn Sound have been highly seasonal, reaching a minimum around the peak of the spawning period (November-December) and a maximum immediately after the spawning period (March-May) each year. In contrast, landings in Geographe Bay peak during the spawning period (October to December). During the spawning period, females are known to aggregate in shallow (< 5m), vegetated areas to deposit their eggs, whereas males are dispersed and are mainly found in deeper waters (Jones *et al.* 2002, also see Sections 2 and 5). Cockburn Sound landings are taken by boat-based netting in offshore waters, whereas Geographe Bay landings are taken by shore-based netting. The reduced catchability of this species in offshore waters during the spawning period can be explained by the absence of females and the dispersed distribution of males.[5] Similarly, the aggregation of females explains their increased catchability in shallow waters at this time.

Insufficient information is currently available to determine the status of the two *H. melanochir* populations targeted in the SCB (i.e. Wilson Inlet and ocean waters around Albany). The stability of the commercial catches and/or catch rates suggests that abundance has remained relatively stable in both populations over the past two decades. However, the catch and effort data from these fisheries is limited and additional information such as age structure would be required to confidently assess the status of these stocks. Recent annual catches in ocean waters around Albany are low compared to historic catches, but there is no evidence (albeit from very limited monitoring) of a decline in the abundance of *H.*

[5] An alternative explanation is that less favourable weather renders boat-based netting less efficient in spring months, compared to autumn. However, this latter possibility is unlikely given that landings of other species (e.g. herring) taken by boat-based netting in Cockburn Sound are maintained in spring.

melanochir in ocean waters. Rather, a shift in targeting is more likely to be the cause of the catch decline in this area.

Due to the low catches currently taken in the ocean fishery, Wilson Inlet is presently the only *H. melanochir* fishery of significance in the SCB. There is evidence of increased targeting of *H. melanochir* in Wilson Inlet in recent years, and the current catch is at an historically high level. This trend is probably being driven by market demand. The recent decline in product being supplied by the other commercial fisheries in WA (Cockburn Sound and SCB ocean waters) is likely to have increased the local market demand for *H. melanochir*. Targeting in Wilson Inlet is predicted to remain high, and potentially increase, to meet this demand.

Although catch rates trends suggest that the abundance of *H. melanochir* in Wilson Inlet has been stable to date, there are some reasons for concern about this stock. The current commercial catch in Wilson Inlet is high (10 t in 2013), given the relatively small area of habitat which supports this stock. Wilson Inlet has a total area of 48 km^2, with seagrass beds covering ~50% of this area (WICC 2013). The sustainable catch level for this stock is not known, but given the vulnerability to overfishing that *H. melanochir* has displayed elsewhere, the increasing catch trend in Wilson Inlet is of concern. Additionally, sampling in 1998-1999 suggested that the catch in Wilson Inlet was "clearly dominated by females" (Jones *et al.* 2002), which is a further threat to the sustainability of this stock. More rigorous monitoring, such as age-based sampling, of the *H. melanochir* stock in Wilson Inlet should be undertaken to determine whether the current catch level in this fishery is sustainable.

Table 4.1. Estimated catch of *Hyporhamphus melanochir* retained by recreational fishers in the West Coast Bioregion and South Coast Bioregion of WA, in 2000/01 (Henry and Lyle 2003) (*assuming 120g per fish).

	West Coast	South Coast
Total retained catch :		
Number of fish	213,072	17,432
Estimated weight (t) *	25.6	2.1
Catch share within bioregion, by fishing platform :		
Ocean, boat	34%	40%
Ocean, shore	59%	21%
Estuary/river	6%	39%

Table 4.2. Estimated catch of *Hyporhamphus melanochir* retained by shore-based recreational fishers in the Perth area during a 12-month survey in 2000/01 and a 3-month survey in 2010 (Henry and Lyle 2003, Smallwood *et al.* 2012). (*assuming 120g per fish). Note: these surveys employed different methods and so are not directly comparable.

	2000/01	Apr-Jun 2010
Total retained catch :		
Number of fish	125,808	56,987
Estimated weight (t) *	15.1	6.8

Table 4.3. Estimated catch of *Hyporhamphus melanochir* retained by boat-based recreational fishers in the West Coast Bioregion (Department of Fisheries unpubl. data). (*assuming average weight of 120g per fish). Note: catch estimates from surveys employing different methods are not directly comparable.

	1996/97	2000/01	2005/06	2008/09	2009/10	2011/12
Total retained catch :						
Number of fish	58,506	72,607	18,938	38,685	28,186	19,728
Estimated weight (t) *	7.0	8.7	2.3	4.6	3.4	2.4

Table 4.4. Release rate (percentage of total catch) of *Hyporhamphus melanochir* by recreational fishers during various surveys in WA.

Bioregion	Sector	Survey period	Release rate (%)
South Coast	Shore, ocean	2000/01	7
	Boat, ocean	2000/01	1
	Estuary	2000/01	3
West Coast	Shore, ocean	2000/01	20
	Shore, ocean, Perth only	Apr-Jun 2010	6
	Shore, ocean, logbook fishers	2005/06 - 2011/12	4
	Boat, ocean	1996/97	5
	Boat, ocean	2000/01	3
	Boat, ocean	2005/06	9
	Boat, ocean, logbook fishers	2005/06 - 2011/12	13
	Boat, ocean	2011/12	15
	Estuary	2000/01	14

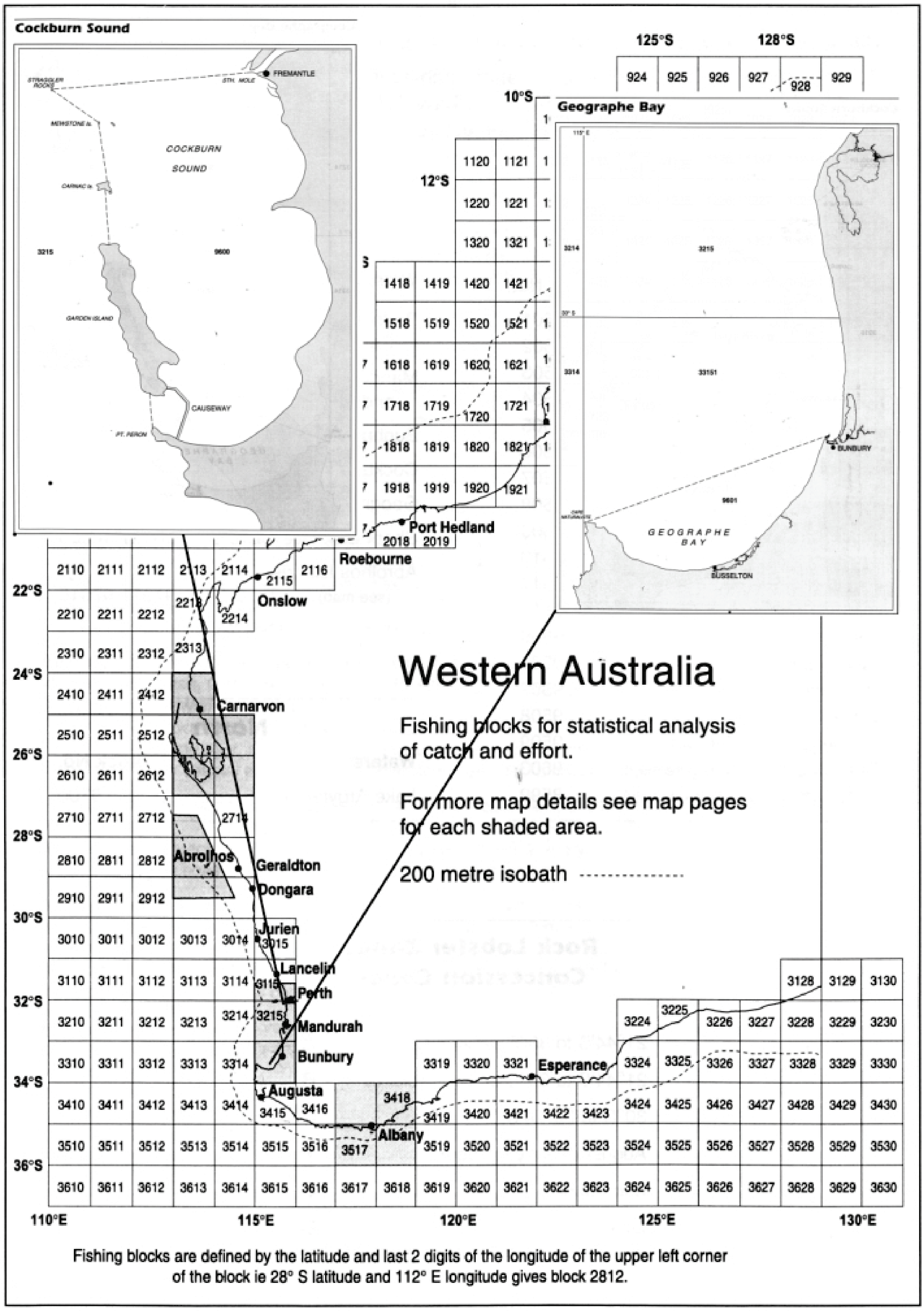

Figure 4.1. CAES block maps used by commercial fishers to report the location of their monthly catch and effort.

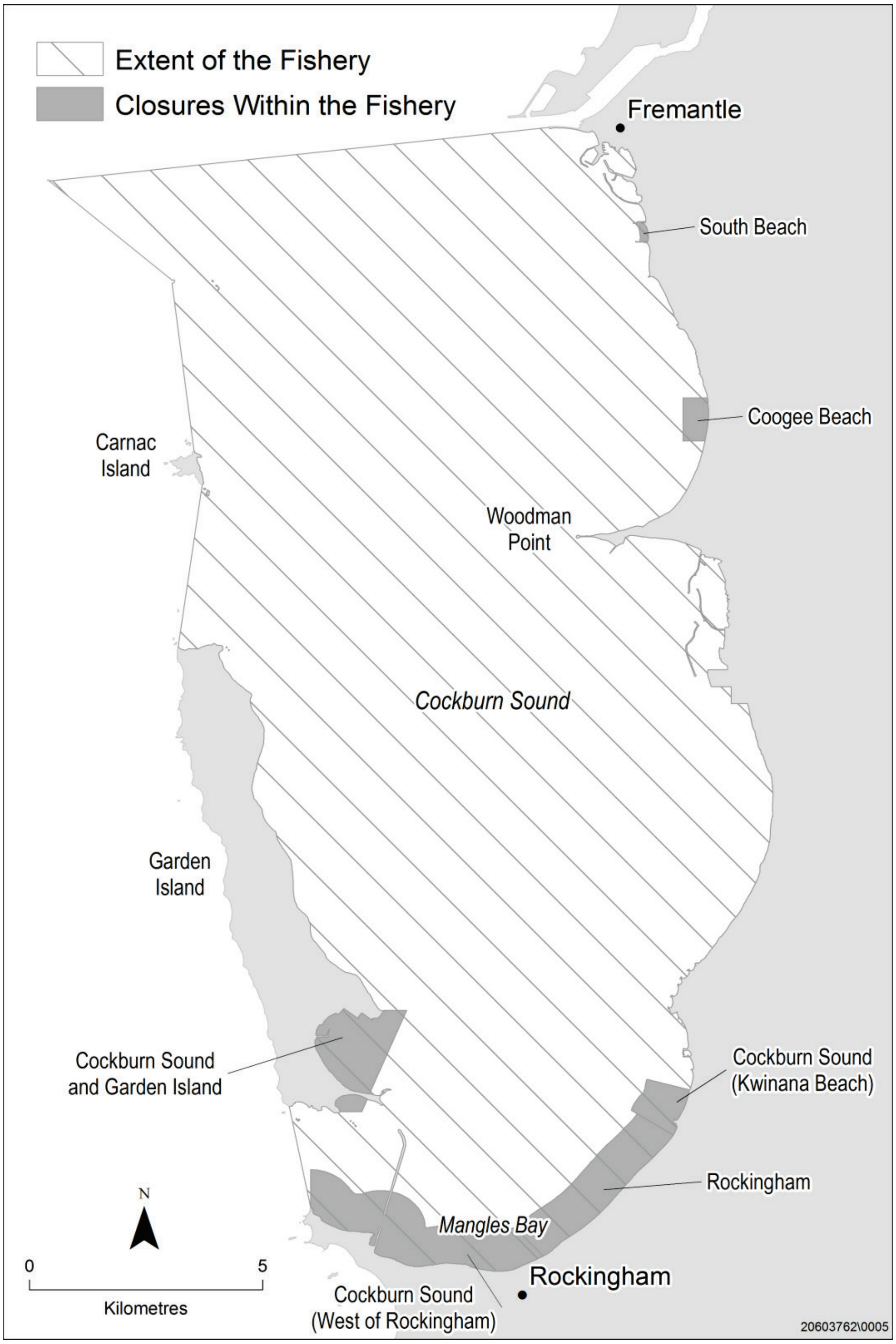

Figure 4.2. Boundaries of the Cockburn Sound (Fish Net) Managed Fishery, including the location of areas within the fishery ('closures') that are closed to fishing.

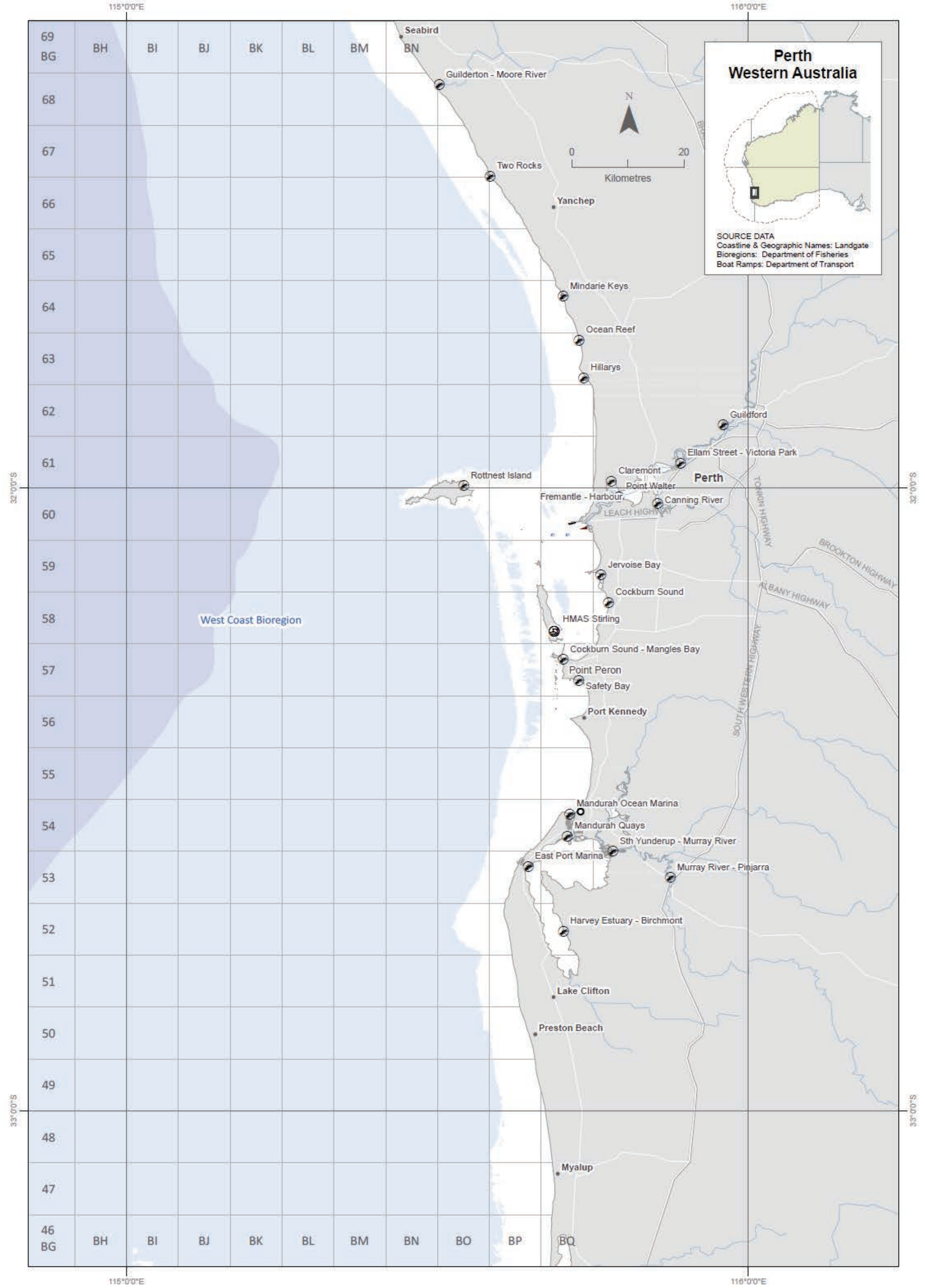

Figure 4.3. Grid map of Perth blocks (5 x 5 nautical miles) used by recreational fishers to report catch and effort in voluntary logbooks.

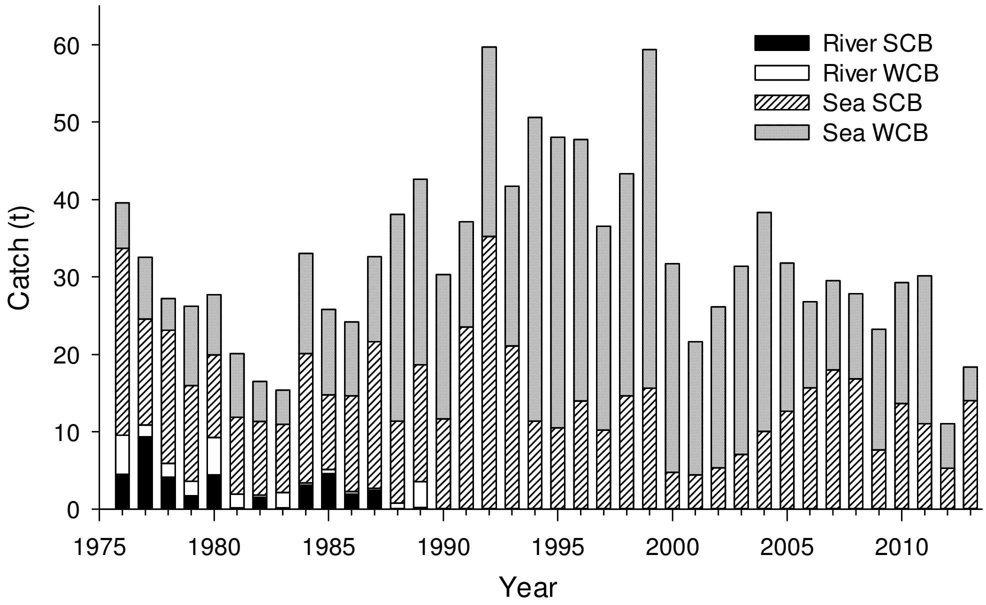

Figure 4.4. Total annual commercial landings (live weight) of garfish species reported in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB), 1976 to 2013 (sea – recorded as 'sea garfish' *Hyporhamphus melanochir*, river - recorded as 'river garfish' *H. regularis*).

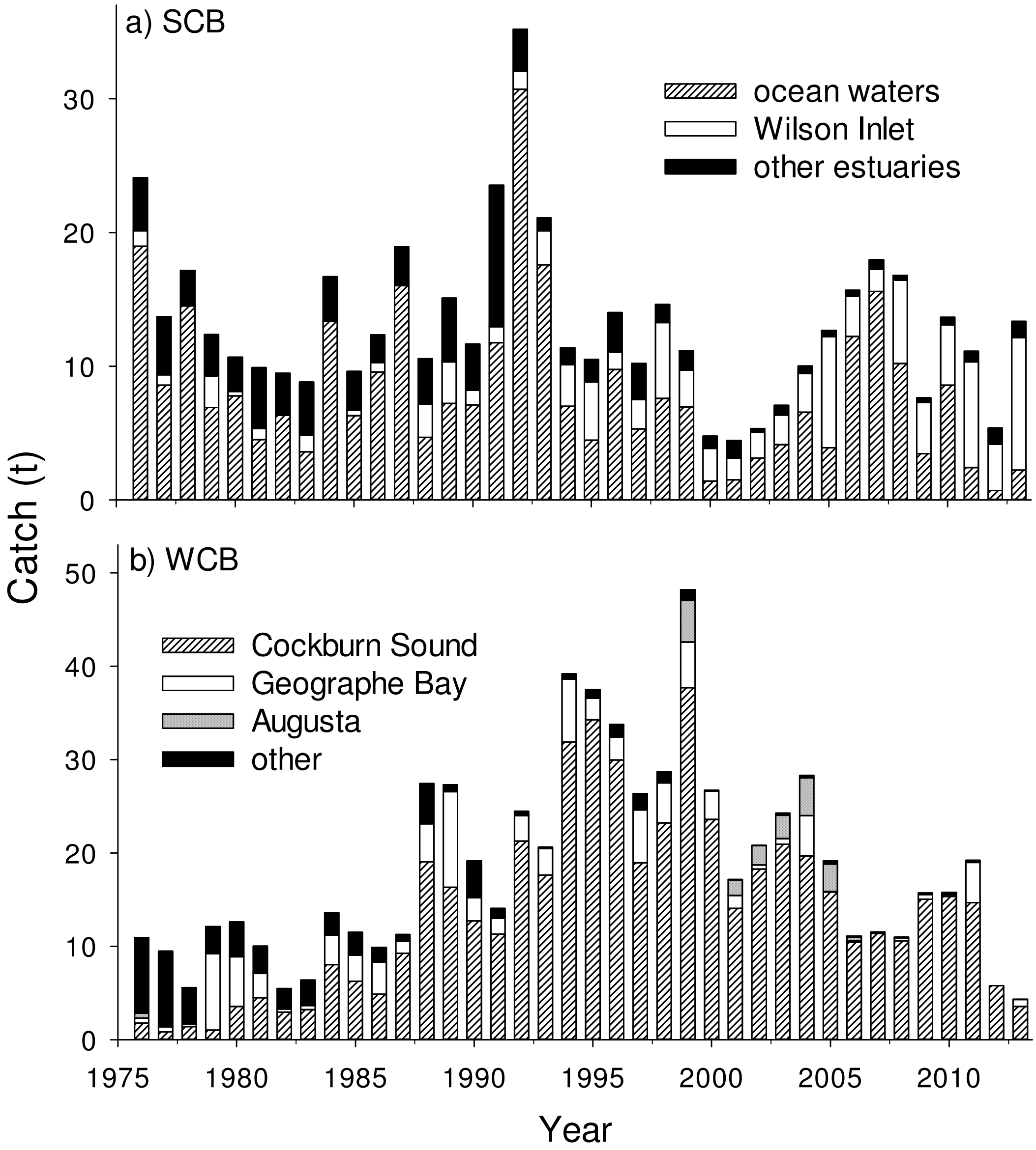

Figure 4.5. Total annual commercial landings (live weight) of *Hyporhamphus melanochir* reported from key locations within the a) South Coast Bioregion (SCB) and b) West Coast Bioregion (WCB), 1996 to 2013. (CAES blocks: Wilson Inlet – 9605; Cockburn Sound – 9600, 3115; Geographe Bay – 9601, 3315, 33151; Augusta – 3415)

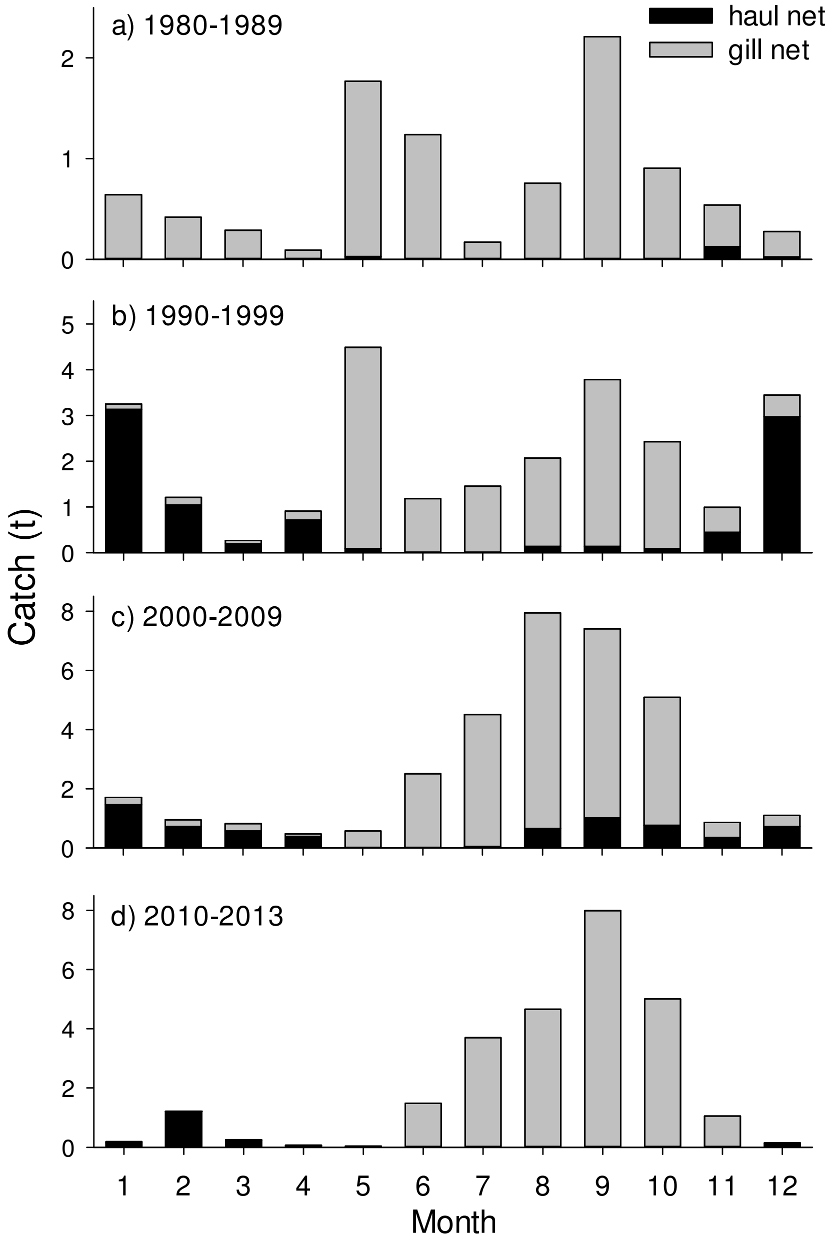

Figure 4.6. Sum of monthly landings of *Hyporhamphus melanochir* by haul nets (including 'beach seine' nets) and gill nets in Wilson Inlet during a) 1980-1989, b) 1990-1999 c) 2000-2009 and d) 2010-13. (Month 1 = January, 2 = February, etc.).

