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Status of nearshore finfish stocks in south-western Western Australia

Part 3: Whiting (Sillaginidae)

NRM Project 09003

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Executive summary

The whiting family (Sillaginidae) is common in nearshore waters of south-western Western Australia (WA) where it is highly valued by recreational and commercial fishers. The importance of these species to recreational fishers is reflected in this category of fishes being ranked as the most or 2nd most retained finfish species group by boat- and shore-based fishers in several recreational fishing surveys in WA. Whiting are commercially important in a number of fisheries, with total state catches averaging over 200 tonnes per annum since 1980. The composition of the whiting catch, however, is largely unknown, with a number of whiting species potentially contributing substantially to the overall catch of this family. The recreational and commercial fisheries that capture whiting can therefore be considered very data-limited, due to the lack of species-specific data that prohibit a robust assessment of the status of the stocks of the different whiting species. The main purpose of this report is to determine the species composition of whiting landings caught recreationally and commercially in south-western WA. This report then investigates the stock status of the key (most abundant) whiting species identified in the recreational catch.

In WA, ten whiting species are known to exist, with six of these found in the south-west of WA. The largest and most easily recognised of these is King George whiting (*Sillaginodes punctata*). The other whiting species, which all belong to the genus *Sillago*, are very alike in appearance, reflecting their very similar body shapes and colouration. This makes identification to species level difficult and as a result, whiting species of the *Sillago* genus are often referred to collectively as 'sand whiting'.

The nearshore finfish resources of the West Coast Bioregion (WCB), including whiting stocks, have been identified as having a high sustainability risk, due to increasing fishing pressure arising from a growing population of recreational fishers and potentially also a shift in targeting away from larger demersal fish species, due to recent effort restrictions for such species, towards nearshore species such as whiting. Currently, the level of risk associated with this family is exacerbated due to the uncertainty about the catch composition of whiting species. Important to any assessment of a fisheries sustainability status is knowledge of species-specific data. Therefore, to fully assess the stock status of nearshore finfish resources in the WCB, the composition of recreational and commercial whiting landings must be resolved. Furthermore, understanding the key biological parameters relevant to stock assessment for the individual species is important for fisheries management.

For this study, whiting (all species) were collected from recreational fishers in south-western WA from July 2010 to December 2012. Whiting from the recreational sector were donated as frames through the Department of Fisheries' 'Sends Us Your Skeletons' program. This program encourages recreational fishers to donate the filleted carcasses of key finfish species for research purposes. Fishers provided a range of details including capture date, location of capture, whether fish were caught from a boat, water depth and, in the case of King George whiting, information on the habitats from which fish were caught. The species composition of the whiting catch was determined from these samples and compared against similar data derived from the boat-ramp component of a state-wide recreational fishing survey in 2011/12. The stock status of the most abundant recreationally caught whiting species in the WCB were then assessed using a 'weight-of-evidence' approach. This involved using all available historical and current information relevant to understanding stock status, including estimates of fishing mortality (F) and spawning potential ratio, annual recruitment trends, commercial and recreational catch and catch rates, and current understanding of the inherent vulnerability of the stock to exploitation due to biological characteristics.

During the 2010–12 sampling period, approximately 10,000 whiting frames were donated from more than 230 recreational anglers. Recreational anglers caught all six species of whiting known to occur in the WCB and all three in the South Coast Bioregion (SCB). The majority of fish were caught in the WCB (84%), and most of these were caught in the Metropolitan and South-west Zones. The majority of whiting were donated by boat-based fishers (94%), with shore-based fishers contributing only 6% of samples.

Overall, southern school whiting and King George whiting were identified as the main species caught by recreational fishers in the WCB and SCB of WA, although the catch composition of whiting species varied between bioregions, management zones and depth (i.e. shore- or boat-based fishers). Southern school whiting and King George whiting were the most common species in the boat-based catch, comprising 73 and 19% of samples, respectively, in the WCB and 34 and 66% of samples, respectively, in the SCB. Of all *Sillago* species in samples (i.e. excluding King George whiting), southern school whiting was the most common species in the boat-based catch in both bioregions, comprising 90% of samples in the WCB and 99% in the SCB. Of shore-based samples, southern school and yellowfin whiting were the most common *Sillago* species, comprising 46 and 38% of samples, respectively in the WCB and 96 and 4% of samples, respectively in the SCB.

This study determined the average whiting composition of the commercial catch in the WCB and SCB to be mainly comprised of yellowfin whiting (62%), King George whiting (21%) and southern school whiting (17%). In 2011/12 in the WCB and SCB, the majority of King George whiting and southern school whiting were estimated to be taken by the recreational sector (~60–100%). For yellowfin whiting, the majority of the SCB catch is also taken by the recreational sector (79%), whereas the majority of WCB catch is landed by the commercial sector (73%).

Southern school whiting stock status

The stock status of southern school whiting was deemed to be <u>acceptable</u>.

- Estimates of fishing mortality based on age data for boat-based samples from the Metropolitan Zone in 2011 (and derived using two alternative approaches) were around the specified target and below the threshold reference points.
- Estimates of spawning potential ratio (determined from per recruit analyses) were likewise around the target reference points, and thus also indicating that the stock is at an acceptable level.
- Although the majority (67%) of the recreational catch of southern school whiting were young (2 or 3 years), substantial numbers of fish were present in all ages up to 5 years and all ages from 1 to 11 years were represented in samples.
- Annual catches for recreational boat-based fishers in the WCB remained stable between 1996 to 2010, although catches in the recent recreational boat-based survey (2011/12) were >35% lower, suggesting a recent decline in abundance or availability.
- The only commercial fishery in the WCB that caught substantial quantities of southern school whiting is the South West Trawl Managed Fishery and overall, the commercial catch is relatively minor (average 5.8 t/year). In addition, southern school whiting is a bypoduct in this fishery and determining trends in catch and catch rate data from this fishery are of limited use for stock assessment.
- Recruitment data for 0+ fish at Metropolitan Zone sites suggest that recruitment is variable, with relatively low recruitment in 2010 and 2011, which may help account for the low catch

levels seen in the 2011/12 recreational boat-based survey. Relatively high recruitment of 0+ fish was observed in 2012.

- The recreational catch comprised roughly equal numbers of females and males and consisted mostly of mature fish, with only 7.1% of the WCB frame donations below the length at which 50% of individuals attain maturity.

As the estimates of fishing mortality and spawning potential ratio lay around the target levels (but with confidence intervals for one of the methods overlapping the threshold levels), based on the control rules developed by the Department of Fisheries for finfish fisheries and *F*-based assessments, current catch levels of southern school whiting can be allowed to be maintained. However, even though this species is categorised as having a low vulnerability to fishing, given the uncertainties associated with the estimate of fishing mortality, the stock should be monitored closely.

For future assessments, the collection of consecutive years of age data will help reduce uncertainties associated with variable recruitment and its influence on obtaining reliable estimates of mortality. Additionally, increased sample collection from the shore-based catch and/or a recreational survey focusing on this aspect would be valuable for improving information on impacts of fishing by shore-based fishers. A known sampling frame would be required for shore-based surveys to be cost effective.

King George whiting stock status

The stock status of King George whiting was deemed to be acceptable.

- Preliminary estimates of fishing mortality (by Fisher *et al.* in prep) suggest that fishing mortality in offshore waters is low, but that in inshore waters, it is high. There is, however, a high vulnerability risk to the sustainability of the stock due to relatively high fishing pressure in the inshore component of the stock, which is entirely comprised of immature fish.
- At current fishing levels for the inshore and offshore regions, the spawning potential ratio (based on the spawning biomass per recruit) is at 42% of unfished levels (by Fisher *et al.* in prep). Per-recruit analyses and associated decision table analyses indicate that if exploitation in inshore regions were to increase markedly, the spawning potential ratio of the Metropolitan stock could be reduced to a low level (i.e. ~30% of unfished levels).
- The current catch from the recreational sector is largely comprised of immature fish that have yet to spawn (79% in WCB and 94% in SCB). Similarly, the majority (>95%) of the commercial catch consists of immature fish. The breeding stock has been offered some protection due to the unidirectional offshore movement of fish to deeper waters where targeting is considerably less. However, the breeding stock may be at an increased risk through increased targeting of this part of the stock due to greater recreational boat ownership, including larger boats, and increases in efficiency through increased use of technology (GPS, sounders, etc.).
- Commercial fishery catch and catch rate data suggest a fairly stable long-term trend in the main fisheries (Wilson Inlet (SCB) and Peel-Harvey Estuary (WCB)), with a large peak in recruitment occurring in both fisheries in the late 1990s. The trends in catch and catch rates can be influenced by a number of factors, including targeting in these multi-species fisheries, recruitment availability due to sand bar openings and environmental impacts in these highly populated estuarine catchments.
- Recreational fishery data suggests declining catches from 1996 to 2010. The estimates for 2011/12 were higher suggesting an increase in stock abundance, availability or targeting.

- King George whiting juvenile recruitment is highly variable, which is likely due to a number of physical processes, including Leeuwin Current strength. Recent consecutive years (2005–2007) of low recruitment in this species appear to have resulted in low recreational catches 2–3 years later. High recruitment indices in 2008 appear to have translated to a higher recreational catch which was observed in the 2011/12 state-wide survey. Recruitment levels in 2009 and 2010 were again low, before increasing in 2012.

Preliminary estimates of fishing mortality in inshore and offshore waters, when analysed together in a per recruit analysis for the overall stock, suggest that King George whiting is not being overfished in waters near Perth. On the basis of the existing control rules for finfish assessed using *F*-based methods, it is recommended that catch levels be allowed to be maintained, with regular monitoring of the age structure to improve estimates of fishing mortality. Consideration should be given to increasing the Legal Minimum Limit to allow more juvenile fish the opportunity to spawn. Sampling of juvenile 0+ King George whiting at nursery sites, particularly Mangles Bay, needs to continue to provide a long-term index of abundance. Stock discrimination is required to ascertain if there are separate breeding stocks in the WCB and SCB, and thereby also ascertain if SCB fish are mainly derived from larvae produced in the WCB. Knowledge of annual fecundity, and associated information on reproductive biology for King George whiting in WA, would allow a more thorough assessment of the reproductive potential of the stock.

1.0 Introduction

1.1 Background

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

The whiting family Sillaginidae (Richardson 1846) is common in nearshore waters throughout the Indian and western Pacific Oceans (McKay 1992). Currently, there are 33 recognised species (McKay 1992; Kaga *et al.* 2010; Gao *et al.* 2011) belonging to three genera: *Sillaginodes* Gill 1862 (1 species), *Sillaginopsis* Gill 1861 (1 species) and *Sillago* Cuvier 1817 (31 species). In Western Australia (WA), ten whiting species are known to occur. The largest and most easily recognised of these is King George whiting (*Sillaginodes punctata*). The other nine species all belong to the genus *Sillago* and have a similar body shape and colouration. These inhabit a range of environments from estuarine and nearshore coastal waters, to deeper waters up to 70 metres, including sand and reef habitats (McKay 1992; Hyndes *et al.* 1996a).

Whiting are an excellent eating fish, which makes them highly prized by recreational and commercial fishers (McKay 1992; Kailola *et al.* 1993). In WA, whiting are among the most common species retained by boat- and shore-based recreational fishers, especially in the West Coast Bioregion (WCB), where the majority of whiting landings occur (Henry and Lyle 2003; Ryan *et al.* 2013). Whiting are targeted commercially in all bioregions of WA, fetching a good price because of those good eating qualities. In 2009/10, the reported commercial catch of whiting (all species) in WA was 152 tonnes and worth an estimated $722,000 (ABARE 2011). However, the actual species composition of the recreational and commercial whiting catches is unknown due to the lack or uncertainty of species-specific data.

The main reason for the limitation of species-specific data for whiting is that species of the genus *Sillago* are difficult to distinguish due to their similar external appearance, slight variation in appearance within species and overlapping distributions (McKay 1992). This is further confounded by the schooling nature of these species, which occasionally comprise more than one *Sillago* species (Hutchins and Swainston 1986; McKay 1992). As a result, fishers often refer to whiting species of the genus *Sillago* collectively as ‘sand’, ‘silver’ or ‘school’ whiting. The varying use of common names also adds to the uncertainty in species-specific catch data. For example, although ‘sand whiting’ is actually the correct Australian standard name for *S. ciliata*, a species that occurs only on the east coast of Australia, the name ‘sand whiting’ is widely, but incorrectly, used in WA for several other *Sillago* species. There is also some confusion with the similarly shaped and named ‘weed whiting’, which do not belong to the whiting family (Sillaginidae) but rather the Odacidae. These factors have resulted in a high level of uncertainty about the species composition of whiting landings reported by recreational and commercial fishers in WA. As a consequence of this uncertainty, previous data analysis for whiting species of the genus *Sillago* has been grouped as 'whiting spp.' for ease of assessment.

Important to any assessment of a fisheries sustainability status is knowledge of species-specific data (Gray and Kennelly 2003; Krück *et al.* 2013). Furthermore, understanding the life histories of individual fished species is important to improving fisheries management (Currey *et al.* 2013). The nearshore finfish resources of the WCB, including whiting stocks, have been identified as having a high sustainability risk (Department of Fisheries 2011), due to increased fishing pressure arising from a growing recreational fishing population and an anticipated shift in targeting away from demersal fish species due to recent effort restrictions for such species, including a two-month closed season and reduced bag and boat limits for recreational fishers (Crowe *et al.* 2013). Currently, the risk level is exacerbated due to uncertainty about the composition of the whiting catch. Therefore, to fully assess the stock status of nearshore finfish resources in the WCB, the composition of recreational and commercial whiting landings must be resolved.

This study determines the species composition of whiting landings caught recreationally and commercially in south-western WA, particularly in the WCB where the sustainability risk is highest. The stock status of the key fished whiting species in the WCB are then assessed by a 'weight-of-evidence' approach, making use of all available historical and current information from fishery-independent and fishery–dependent sources, including estimates of fishing mortality, recruitment trends, commercial and recreational catch rate trends, and current understanding of the inherent vulnerability of the stock to exploitation due to biological characteristics. This approach has been used to assess numerous other finfish stock within WA (Wise *et al.* 2007; Marriott *et al.* 2012; Smith *et al.* 2013a).

1.2 Need

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

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

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

1.3 Resource assessment framework – indicator species

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

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

1.4 Weight-of-evidence assessment

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

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

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

1.5 Objectives

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

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

Specific objectives:

1. Develop methods to identify individual whiting species from fishery-derived samples (e.g. from filleted frames).
2. Determine the contribution of individual whiting species to total recreational and commercial landings of whiting in the West Coast Bioregion and South Coast Bioregion.
3. Review key biological parameters of relevance to stock assessment for the key whiting species identified in the recreational catch of the West Coast Bioregion.
4. Determine the current age structures and estimate the current fishing mortality rates for key whiting species in the West Coast Bioregion.
5. Conduct per recruit analyses for key whiting species in the West Coast Bioregion.
6. Using key whiting species identified in the catch composition assessment as a proxy, evaluate the potential of commercial and recreational catch rates to provide an index of annual abundance for key whiting species.
7. Determine the stock status of key whiting stocks in the West Coast Bioregion using a 'weight-of-evidence' approach.
8. Develop a long-term monitoring strategy for assessing the stock status of key whiting species in the West Coast Bioregion.

1.6 Overview of whiting species of Western Australia

The ten whiting species of WA are abundant in nearshore waters, however, the distribution and ontogenetic migration between these species vary considerably within this region (McKay 1992; Hyndes *et al.* 1996b). These differences have been related to differences in the timing of recruitment and habitat use (Hyndes *et al.* 1996a). They also display marked differences in life history parameters (e.g. growth rate, maximum size and age, length and age at maturity) (Hyndes and Potter 1996; Hyndes *et al.* 1996b; Hyndes and Potter 1997; Hyndes *et al.* 1998).

King George whiting, *Sillaginodes punctata* (Cuvier, 1829)

King George whiting are endemic to southern Australia, occurring from Jurien Bay in WA (Hutchins and Swainston 1986), with unconfirmed reports from Geraldton, to Jervis Bay in New South Wales. The lifecycle of King George whiting involves both inshore and offshore habitats. Juveniles occupy shallow (<1.5 m) nearshore waters in estuaries or coastal embayments then migrate out to slightly deeper waters (5–15 m) over patchy sand/seagrass substrate in those same areas at about 1.5 years and approximately 250 millimetres (mm) in total length (TL) (Hyndes *et al.* 1998). At the onset of maturity at around 3–4 years, they migrate to deeper waters, inhabiting coastal reefs, sand and weed banks where they remain (Hyndes *et al.* 1998). King George whiting are the largest of all whiting species reaching a maximum size of 720 mm TL (McKay 1992). They are the only member of the genus *Sillaginodes* and are easily recognised by their more elongate body shape with the second dorsal fin possessing a higher number of soft rays (25–27). They also have a distinct brown spot pattern.

Southern school whiting, *Sillago bassensis* (Cuvier, 1829)

Southern school whiting are abundant over sandy substrate in southern Australia, occurring from Geraldton in WA to Western Port in Victoria (Hutchins and Swainston 1986). With increasing size/age, juveniles move offshore from their nearshore nursery grounds to deeper waters (20 – 35 m) (Hyndes *et al.* 1996a). Southern school whiting attain a maximum size of approximately 360 mm TL (Hutchins and Swainston 1986). Southern school whiting are best identified by diagonal faint, broken brown lines along the upper side of its body and the lack of dark spots on the pectoral fin muscle (Hutchins and Swainston 1986).

Western school whiting, *Sillago vittata* (McKay, 1985)

Western school whiting are endemic to WA, occurring from Dampier to Geographe Bay. This species is very similar in appearance to southern school whiting and is best distinguished by the presence of numerous dark spots on the pectoral fin muscle and more defined brown lines on the upper side of its body (Hutchins and Swainston 1986). A dark blotch may also exist at the top of the first dorsal fin. Juveniles of this species are usually found in more sheltered waters than those of southern school whiting (Hyndes *et al.* 1996a). By the age of 1+ years, these fish move offshore into deeper (5–15 m depth) areas with sandy substrate. Western school whiting attain a maximum TL of 325 mm (Hyndes *et al.* 1996b).

Yellowfin whiting, *Sillago schomburgkii* (Peters, 1865)

Yellowfin whiting are endemic to western and southern Australia. Two distinct populations are believed to exist in these regions. In WA, yellowfin whiting occurs from Exmouth to Albany, while in South Australia this species occurs from Spencer Gulf to Fleurieu Peninsula. It is abundant in nearshore and estuarine waters, primarily spending its entire lifecycle in waters of <5 m depth (Hyndes and Potter 1997). A maximum TL of 427 mm has been recorded for yellowfin whiting (Department of Fisheries unpublished data). Adults of this species have no distinguishing body markings and are best identified by their yellow ventral and anal fins and a weakly forked caudal fin. Juveniles have faint black blotches on the body and may be confused with western trumpeter whiting. They are best distinguished from this species by the lack of markings on the pectoral fin muscle (Hutchins and Swainston 1986).

Western trumpeter whiting, *Sillago burrus* (Richardson, 1842)

Western trumpeter whiting are found in coastal waters along the west and north coasts of Australia, from Geographe Bay in WA to north-eastern Queensland and also in coastal waters of southern Indonesia and New Guinea (McKay 1992). It inhabits a variety of sandy, silty and muddy substrates in depths from 0–15 m. Juveniles recruit into nearshore and estuarine waters before moving out to deeper water (5–15 m) as they approach maturity towards the end of their first year of life (Hyndes *et al.* 1996b). Adult western trumpeter whiting are also found in the Swan-Canning Estuary. In comparison to the other WA *Sillago* species, western trumpeter whiting grow to a smaller size, with a reported maximum TL in WA of only 251 mm (Hyndes *et al.* 1996b). Western trumpeter whiting are best identified by the dark blotches along the side of their body and a dark blotch on their pectoral fin muscle (Hutchins and Swainston 1986).

Stout whiting, *Sillago cf. robusta* (Stead, 1908)

Stout whiting were believed to occur on both the west coast of Australia, northwards from Mandurah to Shark Bay, and on the east coast, from New South Wales to southern Queensland (McKay 1992). However, recent genetic examination of this species (in this study) supports the earlier findings of Dixon *et al.* (1987) that the western population of stout whiting is a new species. In WA, this species is understood to spend its entire lifecycle in deeper waters >15 m depth (Hyndes *et al.* 1996a). While a maximum size of ~280 mm TL has been reported for the eastern variety of stout whiting (Grant 1965), the largest observed TL in WA is 230 mm (in this study). The western population of stout whiting is best identified by a small yellow blotch behind the pectoral fin. There are no other distinguishing markings on the body and the caudal fin is strongly forked.

Goldenline whiting, *Sillago analis* (Whitley, 1943)

Goldenline whiting occur across northern Australia, generally from Shark Bay in WA, however low numbers have been reported further south at the Houtman Abrolhos Islands (Hutchins 1997), to Moreton Bay in southern Queensland (McKay 1992). The species has also been reported in southern New Guinea (McKay 1992). Goldenline whiting is usually found over sandy areas in shallow waters ranging from 0 to 10 m depths. In Shark Bay, they are often found cohabitating with yellowfin whiting. Goldenline whiting are best distinguished from this species by its lower number of lateral line scales (54–61 compared to 66–76) and dorsal soft rays (16–18 compared to 19–22) (McKay 1992). Because of its larger body scales, goldenline whiting has a rough or coarse feel to its body compared to the smooth or fine scales of yellowfin whiting. Goldenline whiting is also distinguished by a golden-silver to golden-yellow stripe along the middle of its side. A maximum length of 450 mm standard length has been reported for this species (McKay 1992), however the location is unknown but believed to be in Queensland. The maximum length reported in WA (Shark Bay) is considerably lower at ~350 mm TL (Lenanton 1970).

Northern whiting, *Sillago sihama* (Forsskål, 1775)

Northern whiting are considered to occur throughout the Indian and western Pacific Oceans. In Australia, northern whiting occurs from Onslow in WA, northwards to Townsville in Queensland (McKay 1992). Northern whiting mainly inhabit sandy bottoms in nearshore waters <20 m depth. Northern whiting have a plain sandy body colour with no distinguishing features. They reach a maximum TL of 310 mm (McKay 1992).

Bay whiting, *Sillago ingenuua* (McKay, 1985)

Bay whiting have been reported from waters off Thailand, Taiwan, India and Australia. In Australia, they occur from Shark Bay northwards to Adolphus Passage in north-eastern Queensland. They are usually found in protected inshore coastal waters from depths of 20 to 50 m and reach a maximum size of 200 mm standard length (McKay 1992). Bay whiting has a pale sandy brown colour with no distinct markings. Bay whiting can be distinguished from the similar looking northern whiting by the lower number of dorsal rays (17 compared to 20–23) (McKay 1992).

Mud whiting, *Sillago lutea* (McKay, 1985)

Mud whiting have been reported from India, Sri Lanka and northern Australia where they occur from Exmouth Gulf to the Gulf of Carpentaria. Mud whiting are mostly abundant over muddy or silty substrates (hence the name) and have been reported at depths of 0 to 60 m (McKay 1992). They are unlikely to be a major fishery species due to their small maximum size of 160 mm standard length. The species has a light sandy brown colour with no distinguishing markings. Mud whiting and northern whiting are very similar in appearance and require examination of the posterior end of the swimbladder to differentiate between the two. Mud whiting has a single posterior extension to the swimbladder while northern whiting has two posterior tapering extensions (McKay 1992).

2.0 Methods

2.1 Fishery catch composition

2.1.1 Species identification

A key was developed to identify the whiting species of south-western WA. As most recreational samples collected were frames (i.e. filleted carcasses), body markings were often unavailable and so the key included additional diagnostic features (e.g. otolith shape). Otolith shape has recently been used to identify *Sillago* species in China (Wang *et al.* 2010; Gao *et al.* 2011). McKay (1992) suggested using the swimbladder shape and vertebrae count to distinguish between some whiting species. In this study we found this to be unsuitable for a number of reasons. Firstly, the swimbladder was often punctured during the filleting process and unusable for identification; secondly, the preparation of the vertebrae was too time consuming for the large number of samples examined; and thirdly, the lower number of whiting species of south-western WA had enough distinguishing features to develop a key without using these criteria.

2.1.2 Sample collection

Samples of whiting (all species) were collected from recreational fishers in the WCB and SCB of south-western WA (Fig. 1) from July 2010 to December 2012. Whiting from the recreational sector were predominantly caught using line fishing methods and were mostly donated as frames through the WA Department of Fisheries (DoF) 'Sends Us Your Skeletons' program. This program encourages recreational fishers to donate the filleted carcasses of key finfish species for research purposes. Fishers provided capture date, location and their contact details for each sample. Where possible, water depth, fishing method (shore- or boat-based fishing) and, in the case of King George whiting, information on the habitats from which fish were caught was also obtained.

Note: Different recreational size and daily mixed species bag limits for whiting species exist in each Bioregion and are likely to influence the catch composition (see Table 1).

To assess whether the species composition of donated whiting samples was representative of the overall recreational catch, donated samples were compared with the species composition of whiting landings estimated during the boat-ramp component of the 2011/12 state-wide recreational boat-based fishing survey (see 'Recreational fishery catch and effort' below). Whiting identification training by the authors was provided to survey staff to improve reliability of species identification.

Determination of the commercial whiting catch composition was performed through past monitoring of retained catches, in combination with knowledge of whiting species distribution by region and habitat type, for each of the main fisheries that land whiting (see 'Commercial fishery catch and effort' below). In addition, *ad hoc* sampling events either directly with fishers, at processor factories or from random samples collected by research staff was undertaken. Species identification of the commercial whiting catch was performed on whole fish.

Juveniles of each whiting species were collected during fishery-independent sampling of nursery areas using fine-mesh beach seine nets. The data from these surveys were used to determine whiting species distribution and to develop recruitment indices (see 'Recruitment dynamics' below for details of sampling methodology).

2.1.3 Catch shares

Catch shares for the recreational and commercial fishing sector were determined using the estimated retained catch from the recent state-wide boat-based survey in 2011/12 (Ryan *et al.* 2013), the estimated catch proportion of the boat-based and shore-based recreational sector from the national survey in 2000/01 (Henry and Lyle 2003) to scale up the boat-based catch estimate to include shore-based catches, and the commercial catch landed during 2011. To enable a comparison with the commercial catch in tonnes, the estimated recreational catch in numbers was converted to a weight by using the average length of the recreational catch (see 'Length structure' in results) and applying the weight-length relationship determined in this study (see 'Morphometrics' in results) to derive an average fish weight. The average weight for the whiting species was then multiplied against the estimated total number retained in the recreational catch (shore- and boat-based fishing) to provide an estimated catch in tonnes.

2.2 Assessment

An assessment of stock status is performed for the key (most abundant) recreationally caught species in the WCB as identified in the sample collection above.

2.2.1 Biological analysis

Fish measurements and dissection procedures

For each fish, the total length (TL) and fork length (FL) were recorded to the nearest 1 mm. Total wet body weight (when whole fish were collected) was recorded to the nearest 0.1 gram (g). Sagittal otoliths were removed, cleaned, weighed to the nearest 0.0001 g and stored in labelled paper envelopes. Gonads were removed and weighed to the nearest 0.01 g.

Morphometrics

As most whiting donated by recreational fishers were provided as frames, weight-length relationships were determined for each species from whole fish that had been caught by recreational and commercial fishers and researchers. This allowed an estimation of the weights of all filleted fish (for use in determining reproductive indices).

Linear relationships were fitted to the natural logarithms of the whole body weights and total lengths of each species, i.e. assuming a multiplicative error structure to account for increasing variance with body length. Thus, the natural logarithm of body weight in grams (lnW), may be estimated from the natural logarithm of total length, ln(TL), (in mm) as:

$$1\mathrm{n}W = b + m * 1\mathrm{n}(TL),$$

where m and b are the slope and y intercept of the linear equation.

Using the above estimates of a and b, the relationships were expressed as power relationships, i.e. as:

$$W = aL^b$$

where b was the same as that estimated above, and a was determined as:

$$a = \exp(m + \sigma^2/2)$$

In the above equation, σ^2 is the variance determined from the sum of squared residuals produced when fitting the linear equation, and is used to correct for the bias associated with back log-transforming the value of the slope parameter in the linear equation.

In instances where the tip of the fish tail were damaged and only a FL was obtainable, TL was determined from linear FL vs TL relationships (see results).

Reproductive analyses

Reproductive data were collected to determine the sex ratio of fish in samples, and for the key whiting species in samples, the time and duration of spawning, and the size and age at maturity.

The sex of each fish was determined by macroscopic examination of its gonads and recorded as either 'male', 'female' or 'unsexed juvenile', *i.e.* for very small juveniles whose sex could not be distinguished. A χ^2 goodness-of-fit test was used to assess whether the sex ratios in samples collected by recreational angling were significantly different from parity.

Based on the criteria of Laevastu (1965), the gonads of each fish were assigned to the following macroscopic stages: 1: Virgin; 2: Maturing virgin/resting adult; 3: Developing; 4: Maturing; 5: Mature; 6: Spawning; 7: Spent; 8: Recovering spent.

Because all the whiting species of south-western WA are multiple spawners (Hyndes 1996) i.e. individual females spawn on more than one occasion in a spawning season, it was often difficult to differentiate macroscopically between stages 5, 6 and 7. Therefore, the macroscopic stages were grouped for analysis into 'immature/resting' (Stage 1, 2 and 8), 'developing' (stage 3 and 4) and 'mature/spawning' (stage 5, 6 and 7).

The time and duration of spawning was assessed by trends in monthly prevalence of fish with different stages in gonadal development and on the basis of the annual trend in mean monthly gonadosomatic indices for each sex for all fish ≥length at 50% maturity (see below). The gonadosomatic index (*GSI*) for each fish was calculated as

$$GSI = 100(W_1/W_2)$$

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

GSI values were plotted against mean monthly sea surface temperature (SST) data for the sampling period for Fremantle (WCB) and Albany (SCB). SST records were derived from Commonwealth Scientific and Industrial Research Organisation (CSIRO) satellite measurements, supplemented by *in situ* measurements, of 1 degree latitude/longitude blocks (approximately 100 km^2).

The probability, P, that a female, or male, is mature at total length L (mm) was calculated using the following logistic curve:

$$P = 1/\{1 + \exp[-1\mathrm{n}(19)(L - L_{50})(L_{95} - L_{50})]\},$$

where L_{50} and L_{95} are the lengths at which 50 and 95% of fish would be expected to be sexually mature, respectively. Logistic curves were fitted employing SOLVER in Microsoft Excel by maximising the log-likelihood, λ, which was calculated as $\lambda = \sum_j \{X_j \ln P_j + (1 - X_j)\ln(1 - P_j)\}$, where the jth fish was represented by $X = 0$ if it was immature and $X = 1$ if it was mature. The maturity data were randomly resampled, with replacement, and analysed to create 200 estimates of the parameters of the logistic equation. The point estimate and lower and upper 95% confidence limits for the logistic parameter were taken as the median, 2.5 and 97.5 percentiles, respectively, of the 200 estimates for each parameter. The same form of regression analysis was used to determine the ages at which 50% (A_{50}) and 95% (A_{95}) of females and males reach sexual maturity, together with their 95% confidence limits.

For each species, the proportion of total recreational catch that was below the mean length-at-maturity (L_{50}), i.e. juveniles, was calculated.