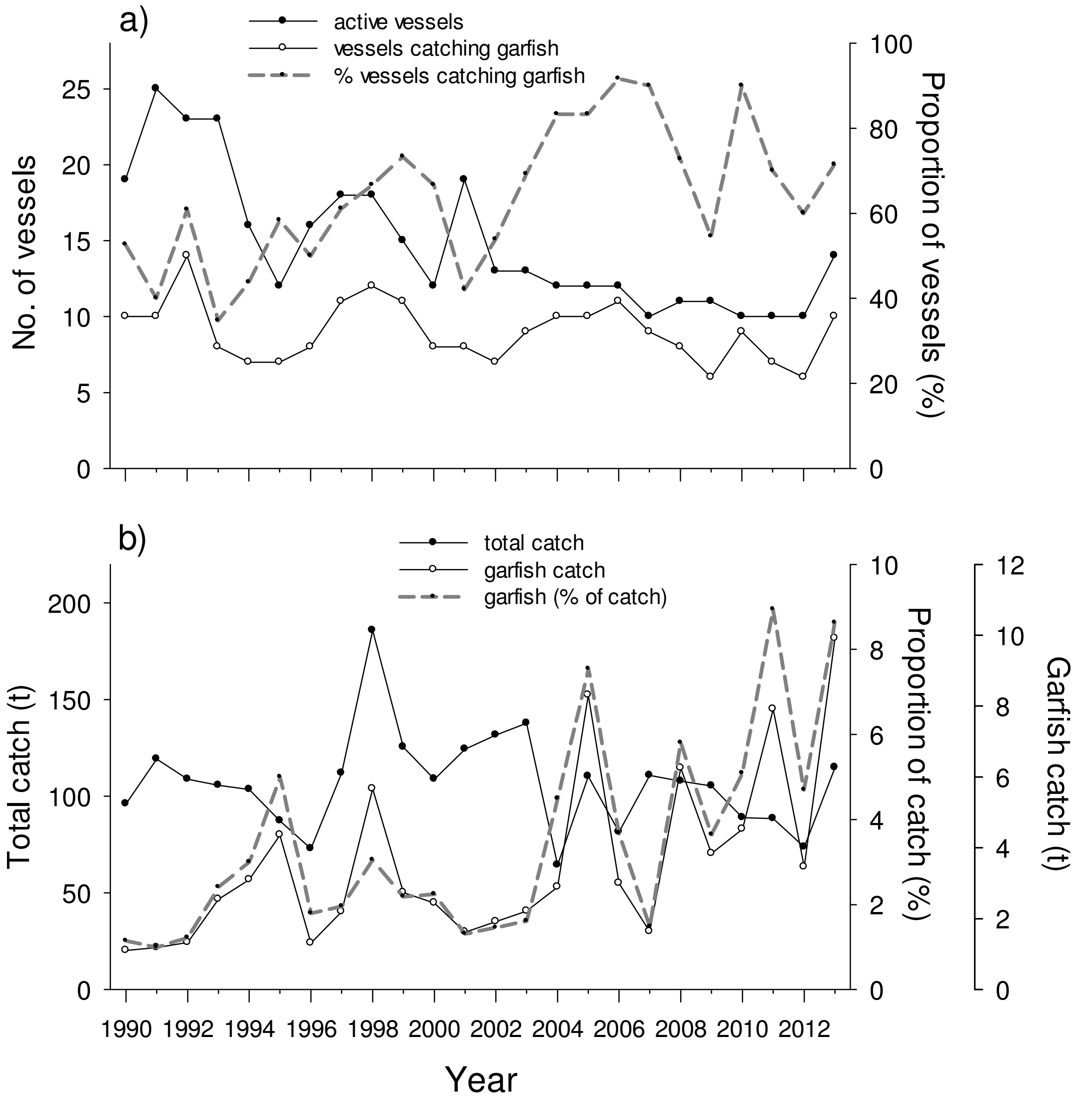

Figure 4.7. a) Total number of active vessels, number of vessels capturing *Hyporhamphus melanochir* and percentage of vessels capturing *H. melanochir*, b) total fishery catch, total *H. melanochir* catch and *H. melanochir* catch as proportion of total landings per year in Wilson Inlet, 1990-2013.

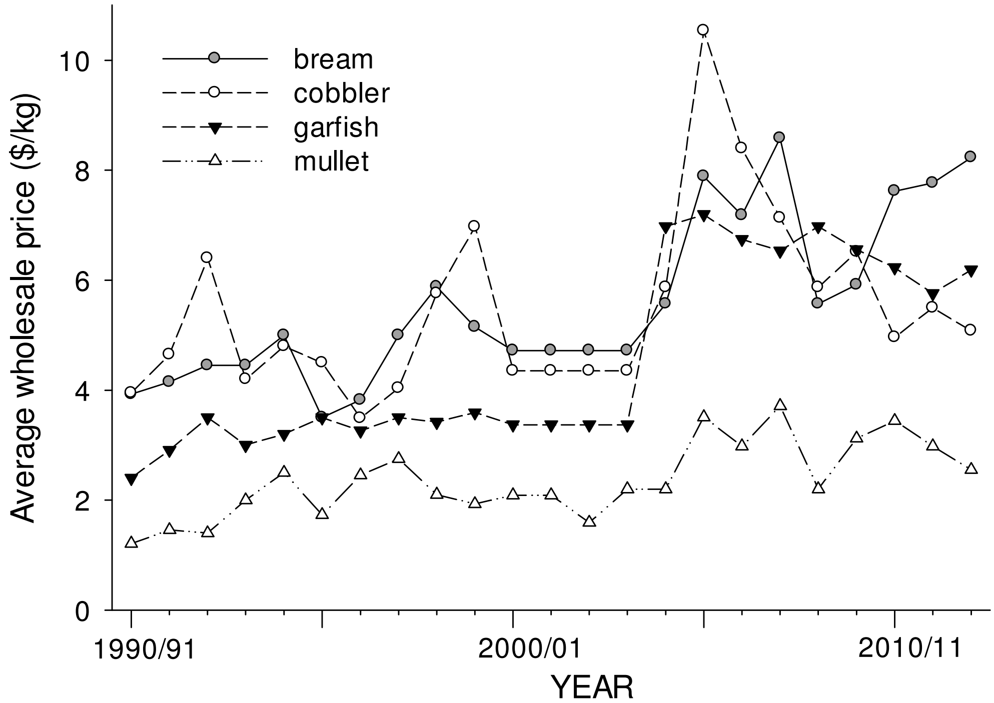

Figure 4.8. Average annual wholesale price* paid for the main species (black bream, cobbler, southern garfish *(Hyporhamphus melanchir)*, sea mullet) captured in the Wilson Inlet commercial fishery, 1990/91-2012/13. (*Perth auction price).

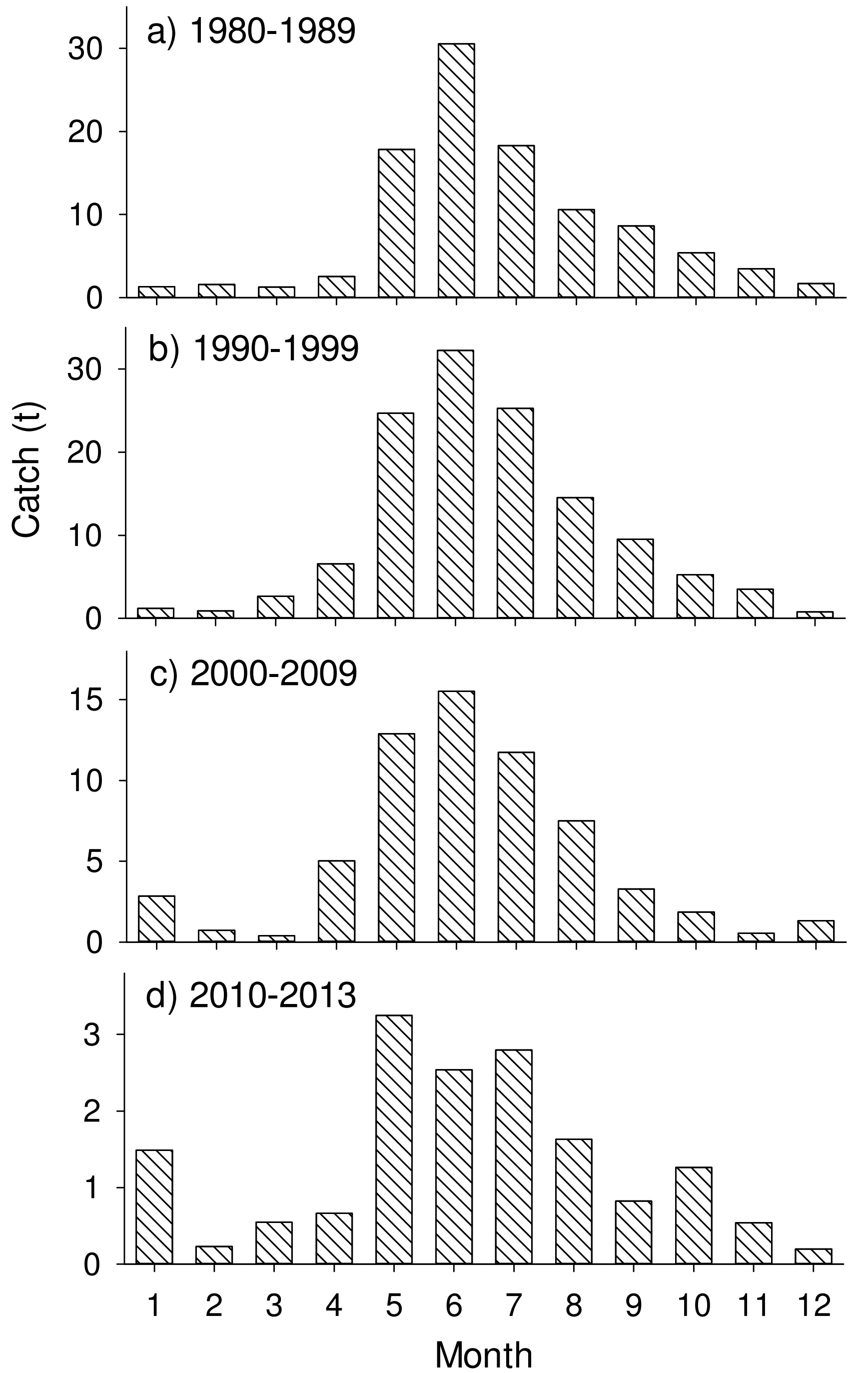

Figure 4.9. Sum of monthly commercial landings of *Hyporhamphus melanochir* in coastal waters of the South Coast Bioregion during a) 1980-1989, b) 1990-1999, c) 2000-2009 and d) 2010-2013. (Month 1 = January, 2 = February, etc.).

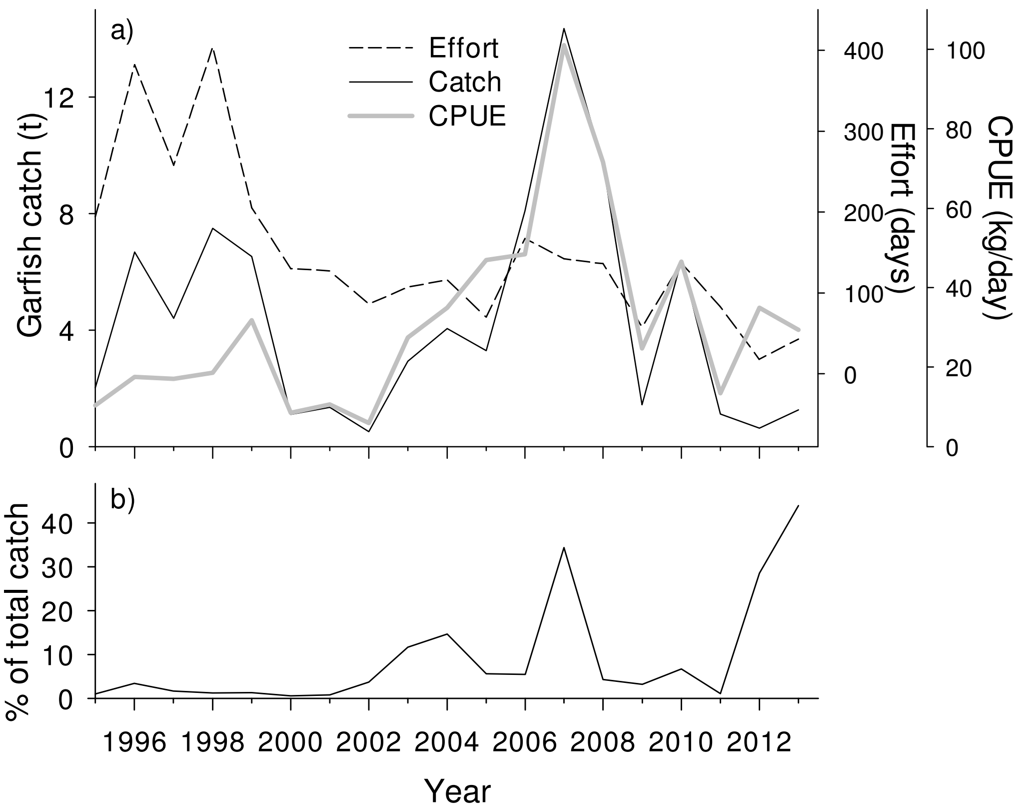

Figure 4.10. a) Annual catch and average catch rate of *Hyporhamphus melanochir*, and total reported effort, and b) percentage of total annual catch represented by *H. melanochir* during May-September by beach-based netting (haul nets and beach seines) in South Coast Bioregion ocean waters, 1995 to 2013.

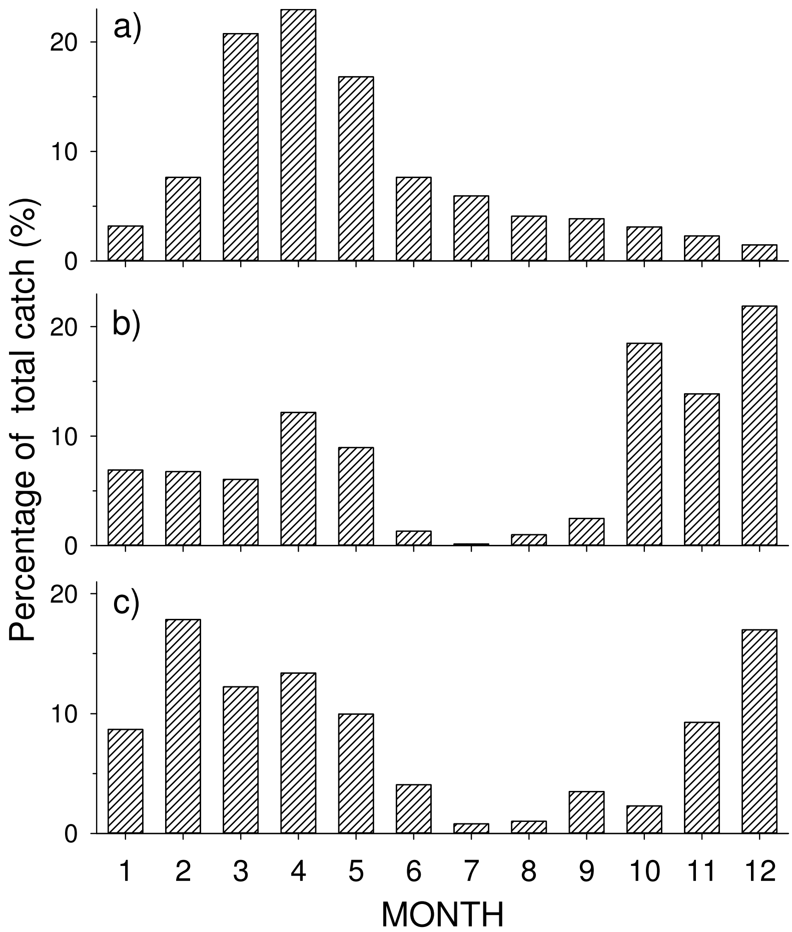

Figure 4.11. Monthly distribution of all commercial landings of *Hyporhamphus melanochir* in a) ocean waters of Perth/Mandurah area including Cockburn Sound (CAES blocks 9600, 3114, 3115, 3215), b) ocean waters of Geographe Bay area (9601, 3114, 3115, 3151) and c) West Coast Bioregion estuaries (Peel-Harvey (9502) and Leschenault (9503)), from 1976 to 2005. (Month 1 = January, 2 = February, etc.).

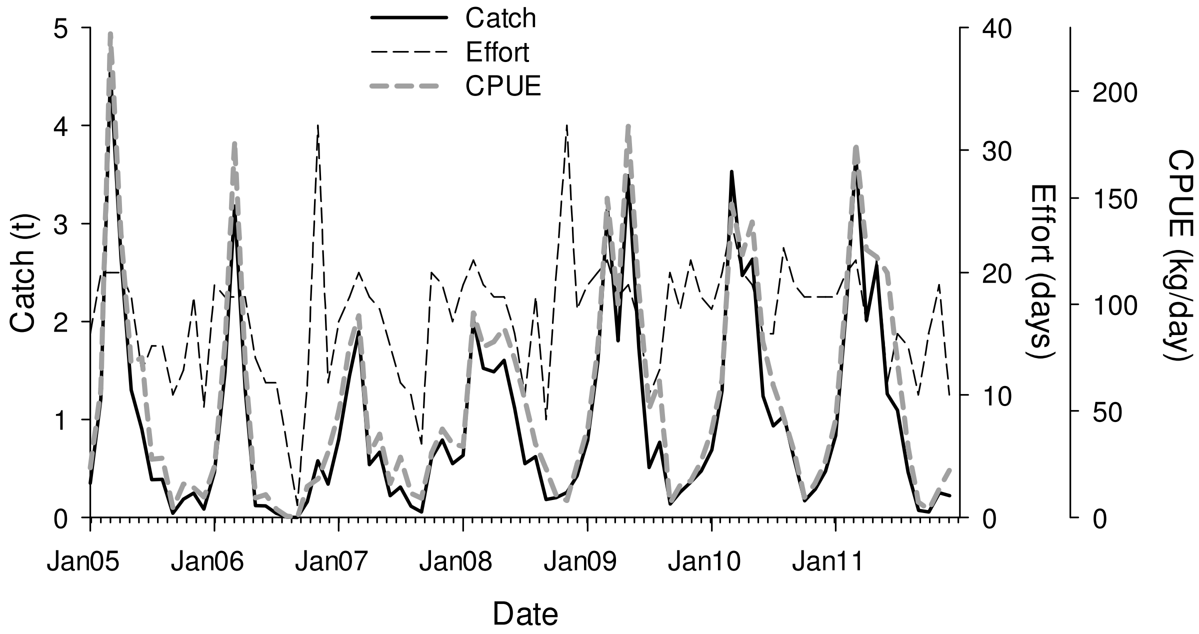

Figure 4.12. Monthly catch and catch rate of *Hyporhamphus melanochir* and total monthly netting effort trends reported by the Cockburn Sound (Fish Net) Managed Fishery, in recent years (the period 2005 to 2011 is shown as an example). A pronounced peak in catch rate occurs each year during autumn.

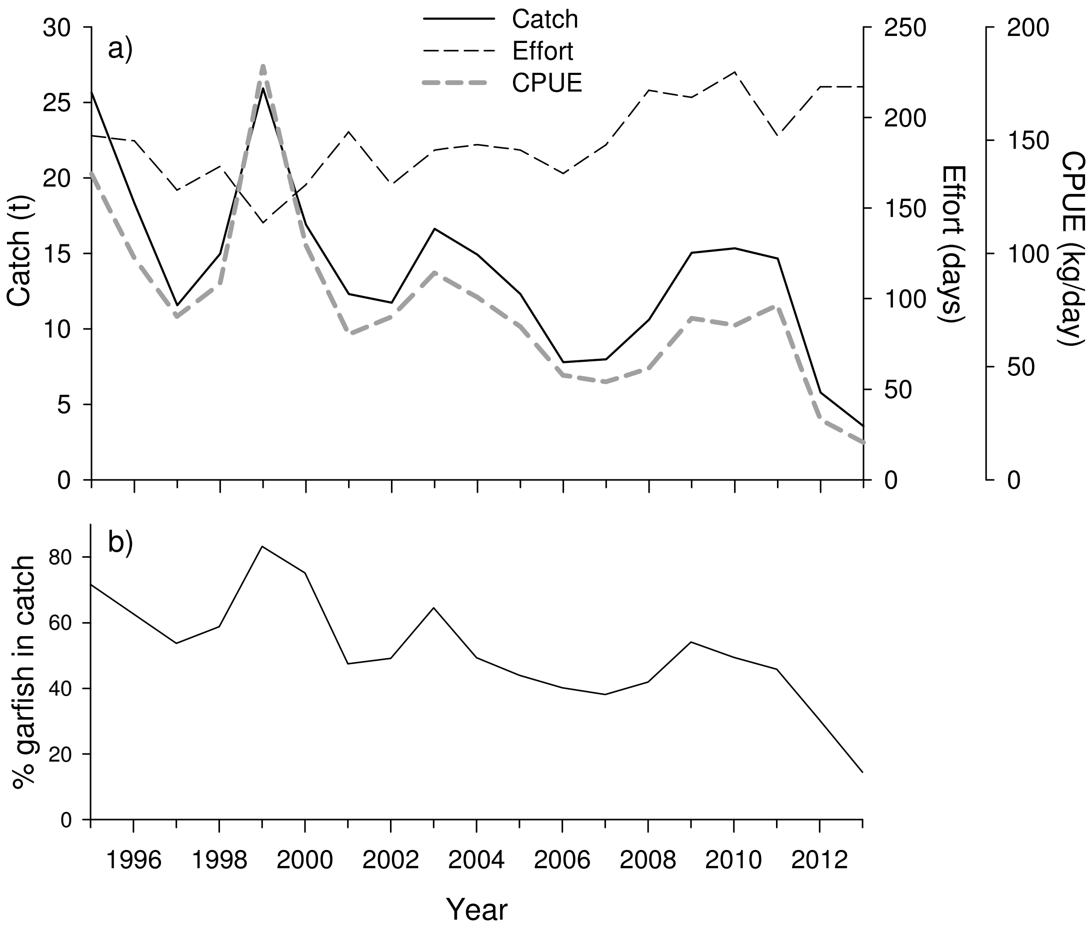

Figure 4.13. a) Annual catch and average catch rate of *Hyporhamphus melanochir* and total annual netting effort, and b) percentage of total annual catch comprised of *H. melanochir*, reported by the Cockburn Sound (Fish Net) Managed Fishery, 1995 to 2013.)

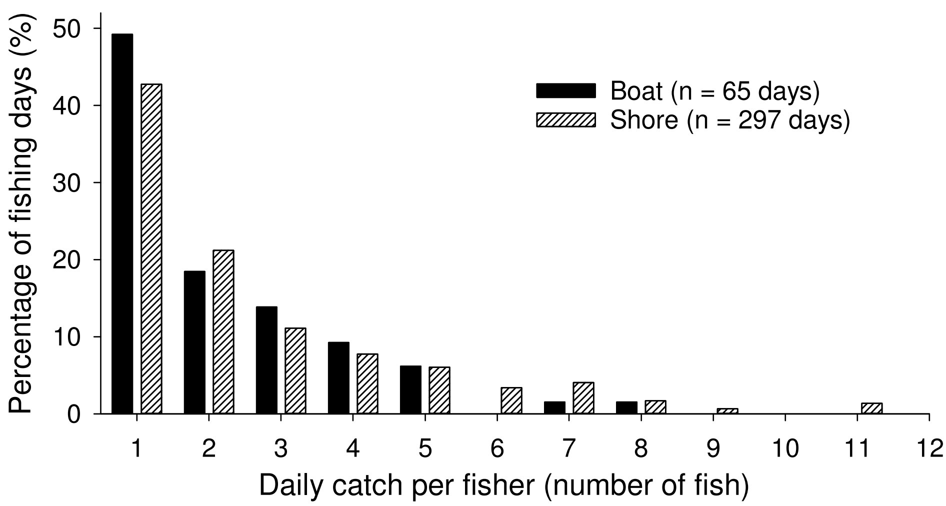

Figure 4.14. Frequency of daily catch levels of *Hyporhamphus melanochir* reported in voluntary logbooks by West Coast Bioregion shore- and boat-based recreational fishers, 2005/6 to 2011/12 (catch includes retained and discarded fish; nil catches not included).

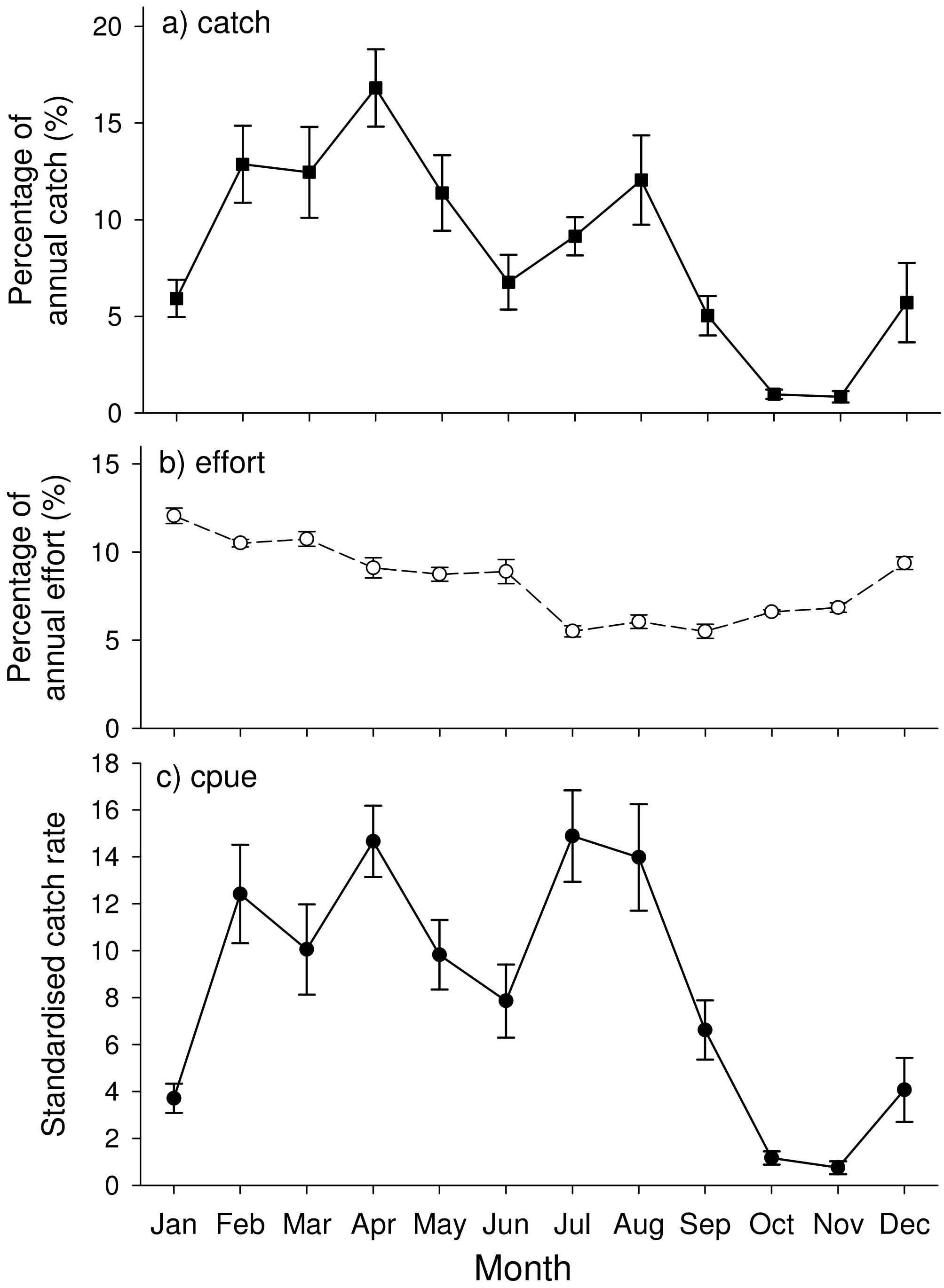

Figure 4.15. a) Mean (± s.e.) monthly percentage of total annual *Hyporhamphus melanochir* catch, b) mean (± s.e.) monthly percentage of total annual effort, and c) mean (± s.e.) monthly catch rate reported by shore-based voluntary logbook fishers in the Perth area, 2005/6 to 2011/12*. (catch includes retained and released fish; effort includes fishing trips resulting in nil catch and non-garfish catches) (*2012/13 and 2013/14 not included due to negligible catch in these years)

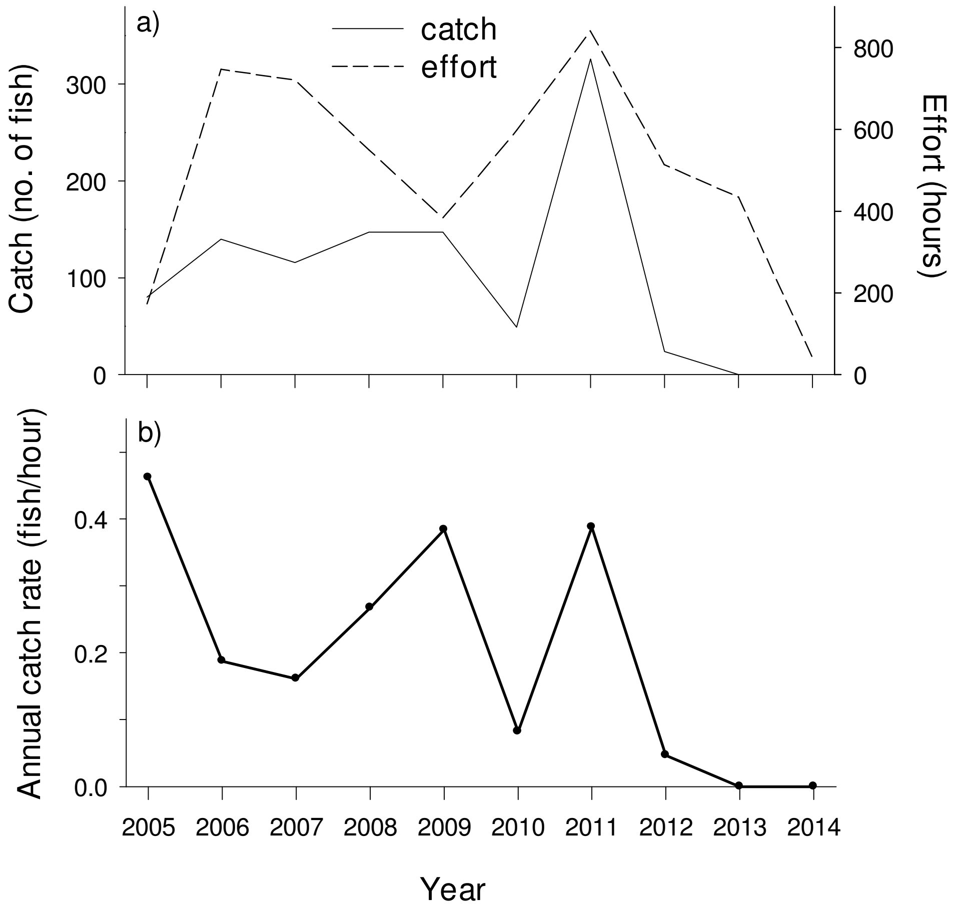

Figure 4.16. a) *Hyporhamphus melanochir* catch and effort, and b) average annual catch rate reported by shore-based voluntary logbook fishers in the Perth area, 2005 to 2014. (catch includes retained and released fish; effort includes fishing trips resulting in nil catch and non-garfish catches; catch and effort data from October/November excluded due to low catch; only partial data available for 2005 and 2014).

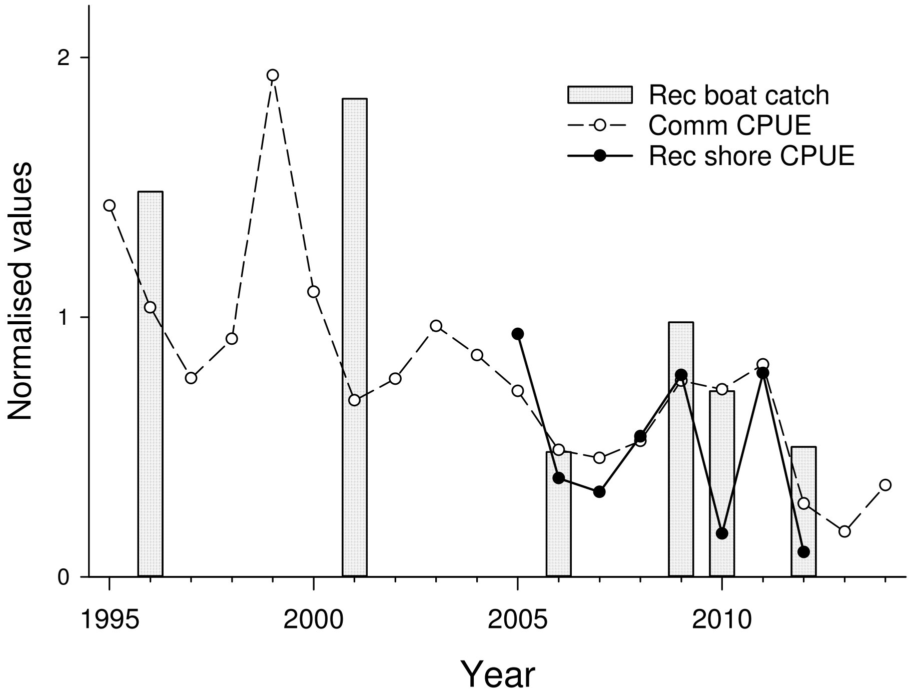

Figure 4.17. Comparison of annual trends in Cockburn Sound commercial catch rate (Comm CPUE), Perth shore-based recreational logbook catch rate (Rec shore CPUE) and West Coast Bioregion boat-based recreational catch (Rec boat catch) for *Hyporhamphus melanochir*. Values are adjusted to the same scale to enable comparison. Note: catch estimates from surveys employing different methods are not directly comparable.

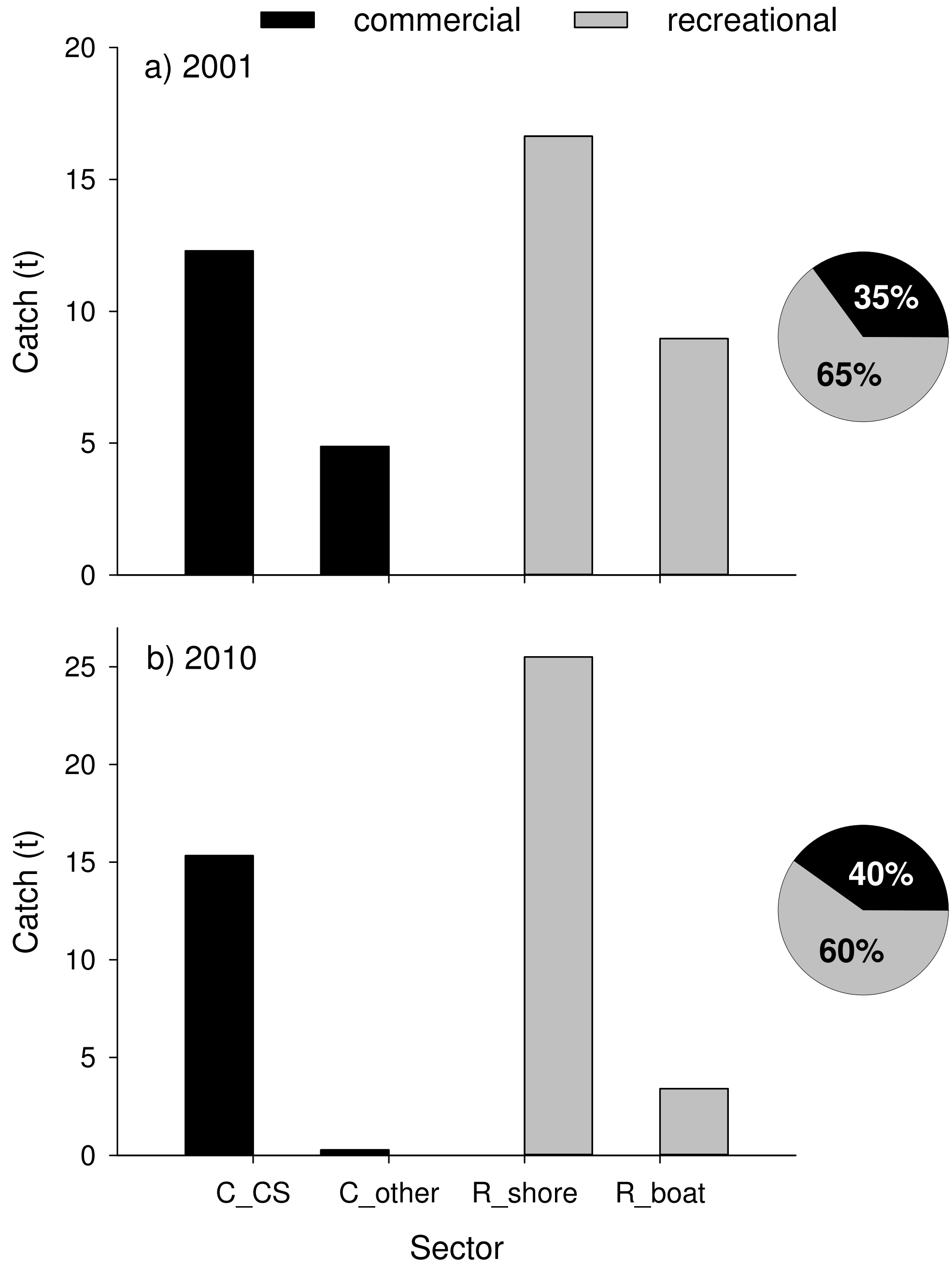

Figure 4.18. Approximate catch shares of *Hyporhamphus melanochir* estimated for commercial and recreational fisheries in the West Coast Bioregion (WCB) in a) 2001 and b) 2010. (C_CS: Cockburn Sound commercial catch; C_other: other WCB commercial catch; R_shore: WCB shore-based recreational catch; R_boat: WCB boat-based recreational catch.)

5 Composition of fishery catches

Summary

- The composition (age, length, sex) of commercial and recreational landings of *Hyporhamphus melanochir* in the WCB was estimated from samples collected in 2009-2012. The Cockburn Sound fishery was the focus of sampling effort. Results were compared with WCB samples collected in 1998-1999. Limited data from the SCB was also examined.
- The sex ratio of *H. melanochir* in fishery landings is strongly biased towards either males or females, depending on the depth/timing of landings. Landings in the two main commercial fisheries, Cockburn Sound and Wilson Inlet, are predominantly male and female, respectively. The sex ratio in recreational landings is unclear due to limited data, but probably biased towards females.
- In 2009-2012, the majority (>95% in WCB, >90% in SCB) of *H. melanochir* in commercial and recreational landings were estimated to be above L_{50} (i.e. the length at which 50% of fish are sexually mature).
- The ages of *H. melanochir* in commercial landings in Cockburn Sound ranged from 0+ to 5+ years in 1998-1999 and from 0+ to 4+ years in 2009-2012. Between these periods, the modal age declined from 2+ to 1+ years, and the proportion of fish aged >2 years fell from 30% to less than 5%. The average length also declined between periods.
- Considering the maximum reported age of 10 years for *H. melanochir*, the age structure of the Cockburn Sound stock in 2009-2012 was heavily truncated.
- The WCB commercial and recreational fisheries are strongly recruitment-dependent. *H. melanochir* recruit to both fisheries in summer when aged ~1 year. The 1+ year class then dominates landings until the following summer, when they are replaced by the next 1+ year class. This characteristic makes the fisheries vulnerable to collapse in the event of a single year of poor recruitment. Recruitment failure during the ‘heatwave’ event in 2011 would explain the dramatic decline in catches after 2011.
- Future efforts to monitor the status of *H. melanochir* in WA should focus on the Cockburn Sound fishery, due to the relatively high sustainability risks identified for this stock. However, it is recommended that some age-based monitoring should also be undertaken in Wilson Inlet, the state’s second largest commercial fishery for *H. melanochir*. Threats to the sustainability of the Wilson Inlet stock have been identified, but insufficient biological information is currently available to determine stock status.
- There are currently no cost-effective methods available to monitor the age composition of *H. melanochir* in recreational landings. Thus, assessments of *H. melanochir* stock status in the WCB will be reliant on commercial or fishery-independent data. In Cockburn Sound, the main WCB fishery for this species, commercial fishery sampling is currently more cost-effective than fishery-independent sampling.

5.1 Introduction

In WA, *H. melanochir* is found in temperate coastal waters from Lancelin southwards, including the lower WCB and entire SCB. Despite this relative wide distribution, commercial targeting of *H. melanochir* in WA is currently concentrated in just two locations – Cockburn Sound (WCB) and Wilson Inlet (SCB) (Section 4). Cockburn Sound produces over 80% of the WCB commercial catch, and also supports a significant recreational fishery for this species (Section 4). Recent catch and CPUE trends in both fishing sectors have suggested a decline in stock abundance in Cockburn Sound. High fishing pressure and multiple unfavourable environmental factors have been identified as threats to the sustainability of the Cockburn Sound stock (Section 7).

In response to concerns about the sustainability of *H. melanochir* in Cockburn Sound, biological monitoring of the fishery was undertaken during 2009-2012 to facilitate a more definitive assessment of stock status. The age, length and sex composition of commercial and recreational landings was sampled. Since fishers generally harvest the largest (or oldest) fish in a population, heavy exploitation may result in a decline in the average size (or age) of the catch. Thus, biological monitoring can provide important insights into stock status.

Biological indicators, particularly age structure, have been successfully used by DoF to monitor the status of many key finfish species in WA (Wise *et al.* 2007, Marriot *et al.* 2012, Smith *et al.* 2013b). Only limited biological monitoring has previously been undertaken for *H. melanochir* stocks in WA (Jones *et al.* 2002). However, fishery scientists in South Australia have demonstrated that trends in age and length composition can provide indicators of exploitation status in local *H. melanochir* stocks (Fowler and Ling 2010, Steer *et al.* 2012).

During 2009-2012, sampling effort was focused on the Cockburn Sound fishery, due to the strong concerns about stock status identified there. However, other exploited stocks of *H. melanochir* in WA are also viewed as 'at risk' due to the inherent biological characteristics of this species that make it particularly vulnerable to depletion (Section 2). Therefore, this section summarises the catch composition data available for other exploited stocks in WA, to provide a basis for future assessments, as required.

Objectives of this Section:

- Determine the age, length and sex composition of current fishery landings of *H. melanochir* in Cockburn Sound and elsewhere in WA.
- Compare the composition of current fishery landings with the composition of historical landings in WA, where data is available, to identify changes over time.
- Identify cost-effective methods for future monitoring of catch composition to provide biological indicators of stock status, particularly in Cockburn Sound.

5.2 Methods

5.2.1 Composition of fishery landings - current

During 2009-2012, *H. melanochir* in commercial and recreational fishery landings in the WCB were sampled monthly.

From September 2009 to January 2012, a random sample of 30-60 *H. melanochir* (whole fish) was obtained each month from landings by the *Cockburn Sound (Fish Net) Managed Fishery*, which is the main commercial fishery for this species in the WCB. Landings were not available in some months, resulting in a total of 20 months being sampled over this 30-month period. A total of 928 fish were collected. All commercial landings were taken by a surface haul net (260 m length x 18 m depth) consisting of panels of 50 mm (2 inch) and 37 mm mesh (1.5 inch) in the wings and 25 mm (1 inch) in the bunt.

From September 2009 to June 2012, samples of *H. melanochir* (either whole fish or filleted frames) caught using line fishing methods in the WCB were donated by recreational fishers. These donations were obtained via the "Send Us Your Skeletons" project, which is an ongoing fish frame collection program targeted towards recreational fishers. A total of 314 fish were obtained from recreational fishers over this 34-month period (Table 5.1). The number of fish collected per month ranged from 0 to 79 over this period. Donated fish were mainly caught in the Perth region.

In the SCB, limited sampling was undertaken, and insufficient data was obtained to yield a representative sample of the length or age structure. Thus, the composition of SCB fishery landings was not estimated in 2009-2012.

5.2.2 Composition of fishery landings – historical

Limited sampling of *H. melanochir* in fishery landings in WA was conducted during 1998-1999. Full details of the methods and results of this sampling are reported by Jones *et al.* (2002).

Briefly, in the WCB, monthly samples (30 to 74 fish per month) were obtained from commercial landings by the *Cockburn Sound (Fish Net) Managed Fishery* from February 1998 to May 1998 (i.e. 4 months only). The same commercial fishing gear (i.e. haul net) with the same specifications (dimensions, mesh size) was used by the fishery in 1998 and 2009-2012. Therefore, the catch composition in 2009-2012 was directly comparable with that observed in 1998, for the months of February-May only.

In the South Coast Bioregion (SCB), monthly samples (0 to 147 fish per month) were obtained from commercial landings in Wilson Inlet from January 1998 to April 1999. Fish from Wilson Inlet were a mixture of beach seine and gill net landings.

A small number of samples were also collected opportunistically from commercial fishers at various other locations within the WCB and SCB during 1998-1999 (see Tables 4.1 and 4.2 in Jones *et al.* 2002 for number of samples per month).

5.2.3 Analysis

The total length, age and sex were determined for each individual of *H. melanochir* collected from WCB fishery landings in 2009-2012, using methods described in Section 3 and DoF (in prep.).

The length composition of commercial landings in Cockburn Sound was observed to vary between months, due to variations in sex ratio (Section 3). Therefore, the length composition of the total annual commercial catch in Cockburn Sound was constructed from weighted monthly samples. First, a length frequency distribution for males and females for each month was generated from all lengths collected in 2009-2013 (i.e. years pooled). These male and female frequencies were weighted, according to the average proportion of males and females in the commercial catch in that month, and then summed to create a length frequency distribution of the total catch for each month. These monthly length frequencies were weighted according to the average monthly catch level (% of annual catch) and then summed to create an average annual length frequency distribution. The catch proportions used to weight monthly samples are illustrated in Section 4 (Figs. 4.11a and 4.12).

Unweighted (raw) age data was aggregated to generate the monthly and annual age frequency distributions of males and females in commercial and recreational landings.

During 1998-1999, the lengths of all fish were measured (DoF unpubl. data, Jones *et al.* 2002). Ages were determined for a subset of these fish, and used to develop ‘age-length keys’ for the WCB and the SCB (Jones *et al.* (2002). The age composition of commercial landings in each Bioregion was then estimated from length data using the age-length keys. The sex of fish collected in 1998-1999 was noted, but the original (raw) data was not available to this current study. Some aggregated data regarding sex ratios in landings was available from Jones *et al.* (2002).

Raw length data (DoF unpubl. data) collected in 1998-1999 was re-analysed in this report to determined average monthly values in WCB and SCB fisheries. Age data from 1998-1999 were not re-examined, and thus the age composition data described below are reported directly as described by Jones *et al.* (2002).

5.2.4 Recreational fishing surveys and logbooks

In the WCB, the catch and effort of recreational fishers was estimated by DoF during 12-month surveys of boat-based recreational fishing in 1996/97, 2005/06, 2008/09, 2009/10 and 2011/12[6]. The length composition of the retained catch of selected species (including *H. melanochir*) was estimated from onsite (e.g. boat ramp) interviews during these surveys. Details of the boat-based surveys from 1996/97 to 2009/10 are given by Sumner *et al.* (2008). Details of the statewide boat-based survey in 2011/12 are given by Ryan *et al.* (2013).

A voluntary recreational fisher logbook program (part of the DoF Research Angler Program (RAP) commenced in 2005 and is ongoing. Participants in the RAP logbook scheme include shore- and boat-based recreational fishers in the WCB and SCB. Logbook fishers are asked to record fishing date, location, start and finish times of each fishing session, number and name of each captured species, whether fish were retained or released, and the total length (TL) of each fish to the nearest mm.

[6] another 3-month survey of shore-based fishing was conducted April-June 2014, but results were not available at the time of writing.