Age and growth

Age and growth was examined for the key whiting species identified in the recreational catch.

Whiting were aged by counting validated annual increments in either whole or sectioned sagittal otoliths (Hyndes 1996). Briefly, for ageing whole otoliths, one sagittal otolith per fish was placed in a black dish containing methyl salicylate. For sectioned otoliths, one sagittae per fish was embedded in clear polyester (epoxy) resin and a transverse section (~0.2 mm thick for southern school whiting and ~0.3 mm thick for King George whiting) was then taken through the primordium using a low-speed Buehler-Isomet diamond saw. Otolith sections were mounted on a glass slide with casting resin, and using a cover slip.

Whole and sectioned otoliths were then examined under reflected light against a black background using a dissecting microscope. Images were captured using a digital camera (Jenoptik ProgRes® Model C7). The number of opaque annuli was then recorded. A marginal increment category was assigned, where 0: opaque zone on edge; 1: <50% translucent edge; 2: >50% translucent edge. A readability index was assigned, where 1: poor; 2: fair; 3: good. The very small number ($n = 3$) of otoliths assigned a poor readability were not included in the age analysis.

Ageing of King George whiting was undertaken as part of a joint project with Murdoch University. For more detail on the methodology employed see Sulin (2012) and Fisher *et al.* (in prep).

A birth date was assigned for each species as the mid-point of the spawning period as indicated by trends throughout the year in the mean monthly gonadosomatic indices and different stages in gonadal development.

Growth was described by fitting von Bertalanffy growth curves to length-at-age data for each of the key whiting species. The von Bertalanffy growth equation is:

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

where L_t is the predicted mean length (TL in mm) of fish at age t (years), L_∞ is the asymptotic mean length (mm), k is the growth coefficient (year^{-1}), and is the hypothetical age (years) at which fish would have zero length. Prior to fitting the curves, the lengths at age for small juveniles that could not be sexed were assigned randomly, but in equal proportions, to the data sets for females and males. von Bertalanffy growth curves were fitted to the length-at-age data sets for each sex, and to pooled data for the two sexes. A likelihood-ratio test (Cerrato 1990) was used to determine whether the growth curves for the two sexes were significantly different. The test statistic was determined as twice the difference between the log-likelihoods obtained by fitting a common growth curve to the data for the two sexes combined and by fitting separate growth curves to the data for each sex. The hypothesis that the growth of the two sexes could be appropriately described by a single growth curve was rejected at the $\alpha = 0.05$ level of significance if the above test statistic exceeded $\chi^2_\alpha(q)$, where q is the difference between the numbers of parameters in the two approaches, i.e. 3 (Cerrato 1990).

Using samples of King George whiting collected in this study, Sulin (2012) presented growth parameters for the traditional form of von Bertalanffy growth model and for an adjusted form which accounts for offshore size-related movement. To facilitate comparisons with the earlier work of Hyndes *et al.* (1998), the parameters derived for the traditional form are presented here.

Mortality estimation

The instantaneous rate of total mortality (Z, year^{-1}) was estimated by applying two commonly-employed, traditional forms of catch curve analysis, *i.e.* the least squares regression (linear) catch curve (Ricker 1975) and the nonregression-based method of Chapman and Robson (1960). These catch curves were fitted to age composition data collected in this study for southern school whiting (the most abundant species in recreational boat-based catches). Note that although some individuals of this species are known to be caught by shore-based fishers, the majority of the catch is believed to be taken by boat-based fishers (see 'Discussion').

The linear catch curve employed was

$$1\mathrm{n}(N_t) = 1\mathrm{n}(N_0) - Zt$$

where N_t is the number of fish sampled at age t years, Z is the total mortality and N_0 is the number of fish at age zero. The catch curve was fitted to the natural logarithms of the frequencies of fish in the sample, from the most abundant age class (assumed age at full recruitment to the fishery) to the maximum age of fish prior to the first age class for which the frequency was zero. Z was taken as the negative of the slope parameter in the regression equation.

Values of total mortality (Z) were estimated from the age composition of fully-recruited fish using the equation of Chapman & Robson (1960), *i.e.*

$$\mathrm{Z} = 1\mathrm{n}[1 + \bar{X} - n^{-1}] - 1\mathrm{n}\,\bar{X} - \{(n-1)(n-2)[n(T+1)(n+T-1)]^{-1}\},$$

where $\bar{X}$ is the mean of the integer ages of fully-recruited fish relative to the age at full recruitment, n is the number of such fish and $T = n\bar{X}$. The age at full recruitment was taken as the peak in the age-frequency distribution.

In the case of analyses, the catch curves were fitted to 1000 sets of age resampled (with replacement) composition data. The point estimate and lower and upper 95% confidence limits for Z were taken as the median, 2.5 and 97.5 percentiles, respectively, of the resultant estimates of Z.

Both catch curve methods assume that recruitment and mortality were constant over the lives of all fish in the samples, and that all fully-recruited fish were equally vulnerable to capture. It is also assumed that the age composition sample represents a random sample from the fish stock (for fish above the age at full recruitment). Note that these represent relatively strong assumptions which, to a certain extent, are likely to be violated. The DoF is currently exploring several other catch curve approaches, which enable some of the assumptions to be relaxed, and thereby, may potentially produce more robust estimates of Z. It is thus likely that the estimates of Z may be revised, if the new approaches being trialled can be demonstrated to produce more reliable estimates of Z than either of the catch curve methods reported here.

An approximate estimate for the instantaneous rate of natural mortality (M, year^{-1}) was derived by inserting the maximum recorded age for southern school whiting into the equation of Hoenig (1983) (for all taxa), which is

$$\mathrm{Z} = 1.44 - 0.982(t_{max})$$

where t_{max} is the maximum age in years either observed in the stock (recorded in this study), and noting that the estimate of Z produced by this equation for lightly-fished stocks is often taken as an approximate value for M, and also noting that the values for M typically derived from the Hoenig (1983) equation are usually lower than estimates of M derived using others that commonly-employ life history equations, leading to conservative stock assessment results.

An estimate of the instantaneous rate of fishing mortality (F) was calculated by subtracting the value of M, derived from Hoenig's (1983) equation from the value of Z determined from catch curve analysis, i.e. $F = Z - M$. A range of F, taking into account uncertainty in Z, was calculated by subtracting the upper and lower 95% confidence intervals for Z.

Per recruit analyses

The yield per recruit (*YPR*) and spawning stock biomass per recruit (*SSBR*) for southern school whiting were calculated from age zero and assuming constant recruitment at age zero and constant mortality for full-recruited fish. For female whiting, the yield per recruit, *YPR*, was calculated as

$$YPR = \sum_{a=0}^{A} \frac{S_a F}{M + S_a F}\{1 - \exp[-(M + S_a F)]\} W_a \exp[-(M + S_a F)]$$

where A is the assumed maximum age for each species (100 year) for this analysis, F and M are the instantaneous rates of fishing and natural mortality, respectively, S_a and W_a are the relative selectivity and weight of females or males at age a, respectively. As selectivity was assumed to be knife-edged, 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.

The female spawning stock biomass per recruit, *SSBR*, was estimated as

$$SSBR = \sum_{a=0}^{A} W_a \psi_{mat_a} \exp[-(M + S_a F)]$$

where ψ_{mat_a} is the proportion of fish that are mature at age a.

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

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

Reference points

As is consistent with several previous stock assessments undertaken by the DoF (e.g. Wise *et al.* 2007) and based on internationally accepted benchmarks for stock assessments (e.g. Caddy and Mahon 1995; Gabriel and Mace 1999), the performance indicators (*F* and *SPR*) were assessed against target, threshold and limit reference points for these variables.

<u>F-based reference points:</u>

Target level, $F = 2/3M$; Threshold level, $F = M$; Limit level, $F = 3/2\ M$.

<u>SPR-based reference points:</u>

Target level, SPR = 0.4; Threshold level, SPR = 0.3; Limit level, SPR = 0.2.

If the stock is within the target level, this indicates that the stock is at very low risk of recruitment failure (in some cases, the target reference point also represents an economic or social reference point, well above the point at which sustainability is likely to be compromised). If the threshold level is breached, this serves as an 'early warning' that the stock is at increased risk of recruitment failure (due to overfishing and/or environmental perturbations), indicating that management action should be taken to increase the level of spawning biomass. Breaching of the limit reference point indicates that there is an unacceptable risk of recruitment failure and that severe and immediate management intervention is required. Confidence limits were used to report the probability of an estimate range against *F* and *SPR* reference points.

'Weight-of-evidence' assessment

For the key whiting species (southern school whiting and King George whiting) in the WCB, stock status was assessed using what the DoF has termed a 'weight-of-evidence' approach. This approach has previously been used to determine stock status for demersal indicator species in the WCB (Wise *et al.* 2007) and in the GCB (Marriott *et al.* 2012), and for Australian herring and tailor, which are considered as indicator species for the suite of nearshore species in the WCB (Smith *et al.* 2013a; Smith *et al.* 2013b). In this assessment approach, a range of methods are used to infer the status of the stock, including quantitative measures, that may result from several types of assessment, as well as subjective measures describing aspects influencing the productivity and susceptibility of this stock. Overall, the use of all of the available information is expected to reduce uncertainty.

The quantitative measures employed in a 'weight-of-evidence' assessment 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 levels of monitoring associated with the different assessment levels considered by the Department, for deriving quantitative measures of stock status, are as follows:

Level 1: Catch data only

Level 2: Level 1 plus fishery-dependent effort

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: Levels 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.

The qualitative information used to further infer likely stock status are based around attributes describing the productivity and susceptibility of the stock, refined from the approaches employed by Patrick *et al.* (2010) and Hobday *et al.* (2011). Productivity measures include growth parameters, trophic level, longevity, age at maturity, fecundity, recruitment variability, and resilience to other sources of mortality. Susceptibility scores include selectivity to the fishing gear, schooling/aggregating behaviour, model of reproduction (*i.e.* hermaphroditism or gonochorism), distribution of adults and level of post-release mortality. All of the productivity and susceptibility measures are classed as either low, medium or high, to provide and overall, generalised score (*i.e.* low, medium or high).

Although the strongest weighting of information is provided to the qualitative measures of stock status, the management response is refined based on the generalised score produced by the productivity and susceptibility analysis. For example, if the measure of F and SPR lay between the threshold and limit values, this would indicate a management response of reducing catch and/or effort by 10–50%. The scientific advice, to managers, as to the level to which catch and/or effort should be reduced would then be decided taking into account the extent to which F and SPR were above and below the threshold, respectively, and the overall productivity and susceptibility score. Note also, that management is undertaken in consultation with industry.

2.2.2 Recruitment dynamics

Since 1993, the DoF' Research Division has monitored the annual abundance of juvenile fish by netting at various nearshore nursery sites along the south-western coast of WA. This sampling program aimed to monitor the annual recruitment levels of juveniles of various recreationally and commercially important species (including whiting), in order to assess relative stock abundance and potentially predict fishery landings. For a full description of the methodology used for the recruitment sampling see Ayvazian *et al.* (2000) and Gaughan *et al.* (2006).

Briefly, juvenile fish were sampled monthly using a fine-mesh beach seine net (total length 60.6 m, height 2.0 m, composed of 2 wings of length 29.1 m with 22 mm mesh and bunt of length 2.4 m with 8 mm mesh) at a number of sites along the south-western coast of WA. A smaller seine net (total length 21.5 m, height 1.5 m, composed of 2 wings of length 10 m (6 m of 9 mm mesh and 4 m of 3 mm mesh) and bunt of length 1.5 m with 3 mm mesh) was used at one of the sites (Leschenault Inlet – WCB) due to confined conditions preventing the deployment of the larger 61 m net. Typically, three or four replicate net hauls were undertaken each month at each site. Captured fish were identified to the lowest possible taxon (usually species) and measured (TL) to the nearest mm. When whiting species were unable to be identified to species level, they were assigned to either 'school whiting' (if western school whiting or southern school whiting) or to 'unidentified whiting' (any whiting species).

From 2005 onwards, an 'optimised' sampling program was implemented, based on a reduced number of months and number of sites being sampled annually, compared to previous years. This new sampling regime, which included four sites within the WCB, one site in the western part of the SCB and one site in the eastern part of the SCB (Fig. 1), was designed to provide cost-effective monitoring of the annual recruitment of seven key fishery species, including King George whiting and yellowfin whiting. The sampling design was not optimised for the other whiting species so sites and/or months that may have provided good numbers of these species were not considered for the reduced sampling program.

For the key whiting species identified in the recreational catch, monthly length frequency distributions were produced to examine the sizes of 0+ fish in each month and at each key site to establish recruitment timing. The catch rates of 0+ fish for the key recruitment months and site(s) were then used as a 'recruitment index' to compare relative abundance between years.

The annual recruitment index (R) was calculated as

$$R = C/E$$

where C = total number of 0+ fish caught and E = total number of seine net hauls.

2.2.3 Recreational fishery catch and effort

Where reliable data allows, the key whiting species identified from the catch composition assessment will be used as a 'proxy' for determining catch and catch rates in historical recreational fishing surveys.

Estimates of recreational catch and effort produced in this report are from WCB boat-based creel surveys conducted in 1996/97, 2005/06, 2008/09 and 2009/10 (Sumner and Williamson 1999, Sumner *et al.* 2008, DoF unpublished data), the National Recreational and Indigenous Fishing Survey carried out in 2000/01 (Henry and Lyle 2003), a state-wide boat-based survey in 2011/12 (Ryan *et al.* 2013), a SCB estuarine survey conducted in 2002/03 (Smallwood and Sumner 2006), a shore-based metropolitan creel survey pilot study carried out in 2010 (Smallwood *et al.* 2011) and the Research Angler Program logbook survey which began in 2004 (Smith *et al.* 2007, DoF unpublished data).

In these surveys, catches were identified to species level where possible. However, due to difficulties in distinguishing between *Sillago* species, the catches of all whiting species of the genus *Sillago* (i.e. not King George whiting) were usually pooled together in these surveys as 'whiting spp.'.

West Coast Bioregion boat-based fishing surveys

Surveys of boat-based recreational fishing catch and effort in the WCB were conducted by the DoF in 1996/97, 2005/06, 2008/09 and 2009/10. In brief, boat-based fishers were interviewed at various boat ramps between Kalbarri and Augusta. Catch information was obtained using the 'bus route' method between boat ramps within districts, with complete trip information obtained at the time of the interview. Estimates of total catch and effort in the bioregion were calculated using weightings derived from the distribution of effort observed in the survey. Note that effort spent by boat fishers specifically targeting whiting could not be accurately determined from the boat survey data because only the total number of boating hours per boat was estimated during each survey. Total boating time included time spent travelling and time spent fishing at all locations during a trip (including offshore locations where whiting was not targeted). Therefore, the total number of boating hours was only an approximate measure of boat-based fishing effort spent targeting whiting during each survey and thus also, the catch rate of an individual species while potentially useful, must be treated with caution.

In addition, the total number of boating hours provides an unstandardised measure of fishing effort, i.e. effort was not adjusted to account for any differences between surveys in fishing efficiency due to technological improvements or any increases in targeting of whiting.

The primary focus of the survey was to produce estimates of the retained catches of each species and associated effort. Where time permitted, lengths of fish of different species were measured during each survey to provide a representative length structure (and mean length) of the catch.

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

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

E = total annual number of boating hours using line method.

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

For more information on the survey design and the methods used to estimate the mean of catch and effort in WCB boat-based recreational fishing surveys see Sumner *et al.* (2008)[2].

Other recreational surveys

A National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003) was conducted during 2000/01. In this survey, whiting were identified as King George whiting, yellowfin whiting, 'other whiting', and 'unspecified whiting'. The later three categories are grouped together here as 'whiting spp.' due to possible errors in identification of yellowfin whiting.

Using information obtained from the recently established Recreational Fishing from Boat Licence (RFBL), a state-wide boat-based survey was conducted in 2011/12. The methodology employed included phone-diary, boat-ramp and remote camera surveys. For details on methods used see Ryan *et al.* (2013). As a result of more rigorous training of interviewers compared to

2 Catch estimates have been revised following a more thorough statistical assessment (DoF unpublished).

previous surveys, the identification of *Sillago* species was assumed to be more accurate than in past surveys. At the time of preparing this report only catch data (in numbers) was available. Effort data to determine CPUE for whiting was unavailable.

A recreational fishing survey of the main estuaries (n = 17) in the SCB was conducted in 2002/03 (Smallwood and Sumner 2006). This survey used creel, bus route and census methods to determine recreational shore- and boat-based catch and fishing effort.

A three-month pilot study examining the relative benefits of different survey techniques for measuring shore-based recreational fishing catch and effort in the Perth metropolitan region was conducted during April–June 2010 (Smallwood *et al.* 2011). The pilot study focused on field-based techniques (i.e. angler interviews, aerial surveys, remote cameras) to estimate catch and/or effort for the shore-based fishing sector.

Voluntary recreational logbooks

A voluntary recreational fisher logbook program, as part of the DoF Research Angler Program (RAP), commenced in 2004 and is ongoing. The number of registered recreational fishers exceeded 1,000 as of January 2013. Within this program, recreational fishers were asked to record fishing date, location, start and finish times of each fishing session, captured species, whether fish were retained or released and the TL of each fish to the nearest mm.

The identification of King George whiting by logbook fishers was considered to be reliable, due to the distinct appearance of this species. However, the identification of other whiting to species level, where attempted, was considered to be less reliable. Some logbook fishers also donated frames of their whiting catches which allowed comparison of the results of the identification against their logbook entries. While some fishers accurately reported their whiting catches to species level, many had either incorrectly identified their catch or had used the incorrect Australian standard common name. In fact, many logbook fishers reported whiting catches as ‘sand whiting’ or just ‘whiting’, suggesting recreational fishers either have difficulty in identifying individual *Sillago* species and/or were unaware of the proper Australian standard common names for these species. An article describing the various whiting species of the WCB and a ‘whiting identification guide’ was produced and distributed to logbook holders during the course of this study to improve reporting rates (See Appendix 1).

The majority of ‘whiting spp.’ catches by recreational logbook fishers were taken from the Perth area by boat-based fishers. Based on the catch composition analysis determined from fish frame donations, the annual catch rates of key whiting species by boat-based logbook fishers operating in ocean waters of the Perth area were calculated from January 2006 to December 2011. Catch rates were not calculated for other areas due to low levels of catch data. The total number of ‘whiting spp.’ caught (C) and the total effort (E) per year by all fishers were used to calculate an average annual CPUE (where CPUE = C/E). Catch rate was expressed as ‘number of whiting per hour’. Catch included retained and released fish.

CPUE = C/E, where

C = total annual catch of ‘whiting spp.’ taken by boat-based fishers in the Perth area, including retained and released fish.

E = total annual number of hours fished by all boat-based fishers in the Perth area.

The Perth area was defined as logbook reporting blocks BN56-BN64, BO56-BO64, BP56-BP64, BQ56-BQ64 and BR56-BR64 (see Fig. 2).

The sum of catch and effort from all boat-based logbook fishing sessions was used to calculate an average annual catch rate. In addition, as a large number of fishing sessions did not capture whiting (i.e. recorded either non-whiting or nil catches), an average annual catch rate was also determined using only effort where ‘whiting spp.’ were captured (i.e. excluding sessions resulting in non-whiting and nil catches). Using effort from boat-based logbook sessions that resulted in the capture of ‘whiting spp.’ was more likely to reflect the actual catch rate of boat-based fishers who were targeting ‘whiting spp.’ as these species are usually caught easily when targeted recreationally.

2.2.4 Commercial fishery catch and effort

The commercial catch and effort data summarised here is from compulsory monthly returns from 1980 to 2011. The DoF commercial catch and effort statistics (CAES) database records individual fisher’s monthly catch and effort by commercial fishing block and by fishing method. The CAES database contains the following fields for whiting entries:

- Whiting, general/sand
- Whiting, western sand (i.e. yellowfin whiting)
- Whiting, school southern/silver
- Whiting, trumpeter (i.e. western trumpeter whiting)
- Whiting, King George
- Whiting, golden-lined (i.e. goldenline whiting)

As with recreational fishers, most commercial fishers are able to easily identify King George whiting. However, the catch of *Sillago* species are not as easily determined, with incorrect naming used throughout the historical records. As the often mixed species composition of some whiting catches would be too time consuming for a commercial fisher to separate into species, the entire catch is often reported simply as ‘whiting spp.’. In some instances, DoF’ data entry staff assign a whiting catch to a particular species (listed above) based on advice from the Research Division. Otherwise, it is recorded as ‘whiting, general/sand’.

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

For the key commercial whiting species, the annual CPUE was calculated for the main commercial fisheries in the WCB and SCB that have historically captured these whiting species. These fisheries all use various netting methods to target multiple finfish and invertebrate species. Due to the multi-species nature of these fisheries and the monthly aggregation of data reported by commercial fishers, it is often not possible to establish the level of effort spent targeting whiting by a particular method. In an attempt to overcome the lack of knowledge of targeted effort, refined CPUE’s were calculated where certain methods and/or months were identified as the main capture method/period for whiting. Effort was calculated as the number of days spent using a specified method(s) and for the specified months within a particular CAES reporting block.

For the key fisheries and whiting species identified, the average annual CPUE was calculated. CPUE = C/E, where;

C = sum of catch (live weight) by specified method and months by all vessels.

E = sum of fishing days by specified method and months by all vessels.

Southern school whiting CPUE

The average annual CPUE of southern school whiting by trawl netting in the WCB was calculated as CPUE = C/E, where;

C = sum of all whiting catches by trawl nets in the WCB. All months included. All vessels included.

E = sum of block days by trawl nets in the WCB. All months included. All vessels included.

King George whiting CPUE

The average annual CPUE of King George whiting by gill and haul netting in Peel-Harvey Estuary was calculated as CPUE = C/E, where;

C = sum of King George whiting catches by gill and haul nets in CAES block 9502, from March to October, inclusive. All vessels included.

E = sum of block days by gill and haul nets in CAES block 9502, from March to October, inclusive. All vessels included.

The average annual CPUE of King George whiting by gill and haul netting in Wilson Inlet was calculated as CPUE = C/E, where;

C = sum of King George whiting catches by gill and haul nets in CAES block 9506. All months included. All vessels included.

E = sum of block days by gill and haul nets in CAES block 9506. All months included. All vessels included.

3.0 Results

3.1 Fishery catch composition

3.1.1 Species identification

All whiting were identified to species level using the key developed as part of this study (below) for whiting of south-western WA. Most fish could be identified using external morphological characters (see Appendix 1) while all fish could be identified using a combination of external morphological characteristics and details describing otolith shape, noting that the sagittal otoliths of each of the six whiting species have unique shape characteristics (see Appendix 2). Use of otolith shape is useful when the fish are in poor condition or when working with fish frames, as often the markings and colouration needed to identify the different species are no longer visible. For example, southern school whiting and stout whiting were the two most similar and hardest to distinguish species, particularly when the yellow marking behind the pectoral fin in stout whiting had faded in older frozen samples.

Key to *Sillaginidae* species of south-western Australia.

1. Markings on pectoral fin muscle…………………………………………………….……….............. 2

   No markings on pectoral fin muscle……….........…………………………………………….….... 3

2. Numerous black spots on pectoral fin muscle; black marking on top of first dorsal fin; brown lines running diagonally on upper side of body…………..….*Sillago vittata* (western school whiting)

   Dark blotch on pectoral fin muscle; yellow pelvic and anal fins; dark blotches on side of body ………………………………………….................… *Sillago burrus* (western trumpeter whiting)

3. Second dorsal rays <25; lateral line scales <129……………..……………………….…….…...... 4

   Second dorsal rays 25–27; lateral line scales 129–147; numerous small brown spots on side of body and head……………………....…………………*Sillaginodes punctata* (King George whiting)

4. No yellow colouration to ventral and anal fins……..………..………………..……………..............… 5

   Yellow ventral and anal fins; weakly forked caudal fin; no body markings except in juveniles who have dark blotches………….................................…… *Sillago schomburgkii* (yellowfin whiting)

5. Yellow spot behind pectoral fin; no body markings, head width wide, otolith shape elongate ....……………………………………………………………..…*Sillago cf. robusta* (stout whiting)

   No yellow spot behind pectoral fin, faint broken brown lines running diagonally on upper side of body, head width narrow, otolith shape rounded…...*Sillago bassensis* (southern school whiting)

This study proposes the identity of a new species of *Sillago* in WA, previously believed to be stout whiting (*S. robusta*). Stout whiting's distribution is listed in some literature as across northern Australia, from Fremantle (WA) to New South Wales (e.g. www.ala.org.au). However, in his revision of the fishes of the family Sillaginidae, McKay (1985) proposed two distinct populations of stout whiting, one on the east coast of Australia and one on the west and north coast of Australia. He noted Cape York Peninsula as the boundary for the two populations and stated that more samples were needed from northern areas to determine the extent to which northern and western populations are connected. Morphological counts, measurements and colour descriptions for both populations were provided by McKay (1985).

A genetic study of commercially important whiting species in Australian waters found that the liver and muscle enzymes of stout whiting differed markedly between three locations (Rottnest Island, WA, northern New South Wales and Gulf of Carpentaria, Northern Territory) and suggested they represent three different species (Dixon *et al.* 1987). The western population of stout whiting differed at 13 of 27 and 7 of 27 fixed gene loci for N.S.W and N.T., respectively. These differences were all greater than was found between the three different species of school whiting, i.e. *S. bassensis*, *S. vittata* and *S. flindersi*, the latter of which is known as eastern school whiting.

In McKay's (1992) more recent work, an eastern and western population of stout whiting was still defined, with the western population now confined between Fremantle to Shark Bay and not extending across northern Australia. Only the eastern population description is reported in this work. Hyndes (1996) has since reported samples of stout whiting further south of Fremantle at Comet Bay, near Mandurah.

In this study, notable differences in the morphology between the western and eastern population were apparent. Namely, unlike the eastern population, the western population lacks a yellow blotch on the cheek and has no sharply-keeled anterior edge to the first dorsal fin spine. Also, the western population is characterised by a yellow blotch behind the lower end of the pectoral fin. The caudal fin in the western species is also more strongly forked (see Appendix 3). In this study, genetic analysis of the Cytochrome Oxidase I (COI) gene in western and eastern populations of stout whiting have shown that these are indeed two separate species. The genetic analysis indicates that the western population of stout whiting is more closely related to bay whiting (*S. ingenuua)*, which have a similar external appearance. This genetic work will be published in a later paper. We believe that previous reports of stout whiting in northern Australia were most likely to have been bay whiting. This theory is supported by the results of Dixon *et al.* (1987) who, like this study, found a greater similarity of the WA stout whiting with samples collected from the Northern Territory than those of stout whiting from New South Wales.

3.1.2 Recreational catch composition

Frame donations – spatial trends

More than 230 recreational anglers donated a total of 9,909 whiting frames during the collection period (July 2010 to December 2012). The majority of samples were caught in the WCB (83.6%). In the WCB, the majority of samples were captured in the Metropolitan Zone (77.0%), with the South-west (21.5%), Mid-west (0.9%) and Kalbarri (0.6%) Zones providing the remainder.

Recreational anglers caught all six species of whiting known to occur in the WCB and all three in the SCB. Nearly all whiting were caught using hook-and-line methods (99.8%), with the exception of 15 yellowfin whiting, which were caught with a net in the Mid-west Zone of the WCB. Approximately 23% of recreationally caught whiting samples that were taken on a given day contained more than one whiting species.

The majority of whiting were donated by boat-based fishers (94.1%), with shore-based fishers contributing only 5.9% of samples. Southern school whiting was the most common species in the WCB boat-based catch, comprising 73.2% of donated samples (Fig. 3a). King George whiting (19.1%) and western school whiting (6.9%) were the next most abundant species. The remaining three whiting species, yellowfin, stout and western trumpeter, collectively comprised <1% of the WCB boat-based donated catch. In the SCB boat-based catch, King George whiting was the most donated species, comprising 66.1% of samples (Fig. 3b). Southern school whiting (33.6%) and yellowfin whiting (0.3%) comprised the remainder of boat-based samples from the SCB.

In the WCB, all six species known to occur in the Metropolitan Zone were caught by boat-based fishers. Southern school whiting was the most abundant species in boat-based samples, representing 84.6% of Metropolitan Zone samples (Fig. 4a). Only three of the five whiting species known to occur in the South-west Zone contributed to samples donated by recreational fishers. King George whiting comprised 71.3% of donated samples, with southern school whiting (28.1%) and yellowfin whiting (0.6%) comprising the remainder (Fig. 4b). No western school whiting and western trumpeter whiting were caught from this Zone, although their range is believed to extend only to the northern part of this Zone. A low number of whiting were donated from boat-based fishers in the Mid-west Zone (*n* = 25). No whiting were donated by boat-based fishers in the Kalbarri Zone.

Of all *Sillago* species in samples (i.e. excluding King George whiting), southern school whiting was the most common in boat-based catches in both bioregions, comprising 90.5% of donated samples in the WCB and 99.0% in the SCB. Within the WCB, southern school whiting was the most common *Sillago* species caught in the Metropolitan and South-west Zones, representing 90.0 and 97.8% of donated boat-based samples, respectively.

The species composition of the boat-based catch in the WCB Metropolitan Zone varied with depth. In shallow waters (<20 m), southern school whiting was the dominant species (78.5%), followed by western school whiting (18.3%), and with King George, yellowfin, stout and western trumpeter whiting comprising the remaining catch (3.2%). In deeper waters (>20m), southern school whiting comprised nearly all samples (96.6%) from boat-based fishers, with western school, King George and stout whiting comprising the remainder of the samples (3.4%). No yellowfin or western trumpeter whiting were represented in the samples obtained from the deeper waters.

The number of whiting donated from the shore-based sector was low compared to the boat-based sector, representing only 5.9% (*n* = 587) of all samples from the two bioregions. There is uncertainty as to whether the 'sampling' was representative of the total catch with respect to the proportion of shore vs boat-based catch. Therefore, any interpretation of the shore-based catch composition must be treated with caution as to the representative nature of the samples to the overall fishery sector's catch. Of shore-based samples, southern school and yellowfin whiting were the most common species donated in the WCB, comprising 45.8% and 38.1% of samples, respectively. Western school (11.0%), King George (3.8%) and western trumpeter (1.2%) whiting comprised the remaining shore-based catch (Fig. 5a). No stout whiting were donated by shore-based fishers. Of the SCB shore-based catch, southern school whiting was the most donated species, comprising 67.3% of samples. King George (29.9%) and yellowfin (2.8%) whiting comprised the remainder (Fig. 5b).

In shore-based samples from the WCB Metropolitan Zone (*n* = 171), southern school whiting was the dominant species (74.3% of samples), with yellowfin (10.5%), western school (8.2%), western trumpeter (3.5%) and King George (3.5%) whiting comprising the remainder (Fig. 6a). In the South-west Zone (*n* = 209), yellowfin whiting was the most donated species by shore-based fishers, comprising 56.0% of samples. Southern school (38.3%) and King George (5.7%) whiting comprised the remainder (Fig. 6b). The composition of the overall shore-based catch for the South-west Zone are biased by the large donations of one fisher, who provided 45% of all shore-based whiting samples from this zone, all of which were yellowfin whiting. The whiting composition in this zone without his shore-based catch is markedly different, with southern school whiting (70.2%) the most caught species, with yellowfin (19.3%) and King George whiting (10.5%) comprising the remainder.