5.3 Results

5.3.1 Cockburn Sound (WCB) commercial catch composition

During 2009-2012, the average annual catch of *H. melanochir* by the *Cockburn Sound (Fish Net) Managed Fishery* had a mean length of 275 mm TL (Fig. 5.1a). Males ranged from 203 to 334 mm (mean 269 mm) and females from 218 to 364 mm (mean 292 mm).

In 2009-2012, the vast majority (96%) of *H. melanochir* caught commercially in Cockburn Sound were sexually mature (>L_{50}). Only 4% of the total annual commercial catch were immature or the sex could not be unidentified (<L_{50}). (Fig. 5.1a)

The average length of *H. melanochir* in landings was larger during the cooler months. The trend was more pronounced for females than for males (Figs. 5.2, 5.3a).

Historical sampling of the length composition of commercial landings in Cockburn Sound was limited. In 1998, monthly samples were collected during February-May. The same commercial fishing gear (i.e. haul net) was used in 1998 and 2009-2013. Therefore, the catch composition in 2009-2012 was directly compared with that observed in 1998, for the months of February-May only.

In commercial landings during February-May, the average length of *H. melanochir* (sexes pooled) was lower in 2009-2012 (281 mm) than in 1998 (300 mm) (Fig. 5.1b and 5.1c). Lengths ranged from 203 to 363 mm in 2009-2012, and 229 to 381 mm in 1998.

In 1998 and 2009-2012, the monthly average length of *H. melanochir* (sexes pooled) in commercial landings displayed a similar trend. In both periods, the average length increased between February and March, and was then relatively stable until May (Fig. 6.3b). However, in each month, the average length was significantly larger in 1998 than in 2009-2012 (Fig. 5.3b).

During 2009-2012, the sex ratio of commercial landings in Cockburn Sound followed a seasonal trend. The sex ratio was strongly biased towards males in the warmer months. In summer, males comprised approximately 80-90% of the catch (Fig. 5.4). In winter, the sex ratio was equal (males comprised about 50% of the catch). Overall, due to the majority of landings occurring in autumn (see Section 5), the sex ratio of the total annual commercial catch in Cockburn Sound was biased towards males, which comprised 63% of total annual landings (Fig. 5.1a). The remainder comprised females (33%) and unidentified/juvenile individuals (4%). Excluding unidentified individuals, the male:female ratio in annual landings was 66:44.

During 2009-2012, the ages of *H. melanochir* in commercial landings in Cockburn Sound ranged from 0+ to 4+ years for males and 0+ to 3+ for females (Fig. 5.5, 5.6). In each month the dominant (modal) age group of both sexes was 1+, with the exception of December (and also November for females) when the dominant age was 0+ (Fig. 5.5). 0+ fish were rare/absent from samples in the first half of the year (January-June) and were mainly observed in the second half of the year (July-December). The dominance of 0+ fish in November/December marked these as the months in which annual recruitment of the next year class to the fishery primarily occurred. 0+ fish in December progressed to the next age group in January (i.e. were aged 1+ in January) due to the assignment of a universal birthday of 1 January.

When samples were aggregated by year, the modal age of commercial landings was 1+ in 2009, 2010 and 2011 (Fig. 5.6). In 2012, the modal age was 2+, although the representativeness of this sample is questionable given the very small sample size. In 2009, 2010 and 2011, less than 5% of the catch was aged >2 years.

Overall, the trends in monthly and annual age composition suggested that the commercial fishery in 2009-2012 was mainly comprised of a single year class that recruited to the fishery in December and was replenished by a new year class the following December.

Limited historical sampling of the age composition of commercial landings in the WCB was undertaken in 1998-1999 by Jones *et al.* (2002). Their sample was dominated by fish collected in Cockburn Sound, with small numbers of fish from Geographe Bay. Hence, their estimated age structure for the WCB (sexes pooled) was effectively reflecting the composition of landings within Cockburn Sound. In 1998-1999, ages within Cockburn Sound ranged from 0+ to 5+ years, with a modal age of 2+ years (Fig. 5.7). Approximately 30% of the catch was aged >2 years.

Since the same commercial fishing gear was used within Cockburn Sound in 1998-1999 and 2009-2012, the catch composition in these periods can be directly compared. Between these periods, the modal age declined from 2+ to 1+ years, and the proportion of fish aged >2 years fell from 30% to less than 5%.

5.3.2 WCB recreational catch composition

The length composition of *H. melanochir* retained by boat-based recreational fishers in the WCB was similar during surveys in 1996/97 and 2005/06 (Kolmogorov-Smirnov test, $p > 0.05$). During these surveys, garfish ranged from 200 mm to 455 mm TL (Figs. 5.8a and 5.8b). The distributions were skewed towards smaller fish, with a modal length of approximately 290 mm TL. In 2011/12, the modal length of *H. melanochir* retained by boat-based recreational fishers in the WCB was similar to that observed in 1996/97 and 2005/06 (Fig. 5.8c). However, the length range was smaller in the 2011/12 survey due to the absence of larger fish (>390 mm), which were present in the 1996/97 and 2005/06 surveys. During each survey, negligible quantities of immature fish (i.e. below the WCB L_{50} of 225 mm) were observed in the retained catch.

The average length of *H. melanochir* reported in voluntary logbooks by boat-based fishers in the WCB during 2009-2012 was larger than that observed in surveys of boat-based fishing. Boat-based logbooks fishers reported a similar length range (200-460 mm) to that observed in surveys (Fig. 5.8d), but displayed an approximately normal distribution with a mean length of 323 mm, which was significantly different to the skewed distribution with a modal length of 290 mm observed during the boat-based surveys (Kolmogorov-Smirnov test, $p < 0.001$).

The average length of *H. melanochir* reported by shore-based logbook fishers was larger than that reported by boat-based logbook fishers (Fig. 5.8e). The lengths of *H. melanochir* reported by shore-based logbooks fishers in the WCB had a greater range (140-480 mm) and displayed a significantly different distribution to those reported by boat-based logbooks fishers (Kolmogorov-Smirnov test, $p < 0.001$). The shore-based catch was positively skewed with a modal length of approximately 340 mm TL. During 2009-2012, there was no obvious difference between years in the average length of *H. melanochir* reported by shore-based logbook fishers.

From July 2005 to August 2012, only 3% of all *H. melanochir* (including retained and discarded fish) recorded by shore-based logbook fishers and 5% by boat-based logbook fishers were likely to be immature (i.e. with a length < L_{50}). The estimated L_{50} for *H. melanochir* in the WCB is 225 mm TL (see Section 3).

The average length of *H. melanochir* donated by recreational fishers during 2009-2012 was considerably smaller than those reported by logbook fishers in the WCB over the same period (Fig. 5.8f). Donated fish included boat- and shore-caught individuals, mainly caught in the Perth area.

The sex of *H. melanochir* was not recorded in recreational fishing surveys or by logbook fishers. However, sex was determined for a small sample (*n*=237) of *H. melanochir* donated by recreational fishers (boat- and shore-based) during 2009-2012. Based on this donated sample, the average length of males in recreational landings appeared to be relatively constant throughout the year, but the length of females varied seasonally. Females were larger than males in summer/autumn but similar in size to males in winter/spring (Figs. 5.3c).

The monthly trend in average length of *H. melanochir* reported by logbook fishers (Fig. 5.3d) differed to that evident in donated samples (Fig. 6.3c). The average length (sexes pooled) reported by logbook fishers peaked during spring/summer and reached a minimum in winter. The majority of logbook data were reported by shore-based fishers. The reason for the difference in monthly length trends between logbook records and donated fish is unclear. Differences in the location of capture (shore-v. boat-based) may have contributed to the difference in size composition. Alternatively, it is possible that the size composition of donated fish was unrepresentative of recreational catches due to the relatively small sample sizes.

The total sample of *H. melanochir* donated by recreational fishers during 2009-2012 was comprised of 60% males and 40% females. Any seasonal trends in the sex ratio of donated samples were unclear due to the limited number of months sampled, and relatively low samples sizes within those months (Fig. 5.4).

The age of *H. melanochir* donated by recreational fishers in the WCB in 2009-2012 ranged from 0+ to 5+ years for males and 0+ to 5+ years for females, with a modal age of 1+ for both sexes (Fig. 5.9). The vast majority of fish were donated in 2011. In 2011, 4% of females and 5% of males were aged >2 years (Fig. 5.10).

5.3.3 SCB commercial catch composition

The composition of the commercial catch in the SCB was not sampled during the current study (2009-2012).

During 1998-1999, limited length sampling of *H. melanochir* in commercial landings occurred in Wilson Inlet, Oyster Harbour, Princess Royal Harbour and on some ocean beaches (Cheynes Beach and Peaceful Bay) (DoF unpubl. data). The majority of samples were collected in Wilson Inlet.

In Wilson Inlet, the monthly average length of *H. melanochir* ranged from 295 to 322 mm for haul net landings (November-February only) and from 336 to 359 mm for gill net landings (May-October) (Figs 5.11a, 5.12a, 5.12b). The mesh size used in these gill nets was 44 mm. The average monthly length of garfish caught by haul nets in the other estuaries and ocean beaches was typically smaller (range 258-302 mm) than in Wilson Inlet Fig (5.11b, 5.12d).

Assuming that *H. melanochir* in the SCB attain maturity (L_{50}) at 242 mm TL (see Section 3), then mature garfish ($>L_{50}$) comprised 100% of commercial gill net landings and haul net landings in Wilson Inlet and on ocean beaches and comprised 91% of commercial haul net landings in other estuaries in 1998.

In 1998-1999, the sex ratio of *H. melanochir* sampled from commercial landings in the SCB (mainly sampled in Wilson Inlet) followed a seasonal trend (Jones *et al.* 2002). In summer, landings were predominantly females (~90% of the catch). In winter, the sex ratio approached parity (females comprised about 50-60% of the catch).

5.3.4 SCB recreational catch composition

Limited information is available regarding the length composition of recreational landings of *H. melanochir* in the SCB.

During 2006/07-2011/12, the lengths of *H. melanochir* caught in Wilson Inlet were reported by a single voluntary logbook fisher. This fisher captured small daily quantities of *H. melanochir* (1-7 fish per day), and reported a total of 90 lengths over this 2 year period (representing the sum of 40 daily catches). Lengths ranged from 200 to 480 mm TL (average 383 mm) (Fig. 5.13a). During 2009-2012, 11 *H. melanochir* captured by recreational fishers in Wilson Inlet were donated as specimens. These fish ranged from 293 to 410 mm TL (average 325 mm) (Fig. 5.13a).

During 2005/06-2006/07, the lengths of 41 *H. melanochir* caught in Oyster Harbour were reported by voluntary logbook fishers. Lengths included retained and released fish. Lengths were reported by 4 logbook fishers, who each captured small daily quantities of *H. melanochir* (1-6 fish per day per fisher) over this 2 year period. Lengths ranged from 290 to 440 mm TL (average 366 mm) (Fig. 5.13b). During 2009-2012, 23 *H. melanochir* captured by recreational fishers in Oyster Harbour were donated as specimens. These fish ranged from 214 to 297 mm TL (average 250 mm) (Fig. 5.13b).

H. melanochir donated as specimens by recreational fishers were typically smaller than those recorded by logbook fishers in both Wilson Inlet and Oyster Harbour.

Assuming that *H. melanochir* in the SCB attain maturity (L_{50}) at 242 mm TL (Section 3), then mature garfish ($>L_{50}$) comprised 92% of the recreational catch reported from Oyster Harbour and 93% of the recreational catch reported from Wilson Inlet (logbook and donated specimens pooled).

Insufficient data was collected to determine the age composition or sex ratio of recreational landings of *H. melanochir* in the SCB in either 1998-1999 or 2009-2012 sampling periods.

5.4 Discussion

5.4.1 Sex ratio

A strongly biased sex ratio is characteristic of *H. melanochir* landings in fisheries that target this species. This bias arises as a consequence of different behaviours by males and females during the spawning period. At this time, mature females typically form large schools in shallow (<5 m) waters while mature males are more widely dispersed and are found in deeper, offshore waters (Jones *et al.* 2002). The sex ratio in a particular fishery may be strongly skewed towards either males or females, depending on season and depth of capture (Fowler *et al.* 2008).

In SA, schooling fish in shallow waters are estimated to comprise 92% females, while non-schooling fish in deeper water comprise 84% males during the reproductive season in November-April (Jones *et al.* 2002). The majority of commercial fishery landings in SA are taken in this period by haul nets, which are deployed in shallow (<5 m) waters. Consequently, commercial fishery landings in SA are strongly dominated by females (Fowler *et al.* 2008). A small proportion of commercial landings in SA are taken by 'dab nets' in deeper, offshore waters and these landings are typically dominated by males. Similarly, *H. melanochir* sampled by gill nets in the deeper waters of Baird Bay, SA, were predominantly male (Jones 1990).

In WA fisheries, the sex ratio of landings follows similar trends to those seen in SA. In Cockburn Sound, commercial landings are mostly taken in deeper waters (>5 m). These landings comprise 80-90% males in the spawning period and ~50% males during the non-spawning period. The Cockburn Sound commercial fishery operates in deeper water and so the inaccessibility of females due to their inshore distribution would explain the low proportion of females in landings during the spawning period. Since the main commercial fishing season for *H. melanochir* in Cockburn Sound overlaps with the end of the spawning period, the total annual catch by this fishery is dominated by males.

In contrast to Cockburn Sound, commercial landings in Wilson Inlet are taken in shallower waters (<4 m). These landings comprise ~90% females in the spawning period and 50-60% females during the non-spawning period (Jones *et al.* 2002). Since the main commercial fishing season for *H. melanochir* in Wilson Inlet overlaps with the spawning period, the total annual catch by this fishery is dominated by females. In Wilson Inlet, the majority of landings in the warmer months (i.e. the spawning season) are taken by haul nets, which are deployed in very shallow water (<2 m). The use of haul nets during summer probably contributes to the high proportion of females taken in Wilson Inlet.

The sex ratio of *H. melanochir* in recreational landings in WA remains unclear due to limited sampling. The available evidence from the WCB, where the majority of the state recreational catch is taken, indicates a high level of variation between months in the average length of fish, with females displaying more variability in length than males. This evidence is consistent with movement by mature females in/out of the fishery, as seen in the commercial fishery, suggesting that the sex ratio of recreational landings is similarly variable. Based on the known movement patterns of this species, and the effect they have on commercial catch composition, it is predicted that the annual shore-based recreational catch of *H. melanochir* will be dominated by females and the boat-based catch in deeper waters will be dominated by males. Further monitoring of recreational catch composition in the WCB is required to confirm this.

More information about catch composition, in conjunction with information about the spatial and temporal distribution of landings, is needed to understand the full impact of recreational fishing on *H. melanochir* stocks in key areas such as Cockburn Sound. The impact of shore-based fishers is especially important, since this sector is believed to take the majority share of the recreational catch in the WCB (Section 4).

5.4.2 Proportion of immature fish in catch

Prior to the commencement of this study, the percentage of sexually immature *H. melanochir* in commercial and recreational fishery landings within WA was uncertain. Previously, an L_{50} of 261 mm TL was reported for female *H. melanochir* in WA (Jones *et al.* 2002) which suggested that a substantial proportion of the total commercial and recreational catch in the WCB was immature. However, this preliminary estimate of L_{50} was based on a relatively small number of fish collected from various locations in the SCB and WCB. Approximately 70% of these fish were collected from the SCB (and ~50% from Wilson Inlet) and so this value reflected the size at maturity in these areas, rather than in the WCB.

During 2009-2012, intensive sampling of *H. melanochir* in the WCB, particularly in Cockburn Sound, yielded a local L_{50} of 225 mm TL for both sexes (Section 3). Also, additional sampling in the SCB yielded a new L_{50} of 242 mm TL for both sexes. Based on these new values, the percentage of sexually immature fish in all commercial and recreational catches in WA is estimated be low. In all fisheries, at least 90% of all *H. melanochir* captured, including released fish, are likely to be sexually mature (i.e. length is $> L_{50}$).

It is important to note that an L_{50} of 242 mm TL in the SCB is still a preliminary estimate, based on limited sampling. Additional samples from a range of locations are required to generate more reliable estimate(s) of L_{50} in the SCB. Given the circumstantial evidence of differences in growth rate between Wilson Inlet and other sites, it is possible that *H. melanochir* attain maturity at different sizes depending on location (e.g. L_{50} in the Wilson Inlet stock may be higher than in other SCB stocks). The proportion of mature fish in SCB fishery landings should be recalculated when more reliable estimate(s) of L_{50} become available.

5.4.3 Length composition of WCB fishery catch

Historical (1998-1999) and recent (2009-2012) sampling of *H. melanochir* in Cockburn Sound both indicated that the average length of fish in commercial landings displays marked monthly variation, peaking in the cooler (non-spawning) months each year. This trend can be largely explained by the seasonal movement in/out of the fishery area by mature females, which attain a larger size-at-age than males. Female *H. melanochir* move into shallow waters during the spawning period and become less catchable by the boat-based commercial fishery in Cockburn Sound, resulting in catches dominated by males at this time. Similar *H. melanochir* movement patterns have been observed in SA commercial fisheries, where boat-based landings are typically biased towards males and shore-based landings are typically biased towards females (Jones *et al.* 2002).

There is very limited information about spatial or temporal trends in the length composition of *H. melanochir* in recreational landings in the WCB but the available data, from voluntary recreational logbooks, is consistent with-spawning-related movements. Logbooks indicate that the average length of fish caught by shore-based recreational fishers is larger than those caught by boat-based recreational fishers. Logbooks also indicate that the average length of fish in the shore-based recreational catch follows the inverse monthly trend to that seen in the commercial catch, i.e. peaking in the warmer (spawning) months. These trends in the recreational catch are consistent with the movement of larger females into shallow water during the spawning period.

In summary, there is strong evidence that the length (and sex) composition of *H. melanochir* in fishery landings are highly variable between months, due to the spawning-related movements of adult fish. These sources of variation must be recognised when designing a sampling regime to monitor trends in annual size composition in *H. melanochir* stocks.

After monthly variations in length are taken into account, data collected in 1998-1999 and 2009-2012 indicate that the average length of *H. melanochir* in commercial landings in Cockburn Sound declined between sampling periods.

Limited evidence suggests that the average length of *H. melanochir* in WCB recreational catches also declined over this period. Measurements of fish taken during surveys of boat-based fishing in 1996/97, 2005/06 and 2011/12 indicate a progressive decline between surveys in the average size of *H. melanochir* being retained by recreational fishers.

5.4.4 Age composition of WCB fishery catch

During 2009-2012, *H. melanochir* in the Cockburn Sound commercial catch were mostly aged 0-2 years with a modal age of 1 year. In all years, the catch was dominated by a single age class (1+), which recruited into the fishery in November/December each year when aged 11-12 months. This consistent pattern suggests that the availability of fish over this period was strongly recruitment driven, with commercial catch rates primarily determined by the strength of recruitment in the previous year.

Recruitment to the commercial fishery after 11-12 months coincides approximately with the onset of sexual maturity in both males and females and with the peak in the spawning period (Section 4). Since the majority of commercial landings are taken after the spawning period, it is likely that most newly recruiting *H. melanochir* have the opportunity to spawn once before becoming vulnerable to capture by the commercial fishery. The vulnerability of virgin recruits to capture by recreational fishers in Cockburn Sound, or elsewhere in the WCB, is unclear because the quantity of recreational landings taken during the spawning period is not known.

The average age of *H. melanochir* taken recreationally was slightly older than that taken commercially in the WCB. In 2009-2012, fish in commercial landings ranged from 0 to 4 years, whereas those in recreational landings ranged from 0 to 5 years. However, the modal age was 1+ in both fisheries.

WCB commercial and recreational fisheries are both effectively recruitment-dependent. *H. melanochir* recruit to both fisheries in summer when aged ~1 year. The 1+ year class then dominates landings until the following summer, when they are replaced by the next 1+ year class. This characteristic makes the fisheries vulnerable to collapse in the event of a single year of poor recruitment. Recruitment failure during the 'heatwave' event in 2011 would explain the dramatic decline in catches after 2011 (Section 4).

Considering the maximum reported age of 10 years for *H. melanochir*, the age structure of the Cockburn Sound stock in 2009-2012 was heavily truncated. The composition of both commercial and recreational fishery landings suggested that approximately 95% of this population was aged 2 years or less. The age structure in 2009-2012 was more truncated than in 1998-1999, when the stock was previously sampled. Between these periods, the modal age declined from 2+ to 1+ years, and the proportion of fish aged >2 years fell from 30% to less than 5%.

5.4.5 Future monitoring of recreational catch composition

Lack of information about the quantity and composition of recreational landings of *H. melanochir* in the WCB is a key knowledge gap that should be addressed in future monitoring. This gap contributes some uncertainty about the status of *H. melanochir* in Cockburn Sound, the most heavily targeted stock in WA. Shore-based recreational fishers are estimated to take the largest share of landings in Cockburn Sound (Section 4). The available evidence suggests that shore-based fishers pose a risk to the sustainability of the Cockburn Sound stock that is equal to, or greater than, the risk posed by the commercial fishery. This risk is the consequence of a higher catch level and a higher proportion of females in the catch, compared to the commercial fishery.

Incomplete information is available about the length, age and sex composition of recreational landings of *H. melanochir* in the WCB. Several recent surveys of boat-based fishing estimated the length composition of the boat-based catch, but age and sex was not recorded in these surveys. The length composition and sex ratio of the shore-based recreational catch in the WCB is not known due the absence of any comprehensive recent survey of the shore-based sector. Some information about the shore-based catch is available from spatially and/or temporally limited surveys (e.g. Smallwood *et al.* 2011a) and from voluntary recreational logbooks. However, it is unclear whether the catch composition recorded by these sources is representative of the total annual shore-based recreational catch in the WCB.

Developing reliable, cost-effective methods to monitor the size and/or age of *H. melanochir* in the recreational catch is a challenge. In WA, an ongoing fish frame donation program ('Send Us Your Skeletons') and a voluntary recreational logbook scheme ('Research Angler Program') have been successfully used by DoF to obtain information from recreational fishers about their catches of various demersal and nearshore finfish species. This information has contributed to numerous stock assessments of recreationally important species (Brown *et al.* 2013, Smith *et al.* 2013b and 2013c, Fairclough *et al.* 2014a). However, it is unclear whether these methods can provide representative data about WCB recreational landings of *H. melanochir*.

Specimens of *H. melanochir* donated fishers to the 'Send Us Your Skeletons' program in 2009-2012 were typically smaller than the average length recorded by logbook fishers in both the WCB and SCB over the same period. This suggests that recreational fishers tended to donate the smallest *H. melanochir* in their catch. This tendency is not surprising considering that *H. melanochir* were generally donated as whole fish, unlike other species which were donated as filleted frames. *H. melanochir* are usually not filleted, due to their small size. Since donated samples of *H. melanochir* are biased towards small fish, they are not representative of the total recreational catch (and probably not representative of the stock) and should not be used to monitor trends in the size (or age) composition of *H. melanochir*.

The biases associated with length data recorded by voluntary logbook fishers are less clear than those associated with donated specimens. The only comparable data that can be used to verify the representativeness of *H. melanochir* lengths recorded by shore-based logbook fishers is from a preliminary survey of shore-based recreational fishing in the Perth region during April-June 2010 (Smallwood *et al.* 2011a). *H. melanochir* observed during this survey included retained fish only (n=141) and ranged from 230 to 440 mm TL, with a median length of 320 mm. *H. melanochir* recorded by shore-based logbook fishers in the WCB during April-June (2009-2012 years pooled) ranged from 180-440 mm, with a mean of 324 mm and median of 330 mm. Logbook data included retained and released fish. This limited comparison suggests that the length distribution of *H. melanochir* reported by shore-based logbook fishers is similar to the length distribution of fish captured by other shore-based recreational fishers in the WCB.

To verify the representativeness of *H. melanochir* lengths recorded by boat-based logbook fishers, a small amount of comparable data is available from surveys of boat-based recreational fishing in the WCB (Fig. 5.8a-d). This comparison suggests that the average size of *H. melanochir* captured by boat-based logbook fishers is slightly larger than that captured by other boat-based recreational fishers.

Discrepancies in length data between survey and logbook length data could also be partly due to measurement errors. Although all logbook fishers were instructed to measure the total length of garfish from the tip of the upper jaw, it is possible that some lengths were taken from the tip of the lower jaw. If so, then the true lengths of some fish reported by logbook fishers would be smaller than reported. Some length data recorded during past DoF surveys may also be biased by this measurement error (K. Ryan, pers. comm.).

5.4.6 Future monitoring of commercial catch composition

Until methodology is developed to ensure representative sampling of the recreational catch, assessments of *H. melanochir* stock status in the WCB will be reliant on commercial fishery or fishery-independent data. In Cockburn Sound, the main WCB fishery for this species, commercial fishery sampling is currently more cost-effective than fishery-independent sampling.

In 2009-2012, the commercial catch in Cockburn Sound displayed some monthly variation in length structure but limited monthly variation in age structure within each year, for age classes that were fully recruited to the fishery (i.e. 1+ and older). This suggests that a representative sample of the annual age structure could be obtained from sampling within a restricted number of months. A sampling period around February-June, which encompasses the main commercial fishing season, appears to be optimal for several reasons. Firstly, this occurs after the spawning period when mature males and females are both well represented in landings and the sex ratio is approaching parity. At other times, the absence of mature females may bias the sample towards younger/smaller fish. Secondly, *H. melanochir* are readily available from the commercial fishery at this time. Outside the main fishing season, landings are spasmodic and very low (i.e. 0-300 kg per month), and so fish are not always obtainable. Sampling at this time is less cost-effective because more staff time is required per sample, compared to during the main fishing season.

Future efforts to monitor the status of *H. melanochir* in WA should focus on the Cockburn Sound fishery, due to the relatively high sustainability risks identified for this stock (Section 3). However, it is recommended that some age-based monitoring should also be undertaken in Wilson Inlet, the state's second largest commercial fishery for *H. melanochir*. Threats to the sustainability of the Wilson Inlet stock have been identified, including a substantial increase in catch over the past decade (see Section 4), but insufficient biological information is currently available to determine stock status.

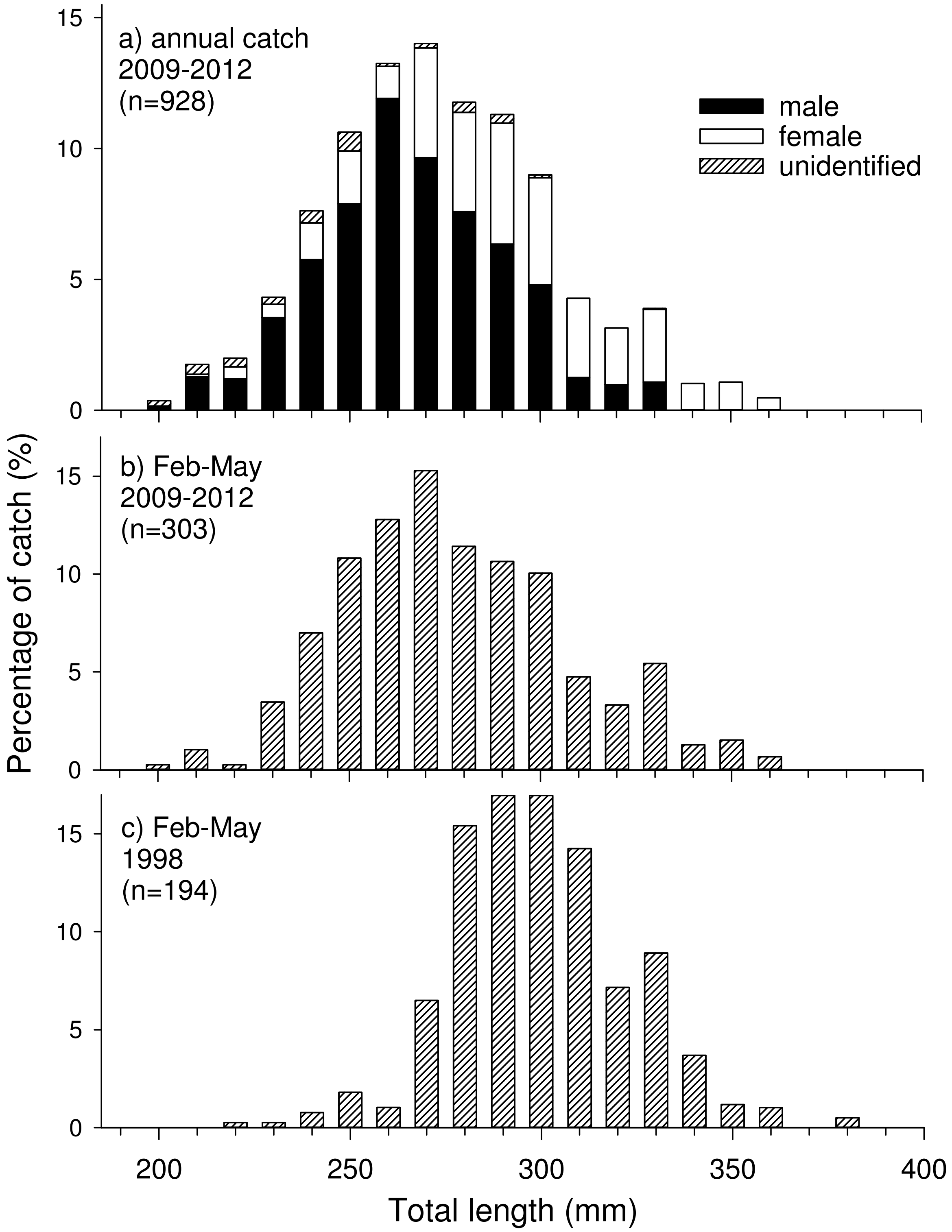

Figure 5.1. **Length composition of the commercial catch of *Hyporhamphus melanochir* in Cockburn Sound. a) average annual catch, 2009-2012, b) average catch during February-May, 2009-2012, and c) average catch during February-May, 1998.**

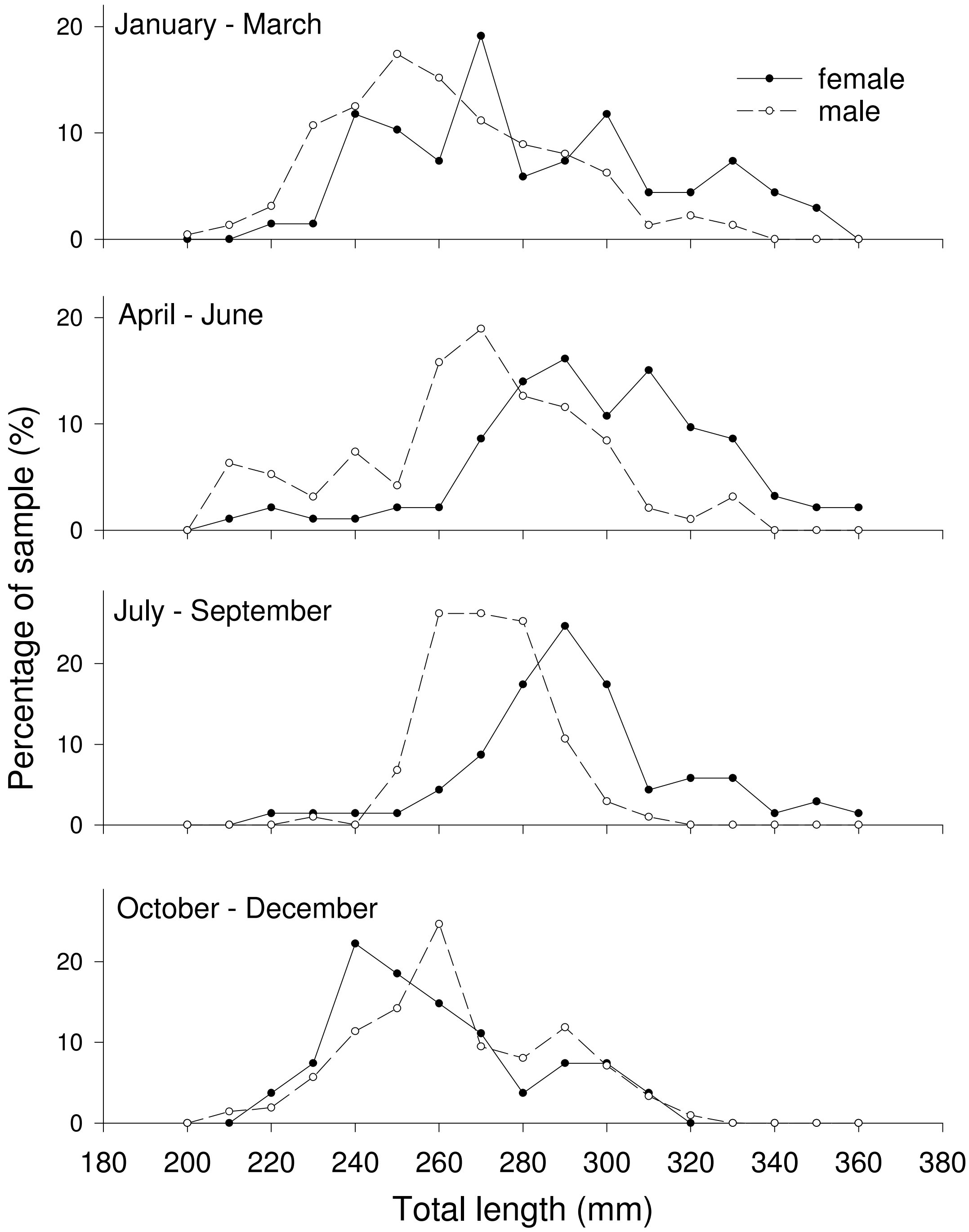

Figure 5.2. Seasonal length composition of males and females in commercial landings of *Hyporhamphus melanochir* in Cockburn Sound, sampled 2009-2012.

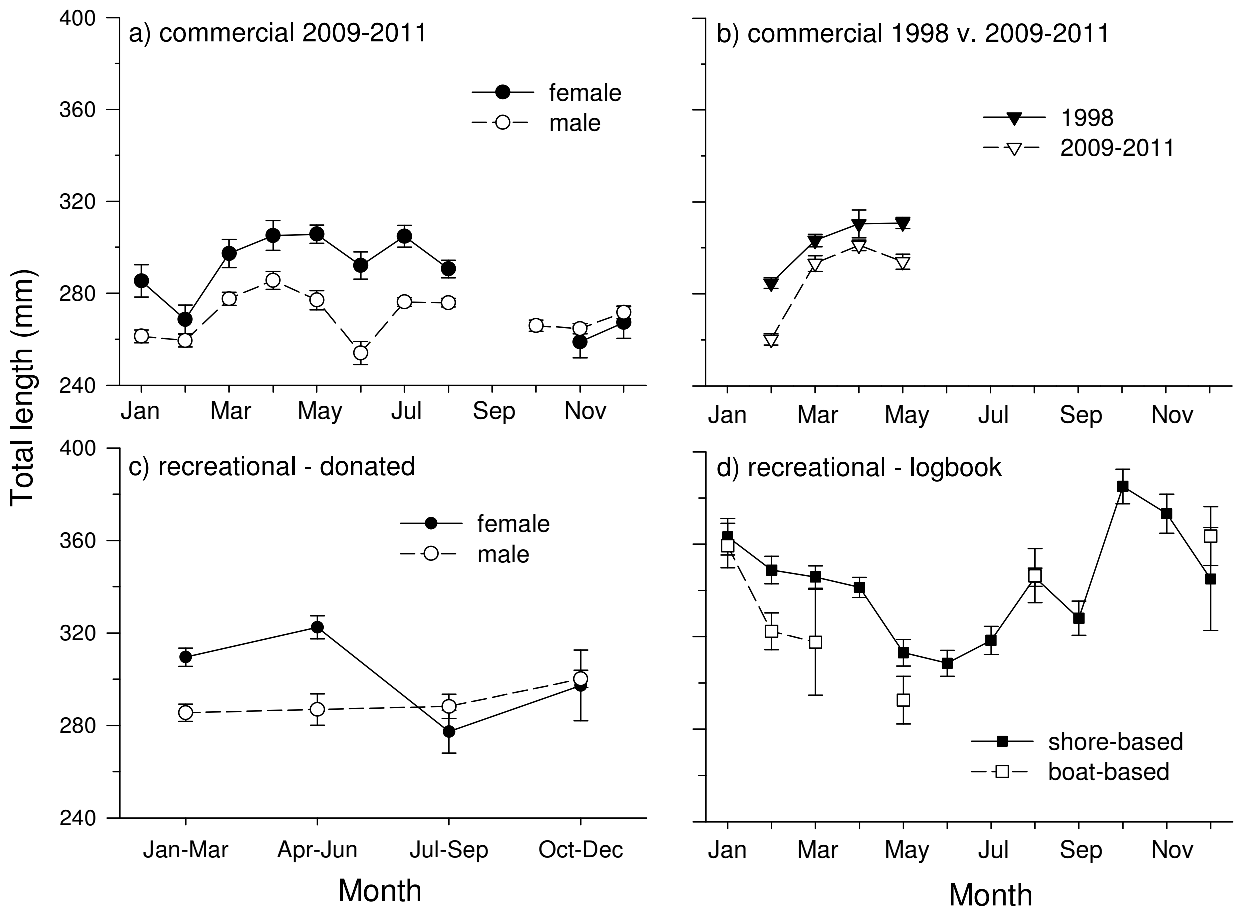

Figure 5.3. Average (± s.e.) monthly length of *Hyporhamphus melanochir* a) males and females in commercial landings in Cockburn Sound, sampled 2009-2012, b) all fish (sexes pooled) in commercial landings in Cockburn Sound, sampled 1998 and 2009-2012, c) males and females samples donated by recreational fishers in the West Coast Bioregion (WCB), collected 2009-2012 (months grouped to increase sample size) and d) all fish (sexes pooled) recorded in voluntary logbooks by shore- and boat-based recreational fishers in the WCB, 2005-2011. (data not shown where sample size was <10 fish)

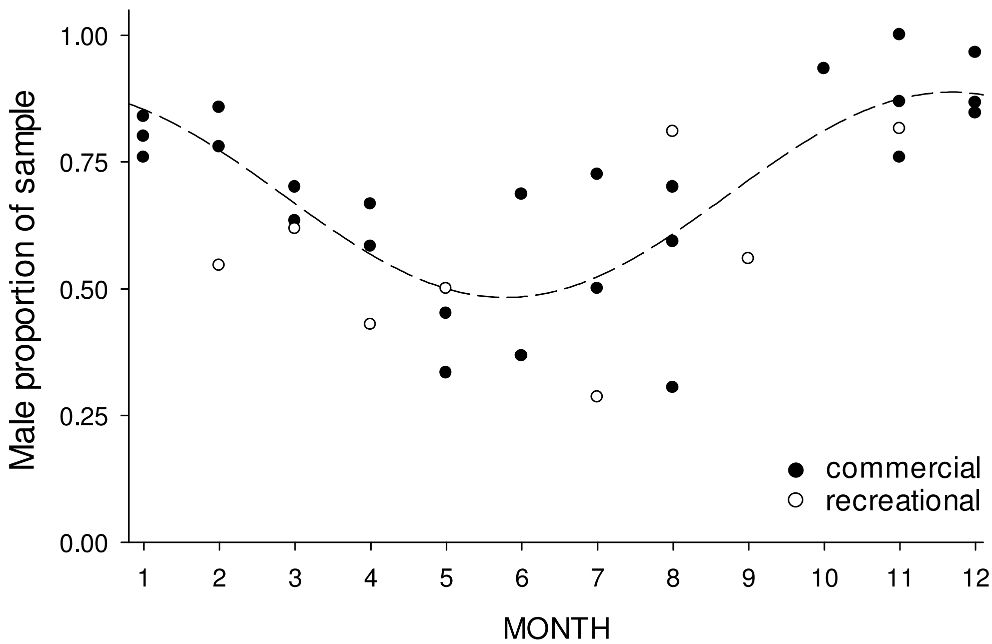

Figure 5.4. Proportion of male *Hyporhamphus melanochir* in monthly samples from commercial landings and samples donated by recreational fishers in the West Coast Bioregion, 2009-2012. Month 1 = January, 2 = February, etc. (commercial - data points represent individual months over the period 2009-2012; recreational - data points represent aggregated monthly data (i.e. years pooled)). Fitted curve for commercial samples is intended as guide only. (Month 1 = January, 2 = February, etc.).

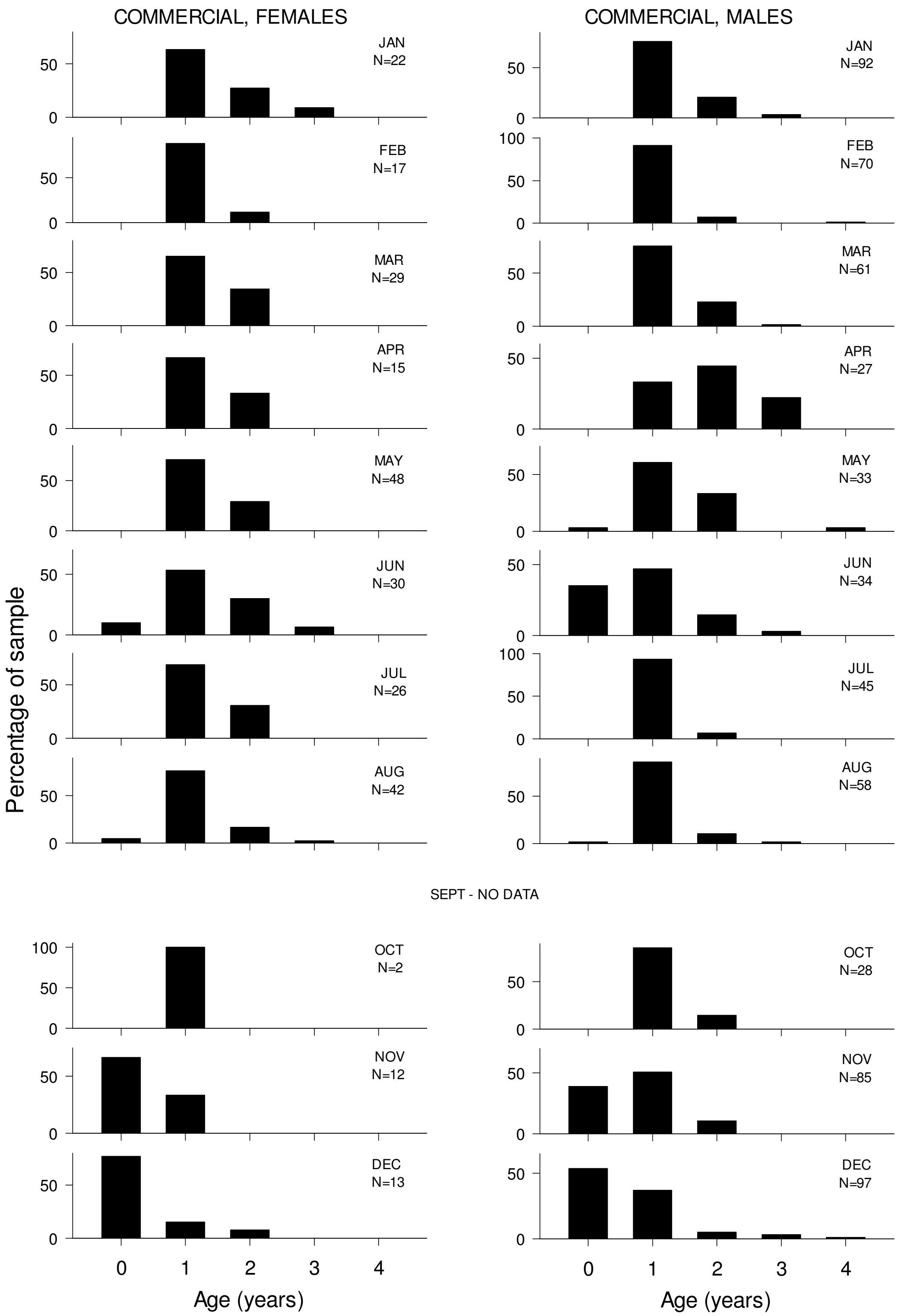

Figure 5.5. Age composition of female and male Hyporhamphus melanochir sampled from WCB commercial fishery landings during 2009-2012, aggregated by month (years pooled).

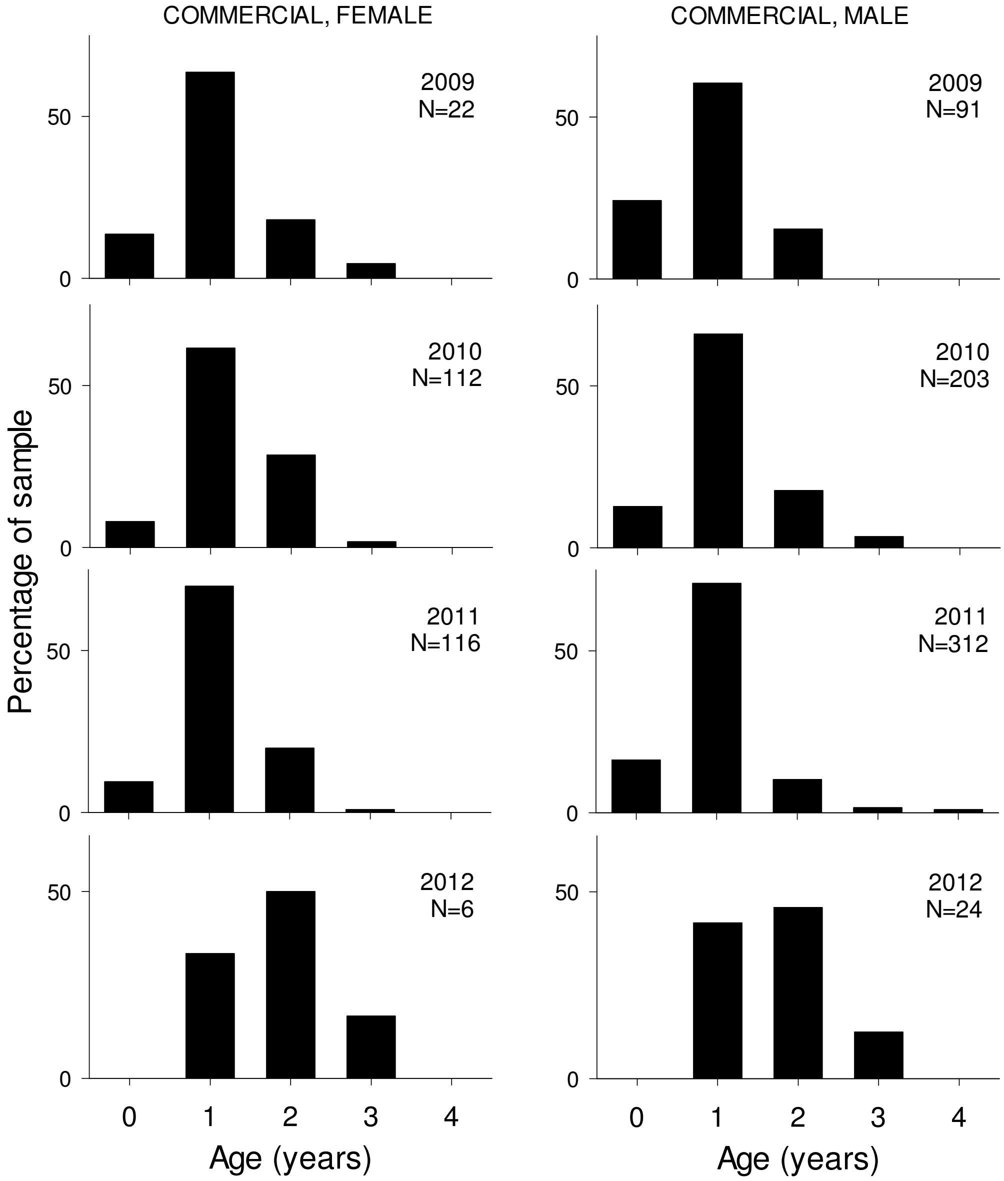

Figure 5.6. Age composition of female and male *Hyporhamphus melanochir* sampled from WCB commercial fishery landings during 2009-2012, aggregated by year (months pooled).

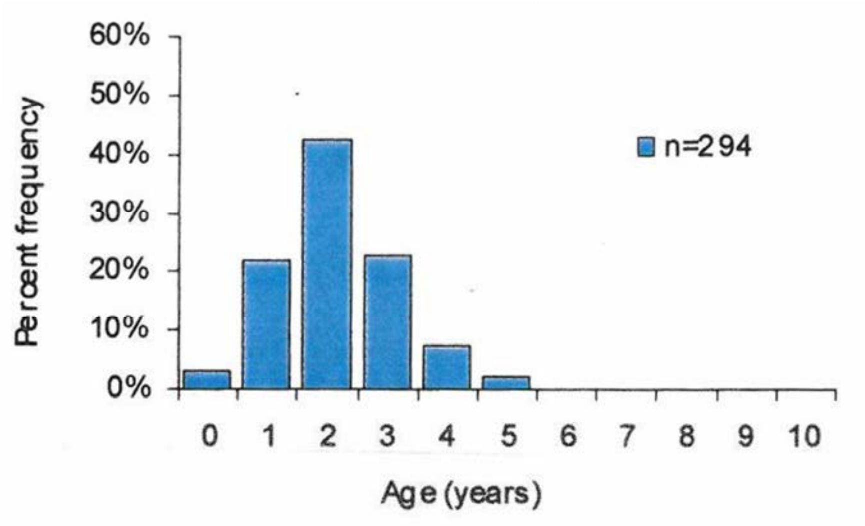

Figure 5.7. Age composition of female and male *Hyporhamphus melanochir* sampled from WCB commercial fishery landings during 1998-1999 (reproduced from Jones *et al.* 2002).