Of all *Sillago* species in samples (i.e. excluding King George whiting), southern school whiting was the most common species in the shore-based catch, comprising 47.6% and 96.0% of donated samples in the WCB and SCB, respectively.

Other points of interest:

- Nearly all yellowfin whiting samples were caught from the shore (89%). Of those caught by boats, all were captured in <20 m water depth.
- Nearly all King George whiting samples were caught from boats (98%).
- All stout whiting in samples were caught from boats.
- The majority (82%) of western school whiting samples in 2010–12 were caught in 2012, with the previous 18 months only contributing 18% of the total western school whiting samples.
- The majority (67%) of western trumpeter whiting samples were caught in the Swan-Canning Estuary.

Frame donations – seasonal trends in WCB

Examination of the species compositions of samples donated by recreational fishers from the WCB in different seasons in 2011 and 2012 (i.e. two full years) showed that whiting catches were lowest (16%) during summer and were slightly higher in autumn and winter months (22 and 24%, respectively). The largest numbers of whiting were donated in spring (39%), with most catches occurring in October and November. Nearly a quarter (22.8%) of the whiting samples from the WCB boat-based sector in 2011 and 2012 were donated during the closure of 15 October to 15 December, inclusive, for larger West Coast demersal reef fish species.

King George whiting were predominantly caught from August to December (Fig. 7a). These five months represented 63.6% of donated King George whiting samples.

Catches of southern school whiting were seasonal, although relatively high numbers of southern school whiting were caught in all months. The largest number of catches occurred in spring (41.0%) and the smallest number occurred in summer (12.1%) (Fig. 7b).

Western school whiting was most often caught during winter (41.9% of samples) and least often caught in summer (7.4%) (Fig. 7c).

Yellowfin whiting was most commonly caught over the warmer months, with nearly all samples (98.0%) landed between October to March (Fig. 7d).

While only 22 stout whiting were donated, they were caught over eight months of the year (Fig. 7e). Only 18 western trumpeter whiting were donated, which were caught in February, March and August (Fig. 7f).

2011/12 Boat-based survey

The retained whiting catch identified during the on-site boat-ramp component of the 2011/12 recreational boat-based fishing survey exhibited a very similar species composition to that of whiting frames donated by boat-based fishers over the same period (March 2011–February 2012), in both the WCB and SCB (Fig. 8a and b).

In the WCB, southern school whiting was the dominant whiting species in the two sample groups, comprising 77% of whiting recorded in the recreational boat-ramp survey and 80% of boat-based frame donations. King George whiting was the next most common species, comprising 15% of whiting landings in the recreational survey and 16% of frame donations (Fig. 8a).

In the SCB, King George whiting was the most commonly retained species in the two sample groups, comprising 72% of whiting landings during the recreational boat-ramp survey and 65% of boat-based frame donations. Southern school whiting was the next most commonly retained species, comprising 27% of whiting landings in the recreational survey and 34% of frame donations (Fig. 8b).

3.1.3 Commercial catch composition

The commercial catch of whiting in the WCB and SCB of WA was taken mainly by estuarine and nearshore fishers (see 'Commercial catch and effort' section for more detail). The main whiting species landed commercially are yellowfin whiting, King George whiting and southern school whiting. Minor quantities of the other *Sillago* species (Western school whiting, western trumpeter whiting and stout whiting) are possibly also taken. The majority of the southern school whiting catch is believed to be landed by the South West Trawl Managed Fishery (SWTMF), with the estuarine and beach seine fisheries mainly landing yellowfin whiting and King George whiting.

On average since 1980, the commercial whiting catch in the WCB in each year was comprised of far more yellowfin whiting (62%, annual range 30–89%), than King George whiting (21%, annual range 3–51%) and southern school whiting (17%, annual range 3–37%). In the SCB, the composition of the commercial whiting catch comprised mainly of King George whiting (95%, annual range 84–99%), with minor quantities of yellowfin and southern school whiting also taken. It is important to note that the estimated catch composition in these bioregions varies from year to year due a number of factors, including variable recruitment, market factors and targeting in these multi-species fisheries.

In 2011, commercial catches of whiting in the WCB comprised 53% yellowfin whiting, 34% southern school whiting and 13% King George whiting. It is likely that small catches of other *Sillago* species were present in these catches, but their quantities could not be determined due to the selling of mixed species catches.

3.1.4 Catch shares

Using the average length recorded in this study from recreational frame donations, and the derived weight for that length determined from the length vs weight relationship, the total recreational catch (boat- and shore-based) for the WCB and SCB during 2011/12 was estimated to be 43.0 t for southern school whiting, 30.7 t for King George whiting and 11.7 t for yellowfin whiting (Table 2).

In both the WCB and SCB, the majority of King George whiting and southern school whiting are taken by the recreational sector. For yellowfin whiting, the majority of the SCB catch is also taken by the recreational sector, whereas the majority of WCB catch is landed by the commercial sector (Table 2).

3.2 Assessment

3.2.1 Biological analyses

Biological parameters were estimated for the two main whiting species caught by the recreational sector in the WCB, i.e. southern school whiting and King George whiting. Although yellowfin whiting was identified as a major commercial species and a possible main species of the recreational shore-based catch, the low number of samples collected during this study prohibited an assessment here. Sample collection of whiting species is ongoing which may allow for an assessment of stock status for yellowfin whiting in the future.

3.2.1.1 Southern school whiting

Morphometrics

The relationships between i) total length (TL, mm) and fork length (FL, mm), and ii) TL and whole body weight (W, g), was described using the following equations from pooled data collected from the WCB and SCB during 2010–2012:

i) $TL = (1.0958 \times FL) - 1.4283$ ($r^2 = 0.9983$, $n = 5{,}019$)

ii) $W = 5.4744 \times 10^{-6} \times TL^{3.0737}$ ($r^2 = 0.9971$, $n = 1{,}580$)

Length structure

In 2010–12, recreational fishers donated 4,439 southern school whiting from the WCB and 612 from the SCB. These samples ranged from 108 mm to 351 mm TL (average 239 mm) in the WCB (Fig. 9a), and 126 mm to 333 mm TL (average 230 mm) in the SCB (Fig. 9b).

Age structure

A sample of 626 southern school whiting (594 from boat-based fishers and 32 from shore-based fishers) collected from the recreational sector in the WCB Metropolitan Zone during 2011 were aged. The age of fish in this sample ranged from 1.0 – 10.8 years for females and 1.0 – 11.8 years for males (Fig. 10). The most abundant age class from the boat-based sector was 2+ years, which accounted for 40% of the aged sample. Southern school whiting aged ≤3 years comprised 67% of the boat-based sample. The most abundant age class from the shore-based sample was 1+ years, which accounted for 78% of the aged sample. The majority (97%) of shore-based samples were aged ≤3 years.

Growth

Although the von Bertalanffy growth curves of females and males in the WCB Metropolitan Zone differed significantly ($P>0.05$), the curves for the two sexes were not conspicuously different throughout the full age range (see Fig. 11). As the likelihood ratio test is known to be sensitive to large sample sizes, as available for this study, it was considered that the level of difference between the growth curves detected by this test was not biologically significant. The length-at-age data for the two sexes were thus pooled and a single growth curve fitted to these data. In terms of length, southern school whiting exhibit most of their growth in the first four years of life, attaining 200.7 and 262.9 mm TL at ages 2 and 4, respectively, and 286.3 mm TL at age 10 years. This relatively rapid early growth is reflected in the relatively high value for the growth coefficient (0.64 year^{-1}). The mean asymptotic length was 286.8 mm TL (Table 3).

Seasonal trends in gonadal development

Gonad development in both sexes suggested a highly protracted spawning period in the WCB, extending throughout the year. In the WCB, ‘developing’ or ‘mature/spawning gonads’ (i.e. stages 3 to 7) were observed in all months of 2010–12. Gonad development in female and male southern school whiting followed similar monthly trends with approximately 65–95% of both sexes possessing ‘developing’ or ‘mature/spawning’ gonads in each month of the year, with the peak for both sexes occurring in September. Both sexes displayed the highest level of ‘developing’ or ‘mature/spawning’ gonads during autumn and least level in late winter/early spring. The proportion of ‘mature/spawning’ females (stages 5–7) was highest in May (64%) and lowest in July (15%) (Fig. 12a). Similarly, the proportion of ‘mature/spawning’ males was highest in May (58%) and lowest in July (15%) (Fig. 12b).

In the SCB, a clearly defined summer spawning season was observed, with 'mature/spawning' stage gonads (stages 5–7) in both sexes observed mainly from November to May. Very few southern school whiting in 'mature/spawning' condition were observed in the cooler months of June to September (Fig. 13a and b). Overall for the SCB, gonad development in both sexes suggested a less protracted spawning period than in the WCB, with spawning restricted to the warmer months.

In the WCB, the mean monthly GSIs for female and male southern school whiting were relatively constant throughout the year. Female GSI ranged from 1.4 in February to 2.3 in September (Fig. 14a). Male GSIs were substantially lower than for females, ranging from 0.4 in June to 0.7 in September, with a second lower peak of 0.6 also observed in April (Fig. 14a).

In contrast to the WCB, the mean monthly GSIs for female and male southern school whiting in the SCB followed a strong seasonal trend. Female GSIs ranged from 0.6 in June to 3.2 in March (Fig. 14b) and male GSIs ranged from 0.05 in June to 1.4 in March (Fig. 14b). GSI trends in the SCB suggested a spawning period extended over the warmer months (December to March) with a peak occurring in March. For both sexes, the maximum GSI in the SCB were higher than those observed in the WCB and the minimum values for the GISs in the SCB were lower than that observed in the WCB suggesting spawning was occurring throughout the year in the WCB.

The high mean monthly GSIs in summer on the SCB corresponded with high monthly SST of 19–21°C for Albany in 2010–12. In contrast, the mean monthly GSIs were lowest in the WCB during summer when SST recorded a peak of 24°C in February and March. The mean monthly GSIs were highest in the WCB in September when the SST was at lowest level, but at a similar temperature to the SCB GSI peak of 19°C (Fig. 14).

Sex ratio

The ratio of females to males in the samples donated by recreational fishers was 51:49 (n = 4,472) in the WCB and 47:53 (n = 624) in the SCB. The overall sex ratio for southern school whiting in each bioregion was not significantly different from parity (all P>0.05).

Size and age at maturity

During 2010–12, the smallest maturing/mature (i.e. stage 3–8) females sampled in the WCB and SCB measured 187 and 153 mm TL, respectively and the smallest maturing/mature males measured 169 and 143 mm TL, respectively, for the two bioregions. The proportion of maturing/mature (stage 3–8) females sampled in the WCB during the spawning season (December to March) increased from 50% in the 200–209 mm length class to 100% in fish ≥260 mm. The estimated lengths at which 50% (L_{50}) and 95% (L_{95}) of southern school whiting attain maturity in the WCB were 207 and 240 mm TL, respectively for females (Fig. 15a), and 194 and 231 mm TL, respectively, for males (Fig. 15b) (Table 4). The ages at which southern school whiting (sexes pooled) attain 50% (A_{50}) and 95% (A_{95}) maturity in the WCB were 1.8 and 2.8 years, respectively (Table 4).

There was insufficient data for the SCB to determine size at maturity for males, with all fish sampled (n = 112) except two considered mature. The estimated lengths at which 50% (L_{50}) and 95% (L_{95}) of female southern school whiting attain maturity were estimated to be 178 and 221 mm TL, respectively (Table 4).

Juvenile retention

In the WCB, 7.6% of the donated southern school whiting samples in 2010–12 were classified as juveniles (i.e. length <L_{50}) while in the SCB 4.1% of donated fish were considered juveniles.

Mortality estimates

The point estimate for the instantaneous rate of natural mortality (M) for southern school whiting in WA, derived from Hoenig's (1983) regression equation and a maximum recorded age of 11.8 years, was 0.37.year^{-1} (note that, for this analysis, uncertainty in M has not been considered). The two catch curve methods, i.e. regression-based estimator described by Ricker (1975) and non regression-based estimator of Chapman and Robson (1960), produced similar estimates of total mortality (Z). Based on the age composition data for southern school whiting caught by boat-based recreational fishers in the WCB Metropolitan Zone in 2011, the estimate for Z employing Ricker's (1975) method (0.66.year^{-1}, 95% CLs, 0.57–0.66.year^{-1}) was slightly higher than the one derived from Chapman and Robson's (1960) method (0.61.year^{-1}, 95% CLs, 0.57–0.77.year^{-1}). In addition, the confidence interval for the Chapman and Robson (1960) method was narrower (Fig. 16).

From the above estimates of M and Z, the instantaneous rate of fishing mortality (F) was estimated as 0.28.year^{-1} (95% CLs, 0.19–0.40.year^{-1}), using Ricker's (1975) method and 0.24.year^{-1} (95% CLs, 0.20–0.28.year^{-1}), using Chapman and Robson's (1960) method (Table 5).

The target reference point value for F (0.25.year^{-1}, *i.e.* F=2/3M) lay above and below the lower and upper 95% confidence limits, respectively, for the two estimates of F. The probability that F was below the target F was determined as 0.08, based on the estimate of Z derived from Ricker's (1975) method, compared with only 0.70, based on that derived from Chapman and Robson's method. The threshold value for F (0.37.year^{-1}, *i.e.* F=M) lay above the lower and upper confidence limits for F when Z was derived using Ricker's (1975) catch curve method, and thus the probability that F was below the threshold value for F was determined as 1. In contrast, the threshold value for F lay between the 95% confidence limits for F when applying Chapman and Robson's (1960) approach, and the probability than F was less than the threshold F, when using this approach, was determined as 0.75. The limit value for F (0.56.year^{-1}, *i.e.* F=3/2M) always exceeded the lower confidence limit for the estimated values for F, and thus the probability that F was below the limit value was always 1 (Fig. 16a).

Estimates of yield per recruit and spawning potential ratio

The yield per recruit (*YPR*, in g) for southern school whiting was estimated to increase from zero at F=0 year^{-1}, to a maximum of 18.4 g at F=0.36 year^{-1} (i.e. F_{max}), and subsequently decline. At F=1 year^{-1}, the expected *YPR* was 12.1 g. Based on the estimates of F derived using Ricker's (1975) and Chapman and Robson's (1960) catch curve methods, the estimated levels of yield per recruit for southern school whiting were 18.3 and 17.4 g, respectively. The estimated values of YPR corresponding to the lower and upper 95% confidence limits for F were 17.1 and 17.9 g[2], respectively, using Ricker's (1975) method, and 16.4 and 18.0 g, respectively, for Chapman and Robson's (1960) method (Table 5). The upper confidence limit for F obtained using the method of Ricker (1975), but not when using Chapman and Robson's (1960) method, exceeded F_{max} (Fig. 17).

Using the catch curve estimates of Z derived from Ricker's (1975) method, the current level of spawning biomass per recruit is estimated as 7.2 g (95% CLs, 4.7–9.2 g). Using Chapman and Robson's approach, it is estimated as 8.8 g (95% CLs, 7.7–9.8 g) (Table 5).

2 Note: due to the shape of the yield per recruit (YPR) curve, the median estimate of YPR lies outside the 95% CL determined from fishing mortality (F).

The spawning potential ratio (*SPR*), expressed in terms of spawning biomass per recruit at the current estimated value of *F* relative to the unfished level, was estimated to decrease from 1.0 at F=1 year^{-1}, to 0.50 at F=0.2 year^{-1}, to 0.30 at F=0.38 year^{-1} and to 0.20 at F=0.56 year^{-1}. Based on the estimates of *Z* derived using Ricker's (1975) and Chapman and Robson's (1960) catch curve methods and their associated 95% confidence limits, the current estimated levels of spawning potential ratio for southern school whiting were 0.37 (0.24–0.47) and 0.45 (0.40–0.50), respectively. Applying the Chapman and Robson estimates of *Z*, the probability that the current level of *SPR* is greater than the target level (0.4) was 1, and thus, the probability that it is also above the threshold (0.3) and limit reference points (0.2) was also 1. Applying Ricker's (1975) catch curve estimates for *Z*, the probability that the current level of *SPR* lay above the target level was 0.43. Using the same catch curve method, there was a probability of 0.90 than the current level of *SPR* lays above the threshold, and 1, that it lay above the limit (Fig. 16b).

3.2.1.2 King George whiting

Morphometrics

The relationship between i) *TL* (mm) and *FL* (mm), and ii) *TL* and *W* (g), was described using the following equations from pooled data collected from the WCB and SCB during 2010–2012:

$TL = (1.0669 \times FL) - 1.1029$ ($r^2 = 0.9923$, $n = 2{,}528$)

$W = 4.1354 \times 10^{-6} \times TL^{3.0670}$ ($r^2 = 0.9944$, $n = 302$)

Length structure

In 2010–12, recreational fishers donated 1,570 King George whiting from the WCB and 1,068 from the SCB. These samples ranged in length from 239 mm to 586 mm TL (average 365 mm) in the WCB (Fig. 18a) and 265 mm to 481 mm TL (average 324 mm) in the SCB (Fig. 18b). The largest size recorded for both sexes was 586 mm.

Age structure

A random sample of 664 King George whiting collected from the recreational sector in the WCB and 122 in the SCB were aged. The age of fish from the WCB ranged from 1.6–13.9 years for females and 1.4–13.3 years for males (Fig. 19a). The most common age class in the WCB (sexes pooled) was 2+ years, which accounted for 53% of the sample. King George whiting aged ≤3 years of age comprised 80% of the WCB samples.

In the SCB, the age of King George whiting ranged from 2.6–6.9 years for females and 1.6–5.9 years for males (Fig. 19b). The most common age class in the SCB (sexes pooled) was 3+ years, which accounted for 57% of the sample. King George whiting aged ≤3 years of age comprised 66% of the SCB sample.

The majority (71% in the WCB, 95% in the SCB) of donated King George whiting were caught in inshore waters (i.e. < 20m depth).. In the WCB, the age of fish in inshore waters ranged from 1.4 to 11.1 years and in offshore waters from 2.2 to 13.9 years (Fig. 20a). In the SCB, the age of fish in inshore waters ranged from 1.6 to 5.9 years and in offshore waters from 3.9 to 6.9 (Fig. 20b). The majority (97%) of inshore fish were ≤3 years of age, whereas only 38% of offshore fish were ≤3 years of age.

Growth

The mean asymptotic length for female and male King George whiting in the WCB (Metropolitan Zone) was 565 and 536 mm, respectively. The growth coefficient was estimated to be 0.36 year^{-1} for females and 0.39 year^{-1} for males (Sulin 2012).

Spawning period

In the WCB, nearly all (>92%) female King George whiting caught from November to March had ‘immature/resting’ ovaries (stages 2 and 8) in 2010–12 (Fig. 21a). ‘Developing’ ovaries (stages 3 and 4) first appeared in April, and were most abundant in May and June. ‘mature/ spawning’ ovaries (stages 5– 7) were observed from May to October, but were most abundant from July to September. Male gonad development in the WCB displayed similar monthly trends to those observed in females (Fig. 21b).

In the SCB, all female King George whiting were $<L_{50}$ at maturity. All females from this region (n = 33) had ‘maturing virgin’ ovaries (stage 2) (Fig. 22a). Similarly, all male gonad development in the SCB (n = 73) had ‘maturing virgin’ ovaries (stage 2), with the exception of two males in May observed with ‘developing’ gonads (Fig. 22b).

The mean monthly GSIs for females in the WCB remained below 1.1 from September to April, before increasing sharply to reach a peak of 5.3 in June. The mean monthly male GSIs followed a similar pattern to females, remaining below 0.2 from September to April and then increasing to a peak of 1.0 in July (Fig. 23).

There was insufficient data to determine mean monthly GSI values for either sex in the SCB.

Sex ratio

The ratio of females to males in the samples donated by recreational fishers was 52:48 (n = 1,338) in the WCB and 51:49 (n = 927) in the SCB. The sex ratio in each bioregion was not significantly different from parity (all P>0.05).

Maturity

The smallest maturing/mature (i.e. stages 3–7) female sampled in the WCB and SCB measured 401 and 391 mm TL, respectively. The smallest maturing/mature male in the WCB and SCB measured 327 and 273 mm TL, respectively. In the WCB, the proportion of maturing/mature (stage 3–7) King George whiting (all sexes) during the spawning period (June to September) increased from 20% in the 400–420 mm length class to 100% in the >500 mm length class.

In the WCB, the estimated lengths at which 50% (L_{50}) of female and male King George whiting attained maturity was 440 and 437 mm TL, respectively (Fig. 24a and b) (Table 7). The ages at which female and male King George whiting reach L_{50} in the WCB (Metropolitan Zone) were 4.2 and 4.3 years, respectively, as estimated from the von Bertalanffy growth equation (Sulin 2012). Based on the growth curves for the WCB (Metropolitan Zone), King George whiting was estimated to attain Legal Minimum Length (LML) for retention of 280 mm by ~2 years of age.

Very few large (>400 mm TL) King George whiting were obtained from the SCB and thus the length at maturity was not well estimated. For the SCB, preliminary estimates of lengths at which 50% (L_{50}) of female and male King George whiting attain maturity were 427 and 399 mm TL, respectively, suggesting that maturity is attained at a similar size for both sexes and in both bioregions (Table 7).

Juvenile retention

The proportion of donated fish that were classified as juveniles (i.e. total length $<L_{50}$) was 79% from the WCB and 94% from the SCB.

Mortality

Due to the difficulty in obtaining a representative sample of the population due to the unidirectional offshore movement of maturing fish, it was not possible to perform a simple linear catch curve analysis to determine total mortality (Z) for King George whiting. A novel approach to determine fishing mortality (F) for species with unidirectional movement, using King George whiting data collected from this study was attempted by Fisher *et al.* (in prep). This study attempted to determine estimates of fishing mortality for the different habitats in which King George whiting resides. The simulated model demonstrated the potential for providing robust estimates of fishing mortality for this species, however further samples sizes were required from both regions before a full assessment is capable.

Preliminary estimates of fishing mortality were derived from representative samples of the age structure from recreational catches in 2010–12. The estimated values of fishing mortality were 0.55.year^{-1} (95% CLs, 0.11–1.00.year^{-1}) in the inshore region and 0.06.year^{-1} (95% CLs, 0.00–0.12.year^{-1}) in the offshore region. With an estimated value of natural mortality of 0.30.year^{-1}, the estimate of fishing mortality in the inshore region is quite high (exceeding reference point F_{limit}), however the confidence limits around this range are quite wide adding great uncertainty to the estimate. The estimate of fishing mortality in the offshore region is quite low (below F_{target}).

Per recruit analyses

At current fishing levels for the inshore and offshore regions, the spawning potential ratio (based on the spawning biomass per recruit) is at 42% of unfished levels (Fisher *et al.* in prep).

3.2.1.3 Other whiting species

Length structure

Yellowfin whiting donated by recreational fishers ranged from 189 to 360 mm TL (average 253 mm) in the WCB (Fig. 25a). In this bioregion, females ranged in size from 189 to 360 mm TL (average 258 mm), and males ranged in size from 195 to 303 mm TL (average 241 mm). Only eight yellowfin whiting were donated from the SCB, which ranged from 244 mm to 331 mm TL (average 290 mm).

Western school whiting were only collected in the WCB. The lengths ranged from 156 mm to 311 mm TL (average 239 mm) (Fig. 25b). The largest female was 311 mm TL and the largest male was 299 mm TL.

In the WCB, western trumpeter whiting ranged from 143 mm to 225 mm TL (average 186 mm) (Fig. 25c). The average length for females and males was 197 mm and 176 mm TL, respectively.

Stout whiting in the WCB ranged from 198 mm to 230 mm TL (average 214 mm) (Fig. 25d). The largest female was 229 mm TL and the largest male was 230 mm TL.

Sex ratio

In the WCB recreational catch, the ratio of females to males was significantly different (P<0.01) from parity for yellowfin whiting and western school whiting. In 2010–12, the sex ratio of females to males for yellowfin whiting was 69:31 (n = 175) and for western school whiting was 58:42 (n = 448). There were insufficient numbers of stout whiting (n = 27) and western trumpeter whiting (n = 17) to perform a chi-square test.

Juvenile retention

Using length at maturity estimates previously determined for the other whiting species in WA (Hyndes 1996; Gaughan *et al.* 2006), all of the western school, western trumpeter and stout whiting and nearly all (97%) of the yellowfin whiting donated by recreational fishers were considered mature (i.e. above their respective lengths at 50% maturity).

3.2.2 Recruitment dynamics

From 1993 to 2012, 83,500 whiting (all species) were captured during recruitment surveys by the DoF. These fish were caught at 38 inshore sites extending from Cervantes (115º07'E and 30º49'S) to Eucla (128º88'E and 31º72'S) (Fig. 1). Whiting were most sampled at Mangles Bay (31% of all fish), followed by Koombana Bay, Pinnaroo Point and Warnbro Sound with about 15% each. The whiting catch during these surveys was comprised of southern school whiting (37%), western trumpeter whiting (26%), King George whiting (11%), yellowfin whiting (9%) and western school whiting (9%). The remaining 9% w were unable to be identified to species level. These were mainly small fish (TL <50 mm) and were assigned to the 'school whiting' category (i.e. southern school or western school whiting).

3.2.2.1 Southern school whiting

Southern school whiting were caught at 32 sites, distributed from Cervantes to Eucla. The majority of southern school whiting were captured in the WCB, including at Pinnaroo Point (33% of all captures) and Koombana Bay (31%). In the SCB, southern school whiting were mainly captured at Emu Point (5%) and Poison Creek (4%).

Southern school whiting captured during recruitment surveys ranged from 15 to 232 mm TL, although the vast majority were <150 mm TL in both the WCB and SCB (99%).

The occurrence of small (<60 mm TL, which were estimated to be 0–3 months old) juveniles of SSW was used to infer timing of spawning. In the WCB, small (<60 mm) juveniles were observed in all months of the year, with the main recruitment period from November to April (Fig 26). This implies recruits in this bioregion were mainly derived from a spring/summer spawning, with low numbers of recruits possibly spawned at other times.

In the SCB, sample sizes were smaller, making trends more difficult to interpret. However, small (<60 mm) juveniles of southern school whiting were observed primarily from December to February, implying recruits in this bioregion were also mainly derived from a spring/summer spawning (Fig 27).

For this assessment, southern school whiting <60 mm TL in the period January to April were assumed to represent the 0+ age class . Recruitment of the 0+ age class at the Pinnaroo Point and Warnbro Sound sites (Metropolitan Zone) has been shown to be highly variable. Recruitment indices for these two sites showed different trends in 2000, with relatively high levels at Pinnaroo Point, compared with relatively low levels at Warnbro Sound. The inter-annual trends were similar at both sites in recent years, with low recruitment in 2010 and 2011 and relatively high recruitment in 2012 (Fig. 28a and b). At Koombana Bay (South-west Zone), inter-annual recruitment trends differed to the Metropolitan Zone sites, with recruitment being highest in 2001 and lowest in 2012 (Fig. 28c).

There was an insufficient number of southern school whiting caught at current SCB sites and months to provide a recruitment index for this bioregion.

3.2.2.2 King George whiting

King George whiting were caught at 24 sites, ranging from Cervantes to Noonaera Beach (127º60'E and 32º08'S). The majority of King George whiting were captured in the WCB, including at Leschenault Inlet (49% of all captures) and Mangles Bay (24%). In the SCB, the largest percentage of King George whiting was sampled at Emu Point (6%).

In the WCB, juvenile King George whiting were first caught in September in the 20–30 mm TL size class. Most 0+ recruits were observed in this bioregion from October to January, where the size class increased from 20–50 mm TL to 40–130 mm TL (Fig. 29). In the SCB, the 0+ age class were first observed in November in the 40–50 mm TL size class, with the majority of new recruits in this bioregion captured in December in the 20–60 mm size range. By April, the 0+ age class had increased in size to ~90–130 mm TL (Fig. 30).

The main sites where juvenile King George whiting were captured were Mangles Bay (WCB: Metropolitan Zone), Leschenault Inlet (WCB: South-west Zone) and Oyster Harbour (SCB: South Zone). Sampling at these sites commenced in 1999, 2007 and 2005, respectively. Recruitment at Mangles Bay was highest in 1999, 2000 and 2008 (Fig. 31a), in which years there was a relatively strong Leeuwin Current. Located approximately 100 km to the south, Leschenault Inlet was first sampled as part of the recruitment surveys in 2007. The trend in recruitment at Leschenault Inlet site did not follow that of Mangles Bay, with a relatively low recruitment in 2008 and relatively high recruitment in 2007 (Fig. 31b). At Oyster Harbour (Albany), recruitment was relatively high in 2010 (Fig. 31c) compared with the other years.

3.2.3 Recreational fishery catch and effort

The following results are a summary of the available recreational fishing data for whiting in WA. Due to difficulties in identifying whiting members of the genus *Sillago* (i.e. excluding King George whiting) to species level, past recreational fishing surveys in WA have grouped *Sillago* species together as 'whiting' (referred to here as 'whiting spp.'). Past recreational fishing surveys in the WCB have ranked 'whiting spp.' as the most or 2nd most retained finfish species (see Table 8).

The results of this study have shown that for recreational boat-based fishing surveys in the WCB, the 'whiting spp.' group could potentially comprise five different species. Based on results from frame donations in 2010–12 and the 2011/12 on-site boat-ramp survey, the 'whiting spp.' component of the recreational boat-based catch in the WCB and SCB are dominated by one species, i.e. southern school whiting, which comprised approximately 90% of WCB and 99% of SCB 'whiting spp.' frame donations. Of the shore-based catch, southern school whiting was also the most common *Sillago* species sampled, representing 47% of WCB samples, including 77% of Metropolitan Zone samples, and 96% of SCB samples.

From the results of this study, it may be reasonably assumed that the 'whiting spp.' catch in past years largely consisted of southern school whiting.

3.2.3.1 Southern school whiting

Recreational fishing surveys

Catch

The current recreational catch of 'whiting spp.' in WA is unknown. The only survey of the state-wide catch that included both shore- and boat-based fishing was conducted in 2000/01 as part of the National Recreational and Indigenous Fishing Survey (Henry and Lyle 2003). The estimated WA recreational catch (by number) of 'whiting spp.' during this survey was 2,126,680 fish (Table 9). 'Whiting spp.' was the 2nd most commonly retained finfish category in WA, behind Australian herring, in 2000/01 (Henry and Lyle 2003). By bioregion, 'whiting spp.' was the 2nd most commonly retained finfish category in the WCB (see Table 8), and the 5th most retained finfish category in the SCB.

In the 2000/01 survey, the majority of 'whiting spp.' were caught in the WCB (91% of WA total catch) with the remainder caught in the SCB (5%), North Coast Bioregion (NCB) (2%) and Gascoyne Coast Bioregion (GCB) (2%) (Table 10). In the WCB, 'whiting spp.' were predominantly caught in the Metropolitan (51%) and South-west (42%) Zones, with the Mid-west (6%) and Kalbarri (<1%) Zones comprising only a small component of the total catch. 'Whiting spp.' were primarily taken from inshore coastal waters (70% of the harvest), with the remainder of the catch being taken from offshore waters (19%) and estuaries (11%). The majority of the WA catch of 'whiting spp.' was caught by line fishing (99%), mostly by boat-based fishers (60%).