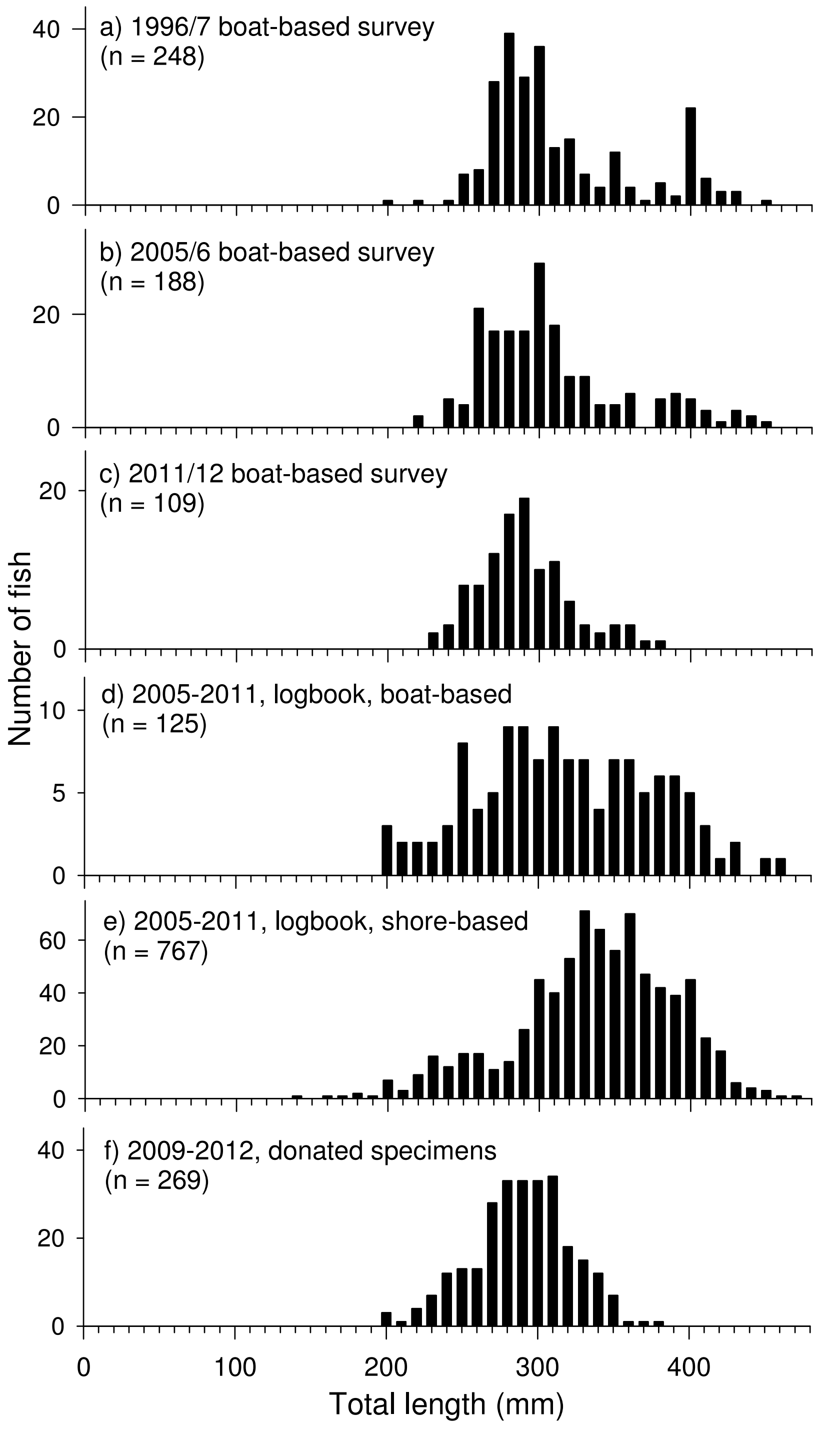

Figure 5.8. **Length composition of recreational landings of *Hyporhamphus melanochir* in the West Coast Bioregion, a-c) observed during surveys of boat-based fishing in 1996/97 2005/06 and 2010/11, d-e) recorded in voluntary logbooks by boat-based fishers and shore-based fishers during 2005-2011 and f) donated as specimens by shore- and boat-based recreational fishers during 2009-2012. (Note: logbook data includes retained and released fish.)**

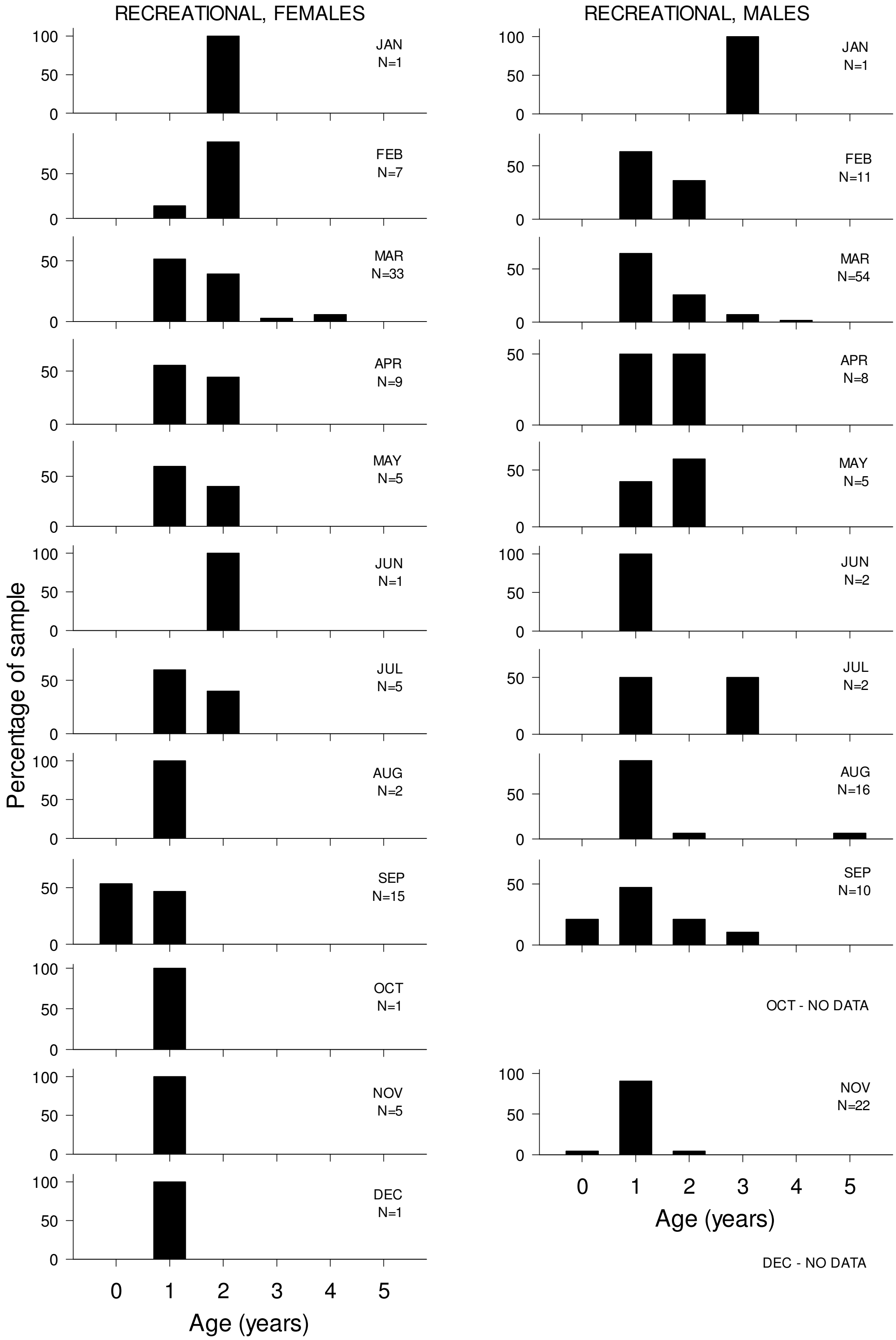

Figure 5.9. Age composition of female and male *Hyporhamphus melanochir* sampled from WCB recreational fishery landings during 2011, aggregated by month.

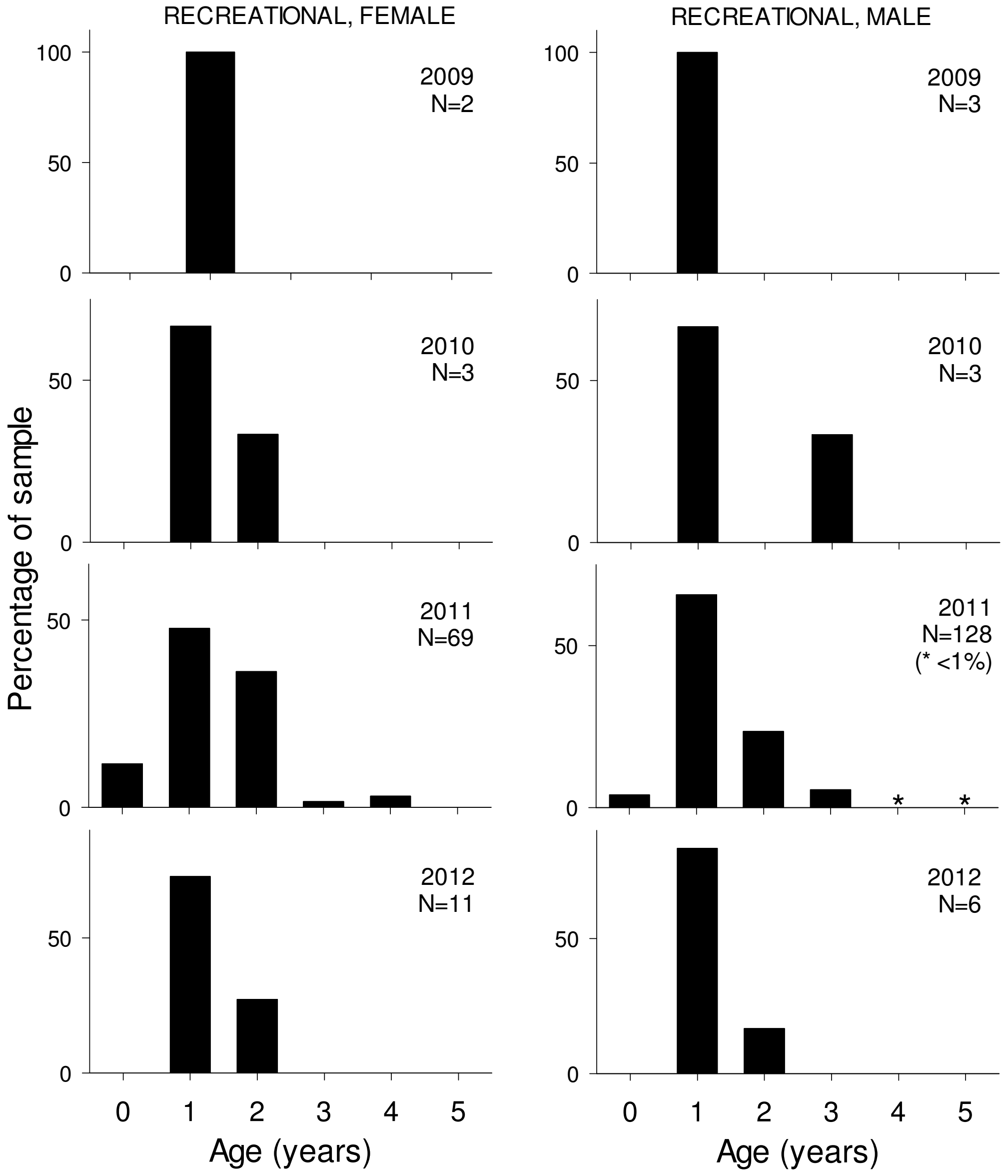

Figure 5.10. Age composition of female and male *Hyporhamphus melanochir* sampled from WCB recreational fishery landings during 2009-2012 (months pooled).

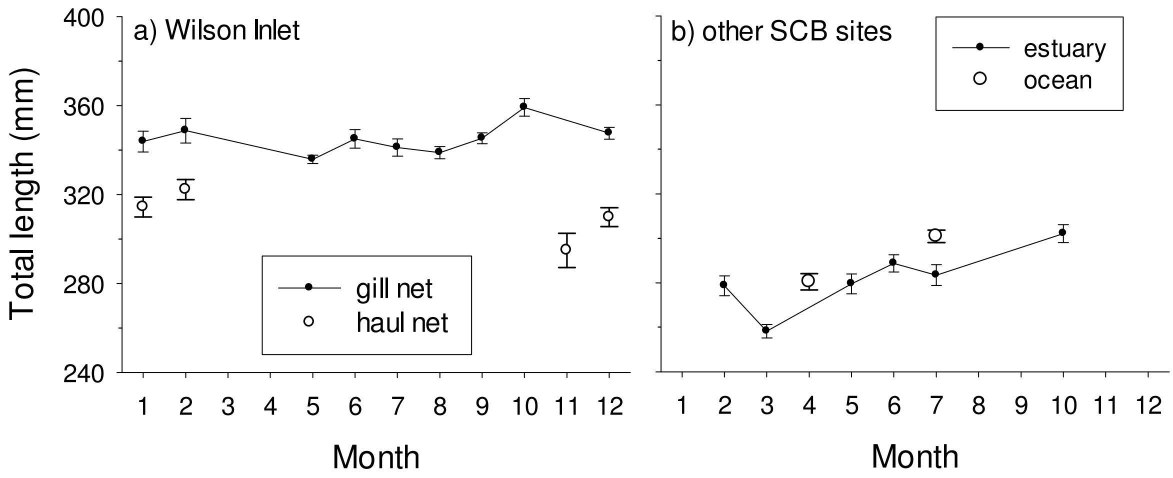

Figure 5.11. Average (± s.e.) length of monthly commercial landings of *Hyporhamphus melanochir* in the South Coast Bioregion (SCB) a) by gill nets* and haul nets in Wilson Inlet and b) by haul nets at other sites (estuary = Oyster Harbour and Princess Royal Harbour) in 1998-1999. Month = January, 2 = February, etc. (*gill net samples in January, February and December collected by researchers using same mesh size as commercial nets, i.e. 44 mm).

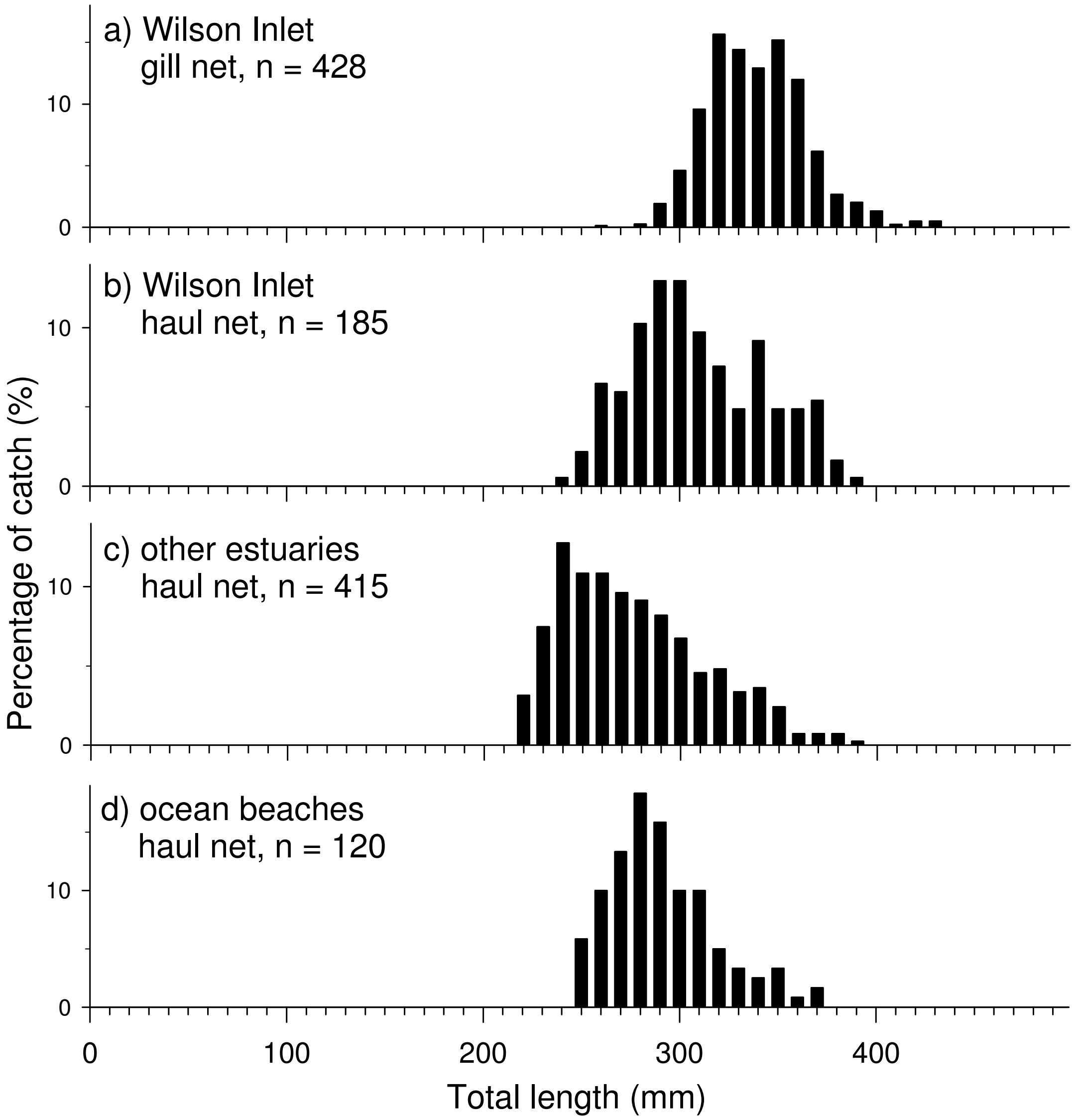

Figure 5.12. Length composition of monthly commercial landings of *Hyporhamphus melanochir* in the South Coast Bioregion in 1998-1999 in a) Wilson Inlet by gill nets (May-October only), b) Wilson Inlet by haul nets (November-February), c) other estuaries (Oyster Harbour, Princess Royal Harbour) by haul nets (February-October), and d) ocean beaches (Cheynes Beach, Peaceful Bay) by haul nets (May-July).

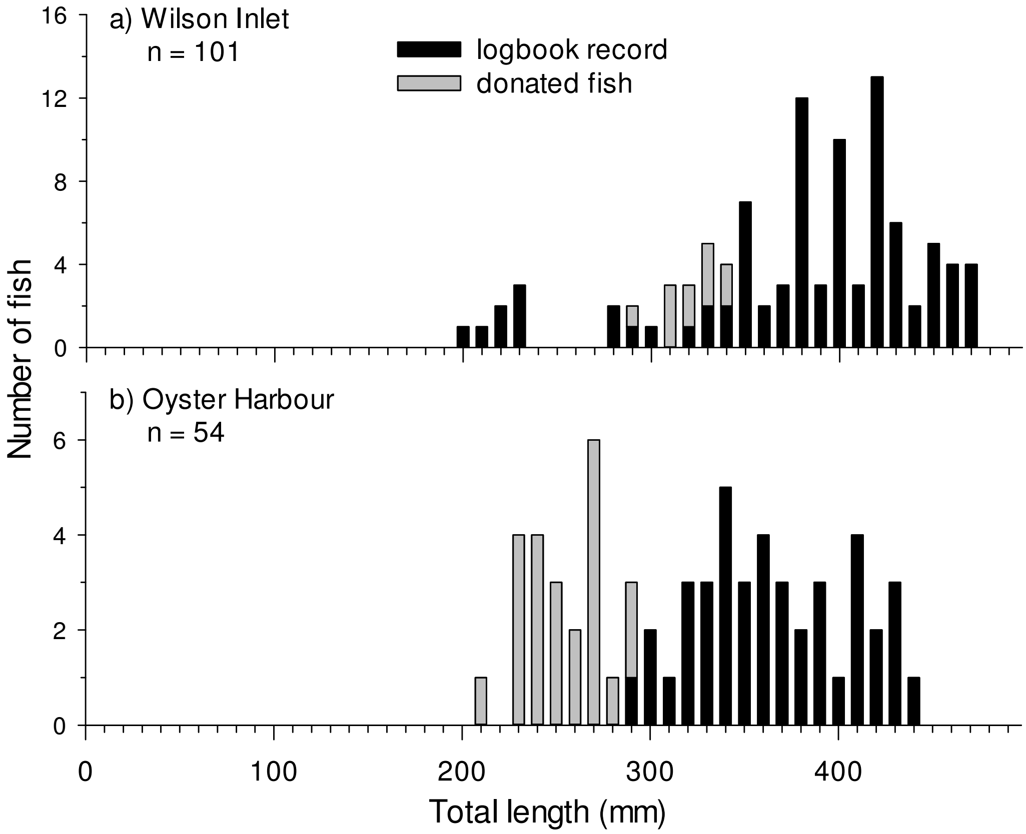

Figure 5.13. Lengths of *Hyporhamphus melanochir* captured by recreational fishers in a) Wilson Inlet and b) Oyster Harbour, recorded in voluntary logbooks and donated as specimens to researchers.

6 Quantitative assessment of stock status of *Hyporhamphus melanochir* in Cockburn Sound

Summary

- In 2010-2011, two biological indicators, fishing mortality (*F*) and spawning potential ratio (SPR), were used to assess the status of the *Hyporhamphus melanochir* stock in Cockburn Sound. The estimates of *F* were well above (*i.e.* breached) the limit reference point for *F*, and the values for SPR were at or just below (*i.e.* close to breaching) the limit reference point for *SPR*.
- *F* values in 2010-2011 were compared with those estimated in a previous study in 1998-1999. Fishing mortality on this stock appears to have more than doubled between 1998-1999 and 2010-2011.
- *F* values in 2010-2011 were estimated by employing two commonly used forms of catch curve analysis, *i.e.* the mortality estimator of Chapman and Robson (1960) (C&R) and linear catch curve analysis (LCC) as described by Ricker (1975). LCC tended to yield similar but less precise Z values compared to C&R, particularly when sample sizes were low (n <300) However, both methods estimated that *F* values in 2010-2011 were well above the limit reference point. The lower 95% confidence limits for all estimates were above the limit reference point.
- Results indicated that, in recent years, the level of fishing mortality to which this stock has been subjected is not sustainable and a substantial reduction in total catch will be required to reduce *F* to an acceptable level.

6.1 Introduction

In WA, *Hyporhamphus melanochir* is distributed from Lancelin southwards (Gomon *et al.* 2008). Fishery landings of this species in WA are highly localised. In the WCB, the vast majority of fishery landings are taken in the Perth metropolitan area, particularly within Cockburn Sound (Section 4). Cockburn Sound is estimated to produce >80% of total commercial and >50% of total recreational landings of *H. melanochir* in the WCB each year (Section 4). Whilst stock structure has not been fully investigated, the available evidence (Section 2) suggests that *H. melanochir* in Cockburn Sound may host a largely self-replenishing population, and should therefore be managed as a discrete stock.

H. melanochir is viewed as moderately 'at risk' due to certain inherent biological characteristics (small stock size, low dispersal, strong habitat dependency, low fecundity) that make it vulnerable to depletion (Table 7.1 in Section 7). In Cockburn Sound, high fishing pressure and multiple unfavourable environmental factors (including high temperatures and habitat loss) have also been identified as threats to the sustainability of the stock (Section 7). A relatively rudimentary 'Level 2' assessment (i.e. monitoring catch and catch rate trends) has previously been used to determine the status of the Cockburn Sound stock (Smith *et al.* 2013a). Recent catch and CPUE trends have suggested a decline in *H. melanochir* abundance in Cockburn Sound. In response to concerns about the sustainability of *H. melanochir* in Cockburn Sound, biological monitoring of the fishery was undertaken during 2009-2012 to facilitate a more rigorous ‘age-based’ assessment of stock status involving both catch curve and per recruit analyses.

6.2 Methods

6.2.1 Estimates of natural mortality

The instantaneous rate of natural mortality (M, y^{-1}) was estimated using the empirical life history equation of Hoenig (1983), employing the equation using data from all taxa.

$$lnM = 1.44 - 0.982ln(t_{max})$$

where t_{max} is the maximum potential age (y) within the stock.

As the above equation of Hoenig (1983) relates estimates of mortality (for lightly-exploited stocks) to maximum age, any estimate of M derived from this empirical equation is sensitive to the value of maximum age assumed for that stock.

In previous studies, maximum ages of 10, 8 and 10 years were recorded (for both females and males) in unexploited (or lightly-fished) *H. melanochir* populations in South Australia, Tasmania and in the SCB of Western Australia, respectively (Section 2). Given the similarity in the maximum recorded ages among these disparate stocks, individuals of *H. melanochir* in Cockburn Sound could also be expected to attain up to 8-10 years in age, if the stock was unexploited or lightly-exploited.

Despite a potential longevity of 8-10 years, the maximum observed age in Cockburn Sound is only 5 years (Sections 2 and 3) which suggests that the stock has relatively recently experienced heavy fishing pressure. This conclusion is consistent with observed declines in commercial catch rates. However, it should also be noted that Cockburn Sound is situated at a lower latitude and experiences warmer coastal water temperatures than Tasmania, the SCB and most areas of South Australia. The lifespans of many fish species have been shown to increase with increasing latitude and decreasing temperature. This trend has been explained by the ‘Metabolic Theory of Ecology’ that links metabolism, which scales directly with temperature, to a range of life history attributes, including lifespan (*e.g.* Charnov and Gillooly 2004, Much and Salinas 2009, Bevacqua *et al.* 2011, Lek *et al.* 2012). Thus, it is possible that *H. melanochir* in Cockburn Sound may naturally have shorter lifespans than stocks further to the south.

Values of natural mortality (M) and fishing mortality (F) for *H. melanochir* in Cockburn were therefore calculated assuming a range of values for the maximum age (6, 8 and 10 y), and the extent to which these variations influence determination of stock status, *i.e.* according to F-based reference points, was assessed. Values of M and F were calculated based on t_{max} values ranging from 6 to 10 years.

Since maximum ages of 8-10 years have been recorded among a range of disparate stocks (see above), higher values of t_{max} in the Cockburn Sound stock are considered more likely than lower values, i.e. t_{max} = 10 years is considered most likely, and t_{max} = 6 years is considered least likely. Therefore, in this Section the default value of t_{max} is 10 years.

6.2.2 Estimates of total mortality

Age composition samples for *H. melanochir* were collected from commercial landings in Cockburn Sound and used to provide estimates of the instantaneous rate of total mortality (Z, y^{-1}) for this stock. Sampling was undertaken monthly from mid-2009 to early 2012 (Section 5). Hence data were available from two complete calendar years (2010 and 2011), plus two partial years (2009 and 2012) (illustrated in Figure 5.6 in Section 5). The data obtained during the partial years were excluded from analyses because i) sample sizes were relatively low and ii) there was a risk of introducing biases associated with seasonal variations in age structure.

Estimates for individual years were presented in this Section for comparative purposes. For the purpose of assessing stock status, only mortality estimates calculated from data where years were pooled were considered. This was done to partly mitigate against any effect of annual recruitment variation.

The following two forms of catch curve analysis were employed:

Catch Curve Method 1: Mortality estimator of Chapman and Robson (1960):

Chapman and Robson (1960) devised an equation that provides an unbiased estimate of survival, based on the assumption that that the age distribution in a population has a geometric distribution. They advised that, with the geometric distribution, an unbiased estimator of the instantaneous rate of mortality does not exist, but that a "nearly unbiased" estimate may be calculated as

$$Z = ln[1 + \bar{X} - 1/n] - ln\bar{X} - [(n-1)(n-2)/n(t+1)(n+t+1)]$$

where Z is the instantaneous rate of total mortality (y^{-1}). In the above equation, ln is the natural logarithm, $\bar{X}$ corresponds to the mean of the values of the integer ages for fish above the assumed age at which fish become fully-recruited into the fishery, *n* refers to the sample size at or above this age and $t = n\bar{X}$. Recruitment into the fishery is assumed to be "knife-edged" with the recruitment age taken as that with the greatest number of fish. This approach also assumes that the proportions of fish at age conform to a geometric distribution.

An approximation to the variance associated with Z may be calculated as

$$\sigma^2 \approx [1 - exp(-Z)]^2/\{n[exp(-Z)]\}$$

(SEDAR 2009). Approximate 95% confidence limits were calculated as 1.96 multiplied by the standard error (i.e. equivalent to the square root of the variance).

Catch Curve Method 2: Linear catch curve analysis:

Linear catch curve analysis, as described in Ricker (1975), involves fitting a linear regression to the natural logarithms of the frequencies of fish at all (integer) ages at and above the assumed age at full recruitment into the fishery, *i.e.*

$$lnN_a = lnN_{a=0} + Za$$

N_a refers to the number of fish of integer age a, and Z is the slope of the linear equation (noting that the estimate of total mortality, y^{-1}, is taken as the negative of the slope). The age at recruitment was taken as that with the greatest number of fish in the sample). Catch curves were fitted to age distributions that had been truncated on the 'right-hand side', *i.e.* at the point when zero frequencies first appeared in samples for older age groups. The linear catch curves were fitted by minimising the negative log-likelihood associated with the natural logarithms of the observed and expected frequencies of fish at age, using AD Model Builder. As with the Chapman and Robson (1960) mortality estimator, approximate 95% confidence limits were calculated by multiplying 1.96 by the estimated standard error associated with the estimate for Z (*i.e.* using the asymptotic standard error calculated in AD Model Builder).

After values of M and Z were estimated, the instantaneous rate of fishing mortality (F, y^{-1}) was estimated as:

$$F = Z - M$$

6.2.3 Per recruit analyses

The yield per recruit (YPR) and spawning stock biomass per recruit (*SSBR*) for *H. melanochir* were calculated from age zero, assuming constant recruitment at age zero and constant mortality for fully-recruited fish. These models employed an age step of 0.1 y (to improve model accuracy, noting that *H. melanochir* is not a long-lived species).

For either sex, the yield per recruit, YPR, was calculated as

$$YPR = \sum_{a=0}^{A} \left(\frac{F_a}{Z_a}\right) \{1 - \exp[-(Z_a 0.1)]\} N_a W_a$$

where A is the assumed maximum age (30 y for this analysis, and thus well above the possible maximum age for *H. melanochir*), F_a and Z_a are the fishing mortality and total mortality age a, W_a is the weight at age a and M is rate of natural mortality (Table 6.1).

F_a was calculated as the $S_a F$, where S_a is the selectivity at age a. S_a was calculated from the following logistic equation

$$S_a = 1/\{1 + exp[-ln(19)(L_a - L_{50})(L_{95} - L_{50})]\}$$

where L_a is the length at age a, as calculated from the von Bertalanffy growth curve, and L_{50} and L_{95} are the lengths at which 50 and 95% of individuals have attained maturity. For determining selectivity, it was assumed that *H. melanochir* first become vulnerable to capture (and thus start to become selected into the fishery) at the approach of first maturity, i.e. the logistic equation describing the relationship between probability of maturity and fish length was the same as that used to describe selectivity. The total mortality at age a, Z_a, was determined as

$$Z_a = F_a + M$$

Thus, the value of S_a was set to zero for fish of ages less than the age at full recruitment into the fishery, and to 1 for all older ages.

Female spawning stock biomass per recruit, $SSBR$, was estimated as

$$SSBR = \sum_{a=0}^{A} \psi_a \exp[-(Z_a 0.1)] N_a W_a$$

where ψ_a is the proportion of fish that are mature at age a.

Eggs per recruit*,* EPR, was calculated as

$$EPR = \sum_{a=0}^{A} \psi_a \exp[-(Z_a 0.1)] N_a Fec_a$$

Spawning potential ratio was calculated both in terms of spawning biomass per recruit and egg per recruit. Note that spawning stock biomass per recruit and egg per recruit were calculated separately for females and males (*i.e.* assuming in each case, an initial number of 1).

Denoting the catch curve estimate for F as $F_{current}$, the spawning potential ratio (*SPR*) for female *H. melanochir* was estimated as

$$SPR = SSBR_{F=F_{current}} / SSBR_{F=0}$$

Similarly, SPR in terms of eggs per recruit was calculated as

$$SPR = EPR_{F=F_{current}} / EPR_{F=0}$$

6.2.4 Biological reference points

As is consistent with several previous stock assessments undertaken by DoF (e.g. Wise *et al.* 2007), the performance indicators (F, YPR and SPR) were assessed against internationally accepted benchmarks (*i.e.* target, threshold and limit reference points) for assessing stock status (e.g. Caddy and Mahon 1998, Gabriel and Mace 1999). The internationally-accepted F-based reference points used in this assessment are based on the principal that when fish stocks are exploited at and beyond their predicted maximum sustainable yields (MSY), experience has shown that this has often led to serious problems (such as stock collapses). Therefore, in principal, the target level of exploitation should be lower than which (theoretically) corresponds to MSY (*e.g.* Die and Caddy 1997).

Several F-based reference points have been used elsewhere as proxies for MSY. For example, values of F ranging from natural mortality ($F = M$) downwards to ~ $F = 0.75M$ have often been considered as proxies for MSY (e.g. Restrepo *et al.* 1998, Gabriel and Mace 1999). Values of spawning potential ratio (derived from per recruit analyses based on spawning stock biomass or eggs per recruit) of 30-40% have also often been considered as proxies for MSY (Gabriel and Mace 1999). In contrast, values of 20-30% have often been used to characterise recruitment overfishing thresholds (Rosenberg *et al.* 1994). For example, Mace and Sissenwine (1993) recommended that the value of F resulting in SPR of 20% be used as a limit reference point, and Mace (1994) suggested a value of 40% as a target. When basing management on the results of yield per recruit analyses, the reference point $F_{0.1}$ (the fishing mortality corresponding to 10% of the initial slope of the yield per recruit curve) is often advocated as a target reference point as management strategies based on $F_{0.1}$ appear more robust than those based on F_{max} (the level of exploitation that maximizes yield per recruit) or MSY (Hilborn and Walters 1992, Haddon 2001).

The reference points for F and *SPR* used in this assessment are consistent with those used previously for stock assessments undertaken by DoF, including for other nearshore fish stocks and inshore demersal fish stocks (e.g. Wise *et al*. 2007, Marriott *et al*. 2012, Brown *et al.* 2013, Smith *et al.* 2013b, Fairclough *et al.* 2014b) (Table 6.2).

6.3 Results

6.3.1 Natural Mortality

Assuming a maximum age of 10 y for *H. melanochir* in Cockburn Sound, Hoenig's (1983) equation yielded an estimate of natural mortality (M) of 0.44 y^{-1} (equivalent to an annual survival of 64%)[7]. In comparison, the estimated levels of M assuming maximum ages of 8 and 6 years were 0.55 y^{-1} (annual survival = 58%) and 0.73 y^{-1} (annual survival = 48%), respectively.

6.3.2 Total Mortality

The Chapman and Robson (1960) method yielded a total mortality estimate of 1.40 y^{-1} for female *H. melanochir* in Cockburn Sound, based on pooled age structure data for 2010-2011 (annual survival = 25%) (Table 6.3). When years were analysed separately, Z was 1.22 y^{-1} for 2010 and 1.61 y^{-1} for 2011.

The estimates of Z for male *H. melanochir* in Cockburn Sound were slightly higher than for females, i.e. 1.66 y^{-1} for 2010-2011 (annual survival = 19%), 1.48 for 2010 y^{-1} and 1.81 y^{-1} for 2011 (Table 6.3).

The estimate for Z employing pooled data for 2010-2011 and sexes combined was 1.57 y^{-1} (annual survival = 21%) (Table 6.3). When sexes were combined but the years of age structure data were analysed separately, Z was 1.38 y^{-1} for 2010 and 1.76 y^{-1} for 2011.

Linear catch curve analysis tended to yield similar but less precise Z values compared to the Chapman and Robson method, particularly when sample sizes were low (n <300) (Table 6.3).

6.3.3 Estimates of fishing mortality and sensitivity to maximum age values

When employing the method of Chapman and Robson (1960) to estimate mortality based on age structure data from 2010-2011, and assuming a maximum age of 10 y when calculating M from Hoeing's (1983) equation, the estimates for F (*i.e.* 0.98, 1.22 and 1.13 y^{-1} for females, males and pooled sexes, respectively), were all well above the F-based limit reference point equating to 3/2M (F_{lim}= 0.66 y^{-1}) (Tables 2.3 and 2.4). In addition, the lower 95% confidence limits for each of these estimates were above the limit reference point (Fig. 6.1).

Estimates of fishing mortality assuming maximum ages of 8 and 6 years respectively, employing the same approach for estimating Z, were still high relative to estimates for M. Assuming t_{max} = 8, the point estimates for F (0.87, 1.11 and 1.02 y^{-1} for females, males and

[7] Annual rate of survival (S), where $S = e^{-Z}$.

pooled sexes, respectively) all breached the limit reference point of 3/2M (F_{lim}= 0.82 y^{-1}) (Table 6.4, Fig. 6.2). When the assumed value for t_{max} was reduced further to 6, the estimates for F (0.69, 0.93 and 0.84 y^{-1} for females, males and pooled sexes, respectively) were either above or just below the threshold reference point (0.73 y^{-1}).

Applying the alternative approach of linear catch curve analysis, a similar situation resulted, with the F estimates exceeding the limit reference point when t_{max} was either 10 or 8 y, and sitting below the limit but exceeding the threshold when t_{max} was 6 y (Table 6.4).

6.3.4 Per recruit analyses

Yield per recruit

Using the method of Chapman and Robson (1960), the estimated current levels of fishing mortality of F = 0.98 y^{-1} for females and 1.22 y^{-1} for males result in a yield per recruit of 33.1 g for females and 33.8 g for males (Table 6.5, Fig. 6.3a). The values of fishing mortality that correspond to the maximum yield per recruit, *i.e.* F_{max}, are 1.11 y^{-1} for females and 1.19 $y^{-1,}$ and thus slightly above and below, the current estimates for F for females and males, respectively. The estimates of $F_{0.1}$, are 0.53 y^{-1} for females and 0.57 y^{-1} for males. The estimated current levels of fishing mortality are therefore about twice the level corresponding to $F_{0.1}$.

Spawning biomass per recruit

The estimated current values of fishing mortality (assuming M = 0.44 y^{-1}, and t_{max} = 10 y) result in a spawning stock biomass per recruit of 367 g for females and 298 g for males (Table 6.5). These values correspond to spawning potential ratios of 0.23 and 0.19, respectively (Fig. 6.3b). Thus, for females the estimate for current SPR lies just above the limit reference point of 0.2, and for males, it breaches the limit. Under the alternative (less conservative scenario) that M = 0.55 y^{-1} (and t_{max} = 8 y), the estimate of SPR rises to 0.26, and therefore is still below the threshold reference point of 0.3. Under the more extreme (least conservative) scenario assuming M = 0.73 y^{-1} (and t_{max} = 6 y), SPR increases to 0.35, i.e. above the threshold but below the target.

Egg per recruit

The level of egg per recruit for female *H. melanochir* in Cockburn Sound, corresponding to the estimated current level of fishing mortality (assuming M = 0.44 y^{-1}), is 3,886 eggs (Table 6.5). This corresponds to a spawning potential ratio of 0.22, which is just above the limit reference point. Note that the estimates of egg per recruit were based on use of an equation for batch fecundity by Jones *et al.* (2002) and that the underlying data used to produce this equation were variable. Therefore the estimates for egg per recruit are less certain that those for spawning biomass per recruit.

6.4 Discussion

6.4.1 Estimates of mortality

The analyses undertaken here provide strong evidence that the rate of fishing mortality experienced by *H. melanochir* in Cockburn Sound has increased markedly over the past decade and is now at a level that poses a high risk to the sustainability of the stock.

The estimates of total mortality (Z) of 1.57 y^{-1} (Chapman and Robson 1960) and 1.58 y^{-1} (linear catch curve analysis) derived in this study using data from 2010-2011 for (both sexes of) *H. melanochir* in Cockburn Sound are substantially larger than the estimate of 0.90 y^{-1} produced by Jones *et al.* (2002) using the method of Chapman and Robson (1960) for the same stock in 1998-1999. The estimates of Z derived from the Chapman and Robson (1960) method equate to an annual survivorship of 41% in 1998-1999 compared with 21% in 2010-2011.

Values of natural mortality (M) and fishing mortality (F) for *H. melanochir* in Cockburn Sound were calculated assuming a range of values for the maximum age (from 6 to 10 y). A maximum age of 5 years has been recorded in Cockburn Sound, which implies that individuals could attain >5 years in the absence of exploitation. Maximum ages of 8-10 years have been recorded in unexploited (or lightly-fished) *H. melanochir* populations in South Australia, Tasmania and in the SCB of Western Australia (Section 2). Given the similarity in the maximum ages among these disparate stocks, *H. melanochir* in Cockburn Sound could also be expected to attain up to 8-10 years, if the stock was unexploited or lightly-exploited. A maximum age of 8-10 years is therefore considered more likely than a maximum age of 6-7 years in Cockburn Sound. However, a range of ages was examined to investigate the influence that this variation may have on determination of stock status.

Assuming a value for M of 0.44 y^{-1} (t_{max}=10 y), the value of F for *H. melanochir* in Cockburn Sound more than doubled (246% increase) from 0.46 to 1.13 y^{-1} (sexes pooled) between 1998-1999 and 2010-11. Alternatively, if it were assumed that M is 0.55 y^{-1} (t_{max} = 8 y), then the value of fishing mortality increased more markedly (291% increase), from 0.35 y^{-1} in 1998-1999 to 1.02 y^{-1}. Under the second alternative assumption that M is 0.73 y^{-1} (t_{max} = 6 y), the value of fishing mortality is estimated to have increased by nearly 500%, from 0.17 to 0.84 y^{-1}. Thus, regardless of the widely varying assumptions regarding the maximum age and therefore the level of natural mortality of the stock, other sources of mortality have increased markedly over the past decade.

The results also demonstrate clearly that, regardless of the assumed value of natural mortality (ranging from 0.44 to 0.73 y^{-1}), estimates of fishing mortality were above the target reference point and in the majority of cases, breached the limit reference point. Only under the least conservative assumption (i.e. the highest value for natural mortality of 0.73 y^{-1}, which implies higher stock productivity than for lower values of natural mortality), did the estimates for F lie below the limit reference point. Even under this scenario, almost all of the F estimates (5 out of 6) breached the threshold reference point, and none approached the target level. Thus, the catch curve-based estimates of F provide strong evidence that the levels of mortality being experienced by *H. melanochir* in Cockburn Sound pose a high risk to the sustainability of the stock.

In a previous assessment of two stocks of *H. melanochir* in South Australia in 1998-1999, Z estimates were 1.77 and 2.15 y^{-1} (which, if applying an M of 0.44 y^{-1}, would correspond to F values of 1.33 and 1.71 y^{-1}) (Jones *et al.* 2002). These levels of mortality were subsequently concluded to be unsustainable for these populations (Steer *et al.* 2012). In the northern Spencer Gulf and northern Gulf St Vincent fisheries in South Australia, catch levels declined sharply in 2002/03 and, despite management intervention, are yet to recover. Both of these stocks continue to display strong age and length truncation, exploitable biomass remains relatively low and egg production is well below the limit reference point of 20% of the virgin level (Steer *et al.* 2012).

6.4.2 Per recruit analyses

Per recruit analyses indicated that the current level of fishing mortality being experienced by *H. melanochir* in Cockburn Sound is similar to that at which yield per recruit is maximized. The relatively high values of F at which yield per recruit is estimated to be maximized (F_{max}) reflects a combination of the very rapid rate at which the individuals of this species approach their maximum length (*i.e.* as indicated by the very high values for the growth coefficient, k) and the relatively high value of natural mortality for *H. melanochir* (*i.e.* 0.44 y^{-1}) compared with other longer-lived species. In other words, as the growth of *H. melanochir* slows markedly very early in life (~1 y old), the loss in yield that would be experienced as a result of natural mortality is greater than the gains in yield associated with increased growth with increasing age. This would therefore suggest that 'growth overfishing' is not occurring.

However, empirical evidence from many fish stocks indicates that levels of fishing mortality equivalent to F_{max} tend to be too high and are likely to lead to stock declines (Haddon 2001). Moreover, yield per recruit models are simple, equilibrium-based models with a range of important limitations which add to uncertainty in stock assessment advice (Haddon 2001). For this reason, management informed by yield per recruit models is now more often based on the more conservative reference point, $F_{0.1}$. For *H. melanochir* in Cockburn Sound, the estimates of F (based on M = 0.44 y^{-1}) were about twice as large as values of $F_{0.1,}$ providing evidence that the current level of fishing pressure is too high. In terms of management, it should also be noted that, as is typical of the results of yield per recruit modelling, large increases in fishing mortality between $F_{0.1}$ and F_{max} would be predicted to lead to only a small loss in overall yield of *H. melanochir*.

Unlike the yield per recruit model, per recruit models based on spawning stock biomass or egg per recruit account for changes in reproductive potential associated with variations in fishing mortality, and may thus be able to detect 'recruitment overfishing', *i.e.* stock collapse. A value of fishing mortality leading to a spawning potential ratio (SPR) of between 0.2 and 0.3 has typically been used to indicate recruitment overfishing for well-known stocks with medium resilience (e.g. Goodyear 1993, Mace and Sissenwine 1993, Gabriel and Mace 1999). SPR represents the estimated ratio between the reproductive output of the population at the current level of fishing pressure, relative to that for an unfished population. Under the assumption that M = 0.44 y^{-1}, the estimates of SPR for *H. melanochir* are very low, and either approach or breach the limit reference point of 0.2. When the higher value for M of 0.55 y^{-1} (t_{max} = 8 y) is assumed, the estimate for SPR of 0.25 is between the limit and threshold values. Only for the extreme scenario of M = 0.73 y^{-1} (i.e. using a value of t_{max} to estimate M that is 4 years lower than the maximum age recorded for this species), did the SPR increase beyond the threshold level, but even in this case was well below the target level). Thus, overall, the F-based analyses presented in this Section provide strong evidence that exploitation in recent years (up to 2011) has been at a level that is placing the stock at a high risk of recruitment failure.

Table 6.1. Parameters used in per recruit models for Hyporhamphus melanochir in Cockburn Sound (assuming a maximum age of 10 y).

Parameter	Female	Male	Source of information
Natural mortality			
M (y^{-1})	0.44	0.44	This study (section 3)
Growth			
L_∞ (mm, TL)	316	304	This study (section 4)
k (y^{-1})	1.242	1.397	This study (section 4)
t_0	-0.328	-0.271	This study (section 4)
Size at maturity			
L_{50} (mm, TL)	228.7	227.3	This study (section 4)
L_{95} (mm, TL)	278.1	279.4	This study (section 4)
Size-based selectivity			
L_{50} (mm)	228.7	227.3	This study (= size at maturity)
L_{95} (mm)	278.1	279.4	This study (= size at maturity)
Weight-length relationship			
a	3.142	3.146	This study (section 7)
b	1.68×10^{-6}	1.77×10^{-6}	This study (section 7)
Fecundity-standard length relationship			
Fec_a	0.0023	-	Jones *et al.* (2002)
Fec_b	4.021	-	Jones *et al.* (2002)
Total length-standard length relationship			
m	1.142		Jones *et al.* (2002)
x	0.773		Jones *et al.* (2002)

Table 6.2. Reference points for fishing mortality (based on levels of natural mortality (*M*)) and spawning potential ratio (SPR) (Wise *et al.* 2007).

Reference Point	Fishing Mortality	SPR	Likely management response
Target	2/3 * *M*	0.4	Sustainable
Threshold	*M*	0.3	Monitor closely
Limit	1.5 * *M*	0.2	Restrict fishing

Table 6.3. Total mortality rate (*Z*) estimated for *Hyporhamphus melanochir* in Cockburn Sound, calculated from the age structure of commercial fishery landings in 2010, 2011 and 2010+2011 (years pooled). Outputs from two independent estimation methods (Chapman and Robson (C&R), and linear catch curve (LCC)) are shown. (95%CI – 95% confidence limits; n – number of fish aged)

Method	Year	Sex	*Z*	95%CI	n
C&R	2010	female	1.22	0.97 - 1.47	103
		male	1.48	1.24 - 1.72	177
		both	1.38	1.20 - 1.55	280
	2011	female	1.61	1.27 - 1.95	105
		male	1.81	1.56 – 2.06	261
		both	1.76	1.55 - 1.96	366
	2010+2011	female	1.42	1.21 - 1.63	208
		male	1.66	1.49 - 1.84	438
		both	1.57	1.44 - 1.71	646
LCC	2010	female	1.44	1.25 - 1.64	103
		male	1.65	1.53 - 1.76	177
		both	1.56	1.42 - 1.71	280
	2011	female	2.20	1.58 - 2.81	105
		male	1.47	1.13 - 1.81	261
		both	1.60	1.31 - 1.91	366
	2010+2011	female	1.70	1.28 - 2.12	208
		male	1.53	1.36 - 1.70	438
		both	1.58	1.45 - 1.71	646

Table 6.4. Estimates, for *Hyporhamphus melanochir* in Cockburn Sound, of (i) natural mortality (M, y^{-1}) assuming either a maximum age (t_{max}) of 10, 8 or 6 y, (ii) F-based target, threshold and limit reference points for the different values of natural mortality, (iii) total mortality (Z, y^{-1}), based on the methods of Chapman and Robson (1960) (C&R) and linear catch curve analysis (LCC) and (iv) values of fishing mortality (F, y^{-1}), for the two methods of estimating Z and three alternative values of M.

					Z estimates (C&R)			Z estimates (LCC)		
					1.42	1.66	1.57	1.70	1.53	1.58
Assumed values		**Reference points**			**F estimates (C&R)**			**F estimates (LCC)**		
t_{max}	M	F_{Limit}	$F_{Threshold}$	F_{Target}	females	males	both sexes	females	males	both sexes
10	0.44	0.66	0.44	0.29	0.98	1.22	1.13	1.26	1.09	1.14
8	0.55	0.82	0.55	0.37	0.87	1.11	1.02	1.15	0.98	1.03
6	0.73	1.09	0.73	0.48	0.69	0.93	0.84	0.97	0.80	0.85

RED: value exceeds the limit reference point; ORANGE: value lies between limit and threshold reference point; YELLOW: value lies between threshold and target reference point.