Annual estimates of the recreational boat-based catch in the WCB were produced for 1996/97, 2005/06, 2007/08 and 2009/10. 'Whiting spp.' was the most retained category by number in each of the four surveys (Table 8). If we are to assume that approximately 90% of the WCB boat-based 'whiting spp.' catch is comprised of southern school whiting, then this species would equate to the most commonly retained individual fish species by this sector. The number of 'whiting spp.' retained across the four WCB boat-based surveys was similar, with 397,199, 367,425, 379,602 and 374,795 fish estimated in 1996/97, 2005/06, 2007/08 and 2009/10, respectively. By comparison, the 2000/01 survey estimated a WCB boat-based catch of 1,204,278, around three times that of the DoF boat-based surveys (Table 8).

A state-wide boat-based survey was conducted in 2011/12 (Ryan *et al.* 2013) which determined that the most common finfish species retained in WA was 'whiting spp.', accounting for 23% of the total finfish catch (n = 264,068 fish kept). By bioregion, 'whiting spp.' was the most kept finfish category (244,162 fish or 33% of total finfish catch) in the WCB and the 4th most kept finfish species (17,440 fish or 9% of total finfish catch) in the SCB.

A pilot study examining the benefits of different survey techniques for measuring shore-based recreational fishing catch and effort in the Perth metropolitan area was conducted during April to June 2010 (Smallwood *et al.* 2011). During this three-month period, 'whiting spp.' was the 3rd most retained finfish species, behind Australian herring and southern garfish, with an estimated 19,879 fish kept (see Table 9). Whiting species were identified as comprising southern school whiting (54%), 'general/sand' whiting (46%) and western school whiting (<1%) (C. Smallwood pers. comm.). No yellowfin whiting were identified in the shore-based survey but may be present in the sizeable 'general/sand' whiting group.

The percentage of 'whiting spp.' released was similar across all WCB boat-based surveys, with approximately 12–21% of catches of 'whiting spp.' not retained. In the SCB, the percentage of ‘whiting spp.’ released by boat-based fishers was slightly higher, ranging from 20 to 29% (Table 9).

Catch rate

Recreational fishing methods for whiting have changed little over the past 15 years (period of recreational fishing surveys assessed), however, advances and uptake in fishing technology (GPS, depth sounders, etc.) may have increased the catch efficiency of whiting. Effort has not been standardised for this potential efficiency creep.

Effort, measured as the total number of ocean boating hours with line fishing method, increased noticeably from approximately 525,000 hours in 1996/97 to 730,000 in 2005/06, then declined slightly to 685,000 hours in 2008/09 and 630,000 hours in 2009/10 (Fig. 32). No effort data was available at the time of preparing this report for 2011/12.

The average annual CPUE of ‘whiting spp.’ by the WCB boat-based sector decreased from 0.756 fish per boating hour in 1996/97 to 0.503 fish per boating hour in 2005/06. The CPUE then increased slightly to 0.555 fish per boating hour in 2008/09 and then to 0.594 fish per boating hour in 2009/10 (Fig. 32).

Length composition of recreational catch

Length composition sample sizes from the WCB boat-based surveys for ‘whiting spp.’ were derived from 615 fish in 1996/97; 2,620 in 2005/06; 1,670 in 2008/09; and 1,427 in 2009/10. During these surveys, ‘whiting spp.’ caught by recreational anglers were mostly between 190–290 mm TL (85%) (Fig. 33). The mean total length between surveys declined slightly over time, from 249 mm in 1996/97, to 237 mm in 2005/06 and 2008/09, and to 231 mm in 2009/10. A small percentage (0.2%) of ‘whiting spp.’ were recorded as >400 mm TL and are likely to be a data record error.

Voluntary recreational logbooks

Based on the recreational logbook data, the composition of the retained catch of ‘whiting spp.’ in WA were southern school whiting (38%), general/sand whiting (31%), yellowfin whiting (20%), western school whiting (11%) and western trumpeter whiting (<1%). No stout whiting have been reported. With limited opportunity to validate logbook data, numerous identification issues were apparent, including whiting species reported outside their known range and above their known maximum length. Also, the numbers of whiting recorded as ‘general/sand’ (31%) indicates that many logbook anglers were unaware of the various whiting species or were unable to identify whiting to species level correctly. As a result, with the exception of King George whiting, all whiting are grouped together here as ‘whiting spp.’.

From 2005 to 2011, ‘whiting spp.’ was the 2nd most common finfish species retained, behind Australian herring, to be reported by shore- and boat-based logbook fishers in WA. ‘Whiting spp.’ comprised 13% by number of all retained catches (finfish and invertebrates).

Approximately 95% of the WA retained catch of ‘whiting spp.’ were caught in ocean waters with 5% caught in estuaries. The majority (83.0%) of ‘whiting spp.’ retained by logbook fishers were caught in the WCB, with 55% of the WCB retained catch landed by boat-based fishers.

The majority (84%) of ‘whiting spp.’ caught by WCB boat-based logbook fishers were taken in the Perth area. Based on catch composition analysis conducted from fish frames donations, southern school whiting was found to be the main whiting species retained by the Perth metropolitan boat-based sector, comprising 90% of the 'whiting spp.' catch. Therefore, the annual catch rate of southern school whiting (using 'whiting spp.' catches as a proxy) was calculated for boat-based logbook fishers operating in ocean waters of the Perth area from January 2006 to December 2011.

The average monthly catch of 'whiting spp.' by boat-based logbook fishers in the Perth area was highest in December, April and November (Fig. 34a). Total monthly effort (including those that did not land a 'whiting spp.') peaked during summer and reached a minimum in winter (Fig. 34b). Monthly average CPUE peaked in December and recorded a low in the following months of January to March (Fig. 34c).

In the Perth area, the total annual catch (retained or released) of 'whiting spp.' by boat-based logbook fishers ranged from 223 fish in 2006 to 855 fish in 2007. The total annual effort expended by these fishers ranged from 308 hours in 2011 to 497 hours in 2008.

The average annual CPUE of southern school whiting during all boat-based logbook fishing sessions (including those that did not capture a whiting) in the Perth area displayed a variable trend, ranging from 0.5 fish/hour in 2006 to 1.7 fish/hour in 2007 (Fig. 35). The average CPUE of southern school whiting during fishing sessions that did capture 'whiting spp.' (i.e. excluding sessions resulting in non-whiting and nil catches) increased from 3.1 fish/hour in 2006 to 7.6 fish/hour in 2007, then remained relatively stable over the following four years, with mean annual CPUE ranging from 6.9 to 7.7 fish/hour (Fig. 35).

3.2.3.2 King George whiting

Recreational fishing surveys

Catch

As with 'whiting spp.', the current recreational catch of King George whiting in WA is unknown with the only survey of the state-wide catch that included both shore- and boat-based fishing conducted in 2000/01 (Henry and Lyle 2003). The estimated WA recreational catch (by number) of King George whiting during the 2000/01 survey was 408,209 fish (Table 11). King George whiting was the 4th most commonly retained finfish in WA during the survey (Henry and Lyle 2003). By bioregion, King George whiting was the 4th most commonly retained finfish category in the WCB (see Table 8), and the 2nd most retained finfish category in the SCB.

In the 2000/01 survey, the majority of King George whiting was caught in the WCB (60% of WA total catch) with the rest reported in the SCB (Table 12). No catches of King George whiting were reported in the NCB or GCB. In the WCB, the majority of King George whiting catches occurred in the Metropolitan Zone (90%), with the South-west Zone providing 8%, Mid-west Zone 1% and Kalbarri Zone <1%. King George whiting were primarily taken from nearshore waters, with inshore coastal and estuarine waters comprising 64 and 14% of the harvest, respectively. The remainder of the King George whiting catch were taken from offshore waters (22%). The habitat composition varied by bioregion, with catches in estuaries comprising only 2% of the WCB catch, but 33% of the SCB catch. King George whiting was caught mainly by line fishing (99%) and mostly by the boat-based sector (88%).

Annual estimates of the recreational boat-based catch in the WCB were produced in 1996/97, 2005/06, 2007/08 and 2009/10. King George whiting was the 4th most commonly retained finfish category in 1996/97, 2005/06 and 2009/10, and the 5th most commonly retained finfish category in 2008/09.

The number of King George whiting estimated to have been retained in the WCB boat-based surveys has declined over time, going from 79,529 in 1996/97 to 42,981 in 2005/06, then to 21,514 in 2008/09 and 18,351 in 2009/10. As with 'whiting spp.', the number of fish retained during the 2000/01 survey is much higher, with an estimated 215,018 King George whiting kept by the WCB boat-based sector in this period. This peak in King George whiting catch was also observed in the commercial catches of the two main estuarine fisheries.

In the 2011/12 state-wide boat-based survey (Ryan *et al.* 2013), King George whiting was the 3rd most commonly retained finfish species with 107,689 fish kept (10% of total finfish catch). In the WCB, King George whiting was the 3rd most kept (48,678 or 7% of total finfish catch). In the SCB, King George whiting was the most kept finfish species (59,011 fish or 30% of total finfish catch).

In 2002/03, a survey of recreational estuarine shore- and boat-based fishing in the SCB found King George whiting to be the most kept species, comprising 30% of all retained landings (Smallwood and Sumner 2006). Approximately 41% of the total catch of King George whiting was estimated to have been released.

During the three-month (April – June 2010) survey period of shore-based fishing in the metropolitan area, only a few King George whiting were caught (Smallwood *et al.* 2011).

The percentage of King George whiting released during past boat-based surveys in the WCB ranged from 9% in 2000/01 to 29% in 2011/12. In the SCB, the percentage of King George whiting released by boat-based fishers was higher at 41–42% (Table 9).

Catch rate

Recreational fishing methods for King George whiting have changed little over the past 15 years (period of recreational fishing surveys assessed). However, advances in fishing technology (GPS, depth sounders) may have increased the catch efficiency on adult King George whiting. Another influence on the catch rate assessment of King George whiting is the increase in the LML from 250 mm to 280 mm and a reduction in the bag limit from 20 to 8 in 2003 for the WCB.

Effort, measured as the total number of ocean boating hours with line fishing method, increased noticeably from approximately 525,000 hours in 1996/97 to 730,000 in 2005/06, then declined slightly to 685,000 hours in 2008/09 and 630,000 hours in 2009/10 (Fig. 36).

The estimated annual CPUE of King George whiting by boat-based fishers in the WCB declined from 0.151 fish per boating hour in 1996/97 to 0.059 fish/hour in 2005/06, 0.032 fish/hour in 2008/09 and remained low at 0.029 fish/hour in 2009/10 (Fig. 36).

Length composition of recreational catch

Sample sizes of King George whiting measured during the WCB boat-based surveys were 553 fish in 1996/97; 1,536 in 2005/06; 631 in 2008/09; and 466 in 2009/10. Over the four WCB boat-based surveys, King George whiting captured by recreational fishers ranged between 128 to 720 mm TL. The length frequency distributions appear similar between surveys, with a mean total length of 398 mm in 1996/97, 397 mm in 2005/06, 411 mm in 2008/09 and 399 mm in 2009/10.

The percentage of King George whiting <280 mm in 1996/97 was 21% whereas following the introduction of the increased LML from 250 to 280 mm in 2003, the percentage of King George whiting <280 mm was 2–3% in each of the three more recent surveys (Fig. 37).

Voluntary recreational logbooks

From 2005 to 2011, King George whiting was the 3rd most common finfish species category reported retained in the recreational logbook, behind Australian herring and 'whiting spp.', by shore- and boat-based fishers in WA. Overall, King George whiting comprised 6% of all retained catches (finfish and invertebrates).

King George whiting was reported only in the WCB (57%) and SCB (43%), and mostly by boat-based landings (85%). Estuary catches in the SCB accounted for 67% of all SCB King George whiting catches whilst in the WCB, estuary catches accounted for only 4%.

In the WCB, the majority of King George whiting retained catches occurred in the Geographe Bay area (69%), with most of this occurring during the months September to February (83%). Other popular areas included Cockburn Sound, Warnbro Sound and Augusta.

The average annual CPUE of King George whiting during boat-based fishing in Geographe Bay for the months September to February, showed an increasing trend from 2006/07 to 2011/12 (Fig. 38).

3.2.4 Commercial fishery catch and effort

In WA, several multi-species commercial fisheries capture whiting as either a target species or byproduct catch. Since 1980, an average of 218 tonnes (t) of whiting was landed annually in WA. The majority of whiting was caught in the GCB (average 141 t or 65%), mostly by the Shark Bay Beach Seine and Mesh Net Managed Fishery (SBBSMNF). Whiting catches also occurred in the WCB (58 t or 27%), SCB (18 t or 8%) and NCB (0.5 t or <1%) (Fig. 39). The majority (95%) of commercial whiting landings are taken in nearshore or estuarine waters by beach seine, haul and gill nets methods.

The most commonly reported whiting species in the CAES database over this period were yellowfin whiting (80% of catch) and King George whiting (13%) (Fig. 40). However, with the possible exception of King George whiting, there was likely to be misidentification or misreporting of some commercial landings of whiting.

Gascoyne Coast Bioregion

The fisheries of the GCB were outside the scope of this study so have not been fully assessed here and are only mentioned due to it being the main bioregion where commercial catches of whiting are landed in WA.

The SBBSMNF uses beach seining and haul netting methods in shallow coastal waters of Shark Bay to target two species of whiting, yellowfin and goldenline (*Sillago analis*), as well as sea mullet (*Mugil cephalus*), tailor and yellowfin bream (*Acanthopagurus morrison*). For the period 1980–2011, the SBBSMNF landed the majority of whiting in WA, averaging 124.9 t or 57% of total annual landings. Yellowfin whiting accounted for 95% of the reported whiting catch in the SBBSMNF over this period. However, commercial fishers generally only reported one whiting species on their returns, with the exception of two fishers who have usually spilt their catch into the two main whiting species from the nearshore zone of this bioregion. From their returns, yellowfin whiting accounted for 88% of the catch (1990–11), with goldenline whiting the remainder. However, with western school and western trumpeter whiting also known to exist in Shark Bay, the true composition of the commercial whiting catch in this fishery is unknown.

A similar beach seine fishery exists to the north in Exmouth Gulf, but landings are substantially lower, producing on average 12.6 t per annum (1980–2011) or 6% of the state's annual catch. Yellowfin whiting is the main species recorded in the catch (74%) in this fishery with the rest reported as goldenline whiting or 'general' whiting. However, the commercial monthly returns often only report "whiting", with this catch usually assigned to yellowfin whiting by data entry staff. Yet, with goldenline, western school and western trumpeter whiting also occurring in the nearshore waters of this fishery, the actual whiting composition of the commercial catch in this fishery is unknown. Also, the literature is unclear as to the occurrence of yellowfin whiting at Exmouth, with northern boundaries reported as Shark Bay (Hutchins and Swainston 1986), Exmouth (McKay 1992: one unconfirmed report), Dampier (Coulson 2003) and Port Headland (www.ala.org.au).

West Coast Bioregion

From 1980 to 2001, an average of 58 t of whiting were landed in the WCB per year, with yellowfin whiting being the dominant species recorded (73%), followed by King George whiting with 20%. The remaining whiting landings were either the 'general' or 'school' whiting categories (Fig. 40). Over half (59%) of the whiting landed in the WCB during this period occurred in four estuaries bybyby a combination of haul and gill net methods.

Prior to 2001, the majority of estuarine landings of whiting in the WCB were taken in Leschenault Estuary (51%). Following the closure of this estuary to commercial fishing in January 2001, WCB estuarine landings were mainly derived from the Peel-Harvey Estuary (57%) and Hardy Inlet (41%). Annual commercial landings of whiting in the Swan-Canning Estuary have always been low, averaging 0.2 t from 1980–2011.

Commercial fishing in Leschenault Estuary landed a number of species including blue swimmer crabs (*Portunus armatus)* and finfish species. From 1980 to 2000, whiting contributed 10–27% per year (by weight) of the total finfish catch. During this period, whiting landings reached a peak of 51.1 t in 1985 before falling to 16.3 t in 1986. The catch then remained steady, averaging 15.1 t from 1986 to 2000. The majority of whiting landings occurred during the cooler months, with 80% of the catch reported between May to October. Yellowfin whiting and King George whiting are the main whiting species reported in the Leschenault Estuary, comprising 65% and 34%, respectively, of the whiting catch for the period 1980–2000.

The Peel-Harvey Estuary is a multi-species fishery that targets blue swimmer crabs and many finfish species. Since 2000, whiting species comprised approximately 7% of the total catch (including crabs and other invertebrates), and 11% of the total finfish catch (excluding invertebrates) in this estuary.

Catches of whiting in the Peel-Harvey Estuary averaged 11.1 t from 1980–2011 but has varied greatly, ranging from a low of 0.2 t in 1990 to a high of 32.3 t in 1998. This highly variable catch is in response to strong fluctuations in recruitment and variable targeting in this multi-species fishery. The main whiting species caught in the Peel-Harvey Estuary are yellowfin and King George, comprising 63% and 37% of the whiting catch for the period 1980–2011, respectively. Yellowfin whiting recorded a peak catch of 21.5 t in 1980. Catches then declined to 2.4 t in 1984, where they remained low averaging 1.2 t from 1984–1995. Following the opening of the Dawesville Channel in April 1994, yellowfin whiting catches increased in the Peel-Harvey Estuary, averaging 10.1 t from 1996–2011.

Since 1980, whiting species comprise the majority of landings (50%) in Hardy Inlet, with sea mullet, yelloweye mullet (*Aldrichetta forsteri*) and black bream (*Acanthopagrus butcheri*) being the other main species. Yellowfin whiting was the main whiting species recorded, comprising 96% of all whiting landings during this period. King George whiting is a minor species in this inlet, averaging 0.4 t since 1980.

The largest commercial ocean catch of whiting in the WCB occurred in the Geographe Bay/ Bunbury area (CAES blocks 3315, 33151, 9601) and was taken mainly by the South West Beach Seine Fishery. This area produced 13% of the WCB whiting landings since 1980, with mostly yellowfin whiting (75%) caught by a combination of beach seine and haul nets. King George whiting was the next most retained species, comprising 20% of the Geographe Bay/ Bunbury whiting catch. The remaining 5% was a mixture of the 'general/sand', 'school/silver' and 'trumpeter' whiting categories, although some of this is likely to be yellowfin whiting. In recent years there has been a range of management changes in the fishery, which has seen the landings reduced by over half with most fish (>99%) now caught by beach seine. The majority of yellowfin landings occurred over the summer months, with 62% of the catch reported from November to February.

The other ocean area that produces the majority of whiting landings is the Metropolitan waters surrounding Perth from Lancelin in the north to south of Mandurah and up to 60 km offshore (Block 3115). This block accounts for 13% of the WCB catch at an average of 7.6 t per year (1980–2011). The South West Trawl Managed Fishery (SWTMF) is responsible for the majority of the catch in this block (83%). Other fisheries that contribute to whiting landings in this block are the Open Access (line fishing) and the West Coast Beach Bait Fishery. Most of the reported landings are yellowfin whiting (73%) and 'general/sand' whiting (25%), with the rest being made up of King George and 'trumpeter' whiting.

The SWTMF is a multi-species fishery that mainly targets invertebrate species including saucer scallops (*Amusium balloti*) and western king prawns (*Melicertus latisulcatus*). The fishery also lands a number of finfish species as a byproduct, with whiting the most abundant finfish species recorded. The main whiting species reported to be caught by the SWTMF is yellowfin whiting (72%), however this is unlikely as this species is known to inhabit only shallow waters (<5 m depth) away from the trawl grounds (Hyndes and Potter 1997). Following extensive trawling in the WCB, Hyndes and Potter (1997) did not find any yellowfin whiting in >5 m water depth with the catch composition of whiting species from trawl sampling comprising mainly southern school whiting (84%), with smaller amounts of stout (11%), trumpeter (3%) and western school whiting (2%). Stout and trumpeter whiting are smaller species and are less likely to be retained for human consumption, so the retained trawl catch is likely to comprise mainly of southern school whiting. In 2011, a 20 kg sample of the whiting catch from a trawler operating in the Metropolitan region at 30 m depth comprised only of southern school whiting (n = 162 fish).

South Coast Bioregion

The SCB on average produces 17.8 t of whiting or 8% (1980–2011) of the annual WA whiting landings, with King George whiting being the most dominant species in the catch (96%), followed by yellowfin whiting (4%) and whiting general (<1%) (Fig. 40). The majority of the commercial whiting catch in the SCB is landed in estuaries (~87%) by the South Coast Estuarine Managed Fishery (SCEF).

The SCEF is a multi-species fishery that targets a number of estuarine finfish species. The main target species are cobbler (*Cnidoglanis macrocephalus*), black bream, sea mullet, Australian herring and King George whiting. King George whiting are spawned in ocean waters and recruit as juveniles into estuarine and protected inshore marine areas, which function as nursery habitats. Juveniles remain in inshore areas to an age of approximately 3–4 years and then migrate offshore. Since 1995, nearly 75% of the SCEF commercial catch of King George whiting was taken in Wilson Inlet by gill net and haul net methods. Irwin Inlet, Oyster Harbour, Broke Inlet and Princess Royal Harbour also landed reasonable numbers of King George whiting, but these landings are inconsistent and are largely dependent on the physical processes of the estuaries, such as the frequency of openings to oceanic water, water quality, salinity and environmental conditions which promote strong recruitment of juveniles into the estuaries.

3.2.4.1 Southern school whiting

The only commercial fishery in WA to regularly catch southern school whiting is the SWTMF. Since 1980, landings of whiting by the SWTMF (assumed to be mostly (>95%) southern school whiting in this fishery) have generally followed a declining trend. A peak catch for this fishery of 36.6 t was recorded in 1985 and a low of 0.9 t was recorded in 2005. The declining trend in whiting spp. landings is mirrored by the decline in effort. Since 1990, the catch of whiting spp. has averaged 5.8 t per year. In 2011, the catch of whiting was 13.3 t, the highest level since 1987 (Fig. 41). As whiting is a byproduct of this fishery, the capture of target species (saucer scallops and western king prawns) and market factors is likely to dictate the quantities of southern school whiting retained each year. Therefore, CPUE in this fishery is considered to be unreliable to make an assessment of trends in abundance for this species.

The average length of southern school whiting measured from one SWTMF catch was 241 mm (n = 162), while the average length of fish not retained was 198 mm (n = 98). A commercial LML of 220 mm existed in WA for southern school whiting until its removal on 29 March 2011.

3.2.4.2 King George whiting

Commercial catches of King George whiting primarily occur in estuaries in the WCB and SCB. Minor catches of King George whiting also occurred in sheltered embayments of the lower WCB. Market monitoring of commercial King George whiting lengths during 1998–2002 as part of a study by Gaughan *et al.* (2006), resulted in 10,739 individuals of this species being measured from the SCB. Nearly all (99%) were caught in estuaries and only 2% of these fish were above the length at maturity (~420 mm). The average length of the SCB commercial catch for the period 1998–2002 was 350 mm for the estuarine catch and 389 mm for the ocean catch.

Since 1980, catches of King George whiting in the Peel-Harvey Estuary have usually remained below 5.0 t per annum, except for a period from 1996–2000 when a strong recruitment pulse, that was also observed on the SCB, resulted in large catches averaging 13.1 t, including a peak of 20.3 t in 1998 (Fig 42a). Nearly all (99.9%) King George whiting landings are primarily taken by gill and haul net methods. The majority (90%) of annual King George whiting landings occurred from March to October.

The annual CPUE of King George whiting in the Peel-Harvey Estuary (by gill/haul net for March to October only) is highly variable. From 1980 to 2011, the annual CPUE ranged from 0 kg/day in 1990 to 13.0 kg/day in 1999. From 1980 to 1985 the average annual CPUE was relatively low, averaging 0.8 kg/day. From 1996 to 2000 the average annual CPUE increased to 10.2 kg/day. Since 2003, the average annual CPUE has declined but is still higher than historical levels at 4.7 kg/day (Fig. 42b). The general trend in the annual CPUE of King George whiting in the Peel-Harvey Estuary for the last 5 years is increasing.

Catches of King George whiting in Wilson Inlet were relatively steady during the 1980s, averaging 3.3 t per year. Catches then increased in the 1990s with historically high catches occurring from 1997 to 2000 (peak of 49.9 t in 1998). This increase is believed to reflect a substantial increase in recruits entering the estuary, and not changes in the overall fishing effort level in this estuary. In other words, the stock abundance in Wilson Inlet over the last few decades has varied independently of fishing effort within the estuary. Since 2001, King George whiting catches were at the more typical pre-1997 levels, reflecting more typical recruitment levels (Fig. 43a). Record low catch levels in 2009 and 2010 of 0.7 t are a likely result of poor recruitment to the estuary due to the sand bar remaining closed in 2007 for the first time since official records were kept in 1955.

From 1980 to 1995, the average annual CPUE of King George whiting by gill/haul nets in Wilson Inlet (based on catch and effort for the whole year) was fairly stable, ranging from 0.9 to 4.3 kg/day. From 1996 to 2000, the CPUE was relatively high, increasing from 5.4 in 1996 to a peak of 20.5 kg/day in 1998. After 2000, the CPUE declined to historical levels. A record low of 0.4 kg/day was recorded in 2009 and 2010 (Fig. 43b).

4.0 Discussion

4.1 Fishery catch composition

4.1.1 Species identification

In total, ten whiting species are known to exist in WA. Of these, six are known to occur in south-western WA (Hyndes *et al.* 1996a), which includes the WCB and SCB. These are King George whiting (*Sillaginodes punctata*), yellowfin whiting (*Sillago schomburgkii*), southern school whiting (*S. bassensis*), western school whiting (*S. vittata*), western trumpeter whiting (*S. burrus)* and stout whiting (*S. cf. robusta*). The remaining four WA species occur in the northern bioregions, i.e. GCB and NCB.

During this study, a key was developed for identifying each whiting species in the recreational catch of south-western Australia, including when fish have been filleted, based on external morphological features and characteristics of sagittal otoliths. A photographic field guide was also produced to assist researchers, fishers and any other interested members of the community in identifying whiting to species level (see Appendix 1).

This study proposes the identity of a new species of *Sillago* in WA, previously considered as stout whiting. Conspicuous external differences were apparent with the samples collected from eastern Australia, including the body location of a yellow botch and the shape of the caudal fin. Genetic analysis confirmed that the WA population of stout whiting is a new species. This finding is planned to be presented in a paper following full morphological and phylogenetic analysis.

4.1.2 Species compositions of whiting catches

Until this study, the composition of whiting species in the recreational and commercial catch has been largely unknown. The lack of species-specific data can be attributed to difficulties in species identification and incorrect recording of common names, which has resulted in inaccurate reporting of catches of whiting species. Consequently, with the exception of King George whiting, which is more easily identified, data for the other whiting species (i.e. *Sillago*) are often pooled as 'whiting spp.' for analysis. While the *Sillago* species look similar, the distribution and ontogenetic movement within the south-west of WA vary considerably (McKay 1992; Hyndes *et al.* 1996b). These differences have been related to differences in the timing of recruitment and habitat use (Hyndes *et al.* 1996a). They also display marked differences in life history parameters (e.g. growth rate, maximum size and age, length and age at maturity) (Hyndes and Potter 1996; Hyndes *et al.* 1996b; Hyndes and Potter 1997; Hyndes *et al.* 1998). Therefore, this grouping of whiting data has reduced the ability to understand the distribution and abundance of individual species within this family and thereby, make a more thorough assessment of their stock status difficult.

Recreational catches

From the large number (~10,000) of whiting frames donated by recreational fishers in 2010–12, southern school whiting and King George whiting were identified as the main whiting species landed by recreational anglers in south-western WA. Of the *Sillago* species, southern school whiting comprised the majority of samples from the boat- and shore-based sector in the WCB and SCB. Given the dominance of this species from recreational boat-based frame donations, southern school whiting is thus considered to be the most landed individual finfish species (by number) in WA in the recent 2011/12 boat-based survey.

This conclusion assumes that the collection of frames donated by recreational fishers is representative of the entire recreational catch. This, at least, appears to be the case for the boat-based sector, for which the species composition of the whiting catch was similar to that recorded in the boat-ramp component of the 2011/12 recreational boat-based survey. Sampling of whiting caught by shore-based recreational fishers, however, may have been under represented. From the only state-wide survey conducted in WA of boat- and shore-based fishing (Henry and Lyle 2003), approximately 39% of the WCB and SCB combined catch of *Sillago* species was estimated to have been taken by shore-based fishers. In this study, only 6% of samples were donated from shore-based fishers, with the majority of samples coming from boat-based fishers. The reasons for the low number of shore-based samples are unclear. Possibly, the proportion of the total whiting catch taken by shore vs boat-based fishers may have changed since the National Recreational and Indigenous Fishing Survey was conducted in 2000/01. A more likely reason is that the lower shore-based contribution was largely attributable to the structure of the fish frame donation ('Send Us Your Skeletons') program, which was initially developed for larger inshore demersal species, and with promotion of the program initially targeted towards boat-based fishers (e.g. signage at boat-ramps). In addition, as DoF staff were employed specifically for collecting fish frames at boat-ramps, they were able to opportunistically collect many whiting in the process from boat-based fishers.

With the exception of shore-based catches, the distribution of whiting catches by bioregion and zone from frames samples compares closely to the National Recreational and Indigenous Fishing Survey conducted in 2000/01. From the 'National Survey', around 95% of the 'whiting spp.' retained catches in south-western WA occurred in the WCB, with the SCB comprising 5% of retained catches. These compositions are similar to the frame collection in this study, with 92% of 'whiting spp.' frames collected in the WCB. The majority of the whiting catches in the 'National Survey' and in this study from frames donations were from the Metropolitan and South-west Zones (~85–90%).

The results of this study also demonstrated that the catch composition of whiting species varied according to location (i.e. bioregions and management zones), shore- and boat-based fishing and water depth. These differences are likely to reflect a combination of factors, including differences in species abundance, distribution, habitat use and extent of offshore movement. For example, the finding that yellowfin whiting were mostly caught by shore-based fishers whereas stout whiting were only caught by boat-base fishers reflects the fact that the former species spends its entire life in shallow (<5 m depth) nearshore waters whereas the latter species lives its entire life in deeper waters (>15 m depth) (Hyndes *et al.* 1996a; Hyndes and Potter 1997). Also, adult western school whiting are also believed to occupy relatively shallow waters (5–12 m depth), whereas southern school whiting adults migrates out into deeper waters (20–35m depth) (Hyndes and Potter 1997).

The composition of the retained whiting catch would also be influenced by aspects of fishers' behaviours, such as their preferences for certain species, size of fish and quantity of fish (which, in turn, is also influenced by factors such as size and bag limits). For instance, the low number of stout whiting and western trumpeter whiting in donated samples is probably due to the fact that individuals of these species rarely grow larger than 200 mm. The low maximum size of these two species means most fish would be either too small to be caught (hook size) or retained (too small to eat). During trawl-fishery research in the south-west of WA in the early 1990s, it was found that stout whiting were equally as abundant as southern school whiting at some of the sites (Laurenson *et al.* 1993). Thus, it cannot be concluded that the overall sizes of the populations of these species is smaller than those of more commonly retained species.

The overall catch composition of whiting would also have been influenced by the lower bag limits during the survey period for King George whiting (8 in the WCB and 12 in the SCB) and yellowfin whiting (12 in the WCB and 16 in the SCB), compared to the other whiting species, which had a mixed daily bag limit of 30 in the WCB and 40 in the SCB. Thus, the lower bag limit of yellowfin whiting compared to the other *Sillago* species may have restricted catches of that former species far more than the latter species. Following a recent review to simplify recreational fishing laws in WA, all *Sillago* species in WA now have a combined mixed species daily bag limit of 30 across the State (effective 1 February 2013). This may therefore be expected to result in an increased contribution of yellowfin whiting to the overall whiting catch if the former bag limit was acting to restrict catches.

This study has also shown that the number of frames donated during the WCB two month closed season for larger inshore demersal fish (15 October to 15 December, inclusive) was relatively high compared to the overall monthly average. The recreational logbook mean monthly catch for the period 2006–2011 (which was mostly before the time when the closed season was introduced), suggests that large catches of *Sillago* spp. are often taken in November, December and April, and thus, often around the time of the closure. Moreover, the frame data show that catches of yellowfin whiting were also seasonal, with highest catches occurring over the warmer months (i.e. again, around the period of the closure). Although there is thus undoubtedly a strong seasonal effect on whiting catches, it is also possible that effort may have shifted from larger inshore demersal species to whiting species, such as southern school whiting and King George whiting, when the closures where put in place.

Commercial catches

The main whiting species landed by the commercial sector in south-western WA are yellowfin whiting, King George whiting and southern school whiting. These catches are mainly taken by estuarine and nearshore net fisheries, with the exception of southern school whiting which is mostly landed by a single trawl fishery (i.e. SWTMF). These three species are the largest of the whiting family in south-western WA. The other three whiting species of south-western WA (i.e. western school whiting, western trumpeter whiting and stout whiting) do not obtain as large a size and may not, currently, be considered a suitable market size.

Catch shares

Adjusted catch estimates from the 2011/12 recreational boat-based survey to factor in shore-based catches, showed that for the period 2011/12, the recreational fishing sector (shore- and boat-based) landed the majority (~75%) of southern school and King George whiting in the WCB. It is important to note, that the average individual fish weights used in this analysis for the recreational sector catch are affected by a number of factors including sample design and biological/environmental factors.

4.2 Assessment

4.2.1 Biological assessment

4.2.1.1 Southern school whiting

Length and age compositions and growth

The largest southern school whiting collected from recreational fishers in 2010–12 measured 351 mm TL, which is just below the maximum recorded length for this species of 360 mm TL

(Hutchins and Swainston 1986). The oldest southern school whiting aged in this study of 11.8 years is the oldest ever reported for the species, with Hyndes and Potter (1996) previously reporting a maximum age of 9+ years.

The asymptotic length estimated for southern school whiting (pooled sexes) in the WCB in this study is lower (6%) than that estimated in 1991–93 by Hyndes and Potter (1996), and the growth coefficient was substantially higher (0.64 vs 0.30 $year^{-1}$) than recorded in the previous study. The increase in the growth coefficient in the 20 years between studies requires further investigation as collection methods varied between studies. Whereas all southern school whiting collected in this study were caught by line fishing, the majority of southern school whiting in the earlier study were collected by trawling and thus the different sampling methods employed or habitats in which the fish were caught may largely account for differences in the growth curves.

Spawning season and size at maturity

Based on macroscopic staging criteria, the majority of adult southern school whiting (i.e. >200 mm TL) in the WCB possessed mature gonads in each month of the year, thereby providing strong evidence for a very protracted spawning period. The lack of a clearly defined mode in monthly length distributions corresponding to small 0+ aged fish also suggests that southern school whiting spawns throughout the year. The above results are similar to those of Hyndes and Potter (1996), who also recorded mature gonads throughout the year in southern school whiting, particularly for females three years in age and above. The results do differ to some extent, however, as the mean monthly GSIs recorded in this study remained at similar levels (ranging from only 1.4 to 2.3) throughout the year, whereas those recorded by Hyndes and Potter (1996) in 1991–93 varied slightly more (from 0.6 to 1.8). Thus, Hyndes and Potter (1996) concluded that although the spawning season of this species is protracted, it was restricted mainly from September to May, with most spawning occurring from December to March. As water temperatures in recent years (2010–12) were on average 2–3 degrees higher in the WCB than during the period (1991–93) when Hyndes and Potter (1996) undertook their study, it would appear plausible that temperature is an important factor that could explain this difference. The finding that southern school whiting spawned over a more restricted period in cooler years also parallels the finding for snapper (*Pagrus auratus*) in New Zealand and South Australia (Scott and Pankhust 1992; Fowler and Jennings 2003).

Although spawning of adult southern school whiting in the WCB was concluded to now occur throughout the year (but less so in the past), the spawning of this species in the cooler SCB is more restricted, i.e. occurring predominantly from December to March. Moreover, the mean monthly GSIs attained larger values in the SCB (max. = 3.2 for females) than the WCB (max. = 2.3 for females) and the magnitude of difference between the minimum and maximum GSIs in the SCB was greater. These differences would suggest that southern school whiting have a more clearly defined spawning season in the SCB. This finding for southern school whiting parallels that observed for several other temperate species, with more protracted spawning season occurring in assemblages at lower latitudes (Pankhurst and Porter 2003), including yellowfin whiting between the GCB and the WCB (Coulson *et al.* 2005). It also parallels that for some other species in south-western Australia, e.g. silver trevally (*Pseudocaranx dentex*) (Farmer *et al.* 2005), foxfish (*Bodianus frenchii*) (Cossington *et al.* 2010) and snapper (Wakefield 2006).

Comparisons between the mean monthly GSIs for southern school whiting compared with local mean monthly water temperatures in the two bioregions indicate that this species, regardless of locality, spawns at temperatures of around 19–21 °C. In this regard, temperature is known to be a key factor in triggering spawning in fishes (Lam 1983). The above finding parallels that found for a number of other marine fish species, e.g. snapper (Wakefield 2006).

Southern school whiting is a multiple spawner i.e. they spawn on numerous occasions during the breeding period (Hyndes 1996). The reproductive strategy of releasing eggs over a protracted period has been suggested as a 'bet-hedging' strategy for enhancing the survival of offspring (Lambert and Ware 1984) through increased egg production (Burt *et al.* 1988) and reducing risk of egg and larvae mortality through 'spreading the risk' by releasing multiple batches at different times (Lambert and Ware 1984). A year-long protracted spawning period was also observed in the temperate species common silverbiddy (*Gerres subfasciatus*) (Sarre *et al.* 1996) which also had a low GSI peak (1.5) and thus, it is not a unique spawning strategy among temperate fish.

The results of the reproductive studies also showed that although the length of spawning season of southern school whiting in the WCB has changed, the length at which fish typically mature (L_{50}) has remained essentially unchanged (*cf* Hyndes and Potter 1996). However, the typical length at maturity of this species in the WCB is substantially higher than in the SCB (201 vs 165 mm). This differs from the situation with yellowfin whiting which spawns longer at a warmer lower latitude, but attains maturity at a similar size (Coulson *et al.* 2005; Hyndes and Potter 1996). Although otolith samples for southern school whiting in the SCB have been collected, the fish have not yet been aged and thus it is not possible to determine whether this difference in maturity is accompanied by a marked difference in growth.

The results of this study also showed that the recreational catch comprised roughly equal numbers of females to males and consisted mostly of mature fish, with only 7.1% of the WCB frame donations below the length at 50% maturity.

Mortality estimation and estimates of spawning biomass per recruit

The fact that the medians of the estimated values of fishing mortality (F), derived from the two forms of catch curve analysis fitted to age composition data collected in 2011, were either just below or just above the target level ($F = 2/3M$), and well below the threshold value ($F = M$) suggests that the current level of exploitation is sustainable. This is also supported by the high probability (0.75 or 1, depending on the method) determined from the confidence limits, that F is below the threshold, and total certainty (i.e. probability = 1) that F is currently below the limit. As the median values for the current estimated levels of spawning potential ratio (SPR), employing the two catch curve estimates of F, are also either just above or below the target level ($SPR = 0.4$), this provides further support for the conclusion that the current level of exploitation is sustainable. Moreover, as the analysis suggests that there is a very high probability (0.9 or 1, depending on the method for estimating F) that the current level of SPR is above the threshold value (0.3), this provides further weight to the conclusion that the current level of fishing is sustainable.

A caveat to the above conclusion that current exploitation is sustainable is that the catch curve methods for estimating F both rely on strong assumptions, including that all individuals in the population have experienced the same level of fishing mortality and that recruitment is constant (Quinn and Deriso 1999; Thorson and Prager 2011). It is thus recommended that the stock assessment result be treated with a level of caution and that, for future assessments, more sophisticated methods of catch curve analysis be explored. This might include the use of multiple years of age composition data and use of methods for estimating recruitment variability (Quinn and Deriso 1999; Fisher *et al.* 2011). In this regard, simulation studies have shown that when recruitment variability exists, ignoring such variability tends to produce estimates of mortality that are overly optimistic, *i.e.* with estimates of mortality underestimated (Fisher *et al.* 2011). To reduce the bias associated with variable recruitment, it is recommended to include two to three consecutive years of age data for more precise results (Fisher *et al.* 2011). Ageing of samples of southern school whiting collected in 2012 and 2013 would provide up to three consecutive years of data and thereby potentially provide more reliable estimates of F.

Catch curve approaches that employ both length and age data may also be of value for this species, as substantial length data exist (from large sample collections) for fish that are not aged. The use of such data may potentially provide mortality estimates with a greater level of precision. Preliminary work has demonstrated that a catch curve model can be fitted simultaneously to length-at-age data and additional length data, and can yield estimates of growth parameters, length-based selectivity parameters and fishing mortality. The use of this type of approach for estimating growth parameters is also potentially of value, as it can provide a description of growth that accounts for effects of selectivity and mortality, i.e. provide a 'truer' description of growth of individuals in the population (Taylor *et al.* 2005). The recent study by Hall (2009) demonstrated that a range of length-based approaches to catch curve analysis exist which may be of considerable value for data-limited fisheries in WA.

Another important consideration when interpreting the stock assessment results is that, while the samples are considered to provide a good representation of individuals in the population that are above the size at full-recruitment into the boat-based recreational line fishery, the catch curves were fitted solely to age composition data for boat-based catches of southern school whiting. Thus, the analysis does not consider the fishing mortality experienced by this species in the inshore region by shore-based fishers. As donations from shore-based fishers were very low, it is possible that the fishing mortality on southern school whiting by shore-based fishers is also low. However, it is also possible that recreational catches of this species from inshore waters were under-represented by the sampling program. As the appropriate weighting to apply to the samples from shore and boat-based fishers is not known, it would have not have been appropriate, statistically, to combine the samples.

Thus, the question remains as to whether the catch of southern school whiting by shore-based fishers is likely to be substantial. All shore-based fish aged in this study (n = 32) were only 1 or 2 years old, which is consistent with the knowledge that this species exhibits an offshore movement with increasing size and age (Hyndes and Potter 1996; Hyndes and Potter 1997; Hyndes *et al.* 1999). Although most recreational fishers tend to target the larger individuals of a species, it is known that at least some recreational fishers catch small individuals of this species (there is no size limit) and cook and eat their catch whole. The National Recreational and Indigenous Fishing Survey conducted in 2000/01 (Henry and Lyle 2003) estimated that around 38% of the *Sillago* catch in the WCB is shore-based. While a large percentage of the shore-based catch would be yellowfin whiting, it is possible that a considerable number of southern school whiting comprised those catches by the shore-based sector that needs to be taken into account. Therefore, the stock assessment results must be considered with the possibility that the estimate of F may be underestimated, due to the non-inclusion of smaller and younger southern school whiting caught by the shore-based sector.

4.2.1.2 King George whiting

The discussion provided below considers, in brief, the results provided by Fisher *et al.* (in prep) for FRDC 2010/001, the studies of Sulin (2012) and the additional analyses undertaken in this study, based on the same data, to provide information on stock status.

Length and age compositions and growth

The analyses of data collected for King George whiting have shown that the largest and oldest individuals collected in 2010–12 are similar to those collected in 1991–93 by Hyndes *et al.* (1998), with a maximum length of ~590 mm TL and age of 13+ years in both sampling periods.

In 2010–12, the majority of the recreationally caught King George whiting were derived from inshore waters (71% of the WCB and 95% of the SCB samples), which consisted mostly of young (≤3 years) fish (80% in the WCB and 66% in SCB). The lengths and ages of King George whiting collected from nearshore and offshore waters of the WCB and SCB are consistent with the fact the juveniles of this species use nearshore, relatively shallow (<15 m deep) waters with sand/seagrass habitats as nursery grounds, whereas adults live over reefs, in deeper waters up to 60 m in depth (Hyndes *et al.* 1998; Fowler *et al.* 2000a).

The focus of recreational fishing on juveniles of King George whiting is emphasised by the results of this study, with juveniles (i.e. fish below the L_{50} at maturity) contributing as much as 79% in the WCB and 94% in the SCB to the total sample derived from frame donations. The high number of juveniles fish in the recreational catch reflects a range of factors, including the accessibility to fishers of the habitats occupied by juvenile King George whiting (estuaries and relatively shallow waters close to shore) and the greater catchability of juveniles than adults, the latter of which tend to be far more dispersed.

As has been recognised by a number of authors, e.g. Hyndes *et al.* (1998), Gaughan *et al.* (2006), Potter *et al.* (2011) and Fisher *et al.* (in prep), most fishing for King George whiting is focused towards juveniles. The use of 280 mm as the minimum size for capture and retention recognises that very different catchabilities of this species exist in the different environments (providing increased protection to adults) and the fact that the stock would otherwise not be accessible to most recreational fishers. However, the fact that the population and boat ownership in WA has risen dramatically over the past two decades presents an increased risk to the overall stock of King George whiting, warranting increased monitoring and management, if required. As recognised by Fisher *et al.* (in prep), the size-related movement of this species makes stock assessment more difficult and uncertain, which also needs to be factored into management. For more discussion on this issue, see further below.

Spawning season and size at maturity

The trends exhibited by the monthly prevalences of King George whiting with gonads at different (macroscopic) stages in development, and in mean monthly GSIs, suggest that in the WCB, spawning occurs mainly from May to August, and is greatest in June and July. This is broadly consistent with the conclusion of Hyndes *et al.* (1998), based on a combination of macroscopic and histological staging of gonads of King George whiting, that spawning occurs from June to September.

Unfortunately, although a substantial number of King George whiting was collected from the SCB (n = 1,068), most individuals were juveniles and very few individuals were collected from over reefs. As discussed by Sulin (2012), the reef environments over which the adults of this species occurs in the SCB are relatively exposed in comparison with those in the WCB. From discussions with fishers and tackle shop owners in that region, it is evident that fishers who own relatively large boats typically focus their fishing activities towards larger species such as West Australian dhufish (*Glaucosoma hebraicum*), samson fish (*Seriola hippos*), snapper (*Pagrus auratus*) and bight redfish (*Centroberyx gerradi*). Based on the preliminary results of Sulin (2012) and the Department's fish frame collection program up to that time, there is now an increased focus on collecting adult King George whiting from over reefs (in deeper, offshore waters) in the SCB. With these data, it will be possible to determine the time and duration of spawning of King George whiting in the SCB, noting that it is possible that spawning may be restricted to the WCB with the southwards flowing Leeuwin Current transporting larvae to nursery areas in the SCB. Such a scenario would be consistent with the long larval phase of 3–5 months of King George whiting in eastern Australia (Jenkins and May 1994; Fowler and Short 1996) and the observation that certain other species that occur in south-western WA spawn in the WCB but not in the SCB, e.g. Australian herring (Fairclough *et al.* 2000; Smith *et al.* 2013a) and blue morwong (*Nemadactylus valenciennesi*) (Coulson *et al.* 2010).

The fact that the preliminary estimates for the length at which King George whiting now typically mature in the WCB (e.g. 440 mm for females) were similar to those recorded by Hyndes *et al.* (1998) (410 mm) suggests that the size at maturity has not changed markedly. As the methods for fitting the maturity curves differed between the two studies (i.e. fitting to observed proportions of mature fish in successive length categories *vs* fitting to observations of maturity status data for individual fish), it is possible that these differences in methodology contributed to the relatively small differences in estimated sizes at maturity. The continued collection of reproductive data for King George whiting will be used to re-examine the question as to whether the size at maturity of this species in the WCB has changed over time, which will also employ a standard approach to analysis.

Mortality estimation and estimates of spawning biomass per recruit

The following discussion is a summary of the outcomes of FRDC project 2010/001 by Fisher *et al.* (in prep), which was focused on developing a model for estimating mortality of species, (including King George whiting), which undertake a pronounced, size-related offshore movement. For fish species which exhibit such a movement, it becomes virtually impossible to obtain representative age and length data for an overall population, as required by traditional stock assessment approaches such as catch curve analysis. This difficulty reflects a combination of differences in the catchability and abundance of fish in the different habitats. Fisher *et al.* (in prep) developed a modeling approach for estimating movement and mortality rates for fish species that exhibit such a movement from size and age composition data. The approach relies on the assumptions that 1) offshore movement is related more to size than to age, whereas 2) fishing mortality (for individuals that are large enough to be fully vulnerable to being caught by the fishing gear), is largely age dependent.

The results of simulation studies by Fisher *et al.* (in prep), using the newly-developed model, highlighted the fact that although fishing mortality for juveniles of King George whiting in inshore waters can be estimated, regardless of sample size, those estimates are likely to be imprecise. This reflects the fact that individuals of this species remain in inshore waters for a very short period of time (typically about two years from age of legal capture), leading to limited information content in the data for estimating mortality.

Although the model was able to be fitted successfully to data collected for King George whiting in the WCB in 2010–2012, several strong assumptions regarding the size ranges over which this species moves offshore were required. Recognising that the preliminary estimates of fishing mortality for inshore waters are uncertain (as the sample size was relatively small and the focus of the study was on model development and testing and not on assessment of this species), the results indicated that fishing pressure on King George whiting near Perth is currently low in offshore waters and high in inshore waters.

A per-recruit analysis, modified to account for size-related, offshore movements of fish, was used to explore the relative impacts of different levels of change in fishing pressure on the reproductive potential (spawning potential ratio) of King George whiting in coastal waters near Perth. The per-recruit analyses indicated that King George whiting in waters near Perth is not currently overfished. However, it also indicated that a moderate increase in fishing mortality (e.g. 40% increase) on King George whiting in inshore waters would be expected to result in the spawning potential ratio (expressed in terms of spawning biomass per recruit) falling below 30% (considered as a threshold reference point). This reflects the fact that King George whiting do not become mature until they move offshore and that individuals caught in inshore waters have thus not had the opportunity to breed. The study also presented the results of a "decision table" analysis that accounted for key uncertainties in the modeling undertaken in that study, and which explored the likely impacts on the overall stock of King George whiting of alternative management scenarios relating to changes in fishing mortality.

4.2.1.3 Other whiting (*Sillago*) species

The results of the study demonstrated that, unlike the situation with King George whiting, the lengths of the four other *Sillago* species in recreational catches (i.e. not considering southern school whiting) were either always or almost always (>95%) above the estimated lengths at maturity (either L_{50} at maturity or length above which all fish are mature). This reflects the fact that recreational netting for these species is low and also that whiting have a relatively small mouth gape, which reduces the susceptibility of juveniles to being caught by more traditional method of hook and line. The fact that nearly all of these species are not caught until they are mature suggests that size limits for each of these species, for the purpose of ensuring that the majority of fish have the opportunity to breed at least once before they are legally able to be retained, are not needed. In the case of southern school whiting, for which there is also no LML for capture and retention, only 7% of individuals donated by recreational fishers were below the typical size at maturity. As discussed elsewhere in this report, it is possible that the overall sampling of fish in this study was not fully representative of the fish actually caught in inshore waters, although the available evidence suggests that the level of fishing on juveniles of southern school whiting by shore-based fishers is much lower than on the adults by boat-based fishers in typically deeper waters.

4.2.2 Recruitment dynamics

The recording, since annual fishery-independent sampling of juvenile recruitment commenced in 1993, of over 80,000 whiting (mostly juveniles) in nearshore waters demonstrates the great importance of these habitats as nursery areas for whiting species, a conclusion previously drawn by a number of authors (*e.g.* Ayvazian and Hyndes, 1995; Hyndes *et al.* 1996a; Gaughan *et al.* 2006). Indeed, the only whiting species which occurs in south-western WA that was not caught in the sampling program for juveniles in nearshore and estuarine waters was stout whiting, a species known to spend its entire life in deeper (>15 m) waters (Hyndes and Potter 1996).

The catch composition of whiting among the various nearshore sites sampled along the coast of the WCB and SCB differed greatly, with yellowfin whiting and King George whiting more commonly found at sheltered sites (e.g. Warnbro Sound), and southern school whiting being most abundant at more exposed sites (e.g. Pinnaroo Point). Again, this is supported by the results of several previous studies (e.g. Lenanton *et al.* 1982; Ayvazian and Hyndes 1995; Hyndes *et al.* 1996a). In this regard, it should be noted that in south-western WA, there are relatively few sheltered beaches in comparison to the number of wave- and swell-exposed beaches and that infrastructure such as jetties, boat ramps and marinas are often built in sheltered locations. Moreover, several marinas have either just been built or proposed at sites (e.g. Peel-Harvey Estuary, Mangles Bay) where very high abundances of juvenile whiting were recorded in this and previous studies (e.g. Hyndes *et al.* 1996a; Whitehead 2000; Gaughan *et al.* 2006). This is therefore an issue that needs to be factored in to management of whiting, and particularly for King George whiting and yellowfin whiting.

Southern school whiting

The finding that small 0+ juveniles of southern school whiting (<60 mm) were caught in substantial numbers in seven months of the year indicates that this species has a very protracted spawning period. This conclusion is supported by the reproductive data presented in this study and by Hyndes and Potter (1996) which indicate that although most activity occurs during summer and early autumn, spawning occurs essentially throughout the year, and thus very protracted. As the seine net used for sampling was relatively large (61 m long, 8 mm bunt) and does not catch very small fish (generally only >30 mm long), it is difficult to link the length frequency data with reproductive data to elucidate the precise timing of settlement of the main pulses of early juveniles. Although the spawning season of southern school whiting in the SCB, as shown by this study, is more defined that in the WCB, it is likely difficult to determine when early 0+ juveniles settle into nearshore nursery habitats. Despite this, the type of sampling has proved effective in detecting differences in the abundance of larger 0+ individuals of this species caught in January to April. These data show that all three WCB sampling sites for southern school whiting, recruitment was relatively low in 2010 and 2011, but higher in 2012 at the two sites within the WCB (Metropolitan Zone), although this was not the case with the remaining site within the bioregion (South-west zone).

The presence of marked inter-annual differences in recruitment of whiting at the survey sites (particularly Metropolitan Zone) suggests that there is potential for such ‘recruitment surveys’ to predict years of low and high abundance of this species in catches. Future work on southern school whiting will investigate whether the difference in recruitment of 0+ juveniles at survey sites translates into marked differences in the strengths of different cohorts in age composition data collected from catches taken by fishers. This could be explored using multi-year approaches to catch curve analysis involving approaches that estimate recruitment variability among year classes (e.g. relative abundance analysis, Deriso *et al.* 1985). If there is a strong link between juvenile recruitment, as measured from recruitment surveys, and recruitment strength as measured in the adult stock from catch curve analysis, this would suggest that the recruitment survey data are useful to management for predicting years of future high or low abundance. Note that as the commercial quantities of this species are very low and vary for a range of reasons including market factors, it has not been possible to link the differences in juvenile recruitment to variations in annual commercial catches.

King George whiting

Despite extensive sampling during this study along the south-western WA coast, 0+ King George whiting have only been recorded in substantial numbers at a few sites. In the WCB, Mangles Bay (Cockburn Sound), Leschenault Inlet and the Peel-Harvey Estuary have been identified as important nursery areas for 0+ King George whiting (see also Sulin, 2012). The first capture, in the WCB, of 0+ recruits of King George whiting in September/October is indicative of a winter spawning season (given its 3–5 month larval phase, Jenkins and May, 1994; Fowler and Short 1996), as is consistent with the reproductive data presented in this report and by Hyndes *et al.* (1998).

In the case of the SCB, the first capture of substantial numbers of King George whiting in December suggests that individuals in this region recruit about two-three months later than in the WCB. It should be noted however, that early 0+ fish were only caught in Princess Royal Harbour (Albany) and that information on the timing of spawning of this species in the SCB (if it occurs) are not yet available.

The results of the recruitment sampling (since 1999) indicate that annual recruitment of 0+ King George whiting to nursery areas in the WCB (Metropolitan and South-west Zone) is highly variable. In south-eastern Australia, KGW recruitment is strongly variable due to various complex interactions with the environment, on both a broad- and local-scale (Jenkins *et al.* 2011). On a broad-scale, strong recruitment strength has been correlated with warmer water temperatures and associated increased larval growth and survival rates (Jenkins and King 2006). The strength of King George whiting recruitment in Victoria has been linked to strong westerly winds (Jenkins and King 2006). On a local-scale, prey availability and habitat structure have also been associated with recruitment strength of King George whiting (Jenkins and Wheatley 1998).

At Mangles Bay, for example, relatively large recruitment occurred in 1999, 2000 and 2008, which coincides with a strong Leeuwin Current in these years. Given that King George whiting are not abundant in areas well to the north of Perth (above about Jurien Bay), it would not appear likely that the Leeuwin Current, which is generally relatively offshore, would be providing the recruits of King George whiting to nursery areas around Perth. It is possible that the larvae of King George whiting, spawned in winter on the west coast, are transported southwards by the Leeuwin Current, but whether this actually occurs remains unknown. There is thus a question as to whether recruitment in the WCB and/or in the SCB) is localised. In this regard, King George whiting in Victorian waters are derived from spawning grounds located in western Victoria and South Australia (Jenkins *et al.* 2000). Furthermore, tagging studies in South Australia have shown that adult King George whiting are capable of moving up to several hundred kilometres (Fowler *et al.* 2002). Thus, it is possible that King George whiting may recruit from distant areas (which is presumably more likely on the south coast given local currents and the timing of spawning) and/or that larger fish may move large distances, possibly to spawn. Of further interest is that the trends in annual commercial catches for the Peel-Harvey Estuary (west coast) and Wilson Inlet (south coast) are similar, suggesting that King George whiting may be recruited from the spawning of adult King George whiting in the same area and/or that environmental conditions influencing the success of spawning and larval survival may be similar among years in the two bioregions.

4.2.3 Recreational fishery catch and effort

Southern school whiting

This study has confirmed that, in 2010–12, up to five species of *Sillago* were retained in the WCB recreational catch and that southern school whiting was the most abundant species in that catch, comprising 90.5% of WCB boat-based samples and 45.8% of shore-based samples. Past surveys of recreational fishing conducted in the WCB, since 1996, demonstrated that, collectively, *Sillago* species were the first or second most abundant species of finfish in the retained catch. Noting that in earlier surveys in the WCB, whiting were not accurately recorded to species level, the results of this study provide a strong indication that southern school whiting was the most abundant finfish species recorded in all of those boat-based surveys (if the whiting composition of the WCB boat-based catch has not changed markedly during those surveys). This therefore demonstrates the great importance of this species to recreational fishers.

The view that southern school whiting was likely to have been the most abundant *Sillago* species in boat-based catches from the WCB since 1996, is consistent with the fact that that 1) yellowfin whiting is a shallow (<5 m depth) nearshore species thus only occasionally caught by boat fishers, 2) western trumpeter whiting and stout whiting are both much smaller than southern school whiting, and rarely attain lengths (>200 mm) at which they are vulnerable to being caught by boat-based line fishers (*i.e.* as most of the recreational boat-based catch of all *Sillago* species is above 200 mm), and 3) adult western school whiting is a sub-tropical species and, although it occurs as far south as Geographe Bay, it is not abundant even in the Metropolitan Zone. Western school whiting also has a relatively restricted depth range of 5–15 m (Hyndes *et al.* 1996a), whereas southern school whiting occurs over a much wider depth range (up to ~55 m), being most abundant in waters over ~20 m (Hyndes *et al.* 1996a).

Using southern school whiting as a proxy for the catch estimate of 'whiting spp.', the retained catch of southern school whiting in previous WCB boat-based surveys has remained relatively constant, averaging approximately 380,000 fish for the four surveys (1996/97, 2005/06, 2008/09 and 2009/10). In the recent state-wide survey of boat-based fishing (Ryan *et al.* 2013), there was a significantly lower retained catch of 'whiting spp.' of 244,162 in 2011/12. This represents a decline of ~36% and may be greater given that the recent survey was more comprehensive and included fishing effort not previously captured in the WCB surveys (e.g. boats launching from marinas). The lower catch of southern school whiting in the most recent recreational survey may be partially attributable to the marine "heat wave" event in 2011 (see Pearce *et al.* 2011), with anecdotal reports from some fishers suggesting that southern school whiting, which is a temperate species, moved to deeper waters, thereby reducing their catchability.

In contrast to the indication from recreational fishing surveys that the abundance of southern school whiting in catches has declined in recent years, catch rates estimated from recreational logbook data suggest that the abundance of southern school whiting in recent years has remained stable. The information from the recreational fishing surveys is considered to be more reliable, however, as the recreational logbook data may be biased by possibly more avid fishers involved in the logbook program (compared with recreational fishers surveyed in general) being able to capture this species when abundance is low. Also, as effort measures in the logbook data include fishers targeting others species such as larger demersal and pelagic species, the catch rates determined from the recreational logbook data may not be reliable as indices of abundance of southern school whiting.

In this study, barotrauma-related injuries (i.e. stomachs protruding from the mouth) were observed in a substantial number of the frames of *Sillago* species donated by fishers. Although the post-release mortality rate of line-caught *Sillago* spp. has not been investigated in WA, a study of the post-release mortality of the sand whiting (*S. ciliata*) in NSW assessed this as low (6%), with the main causes of mortality being attributed to "deep hooking" and how the prevalence of such hooking is influenced by bait type (McGrath *et al.* 2009). However, as that study was undertaken in a shallow estuary rather than in deeper oceanic waters where southern school whiting is abundant, mortality associated with barotrauma may be far higher for southern school whiting. As the percentage of 'whiting spp.' released in past WCB recreational fishing surveys was around 12–25%, post-release mortality could be substantial and therefore could have important implications for stock status (Broadhurst *et al.* 2005; Lenanton *et al.* 2009).

The length frequency data for WCB boat-based recreational surveys suggests that, between 1996 and 2009/10, there has been a progressive (but not large) truncation in the length distribution for 'whiting spp.', with the mean length declining from 249 mm in 1996/97 to 231 in 2009/10. Although the species composition of the fish measured in those surveys is uncertain, it is likely that the reduction in mean length reflects a change in size distribution of southern school whiting. The mean length of fish collected in the WCB in this study, however, was approximately in between these two mean sizes at 239 mm.

King George whiting

Surveys of recreational fishing in WA have identified King George whiting as an important species in both the WCB and SCB, ranking the 4th or 5th most commonly retained finfish species in past WCB boat-based surveys. Although, the number of King George whiting estimated to have been retained by WCB boat-based fishers declined over the four surveys, from approximately 80,000 in 1996/97 to 18,000 in 2009/10. The decline in the catch of King George whiting from 1996/97 is at least partly attributed to an increase in the LML from 250 mm to 280 mm, and probably also the reduction in the bag limit from 20 to 8 in 2003. In this regard, in 1996/97, a substantial amount of the catch (~20%) was between 250–280 mm, before the LML was increased. The most recent state-wide survey conducted suggests, however, that the number of King George whiting retained by boat-based fishers in the WCB increased in 2011/12 (to ~49,000 fish). Note, however, that the state-wide survey was more comprehensive and included fishing effort not previously captured in the WCB surveys (e.g. boats launching from marinas).