Table 6.5. Estimates for *Hyporhamphus melanochir* in Cockburn Sound of fishing mortality (F) assuming a maximum age of 10 y and derived from the method of Chapman and Robson (1960), yield per recruit (*YPR*), values of F for yield per recruit-based reference points (F_{max} and $F_{0.1}$), spawning stock biomass per recruit (SSBR), egg per recruit (*EPR*), and spawning potential ratio (*SPR*) calculated for *SSBR* and *EPR*.

Parameter	Females	Males
F (y^{-1})	0.98	1.22
YPR (g)	33.1	33.8
F_{max} (y^{-1})	1.11	1.19
$F_{0.1}$ (y^{-1})	0.53	0.57
SSBR (g)	367	298
SPR (*SSBR*)	0.23	0.19
EPR	3886	-
SPR (*EPR*)	0.22	-

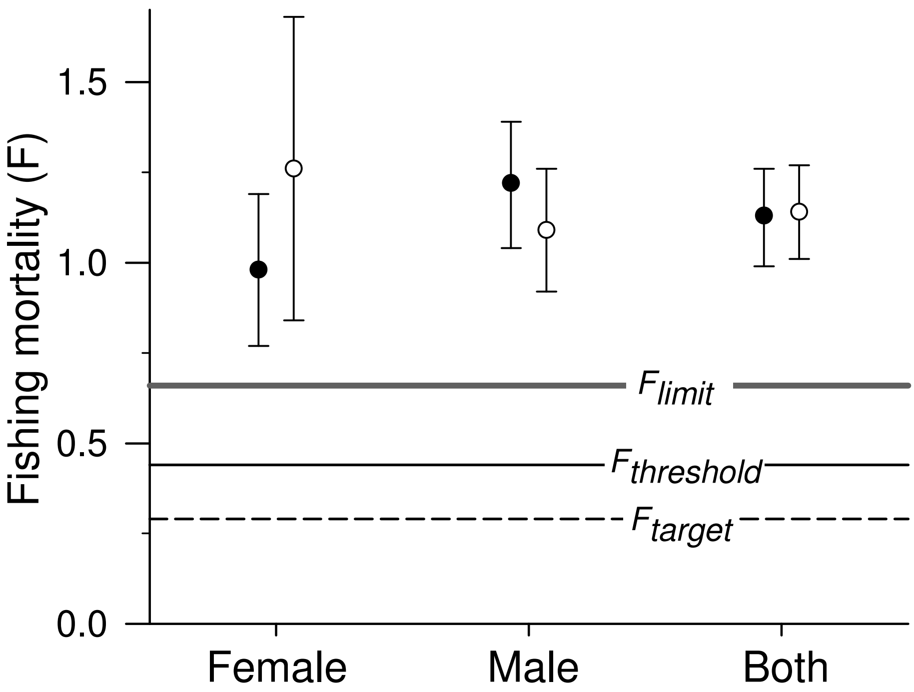

Figure 6.1. Estimates of fishing mortality (*F*) (+ 95% confidence limits) for *Hyporhamphus melanochir*, calculated from the age structure of commercial fishery landings in Cockburn Sound in 2010 and 2011 (years pooled), assuming a maximum age of 10 years. Estimates for males only, females only and sexes pooled ('both') are shown. *F*-based reference points for this stock are shown . Estimates from Chapman and Robson (1960) method (black dot) and linear catch curve analysis (white dot) shown.

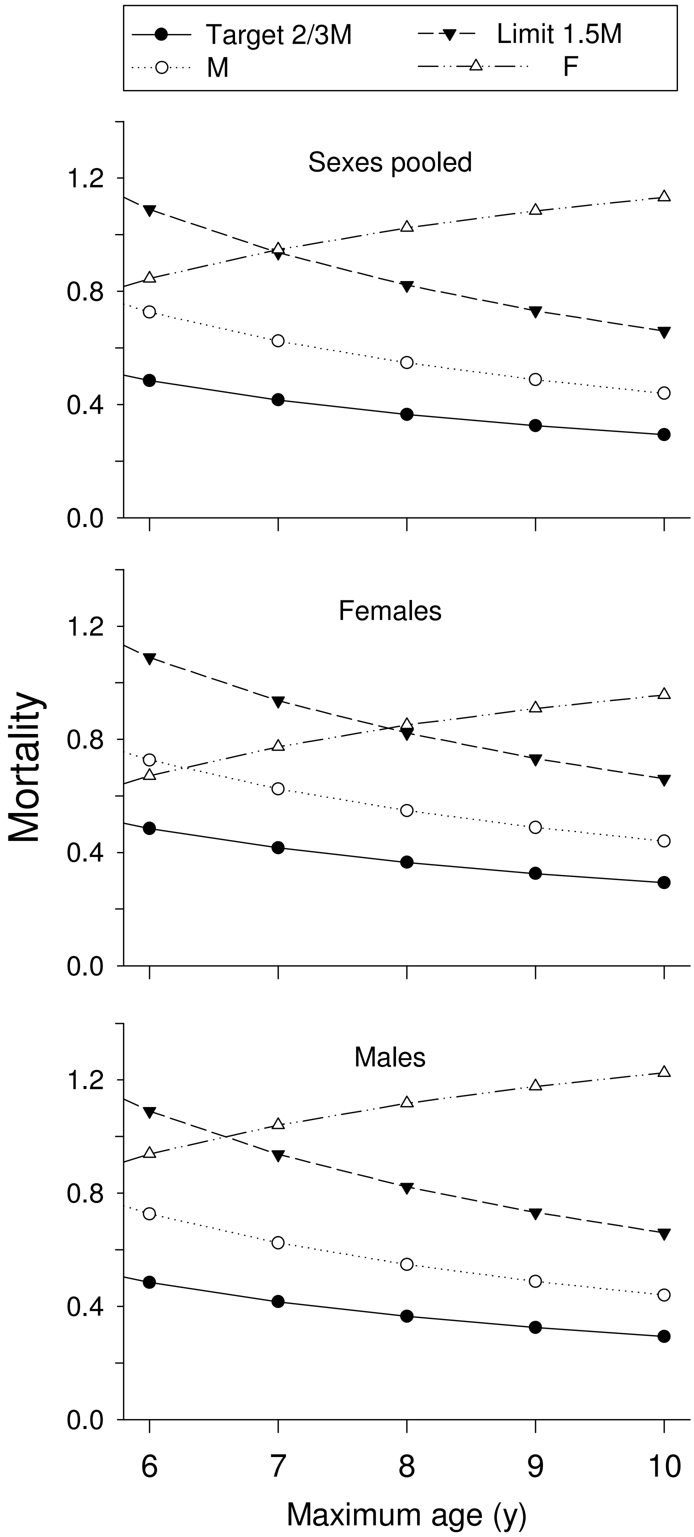

Figure 6.2. Variations in values of fishing mortality (*F*), natural mortality (M) and mortality-based reference points (Target and Limit) for *Hyporhamphus melanochir* in Cockburn Sound during 2010-2011 (years pooled), under different assumptions of maximum age ranging from 6 to 10 years. Estimates for sexes pooled, males only and females only are shown. Estimates of *F* are calculated from the age structure of commercial fishery landings in Cockburn Sound using the Chapman and Robson (1960) catch curve method.

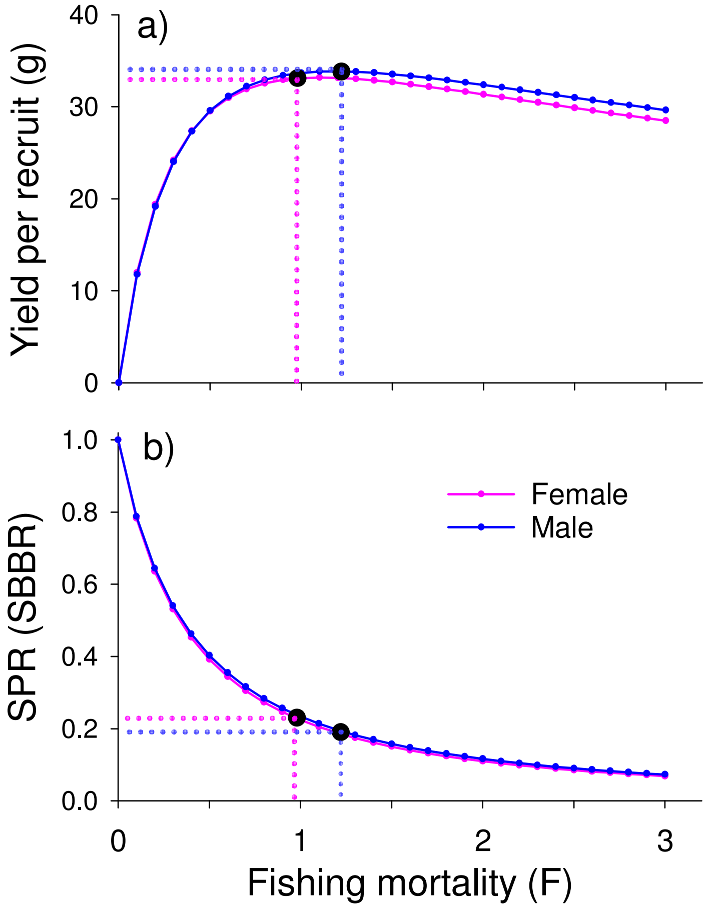

Figure 6.3. a) Yield per recruit and b) spawning potential ratio (SPR, calculated from spawning stock biomass per recruit (SSBR)), estimated for *Hyporhamphus melanochir* in Cockburn Sound. Reference lines and dots indicate values at current levels of fishing mortality (*F*), assuming a maximum age of 10 years.

7 Weight-of-evidence assessment of stock status of *Hyporhamphus melanochir* in Cockburn Sound

Cockburn Sound is assumed to host a semi-discrete stock of *Hyporhamphus melanochir*, which is likely to be mostly self-recruiting with limited capacity for replenishment from stocks of the same species elsewhere. This assumption is based on i) the biological characteristics of the species which discourage dispersal and mixing between stocks (i.e. demersal eggs, no larval phase, strongly habitat-associated in juvenile and adult phases with no evidence of migration), and ii) evidence of complex stock structuring by this species (i.e. differences in otolith chemistry indicate that semi-discrete breeding populations of *H. melanochir* can be separated by distances of <60km (Steer *et al.* 2009a, 2010)).

On the basis of this evidence, *H. melanochir* in Cockburn Sound is treated as a discrete stock for management purposes.

The indicators of stock status of *H. melanochir* presented here are mainly derived from biological data obtained by sampling commercial and recreational landings in Cockburn Sound in 2009-2012 (this study). Some historical data about this stock was also available from a previous study in 1998-1999 (Jones *et al.* 2002).

7.1 Summary of indicators of stock status in Cockburn Sound

Fishery catch and catch rates: All catch and catch rate indicators from both fishing sectors (commercial and recreational) suggest a major decline in availability of *H. melanochir* in Cockburn Sound since the late 1990s (Section 4). In Cockburn Sound, catches and catch rates suggest stock abundance has been declining gradually since 1995 and rapidly since 2011. These indicators suggest a very substantial (70-90%) reduction in abundance over this period, with abundance reaching historically low levels in 2013 and 2014.

Age and length composition of fishery landings: The composition of landings in Cockburn Sound was sampled in two separate periods, 1998-1999 and 2009-2012 (Section 5). The ages of *H. melanochir* in commercial landings in Cockburn Sound ranged from 0+ to 5+ years in 1998-1999 and from 0+ to 4+ years in 2009-2012. Between these periods, the modal age declined from 2+ to 1+ years, and the proportion of fish aged >2 years fell from 30% to less than 5%. The average length also declined between these periods. Considering the maximum reported age of 10 years for *H. melanochir*, the age structure of the Cockburn Sound stock in 2009-2012 was heavily truncated

Mortality: Given a maximum age of 10 y, the instantaneous rate of natural mortality (M) for *H. melanochir* in Cockburn Sound was estimated to be 0.44 y^{-1} which is equivalent to an annual survivorship (S) of 64% (Section 6). Instantaneous rates of total (Z) and fishing (F) mortality for *H. melanochir* in Cockburn Sound were estimated from the age composition of commercial landings in 1998-1999 and 2010-2011 (Section 6). Using the age composition of both sexes pooled, Z was estimated to be 0.90 y^{-1} (equivalent to S = 41%) in 1998-1999 and 1.57 y^{-1} (S = 21%) in 2010-2011. F was estimated to be 0.46 y^{-1} in 1998-1999 and 1.13 y^{-1} in 2010-2011.

This suggests that fishing pressure in Cockburn Sound increased substantially between 1998-1999 and 2010-2011, resulting in a 50% decline in survivorship. In 2010-2011, the estimated F substantially exceeded the limit reference point (with the 95% confidence limit entirely above the limit reference point). This implies that the level of mortality experienced by the stock in recent years is unsustainable.

Yield-per-recruit: In yield per recruit analyses, $F_{0.1}$ (the fishing mortality corresponding to 10% of the initial slope of the yield per recruit curve) was used as the target reference point. In 2010-2011 the estimated F was 0.98 y^{-1} for females and 1.22 y^{-1} for males (and 1.13 y^{-1} for sexes pooled) (Section 6). The estimates of $F_{0.1}$ are 0.53 y^{-1} for females and 0.57 y^{-1} for males. Recent F estimates are therefore about twice the level of $F_{0.1,}$ suggesting that the current level of fishing pressure is too high.

Spawner-per-recruit: In 2010-2011, *SPR* (spawning stock biomass potential ratio) was estimated to be 0.23 for females, and 0.19 for males (Section 6). These values are close to breaching the *SPR* limit reference point of 0.2 (i.e. 20% of spawning level in an unfished stock), which suggests the stock is at high risk of recruitment overfishing.

Recruitment: Annual trends in juvenile (age 0+) recruitment are unknown. However, the current age composition of landings suggests that both commercial and recreational fisheries in Cockburn Sound are strongly recruitment-dependent (Section 5). *H. melanochir* recruit to both fisheries in summer when aged ~1 year. Under the current conditions, the 1+ year class then dominates landings until the following summer, when they are replaced by the next 1+ year class. This characteristic makes the fisheries vulnerable to collapse in the event of a single year of poor recruitment. Recruitment failure during the 'heatwave' event in 2011 could explain the dramatic decline in catches after 2011.

Proportion of immature fish in fishery landings: Immature fish comprise a very low proportion of the current total catch. In 2009-2012, the majority (>95%) of *H. melanochir* in commercial and recreational landings in Cockburn Sound were estimated to be above L_{50} (i.e. the length at which 50% of fish are sexually mature) (Section 5).

Inherent vulnerability due biological characteristics: The overall vulnerability of the Cockburn Sound stock is rated as 'moderate'. The stock has medium productivity and medium susceptibility to fishing (Tables 7.1).

NOTE: Although the most recent estimates of F and SPR reported here were based on samples collected in 2010-2011, it is considered unlikely that stock status has improved since this period because catch and CPUE indicators suggest stock status declined after 2011. Therefore the F and SPR estimates in 2010-2011 are considered to be indicative of the current stock status (at the time of writing).

7.2 Summary of stock status

There is a high risk to the sustainability of the Cockburn Sound stock at the present levels of catch and effort in both fishing sectors. The available evidence suggest that i) there has been a very large decline in stock abundance over the past two decades, ii) the average age and length of the catch has declined and age structure is now very truncated, iii) the fishery is strongly recruitment-dependent such that it is vulnerable to collapse after a single year of poor recruitment, and iv) the current rate of total mortality is very high and not sustainable.

Collectively, the suite of quantitative indicators available for this stock strongly suggest a high risk of recruitment overfishing (Table 7.2).

7.3 Recommendations for future assessments

Commercial and recreational catch rates have followed similar declining trends and have been consistent with other (biological) indicators that suggest declining stock status. Thus, these fishery catch rates appear to be useful indicators of stock level and should be included in future assessments where available. However, it should be recognised that at very low levels of abundance, which is probably the case at present, insufficient catch and effort data may be generated by either fishing sector to allow their catch rate to function as a sensitive indicator of stock level. It must also be recognised that the future availability of catch rates is not assured since commercial data is currently supplied by just one vessel and the recreational data is supplied by volunteers. Fishery-independent surveys could be undertaken as an alternative to indicate stock abundance trends.

The estimation of total mortality (Z), or fishing mortality (F), in the Cockburn Sound stock can be undertaken, even at relatively low stock abundance, by sampling the age structure of the commercial fishery catch which is assumed to represent the age structure of the stock. If commercial catches ceased to be available in future, fishery-independent sampling could instead be undertaken to determine the age structure of the stock although this would likely be at a higher cost than fishery-dependent data. There are currently no cost-effective methods available to monitor the age structure of *H. melanochir* in recreational landings. Samples of *H. melanochir* donated to the Department by recreational fishers via the *Send Us Your Skeletons* program appear to be biased towards smaller fish and so are believed to be unrepresentative of the age structure of the stock. Thus, the age structure of the recreational fishery catch should not be used to estimate mortality until a method to ensure representative sampling of the catch is developed.

Mortality rate is considered to be the most reliable of the available indicators of stock status for *H. melanochir* in Cockburn Sound, especially at low stock levels when fishery catch rates may not be available. Therefore, sampling of the age structure via the commercial fishery, or via fishery-independent methods, should be the focus of future assessments.

Table 7.1. Summary of the productivity (Prod.) and susceptibility (Susc.) attributes and implications for vulnerability of *Hyporhamphus melanochir* in Cockburn Sound (as defined in Appendix 1). The vulnerability scores for Productivity range from low to high, indicating that this stock has overall medium productivity. The vulnerability scores for Susceptibility are mostly medium, indicating that this stock is moderately susceptible to fishing. Overall vulnerability level is MODERATE.

		Vulnerability Assessment		
Attribute	**Type**	**Low**	**Medium**	**High**
Growth (von Bertalanffy K)	Prod.	✓		
Trophic level	Prod.		✓	
Longevity (maximum age = t_{max})	Prod.	✓		
Age-at-maturity	Prod.	✓		
Fecundity (per spawning event) at age of first maturity	Prod.		✓	
Recruitment variability and breeding strategy	Prod.			✓
Resilience to other sources of mortality	Prod.			✓
Availability	Susc.			✓
Aggregating behaviour	Susc.		✓	
Mode of reproduction	Susc.	✓		
Distribution and movement of adults	Susc.		✓	
Post-release mortality	Susc.		✓	
Overall level of uncertainty	**Low**			

Table 7.2. Summary of quantitative indicators of *Hyporhamphus melanochir* stock status in Cockburn Sound. (comm. – commercial; rec. – recreational).

Method	Result	Confidence	Implication for stock status
Catch trends	Comm. catch declining slowly since late 1990s, & rapidly since 2011. Limited data also indicate similar catch declines in rec fishery.	High (comm.) Medium (rec)	Suggests substantially lower availability now compared to late 1990s.
Catch rate (CPUE) trends	Comm. CPUE declining slowly since late 1990s, & rapidly since 2011. Limited data also indicate similar CPUE trend in rec fishery.	High	Suggests substantially lower availability now compared to late 1990s.
Fishing mortality (F)	Fishing mortality has more than doubled since 1998-99. Current F estimated to be substantially above the limit reference point.	High	Fishing mortality is unsustainable. High risk of recruitment overfishing
Spawning potential ratio	SPR is near the limit reference point. Spawning potential is currently ~20% of that of unfished stock.	High	High risk of recruitment overfishing
% immature fish in catch	Less than 5% immature fish (i.e. below L_{50}) in both comm & rec catches.	High	Almost all retained fish are mature.
Age & length truncation in catch	Given the max. age of 10 y reported for this species, current age structure of comm & rec catches is very truncated. Average age & length of comm catch declined between 1998-99 and 2009-2011.	High	Age truncation of comm. & rec catches suggests high exploitation rate.
Recruitment	Comm & rec fisheries are strongly recruitment-dependent, due to a single year class (1+) comprising the bulk of catches each year.	High	Fishery is vulnerable to collapse in the event of a single year of poor recruitment.

Unacceptable	Acceptable

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APPENDIX 1. Attributes indicating vulnerability of stock(s) of indicator species (adapted from Wise *et al*. 2007).

Attribute	Type	Low Vulnerability	Medium Vulnerability	High Vulnerability	Reference*
Growth (von Bertalanffy K)	Productivity	Rapid growth: Steep growth trajectory e.g., $K > 0.25$	Intermediate growth trajectory e.g., $0.25 \geq K \geq 0.15$	Slow growth: gradual growth trajectory. e.g., $K < 0.15$	2, 4.
Trophic level**	Productivity	Low e.g., < 3	Intermediate Eg., 3 to 4	High order predator e.g., > 4	2, 3***
Longevity (maximum age = t_{max})	Productivity	Short lifespan e.g., $t_{max} < 10$ yr	Intermediate lifespan e.g., $10 \geq t_{max} \geq 30$ yr	Long lifespan e.g., $t_{max} > 30$ yr	1, 4
Age at maturity (t_{mat})	Productivity	Early maturing e.g., < 2 yr	Intermediate maturing e.g., $2 \geq t_{mat} \geq 8$ yr	Late maturing e.g. > 8 yr	4
Fecundity (per spawning event) at age of first maturity	Productivity	High e.g., $> 10^4$	Intermediate e.g., 10^2 - 10^3	Low e.g., $< 10^2$	2
Recruitment variability and breeding strategy	Productivity	Regular, or consistent recruitment that is predictable on an annual basis, and/or propagules widely dispersed (e.g., 100s of kms) during pelagic phase or juvenile stage e.g., broadcast spawner with lower (~ 20% annual range) recruitment variability	Average recruitment is consistent but variable among years over short time periods and/or propagules have limited dispersed capacity (e.g., 10s of kms) during pelagic phase or juvenile stage e.g., broadcast spawner with recruitment varying over a range of ~50% within an average 3 year period	Infrequent, highly variable recruitment over time that cannot be predicted (e.g., annual range 0-100%), and/or restricted dispersal of eggs, larvae, juveniles e.g., demersal egg layer or live bearer	1, 3
Resilience to other sources of mortality	Productivity	Highly adaptable to variable environments and/or environments/habitats are healthy and in an optimum condition	Moderate levels of resilience, and/or environments/habitats are not in an optimum condition but are recovering	Limited adaptability to change and/or environments/habitats are degraded and/or under threat	1
Selectivity and availability	Susceptibility	Low overlap (by depth and/or area) and/or selectivity to fishing gear e.g., < 25% of stock is available to fishery. $\leq$50% of age classes selected by fishing gear	Moderate overlap (by depth and/or area) with fishery and/or fishing gear selects a low proportion of immature fish e.g., 25-50% of stock is available to fishery. $t_c \geq t_{mat}$	High overlap (by depth and/or area) with fishery and/or fishing gear selects a high proportion of immature fish e.g., > 50% of stock is available to fishery. $t_c < t_{mat}$	2****
Schooling/aggregation behaviour	Susceptibility	Extended spawning period and/or do not form dense schools at any time. e.g., spawning > 4 months	Limited spawning period and/or forms aggregations that are not predictable in time and space, but are highly catchable e.g., spawning 3 - 4 months; not associated with lunar phase and/or spawning aggregation sites unknown/not well defined.	Forms predictable aggregations in time and space that are highly catchable e.g., spawning 1 - 2 months; and/or associated with particular lunar phase(s) - e.g., full and/or new moons; known spawning aggregation sites.	1, 4

Attribute	Type	Low Vulnerability	Medium Vulnerability	High Vulnerability	Reference*
Mode of reproduction	Susceptibility	Straightforward gonochoristic mode of reproduction (i.e., not sex-changing)	Mode of somewhat complex reproductive development, e.g. pre-maturational sex change or diandric sex change, with males and females found over a broad overlapping range of sizes and ages	Complex mode of reproduction, e.g., functional monandric sex change, with most of the larger older individuals comprised only of one sex.	1
Distribution and movement of adults	Susceptibility	Widespread distribution, and/or highly mobile e.g., capacity to move 100s of kms along coastline	Limited distribution, and/or limited mobility e.g., adults move 10s of kms along coastline	Restricted/endemic and/or sedentary (longshore movement restricted), possibly inshore-offshore movements only e.g., adult home range < 10km	1
Post-release mortality	Susceptibility	Generally high survivorship post-release. Large amount of evidence of post-release and survival. e.g., probability of survival > 67%	Survivorship largely dependent on capture method and depth of capture. Intermediate levels of post-release survival. e.g., probability of survival 33 - 67%	Majority dead or in poor health/showing signs of barotrauma when released, regardless of depth of capture or capture method. e.g., probability of survival < 33%	2
Level of Uncertainty	All	Most attributes known e.g., 0 - 3 unknown	Some attributes known e.g., 4 - 8 unknown.	Few attributes known e.g., 9 - 12 unknown	
Overall Productivity		**Most productivity attributes are low**	**Most productivity attributes are medium**	**Most productivity attributes are high**	
Overall Susceptibility		**Most susceptibility attributes are low**	**Most susceptibility attributes are medium**	**Most susceptibility attributes are high**	

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

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

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

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