The annual trends in recreational King George whiting catches appear to correlate with trends in recruitment, as determined from sampling of juveniles at Mangles Bay. From analysis of the recreational age structure in this study, the majority of the recreational catch in the WCB is comprised mainly of 2 and 3 year old fish, which were caught in nearshore waters. The very low recreational catch estimates in 2008/09 and 2009/10 can be traced back to low recruitment levels from 2005 to 2007. In contrast, in 2008, recruitment levels were relatively high, which may account for the increase in King George whiting catches seen in the 2011/12 survey.

The catch rates for King George whiting determined from the recreational logbook data also suggests that the abundance of this species has increased in recent years. The reliability of this data, however, is uncertain due to one fisher providing approximately half of the overall catch. In addition, the methods employed for calculating catch rates assume that the catchability coefficient is constant over time, which is rarely the case. For example, the main logbook fisher suggested he wasn't able to catch King George whiting as easily in previous years due a high abundance of weeping toadfish (Blowie) (*Torquigener pleurogramma*) preventing capture of King George whiting. He now believes that the local weeping toadfish population has declined in his usual fishing area and is catching King George whiting more frequently, thereby increasing his catch rate.

The finding that the release rate (following capture by fishers) of King George whiting was much higher in the SCB than in the WCB possibly reflects fishers in the SCB mainly catching this species in estuaries and nearshore waters, where all of the individuals of this species are juveniles. In contrast, a substantial number of this species are larger adults caught over offshore reefs. Furthermore, the higher abundance of King George whiting on the SCB may make it easier for fishers to obtain their daily bag limit, after which they may then release fish. Although the post-release mortality of line caught King George whiting in WA has not been investigated, in South Australia, such mortality was estimated to be <3% (Kumar *et al.* 1995). This assessment was based on undersize King George whiting, presumably in shallow nearshore waters where barotrauma was not likely to have been an issue. Given that the majority of King George whiting in WA are caught in shallow nearshore waters, it is expected that post-release mortality will also be low.

The length frequency data for WCB recreational boat-based surveys suggests that there has been no length truncation in King George whiting, with substantial numbers of fish >500 mm recorded in all four surveys.

4.2.4 Commercial fishery catch and effort

On the basis of analyses undertaken in this study, following validation of monthly commercial logbook data, the main whiting species landed by commercial fisheries in the WCB are yellowfin, King George and southern school whiting. Yellowfin and King George whiting are mainly landed in the estuarine fisheries (Hardy Inlet and Peel-Harvey Estuary) and nearshore beach seine fisheries (Geographe Bay/Bunbury region), whereas southern school whiting is predominantly landed by the offshore trawl fishery (SWTMF). Small quantities of western school, southern school and western trumpeter whiting are also likely to be taken in the estuarine and nearshore fisheries. Likewise, small quantities of stout whiting may also be taken in the offshore trawl fishery.

The monthly logbook data indicate that, since 2000, the total commercial fishery landings of whiting in the WCB and SCB have followed a downward trend. Declining catch trends in these bioregions can be at least partly attributed to declining effort in these fisheries, due to a reduction in the number of licensees (i.e. as part of the Voluntary Fisheries Adjustment Scheme run by the Department). Recent commercial catches of whiting in the WCB and SCB are historically low, with 31 t and 10 t landed in 2011, respectively. However, determining trends in catch and catch rate for species-specific data in this family is difficult, due to incorrect identification at the species level and/or wrong use of the accepted Australian standard common names. This extends to the use of generic names (e.g. 'whiting' or 'sand whiting'), which creates confusion to the actual identity of the whiting species caught. Consequently, a level of interpretation by data entry officers, as to what is likely to be the actual species landed for a fishery is required when entering data into the CAES database system. Also, in some fisheries, although the whiting catch is occasionally comprised of more than one species, it is usually 'bundled' and sold together. Note also, that the reliability of the commercial catch rate data is influenced by the fact that the fisheries for whiting, also catch a range of other species and that effort is thus not always directed towards whiting. Catch levels are also influenced by physical processes affecting recruitment into the estuaries (e.g. timing and frequency of sand bar openings).

Southern school whiting

The only commercial fishery identified as catching reasonable quantities of southern school whiting is the SWTMF. An assessment of trends in the catch and catch rate as indices of southern school whiting abundance in this fishery is not possible for a number of reasons. Firstly, species identification is not accurately reported, with the majority of the trawl catch incorrectly assigned to 'western sand whiting' (yellowfin whiting), with some to the 'school' or 'general' whiting categories. Secondly, southern school whiting is a byproduct catch and the abundance and market price of both the target and byproduct species are likely to influence the quantity of southern school whiting retained in this fishery. Finally, quantifying targeted effort in this multi-species fishery is not possible.

An assessment of the southern school whiting stock was undertaken as part of an extensive study on the impact of trawling on benthic communities of south-western Australia (Laurenson *et al.* 1993). In this study, surveys were carried out in trawled and un-trawled grounds to obtain a better understanding of the abundance, distribution and biomass of key recreationally important bycatch species. Southern school whiting were found to be the most abundant whiting species in terms of both biomass and numbers, followed by stout whiting. Total estimated biomass of southern school whiting was calculated between Fremantle and Geographe Bay in 1992 to be 2,806 t. From autumn 1991 to summer 1991/92, the SWTMF caught 22 t of southern school whiting (6.4 t retained and 15.6 t discarded) or 0.8% of the total stock. This total includes the discards (bycatch of juvenile and unwanted adults), which were assumed by that study to have a 100% mortality rate. Using an estimate of natural mortality of 0.3 year^{-1}, the maximum sustainable yield was estimated to be 253 t. The authors concluded that, at the time, southern school whiting was not likely to be over-fished. Although, since that study, effort levels in this trawl fishery have declined and retained catch levels have still averaged about 6 t per year since 1990, suggesting that the percentage of retained southern school whiting in the total catch may have increased from the 29% estimated during the earlier study. The 2011 catch of 13.3 t is the highest since 1987 and may be a result of increasing market demand for this species in this year.

King George whiting

King George whiting is a marine species that uses estuaries and nearshore embayments as nursery areas (Hyndes *et al.* 1998; Potter *et al.* 2011). As King George whiting approach maturity ~420 mm TL, they move out of these areas to deeper waters to spawn and do not return (Hyndes *et al.* 1998; Potter *et al.* 2011). Nearly all of the commercial King George whiting catch in WA is taken in these nursery areas, and thus the fishery targets juvenile fish that have yet to spawn.

The Wilson Inlet commercial fishery mainly captures two age classes (2.5–3.5 age range) of King George whiting, with lengths between the LML of 280 mm to ~410 mm, at which size they move out of the estuary as they approach maturity (Potter *et al.* 2011). This is supported by extensive length monitoring of SCB estuarine commercial catches in 1998–2002 (DoF unpublished data) which showed the majority of King George whiting were caught between these lengths. Therefore, the catch rate of this fishery reflects the relative abundance of these two age classes in any year.

Trends in King George whiting catch rates between Wilson Inlet (SCB) and the Peel-Harvey Estuary (WCB) were similar, with both exhibiting a pronounced peak from 1998 to 2000. The high catch and catch rate during this period can be attributed to successive years of high recruitment into these estuaries. The similarity in catch trends among these separate fisheries suggests a correlation in stock abundance in the two bioregions. However, recruitment strength of juvenile King George whiting in estuaries is influenced by various local physical processes, including environmental conditions and access (i.e. sand bar openings) into the estuary. In the Peel-Harvey Estuary, the opening of the Dawesville Channel in 1994 has been accompanied by a slight increase in the recruitment of juvenile King George whiting into this estuarine system, possibly due to enhanced accessibility, as well improvements in the water quality and/or food availability.

In Wilson Inlet, the frequencies of sand bar openings are likely to have affected King George whiting abundance, particularly in recent years. In WA, King George whiting spawn during winter to early spring which typically corresponds with estuary sand bar openings on the SCB following winter rain. For the first time since official records were kept in 1955, the Wilson Inlet sand bar remained closed in 2007 and then again in 2010 due to low estuary water levels following low rainfall years. The bar closure in 2007 is likely to be the main reason for the record low King George whiting catches of 0.7 t in 2009 and 2010, which is well below the long-term yearly average (1980–2011) of 8.2 t for this estuary. Recruitment by marine-spawned fish, such as King George whiting, will not occur during years when the bar is closed. In future years, the non-breaching of the bar may occur more frequently, due to lower annual rainfall as a result of climate change (Lough and Hobday 2011).

The suitability of the estuarine catch rates to provide a reliable index of abundance for King George whiting is also affected by the multi-species nature of these netting fisheries, making it difficult to determine targeted effort data for a single species. In the Peel-Harvey Estuary, the main target species are blue swimmer crabs, yellow-eye mullet and sea mullet. Since 2000, these three species comprised approximately 85% of all commercial landings in this estuary, whereas King George whiting comprised only <2%. However, given the high price for King George whiting, if the fish are present in sufficient numbers then they are likely to be targeted.

5.0 'Weight-of-evidence' assessment and implications

As discussed throughout this report, the sustainable management of whiting in WA has been hampered by a lack of species-specific data for the various *Sillago* species. The difficulties associated with identifying individual species in this genus have resulted in a poor understanding of the main species caught recreationally and commercially. As a result, whiting were recognised as having a high sustainability risk due to the uncertainty in the catch composition. Furthermore, a growing recreational population and a potential shift in effort from larger inshore demersal species towards whiting have added to that risk.

The main whiting species identified in the recreational catch of south-western WA were southern school whiting and King George whiting. These two species represent the majority of the catch, particularly by the boat-based sector. Although the composition of the shore-based catch is less certain than for the boat-based catch, the sample of nearly 600 fish collected in this study indicates that it is comprised of mainly southern school whiting and yellowfin whiting. The relative contribution of shore-based catches to the overall catch of whiting in WA is also uncertain. The best information available on this contribution is from the recreational survey of boat- and shore-based fishing in WA, undertaken over 12 years ago, which estimated that ~40% of *Sillago* and 12% of King George whiting total landings in south-western WA were taken by shore-based fishers (Henry and Lyle 2003).

As discussed above (in more detail), there are uncertainties around the estimates of fishing mortality derived for both southern school whiting and King George whiting. A key uncertainty regarding southern school whiting is that there is potentially substantial mortality of small fish in inshore waters due to shore-based fishing which was not able to be captured in the catch curve estimates of mortality. In the case of King George whiting, the estimate of fishing mortality for fish in inshore waters was highly uncertain.

In overview, in many regards, the fisheries for whiting in WA may still be considered as data limited, and given the uncertainties that exist regarding quantitative measures of stock status, it is considered highly appropriate that all available sources of information be used (i.e. in a 'weight-of-evidence' approach), to assess the status of the key stocks of whiting. The overall assessment of the status of the stocks of southern school whiting and King George whiting are summarised below.

5.1 Summary of stock status

5.1.1 Southern school whiting

Stock structure: The stock structure of southern school whiting is unknown, but is likely to be comprised of one single stock across its range due to the expected high connectivity between the WCB and SCB from adult migration and larval dispersal. However, a genetic study of commercially important whiting species in Australian waters suggested that the southern school whiting stock may consist of separate sub-populations, although the limited study recommended further research to confirm preliminary results (Dixon *et al.* 1987). Additional research is thus required to determine whether southern school whiting should be managed as a single stock across both bioregions.

Mortality estimation: Estimates of fishing mortality were derived from representative samples of the age structure from recreational boat-based catches. The values of F were 0.28.year^{-1}

(95% CLs, 0.19–0.40.$year^{-1}$), using the linear catch curve method (Ricker 1975) and 0.24.$year^{-1}$ (95% CLs, 0.20–0.28.$year^{-1}$), using Chapman and Robson's (1960) method. The mean F values produced by the two methods lay around the F_{target} reference point and below the $F_{threshold}$ (Table 14).

Per recruit analyses: Spawning potential ratio (determined from per recruit analyses) was estimated as 0.37 (0.24–0.47) based on the current estimated value of F determined from the linear catch curve analysis method and 0.45 (0.40–0.50) based on that from Chapman and Robson's (1960) method. The mean estimates for *SPR* were either slightly below or above the target reference points in 2011, thus indicating the stock is at an acceptable level.

Fishery catch and effort: No suitable commercial fishery data were available to assess trends in catch or catch rate. Recreational fishery data for the WCB boat-based sector suggests that catches were stable from 1996 to 2010. However, the estimated catch for 2011/12 was >35% lower than the average between 1996 and 2010, suggesting that stock abundance may have recently declined.

Recruitment trends: There is low confidence in the assessment of recruitment trends due to a lack of data for the main settlement months at the key sites to provide a long time series. The recruitment data for both the northern and southern metropolitan sites suggest that recruitment was low from 2010 to 2011, but relatively high in 2012.

Juvenile retention: Of recreational samples collected in this study, approximately only 7% were below the length at which 50% of individuals attain maturity. Thus, the capture and retention of juveniles by fishers is apparently low, although the rate for the overall stock may have been underestimated due to relatively limited sampling of shore-based catches.

Overall vulnerability: Overall, southern school whiting were determined to have a 'low' vulnerability (Table 15).

Summary: On the basis of the evidence provided above, the stock status for southern school whiting is deemed as <u>acceptable</u>. Current estimates of fishing mortality and spawning potential ratio suggest that catch levels are around the target reference point and thus below the threshold reference point. Based on the control rules developed by the Department of Fisheries for finfish fisheries and F-based assessments, it is advised that current catch levels can be allowed to be maintained. However, as there are some uncertainties associated with the overall assessment, it is recommended that the stock requires continued monitoring and research to overcome key gaps in knowledge identified in this report (see below).

Future monitoring and assessment: For future assessments, it is recommended that additional and consecutive years of age data be collected, to address uncertainties in estimates of F associated with variations in recruitment in this species. Improved information on the contribution of shore-based catches to the overall catch is very important, particularly as shore-based fishers were previously estimated (about 12 years ago) to land about 40% of the overall catch of *Sillago* species in south-western WA. This could be accomplished through a recreational fishing survey, noting also that a known sampling frame would be required to enable more cost-effective, shore-based surveys (Smallwood *et al.* 2011). As *Sillago* species are difficult to distinguish, continued training of survey field staff in identifying this species will be important for ensuring a high level of accuracy of information from future surveys.

5.1.2 King George whiting

Stock structure: The stock structure of King George whiting in WA is unknown but is expected to consist of a single breeding stock due to a probable high connectivity across its distribution. This hypothesis is supported by research findings in south-eastern Australia where King George whiting were found to have a long larval phase of 3–5 months (Jenkins and May 1994; Fowler and Short 1996) and adults were capable of moving up to several hundred kilometres (Fowler *et al.* 2002). However, hydrodynamic modelling of larval advection pathways in South Australia suggest that the King George whiting stock there consists of numerous, self-sustaining local populations (Fowler *et al.* 2000b), whereas in Victoria, the population consists of a single large stock (Jenkins *et al.* 2000). From limited samples collected in South Australia and Victoria, a preliminary analysis of the stock structure using allozyme electrophoresis suggested that there may be sub-structuring within the King George whiting population, but more comprehensive sampling across the species range was required to confirm these findings (Dixon *et al.* 1987). More recent analysis of stock structure based on mitochondrial DNA and microsatellite primers using samples obtained in WA, South Australia and Victoria found no evidence of long-standing population structure or population differentiation (Haigh and Donnellan 2000). Based on inter-estuarine differences in year classes, Potter *et al.* (2011) hypothesised that the King George whiting population on the south coast of WA may be comprised of relatively discrete, local spawning populations, however, in this study there was no evidence of spawning on the south coast (albeit from limited offshore samples) and the delay in settlement in this bioregion compared to the WCB suggests that the spawning location may be located further to the north. Additional research is thus required to determine the stock structure of King George whiting in WA to enable more effective research and management of this species.

Mortality estimation: Due to the offshore, size-related movement of King George whiting, it was not possible to obtain a representative sample of age structure for the overall population to determine an estimate of fishing mortality using traditional methods. Fisher *et al.* (in prep) developed a model that produced estimates of fishing mortality for King George whiting in inshore and offshore waters that accounts for the offshore movement of this species and then applied these estimates in a per recruit analysis to estimate overall stock status. Preliminary estimates of fishing mortality, estimated using size and age data for King George whiting sampled from catches taken by recreational fishers in 2010–12 were 0.55.year^{-1} (95% CLs, 0.11–1.00.year^{-1}) in the inshore region and 0.06.year^{-1} (95% CLs, 0.00–0.12.year^{-1}) in the offshore region. With an estimated value of natural mortality of 0.30.year^{-1}, the estimate of fishing mortality in the inshore region is high (exceeding reference point F_{limit}), noting however that this estimate is very uncertain (with the confidence interval being very wide). The estimate of fishing mortality in the offshore region, where this species spends the majority of its life and where the breeding stock is located, is very low (below F_{target}). Thus, although there is apparently substantial fishing for juveniles, if those juveniles survive to become adults, there is a high chance that they will survive to breed (Table 16).

Per recruit analyses: At current estimated levels of fishing for King George whiting in inshore and offshore waters, the spawning potential ratio (based on the spawning biomass per recruit) is estimated at 42% of unfished levels.

Fishery catch and effort: The long-term catch and catch rate trends for the commercial fisheries in Wilson Inlet (SCB) and in the Peel-Harvey Estuary (WCB) are fairly stable, except for a large peak in recruitment in the late 1990's. It is important to note, however, that the trends in catch and catch rates can be influenced by various factors. For example, commercial catch rates may be biased due to targeting of other fish species in these multi-species fisheries. Also, commercial catches are focused on juveniles in estuaries and may be low due to a lack of recruitment resulting from the sand bar of an estuary remaining closed in winter (which does not necessarily reflect the actual abundance of adults).

Recreational fishery data suggests declining catches from 1996 to 2010. The estimates for 2011/12 were higher suggesting a recent increase in stock abundance, availability or targeting by boat-based fishers.

Recruitment trends: Recruitment trends for King George whiting have been monitored at Mangles Bay (Cockburn Sound) since 1999. Recruitment levels were relatively high in 1999 and 2000, and have been relatively low since, with the exception of 2008. Since 2010, recruitment has been increasing.

Juvenile retention: Recreational fisheries in the SCB and South-west Zone of the WCB predominantly capture juvenile fish in inshore waters and thus the capture and retention of juveniles is high. An estimated 94% of the SCB and 79% of the WCB recreational catch was of fish below the length at which 50% of individuals attain maturity. Similarly, the majority (>95%) of the commercial catch is also comprised of immature fish.

Overall vulnerability: King George whiting were determined to have a 'low to medium' vulnerability (Table 17).

Summary: On the basis of the evidence provided above, the King George whiting stock status is deemed as <u>acceptable</u>. Current estimates of fishing mortality for offshore fish (breeding stock) are low. There is, however, a moderate risk to the sustainability of the stock due to the apparently high fishing mortality of inshore fish, which is consistent with catch data demonstrating that juvenile (immature) fish comprise most of the overall catch (79% in WCB and 94% in SCB of recreational catch). The current catch from the recreational and commercial sectors is largely comprised of 2 and 3 year old fish that have yet to spawn. The breeding stock has been offered some protection due to the unidirectional offshore migration to deeper waters, where individuals tend to become more dispersed. However, the breeding stock may be at an increased risk through increased targeting of this part of the stock through greater boat ownership, including larger boats, and increases in efficiency through technology creep (GPS, sounders, etc.). Per-recruit analyses have indicated that if exploitation in inshore regions were to increase moderately (by 40%), the spawning potential ratio of the Metropolitan stock could be reduced to a level that would be concerning (i.e. ~30% of unfished levels). King George whiting recruitment is highly variable. Recent consecutive years (2005–2007) of low recruitment in this species appear to have resulted in low recreational catches 2–3 years later. High recruitment indices in 2008 appear to have translated to the higher recreational catch observed in the 2011/12 state-wide survey. Recruitment levels in 2009 and 2010 were low again, but have been increasing to 2012. Recruitment levels are expected to be effected by environmental impacts in the generally highly-populated areas near nursery habitats e.g. seagrass loss.

Based on the control rules developed by the Department of Fisheries for finfish fisheries and *F*-based assessments, the scientific advice is to allow current catch levels to be maintained. However, the high retention of immature fish by commercial and recreational fishers, combined with the range of uncertainties regarding the overall assessment, presents an increased risk to the stock. Thus, it is recommended that consideration be given to increasing the LML to allow more juvenile fish the opportunity to spawn. This would have implications for their accessibility to nearshore and estuarine fishing activities.

Future monitoring and assessment: Regular monitoring of the age structure is recommended to improve estimates of fishing mortality. For the WCB, more samples of King George whiting are required, particularly for inshore waters and for the SCB, more fish are required from offshore waters to improve the reliability of the F-based assessment. Sampling of juvenile 0+ King George whiting at nursery sites, particularly Mangles Bay, Leschenault Inlet and Oyster Harbour, needs to continue to provide a long-term index of abundance. Stock discrimination studies are recommended to ascertain if there are separate breeding stocks in the WCB and SCB, or if SCB fish are mainly derived from fish spawned on the WCB. Knowledge of annual fecundity, and associated information on the reproductive biology for King George whiting in different areas in WA, would allow a more thorough assessment of the reproductive potential of the stock.

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Table 1. Recreational size and mixed species daily bag limits for whiting species in the West Coast Bioregion and South Coast Bioregion of Western Australia during the survey period (2010–2012). LML: legal minimum length. Note: On 1 February 2013, state-wide bag limits were introduced. King George whiting: bag limit of 12, all other whiting (including yellowfin whiting): bag limit of 30.

Whiting species	West Coast Bioregion		South Coast Bioregion	
	LML	Mixed spp. bag limit	LML	Mixed spp. bag limit
King George	280 mm	8	280 mm	12
Yellowfin	-	12	-	16
Southern school	-	30	-	40
Western school	-	30	-	40
Western trumpeter	-	30	-	40
Stout	-	30	-	40

Table 2. Estimated total catch in tonnes (t) of the three main whiting species caught by commercial and recreational (boat- and shore-based) fishers in Western Australia during 2011/12. For each whiting species by bioregion, the percentage catch share of the recreational sector is shown along with the average length (mm) and weight (g) of each species in the recreational catch which was used to estimate the recreational catch in tonnes. SSW: southern school whiting; YFW: yellowfin whiting; KGW: King George whiting; WCB: West Coast Bioregion; SCB: South Coast Bioregion; rec: recreational fishery; com: commercial fishery.

Species	Bioregion	Com Catch (t)	Rec Catch (t)	Total catch (t)	% rec share	Av rec Length (mm)	Av rec Weight (g)
SSW	WCB	13.3	39.7	53.0	74.9%	239	112
	SCB	0	3.3	3.3	100.0%	230	99
YFW	WCB	24.6	9.0	33.6	26.8%	253	123
	SCB	0.7	2.7	3.4	79.4%	253	123
KGW	WCB	5.1	16.7	21.8	76.5%	366	301
	SCB	9.2	14.0	23.2	60.3%	325	209

Table 3. Estimated von Bertalanffy growth parameters for southern school whiting in the West Coast Bioregion of Western Australia, 2011. L_∞, asymptotic total length (mm); k growth coefficient (year^{-1}); t_0, hypothetical age at zero length (year); n, sample size.

	L_∞ (mm)	k (year^{-1})	t_0 (year)	n
Female	287	0.66	-0.12	376
Male	287	0.63	-0.11	326
Both sexes	287	0.64	-0.12	702

Table 4. Estimates of logistic parameters describing the lengths at which 50 and 95% of southern school whiting of a specified sex attain maturity (L_{50} and L_{95}, respectively) and of the ages at which 50 and 95% of such individuals attain maturity (A_{50} and A_{95}). The lower and upper 95% confidence limits for each parameter are provided in brackets. WCB: West Coast Bioregion; SCB: South Coast Bioregion. Note: insufficient data to determine for males in the SCB.

Maturity	Bioregion	Sex	L50	L95	*n*
Length	WCB	Female	207 (202–211)	240 (234–246)	449
		Male	194 (188–201)	231 (224–239)	393
		Both sexes	201 (197–204)	237 (232–241)	842
	SCB	Female	178 (165–190)	221 (192–243)	112
		Male	-	-	
		Both sexes	165 (154–175)	206 (183–220)	247
			***A*50**	***A*95**	
Age	WCB	Female	1.9 (1.8–2.1)	2.9 (2.5–3.3)	147
		Male	1.6 (1.4–1.9)	2.6 (1.4–3.6)	105
		Both sexes	1.8 (1.7–2.0)	2.8 (2.5–3.2)	252

Table 5. Estimates of total mortality rate (*Z*, year^{-1}), natural mortality (*M*, year^{-1}), fishing mortality (*F*, year^{-1}), yield per recruit (YPR, g), spawning stock biomass per recruit (SSBR, g) and spawning potential ratio (*SPR*) for southern school whiting in the West Coast Bioregion (Metropolitan Zone). The estimates of *Z* were derived using age samples from catches of boat-based recreational fishers in 2011, employing the linear catch curve described by Ricker (1975) and the catch curve of Chapman and Robson (1960). Spawning potential ratio is expressed in terms of spawning biomass per recruit. The lower and upper 95% confidence limits are provided in brackets.

	Z	M	F	YPR	SSBR	SPR
Ricker (1975)	0.65 (0.57–0.77)	0.37	0.28 (0.19–0.40)	18.26 (17.05–17.86)	7.2 (4.7–9.2)	0.37 (0.24–0.47)
Chapman & Robson (1960)	0.61 (0.57–0.66)	0.37	0.24 (0.20–0.28)	17.37 (16.43–18.04)	8.8 (7.7–9.8)	0.45 (0.40–0.50)

Table 6. Estimated von Bertalanffy growth parameters for King George whiting in the West Coast Bioregion (WCB) (Metropolitan Zone only) and South Coast Bioregion (SCB) of Western Australia during 2010/11 (Sulin 2012). L_∞, asymptotic total length (mm); *k*, growth coefficient (year^{-1}); t_0, hypothetical age at zero length (year); *n*, sample size. Note that Sulin (2012) presented growth parameters for the traditional form of von Bertalanffy growth model and for an adjusted form which accounts for offshore size-related movement. To facilitate comparisons, the parameters derived for the traditional form are presented here.

Bioregion	Sex	L∞ (mm, TL)	k (year^{-1})	t_0 (year)	*n*
WCB (Metro)	Female	565	0.36	0.01	226
	Male	536	0.39	0.00	203
SCB	Female	406	0.53	0.10	673
	Male	397	0.56	0.12	692

Table 7. Estimates of logistic parameters describing the lengths at which 50 and 95% of King George whiting of a specified sex attain maturity (L_{50} and L_{95}, respectively) in Western Australia. The lower and upper 95% confidence limits for each parameter are provided in brackets.

Maturity	Bioregion	Sex	L50 (95% CL)	L95 (95% CL)	*n*
Length	WCB	Female	440 (427–454)	491 (469–523)	204
		Male	437 (426–449)	485 (459–509)	187
		Both sexes	438 (429–447)	491 (469–514)	398
	SCB	Female	427 (415–448)	484 (445–546)	81
		Male	399 (387–414)	432 (410–426)	61
		Both sexes	415 (406–425)	467 (444–496)	142

Table 8. List of the top ten retained fish species (ranked by abundance in catch) in the West Coast Bioregion (WCB), recorded in seven recreational fishing surveys undertaken between 1996 and 2012.

Year	1996/97	2000/01	2005/06	2008/09	2009/10	2005–11	2011/12
Bioregion	WCB	WCB	WCB	WCB	WCB	WCB	WCB
Sector	Boat	Boat/shore	Boat	Boat	Boat	Boat/shore	Boat
Survey	Creel[1]	National[1]	Creel[3]	Creel[4]	Creel[4]	RAP logbook[4]	Integrated survey[5]
1	Whiting spp.	Australian herring	Whiting spp.	Whiting spp.	Whiting spp.	Australian herring	Whiting spp.
2	Australian herring	Whiting spp.	Australian herring	Australian herring	Australian herring	Whiting spp.	Australian herring
3	Silver trevally	Tailor	Silver trevally	Silver trevally	Silver trevally	King George whiting	Silver trevally
4	King George whiting	King George whiting	King George whiting	West Australian dhufish	King George whiting	Silver trevally	King George whiting
5	West Australian dhufish	Garfish spp.	West Australian dhufish	King George whiting	West Australian dhufish	Tailor	Garfish spp.
6	Snapper	Silver trevally	Breaksea cod	Breaksea cod	Snapper	Garfish spp.	Tailor
7	Breaksea cod	Tarwhine	Snapper	Snapper	Breaksea cod	Black bream	Mullet spp.
8	Blue morwong	West Australian dhufish	Baldchin groper	Baldchin groper	Baldchin groper	West Australian dhufish	Wrasse spp.
9	Baldchin groper	Western butterfish	Red-throat emperor	Red-throat emperor	Blue morwong	Yelloweye mullet	West Australian dhufish
10	Sea sweep	Yellowtail scad	Blue morwong	Sergeant baker	Sergeant baker	Snapper	Snapper

References: 1 = Sumner and Willamson (1999), 2 = Henry and Lyle (2003), 3 = Sumner *et al.* (2008), 4 = DoF unpublished, 5 = Ryan *et al.* (2013). Note: that for the 2000/01National Survey (Henry and Lyle 2003), yellowfin whiting was grouped separately but this species has been included here as part of the 'whiting spp.' group.

Table 9. Annual recreational catches of *Sillago* species (referred to as 'whiting spp.') estimated during recreational fishing surveys in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) of Western Australia (WA).

Region	Survey type	Period	Sector	No. kept	% released
WA	Phone	2000/01	All	2,126,680	21
	Phone/diary	2011/12	All	264,068	21
WCB	Creel	1996/97	Boat	397,199	17
	Phone	2000/01	All	1,942,221	21
	Phone	2000/01	Shore	737,943	25
	Phone	2000/01	Boat	1,204,278	18
	Creel	2005/06	Boat	367,425	14
	Creel	2008/09	Boat	379,602	12
	Creel	2009/10	Boat	374,795	16
	Phone/diary	2011/12	Boat	244,162	21
Perth (WCB)	Multiple	Apr–Jun 2010	Shore	19,879	24
SCB	Phone	2000/01	All	103,806	23
	Phone	2000/01	Shore	50,339	25
	Phone	2000/01	Boat	53,466	20
	Phone/diary	2011/12	Boat	17,440	29
Estuaries (SCB)	Creel	2002/03	All	1,202	56

Table 10. Estimated catches of *Sillago* species ('whiting spp.') retained by recreational fishers in each bioregion of Western Australia (WA), and the percentages of those catches taken by shore- and boat-based fishers (%) in each bioregion, in 2000/01 (Henry and Lyle 2003). Note: that the catches of yellowfin whiting were estimated separately in this study but have been included with the 'whiting spp.' catch here. NCB: North Coast Bioregion; GCB: Gascoyne Coast Bioregion; WCB: West Coast Bioregion; SCB: South Coast Bioregion.

'whiting spp.'	NCB	GCB	WCB	SCB	WA
Total retained catch % of total WA catch	43,337 (2%)	37,316 (2%)	1,942,221 (91%)	103,806 (5%)	2,126,680
% Boat	3%	36%	62%	52%	60%
% Shore	97%	64%	38%	48%	40%

Table 11. Annual recreational catches of King George whiting estimated during recreational fishing surveys in the West Coast Bioregion (WCB) and South Coast Bioregion (SCB) of Western Australia (WA).

Region	Survey type	Period	Sector	No. kept	% released
WA	Phone	2000/01	All	408,209	27
	Phone	2011/12	Boat	107,689	36
WCB	Creel	1996/97	Boat	79,529	16
	Phone	2000/01	All	244,679	11
	Phone	2000/01	Shore	29,661	25
	Phone	2000/01	Boat	215,018	9
	Creel	2005/06	Boat	42,981	17
	Creel	2008/09	Boat	21,514	12
	Creel	2009/10	Boat	18,351	20
	Phone/diary	2011/12	Boat	48,678	29
Perth (WCB)	Multiple	Apr–Jun 2010	Shore	-	-
SCB	Phone	2000/01	All	162,832	43
	Phone	2000/01	Shore	20,062	49
	Phone	2000/01	Boat	142,770	42
	Phone/diary	2011/12	Boat	59,011	41
Estuaries (SCB)	Creel	2002/03	All	71,548	41

Table 12. Estimated catch of King George whiting retained by recreational fishers in each bioregion of Western Australia (WA), and the percentages of each catch taken by shore and boat-based fishers in 2000/01 (Henry and Lyle 2003). NCB: North Coast Bioregion; GCB: Gascoyne Coast Bioregion; WCB: West Coast Bioregion; SCB: South Coast Bioregion.

King George whiting	NCB	GCB	WCB	SCB	WA
Total retained catch % of total WA catch	0	0	244,679 (60%)	162,832 (40%)	408,209
% Boat			88%	88%	88%
% Shore			12%	12%	12%

Table 13. Attributes indicating vulnerability of stock(s) of indicator species (adapted from Wise *et al.* 2007)

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

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

Table 14. Summary of quantitative assessments for southern school whiting (SSW). WCB: West Coast Bioregion; SCB: South Coast Bioregion; Com: commercial fishery; Rec: recreational fishery.

Method	Result	Confidence	Implication for stock status
F (fishing mortality)	Estimates of F derived from two separate methods were around the F_{Target} and below the $F_{Threshold}$	Medium	Estimates of F suggest stock status is acceptable
Per recruit analyses	Spawning Potential Ratio is around the target level (SPR=0.4)	Medium	Current level of exploitation is sustainable
Com catch	The general trend in the SWTMF cpue since early 1990s is increasing, however it is not possible to determine targeted effort for this species in this fishery	Low	Unknown
Rec catch	The catch trend in the WCB has been stable from 1995 to 2010. Catch estimates for 2011/12 were >35% less	Medium	Suggests recent low stock abundance
0+ recruitment trend	The long-term data available for SSW is limited due to infrequent sampling of key months at key sites for this species. Limited evidence suggests relatively low recruitment levels in 2010 and 2011 but high in 2012	Low/medium	Low stock abundance is expected in 2013/14 but higher abundance in the following year
Juvenile retention	WCB rec catch <7% The retention of juvenile (immature) fish is low but limited samples were collected from shore-based sector which is comprised of smaller and younger fish	Medium-High	Relatively low proportion
Length and age truncation	Little evidence of length truncation in the recreational catch.	Medium-High	Suggests no evidence of high exploitation
Change in length and/or age at maturity	No decline in $L_{50\%}$ in past 20 years	High	Suggests no evidence of high exploitation

Unacceptable	Uncertain	Acceptable

Table 15. Summary of the productivity and susceptibility attributes and implications for vulnerability of southern school whiting (as defined in Table 13). The vulnerability scores for productivity were low to medium, which indicates that this stock has relatively high productivity. The vulnerability scores for susceptibility ranged from low to medium, which indicates that this stock has a low susceptible to fishing. Overall vulnerability level is LOW.

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

Table 16. Summary of quantitative assessments for King George whiting. WCB: West Coast Bioregion; SCB: South Coast Bioregion; Com: commercial fishery; Rec: recreational fishery.

Method	Result	Confidence	Implication for stock status
F (fishing mortality)	Offshore: F < F Target Inshore: F > F Limit	Medium	Below target reference point for breeding stock (offshore fish)
Per recruit	Spawning potential ratio at 42% unfished levels	Medium	Acceptable level however if exploitation in inshore regions were to increase markedly, the spawning potential ratio of the Metropolitan stock could be reduced to a low level
Com catch trend	The long term trend appears stable in the WCB and SCB. Recent low catches in Wilson Inlet can be attributed to the estuary bar not opening.	Medium	Trends are consistent with stable exploitation rates although there is some uncertainty with targeting in multi-species fisheries
Com Catch rate trend	The recent trend is increasing in the Peel-Harvey Estuary and declining in Wilson Inlet. Both are influenced by availability of recruits to the estuary.	Low	Uncertain due to targeting in multi-species fishery and environmental influences
Rec catch trend	Long term trend from 1995 to 2010 had been declining. Catch estimates from 2011/12 has seen an increase in the catch.	Medium	Suggests recent strong recruitment however there is evidence of a general long-term decline in abundance.
Rec catch rate trend	Recent trend in rec logbook suggests an increasing trend but data is potentially biased by low number of anglers	Low-Medium	Uncertain due to potential biases in the current dataset
0+ recruitment trend	Relatively high in 2008 but low in other recent years, although trend is increasing to 2012	Medium	Low stock abundance likely in next few years but recruitment trend is increasing. Recent recruitment trends may reflect lower recruitment potential and/ or unfavourable environmental conditions
% immature fish in catch	WCB rec catch: 79%. SCB rec catch: 4% Com Catch: >95% mostly in estuaries and considered immature.	High	Relatively high proportion
Length truncation	WCB rec – no evidence of length truncation in the boat-based surveys.	High	Suggests no influence of high exploitation
Change in length and/ or age at maturity	In comparison with studies in early 1990s, there has been no change in length or age at maturity.	High	Suggests no influence of high exploitation

Unacceptable	Uncertain	Acceptable

Table 17. Summary of the productivity and susceptibility attributes and implications for vulnerability of King George whiting (as defined in Table 13). The vulnerability scores for productivity were low to medium, which indicates that this stock has relatively moderate to high productivity. The vulnerability scores for susceptibility ranged from low to high, which indicates that this stock is moderately susceptible to fishing. Overall vulnerability level is LOW to MEDIUM.

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

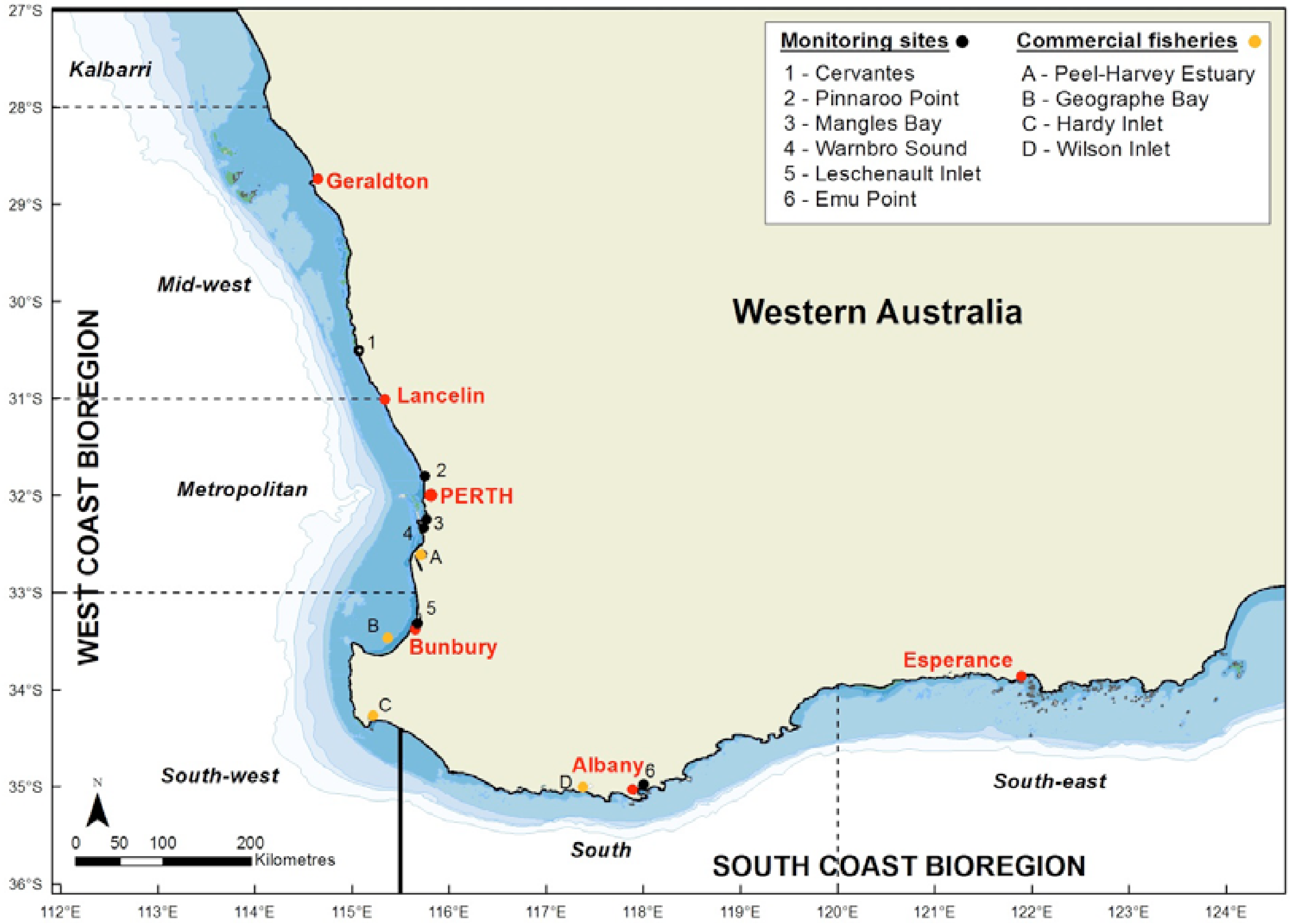


Figure 1. Locations of main recruitment monitoring sites (black dots), commercial fisheries (red dots) and boundaries of Bioregions (West Coast, South Coast) and Zones within Bioregions (Kalbarri, Mid-west, Metropolitan, South-west, South, South-east) of south-western Australia.

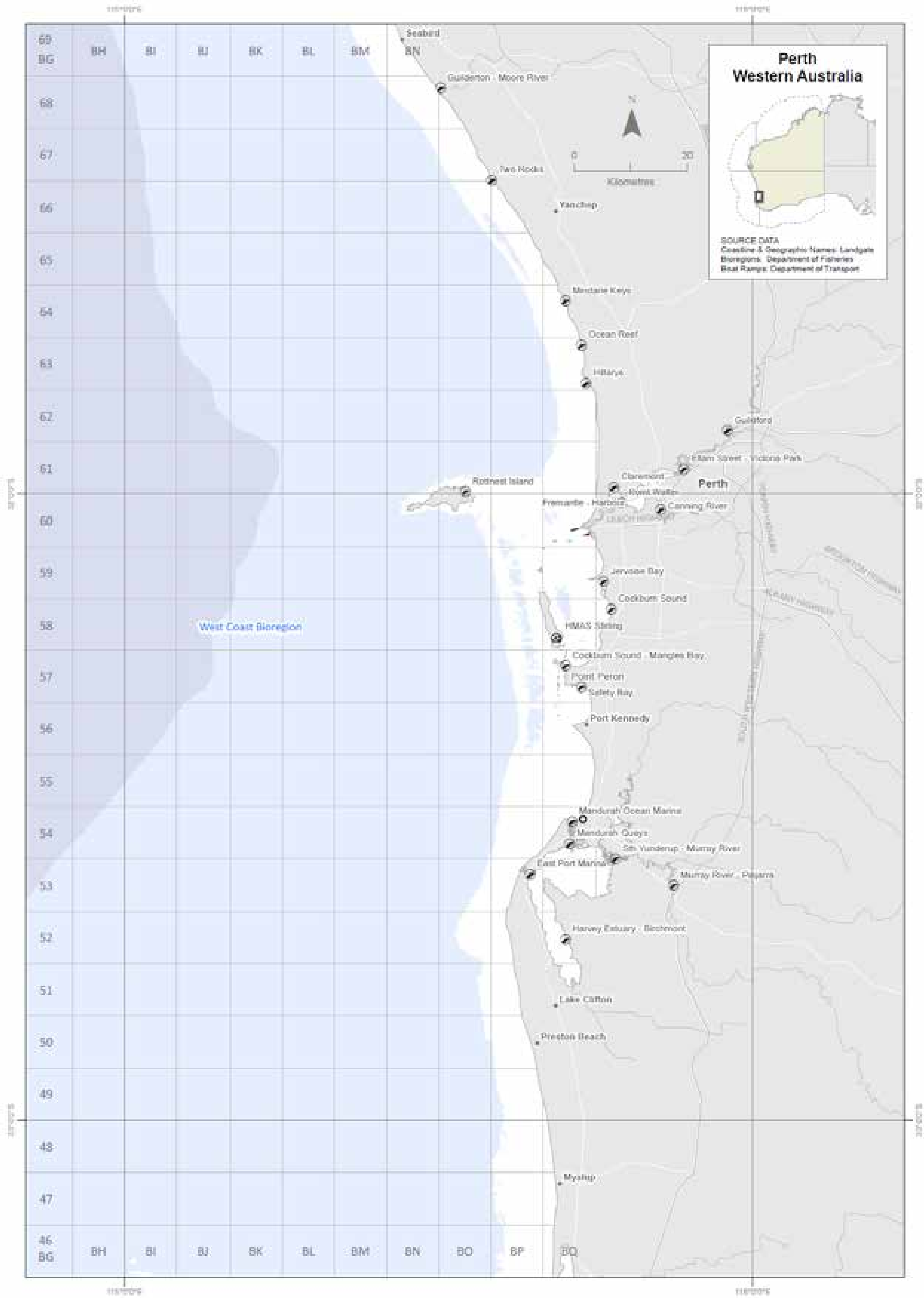


Figure 2. Grid map of Perth blocks (5 x 5 nautical miles) used by voluntary logbook fishers to report catch and effort in the West Coast Bioregion of Western Australia.

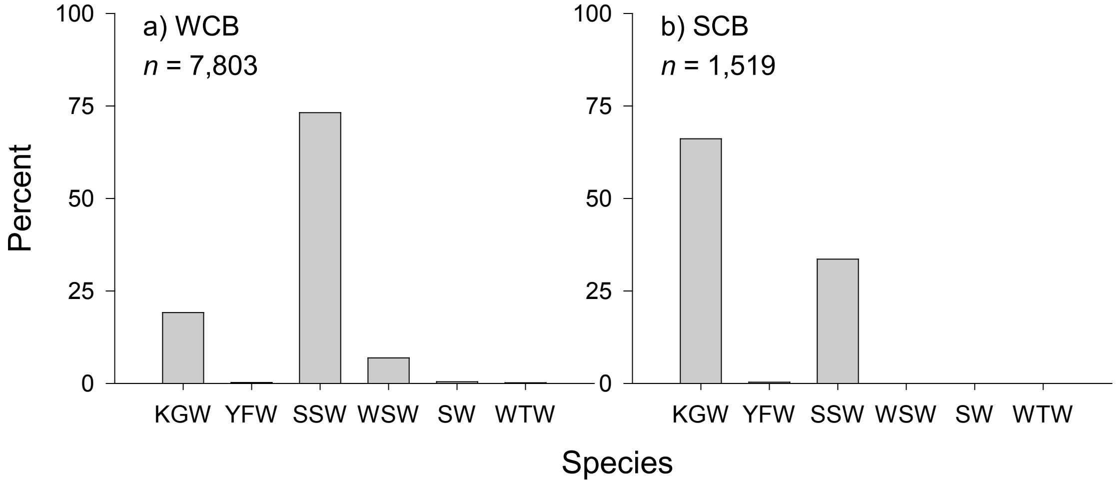


Figure 3. Percentages of different species of whiting in catches of these species taken in July 2010 to December 2012 by boat-based recreational fishers in the **a)** West Coast Bioregion (WCB) and **b)** South Coast Bioregion (SCB). KGW, King George whiting; YFW, yellowfin whiting; SSW, southern school whiting; WSW, western school whiting; SW, stout whiting; WTW, western trumpeter whiting.

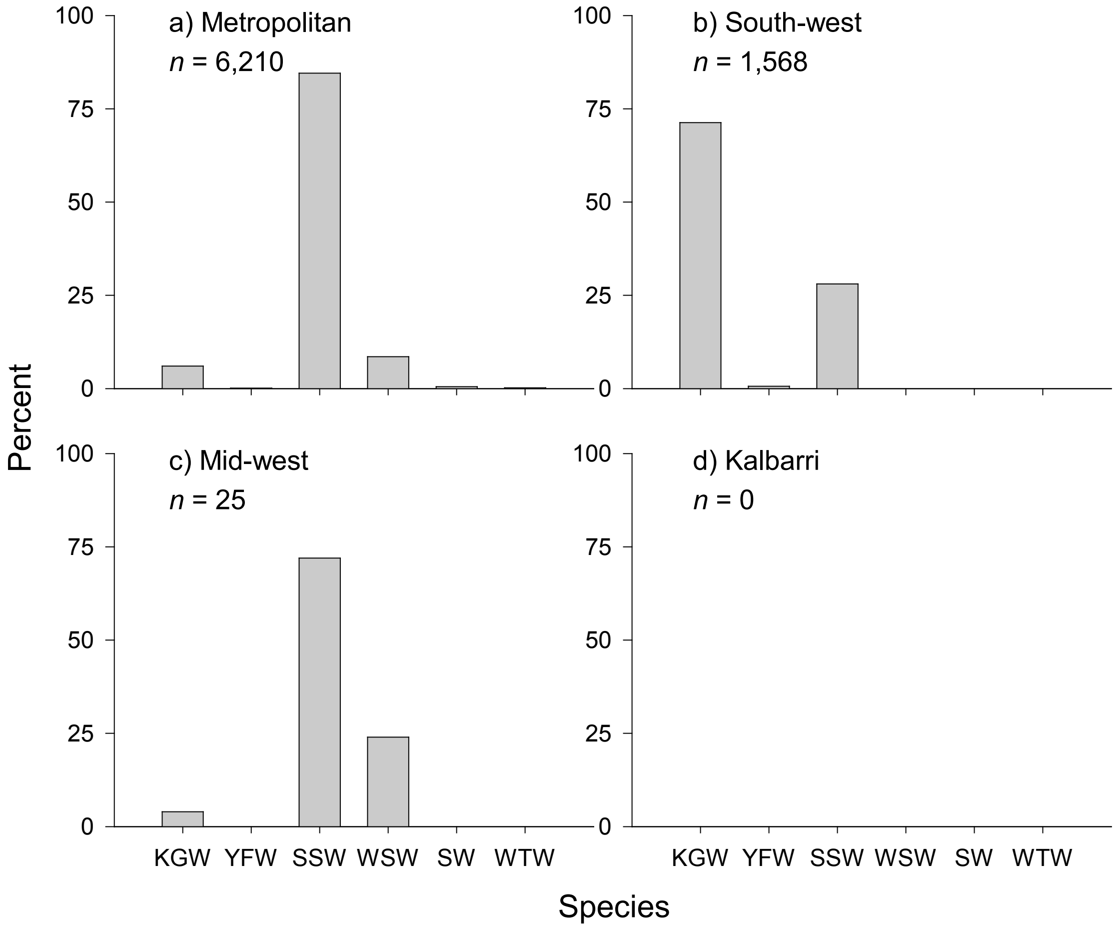


Figure 4. Percentages of different species of whiting in catches of these species taken in July 2010 to December 2012 by boat-based recreational fishers in the **a)** Metropolitan, **b)** South-west, **c)** Mid-west and **d)** Kalbarri Zones of the West Coast Bioregion. KGW, King George whiting; YFW, yellowfin whiting; SSW, southern school whiting; WSW, western school whiting; SW, stout whiting; WTW, western trumpeter whiting.

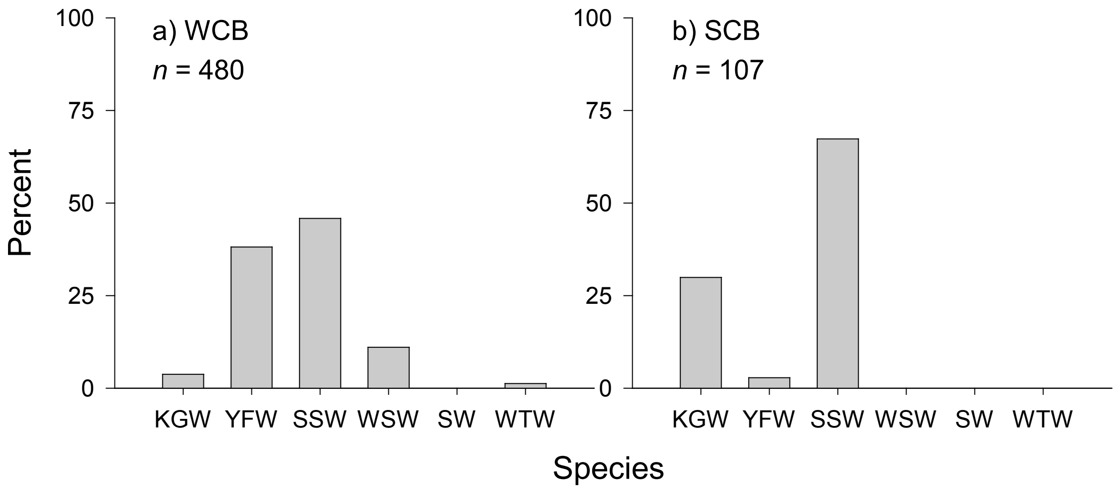


Figure 5. Percentages of different species of whiting in catches of these species taken in July 2010 to December 2012 by shore-based recreational fishers in the **a)** West Coast Bioregion (WCB) and **b)** South Coast Bioregion (SCB). KGW, King George whiting; YFW, yellowfin whiting; SSW, southern school whiting; WSW, western school whiting; SW, stout whiting; WTW, western trumpeter whiting.

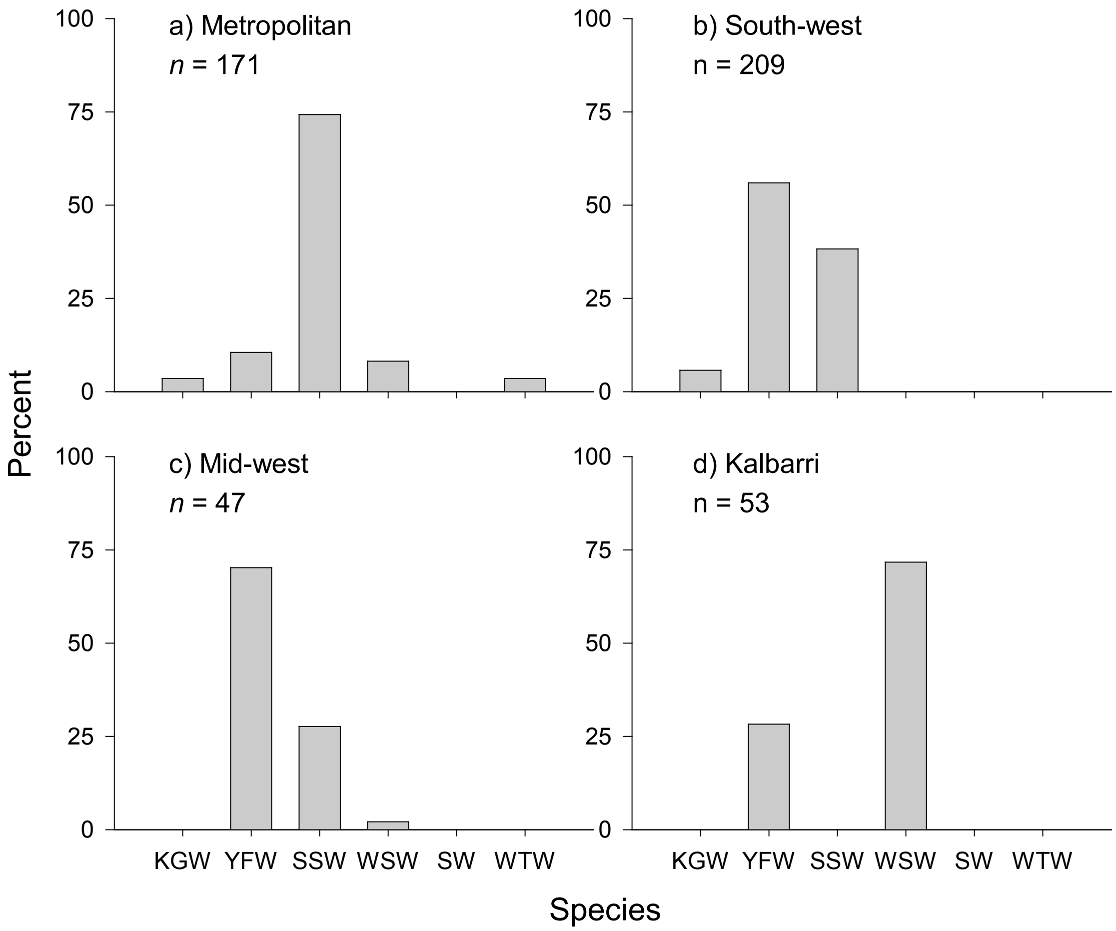


Figure 6. Percentages of different species of whiting in catches of these species taken in July 2010 to December 2012 by shore-based recreational fishers in the **a)** Metropolitan, **b)** South-west, **c)** Mid-west and **d)** Kalbarri Zones of the West Coast Bioregion. KGW, King George whiting; YFW, yellowfin whiting; SSW, southern school whiting; WSW, western school whiting; SW, stout whiting; WTW, western trumpeter whiting.

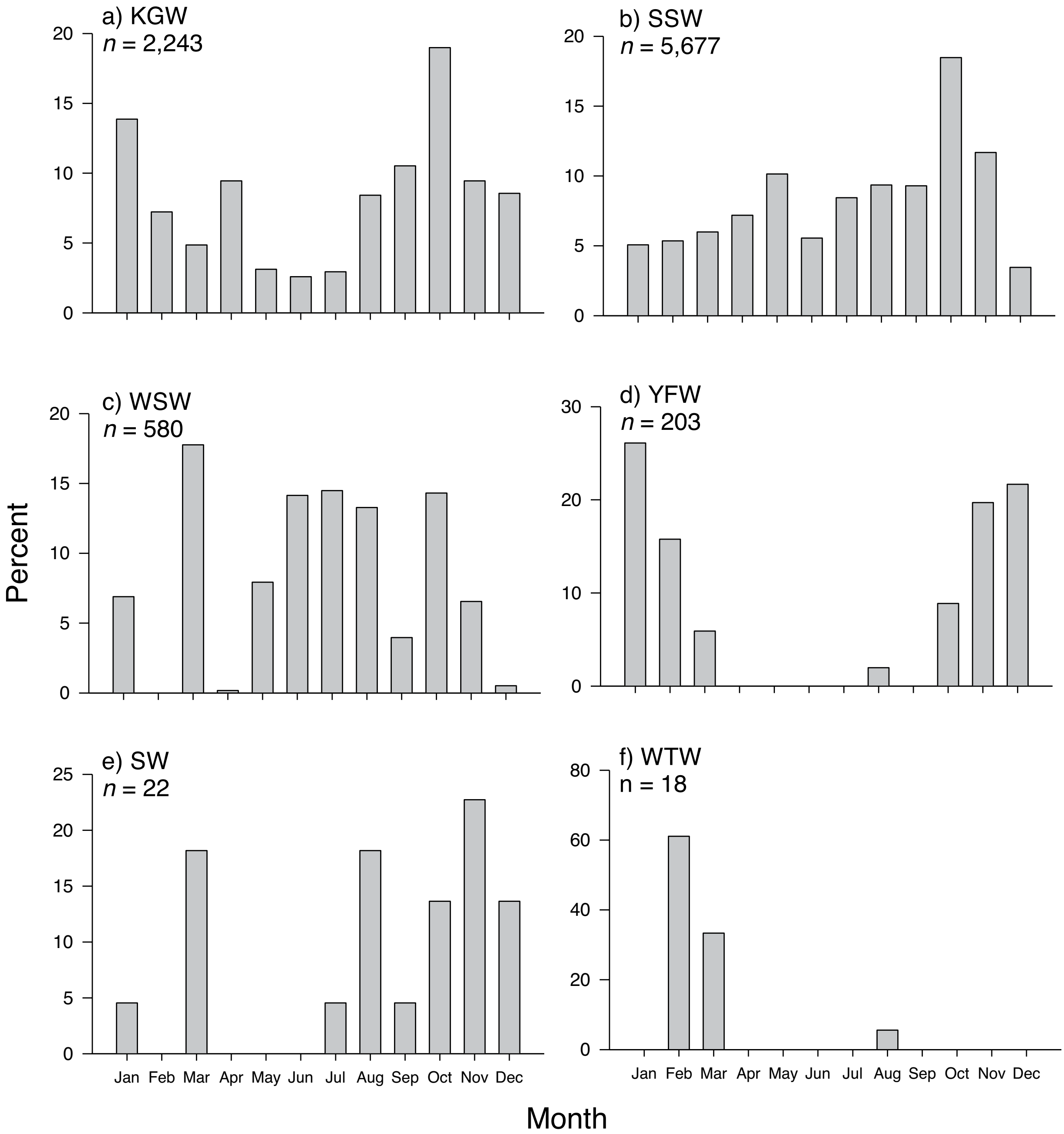


Figure 7. Percentages in each calendar month, of the overall catches of recreationally caught **a)** King George whiting (KGW), **b)** southern school whiting (SSW), **c)** western school whiting (WSW), **d)** yellowfin whiting (YFW), **e)** stout whiting (SW) and **f)** western trumpeter whiting (WTW) in the West Coast Bioregion from January 2011 to December 2012.

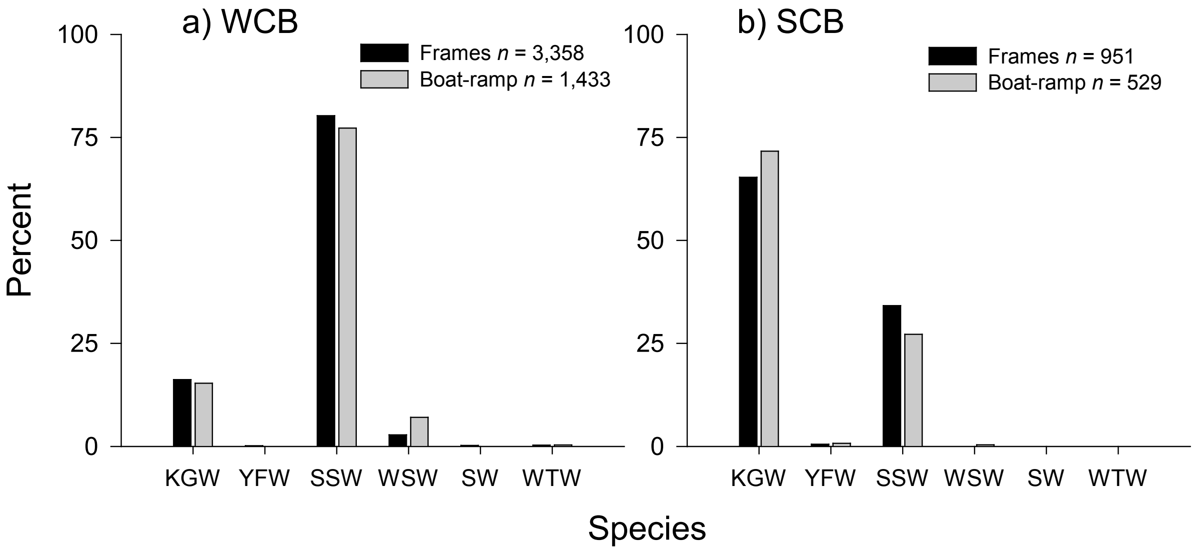


Figure 8. Percentages of boat-based catches of whiting taken by recreational fishers from March 2011 to February 2012 during a fish frame collection program and on-site boat-ramp surveys in the **a)** West Coast Bioregion (WCB) and **b)** South Coast Bioregion (SCB). KGW, King George whiting; YFW, yellowfin whiting; SSW, southern school whiting; WSW, western school whiting; SW, stout whiting; WTW, western trumpeter whiting.

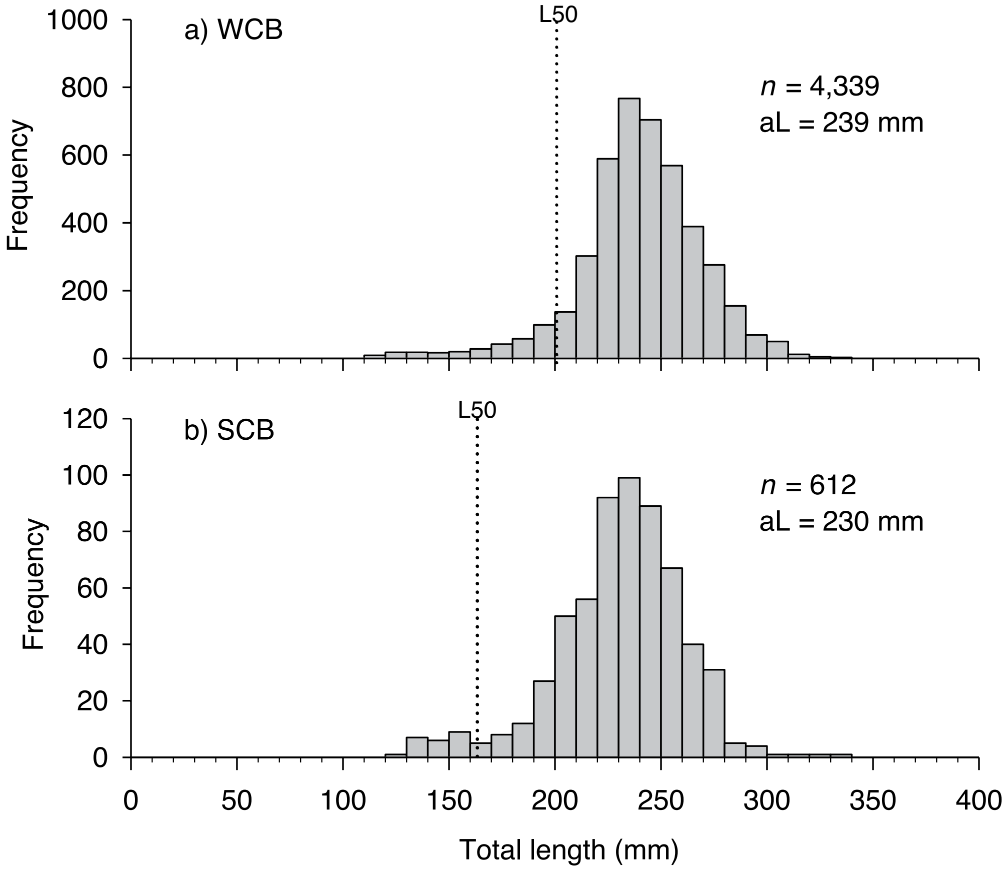


Figure 9. Length frequency distributions of southern school whiting caught in 2010–12 by shore- and boat-based recreational fishers in the **a)** West Coast Bioregion and **b)** South Coast Bioregion. n, number of fish measured; aL, average length of fish in sample. The estimated length at which 50% of fish attain maturity (L_{50}) (all sex) for each bioregion is also shown.

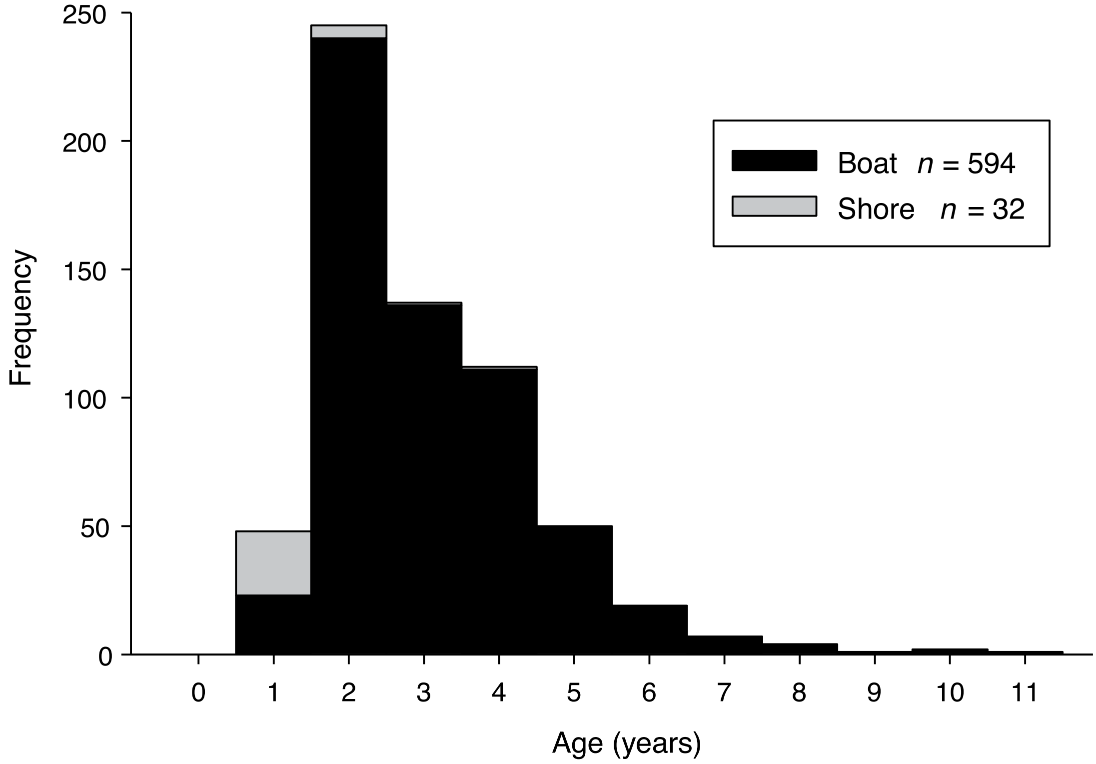


Figure 10. Age frequency distributions of southern school whiting caught in 2011 by boat- and shore-based recreational fishers in the West Coast Bioregion (Metropolitan Zone). *n*, number of fish aged.

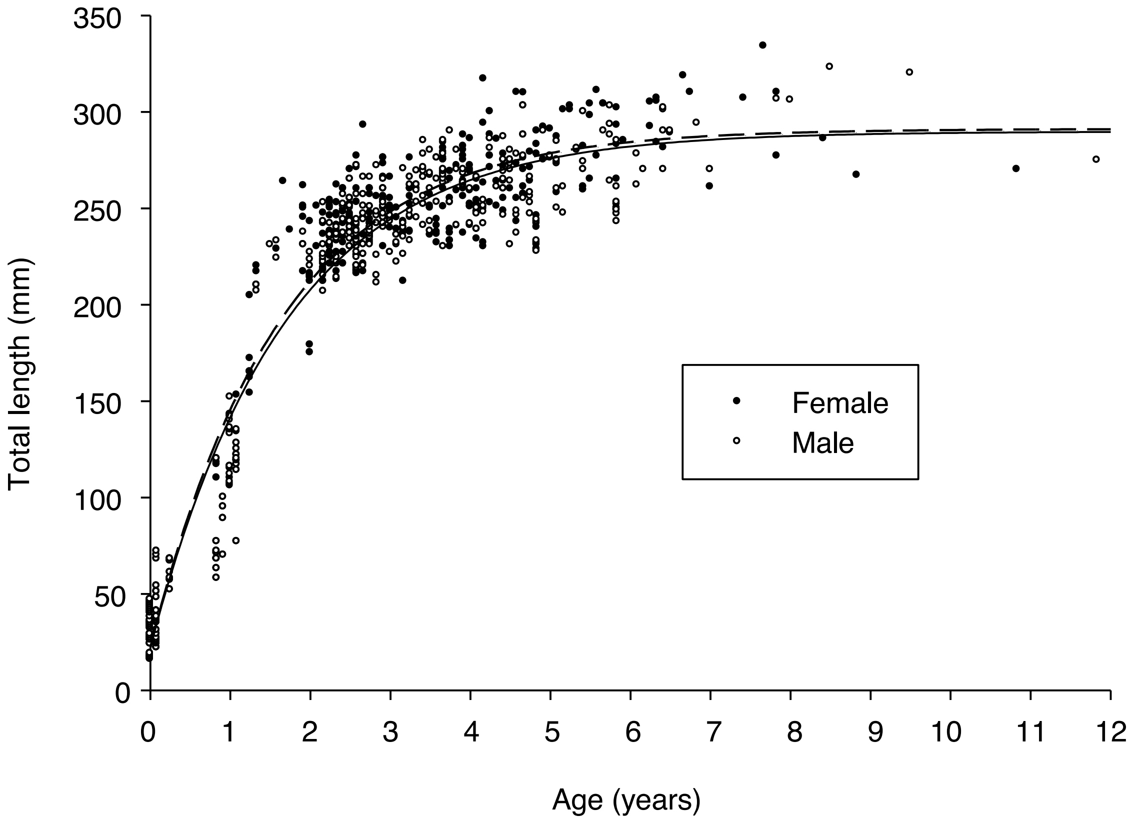


Figure 11. von Bertalanffy growth curves fitted to length-at-age data collected in 2011 for female (dashed line) and male (solid line) southern school whiting in the West Coast Bioregion.

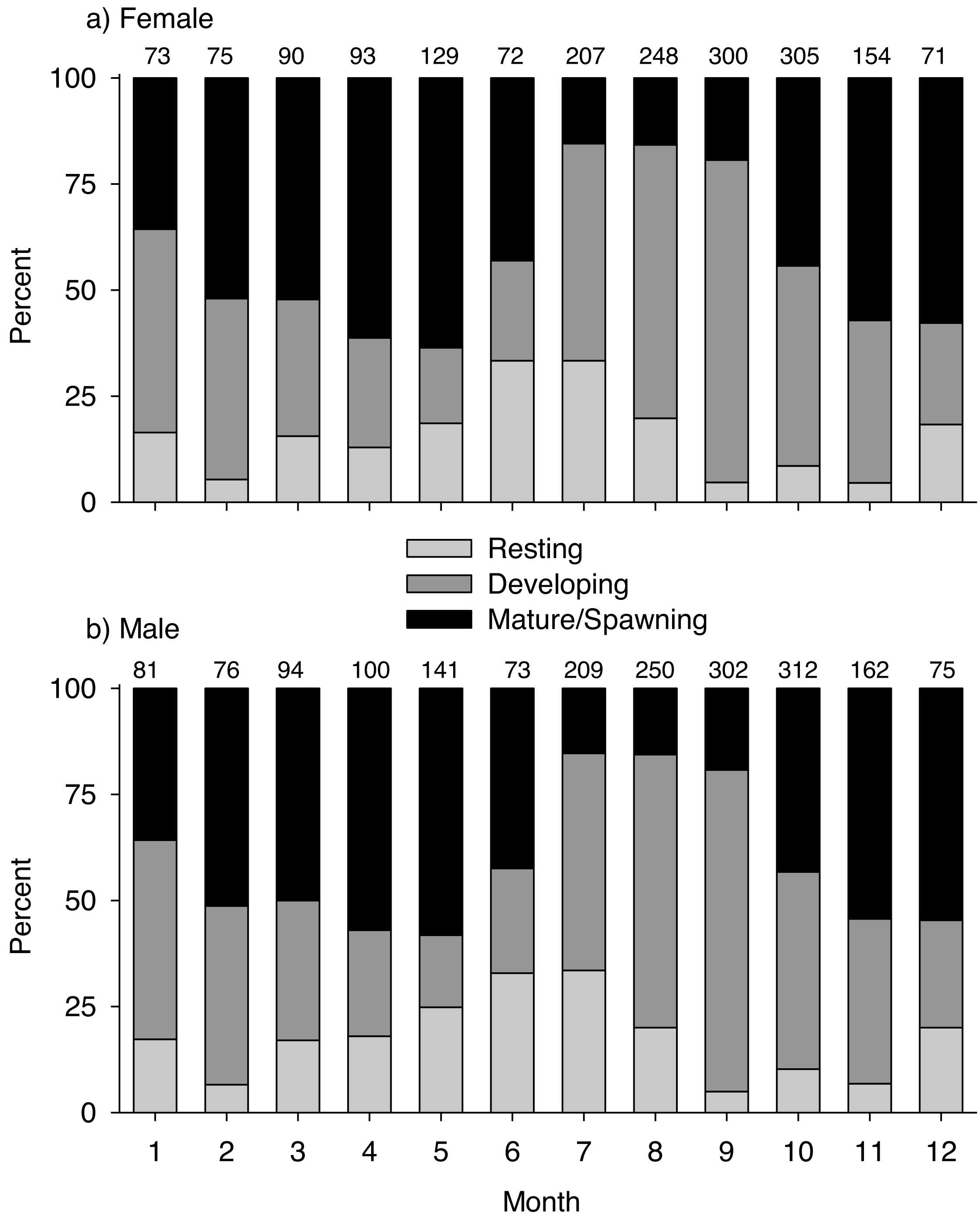


Figure 12. Percentages, in each calendar month for southern school whiting $\geq L_{50}$ at maturity caught during 2010–2012 in the West Coast Bioregion, of **a)** female and **b)** male gonads that were categorised macroscopically as either 'resting', 'developing' or 'mature/spawning'. Sample sizes for each calendar month are shown above each bar. (Month 1 = January, 2 = February, etc.).

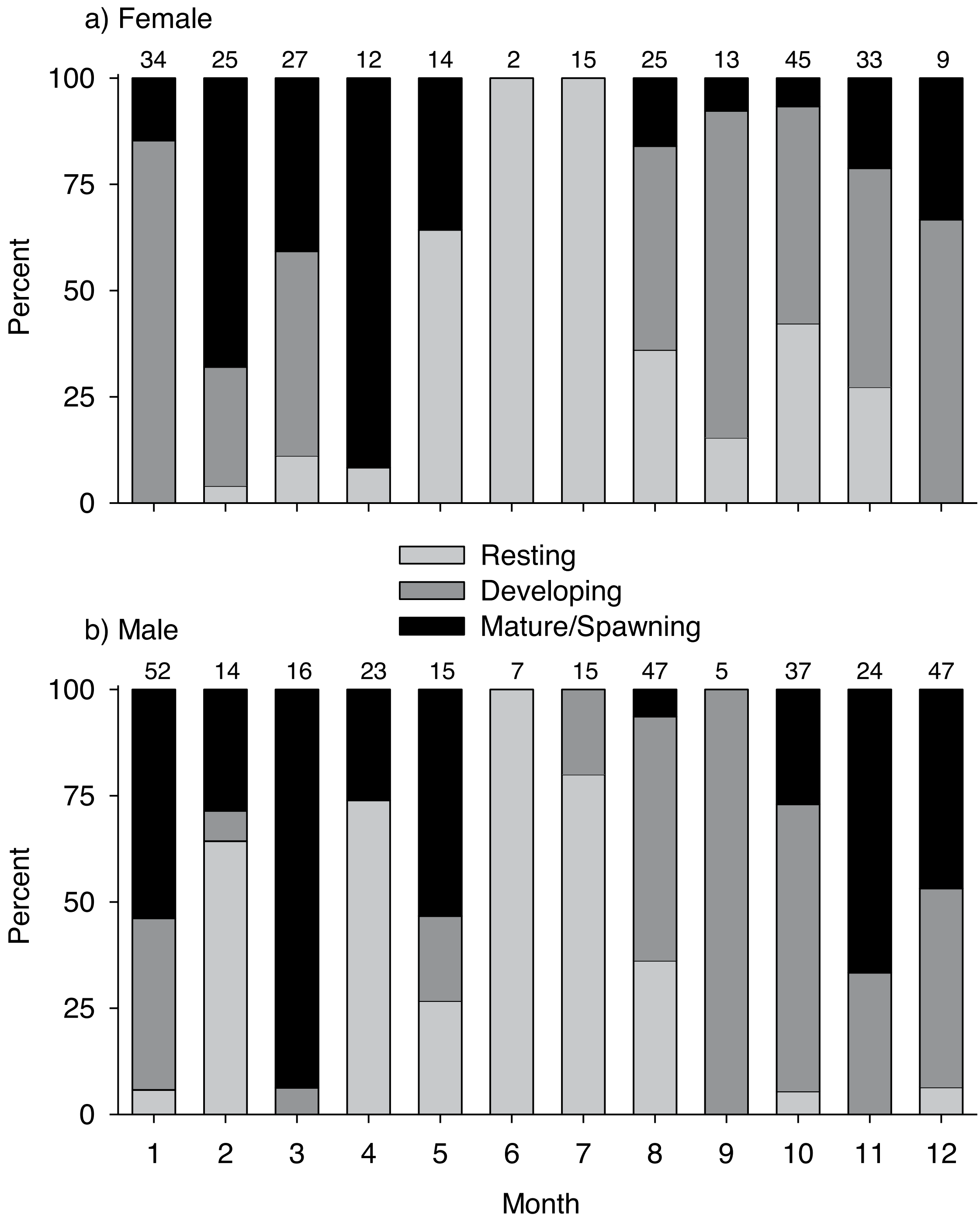


Figure 13. Percentages, in each calendar month for southern school whiting ≥L_{50} at maturity caught during 2010–2012 in the South Coast Bioregion, of **a)** female and **b)** male gonads that were categorised macroscopically as either 'resting', 'developing' or 'mature/spawning'. Sample sizes for each calendar month are shown above each bar. (Month 1 = January, 2 = February, etc.).

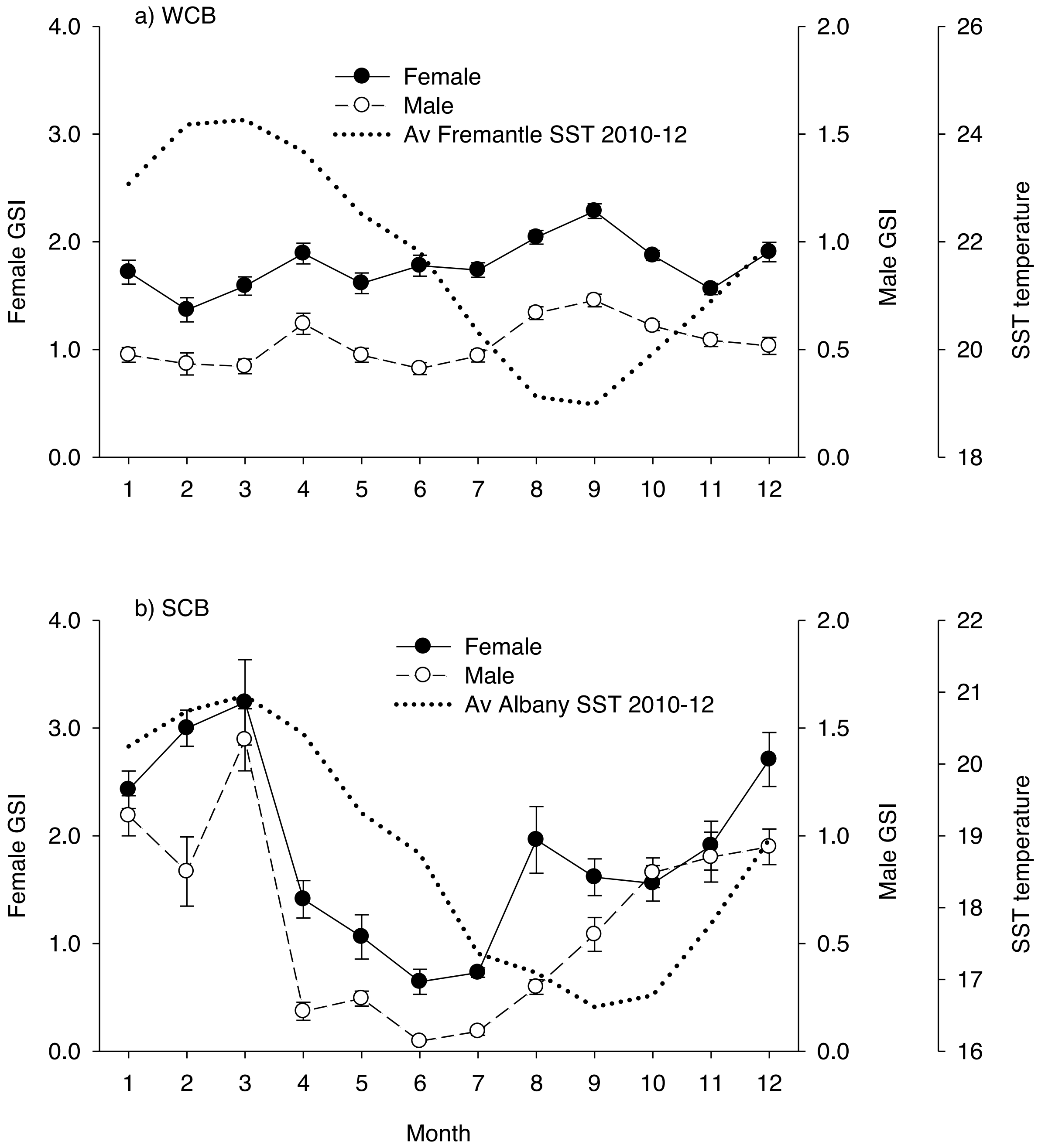


Figure 14. Mean monthly gonadosomatic indices (GSI) (± 1s.e.) for female and male southern school whiting in the **a)** West Coast Bioregion (WCB) and **b)** South Coast Bioregion (SCB), 2010–2012. (Month 1 = January, 2 = February, etc.). Average sea surface temperature (SST) for Fremantle (WCB) and Albany (SCB) for 2010–2012 is shown.

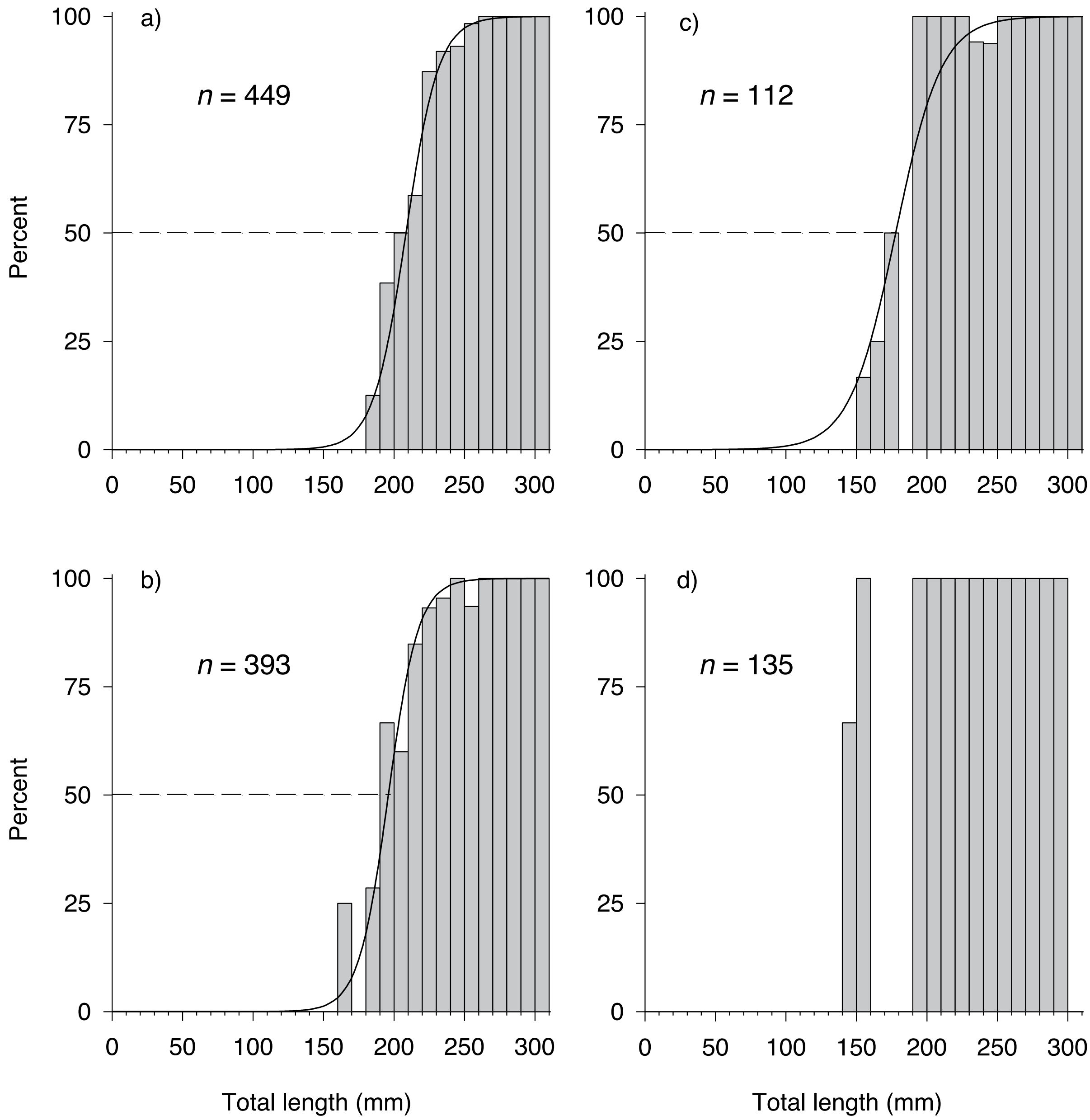


Figure 15. Percentages, in successive 10 mm length classes of **a)** West Coast Bioregion female, **b)** West Coast Bioregion male, **c)** South Coast Bioregion female and **d)** South Coast Bioregion male southern school whiting caught in 2010–2012 that were mature. Logistic curves describing the probability of individuals being mature at any length, and the lengths at which 50% of females and males attain maturity (L_{50}s), are also presented.

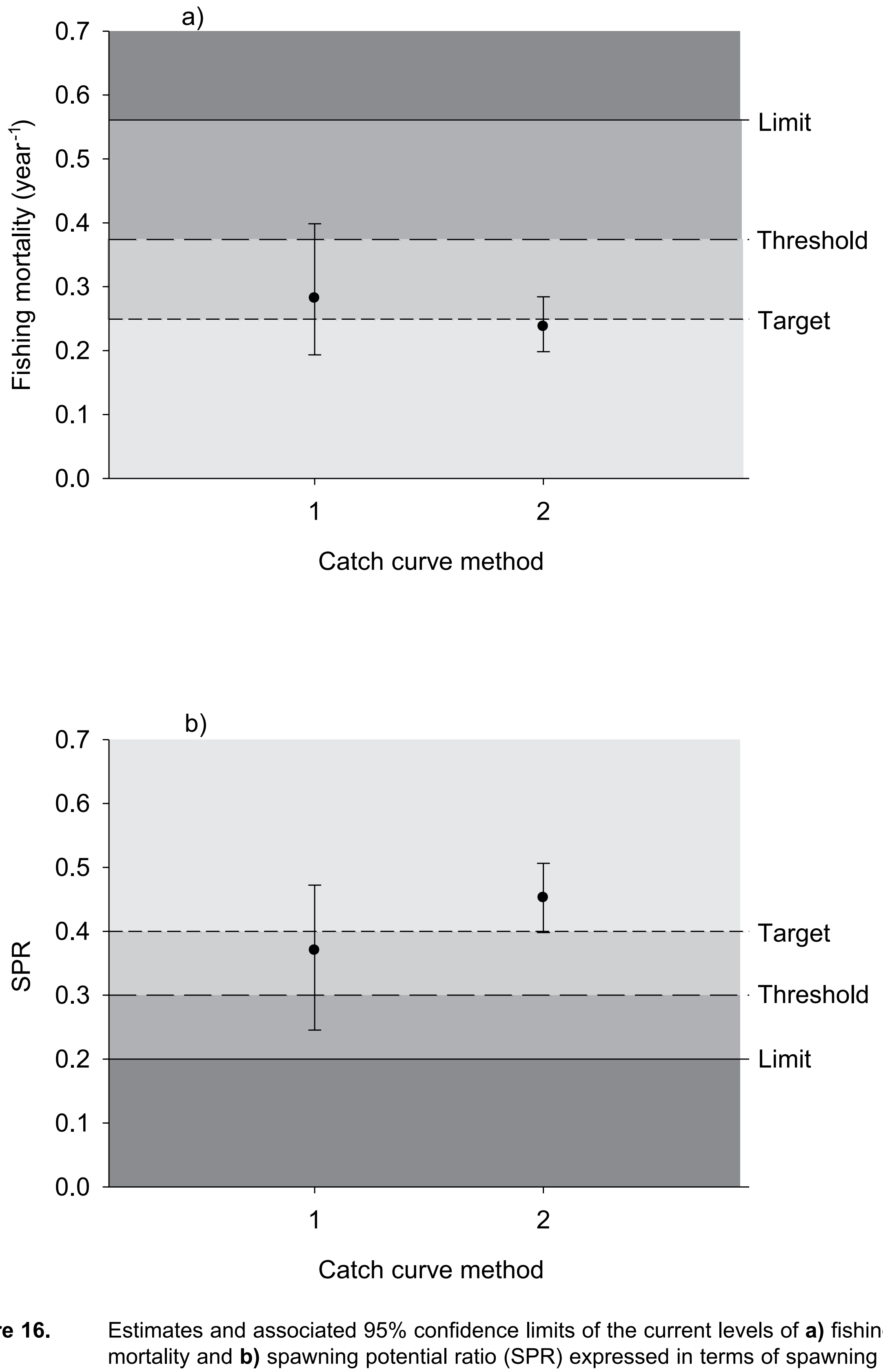


Figure 16. Estimates and associated 95% confidence limits of the current levels of **a)** fishing mortality and **b)** spawning potential ratio (SPR) expressed in terms of spawning biomass per recruit, for southern school whiting derived in the West Coast Bioregion (Metropolitan Zone), 2011. The estimates have been produced using two catch curve methods, namely the linear catch curve described by Ricker (1975) and the catch curve of Chapman and Robson (1960). Fishing mortality-based biological reference points (F_{limit}, $F_{threshold}$ and F_{target}) are shown on the plot.

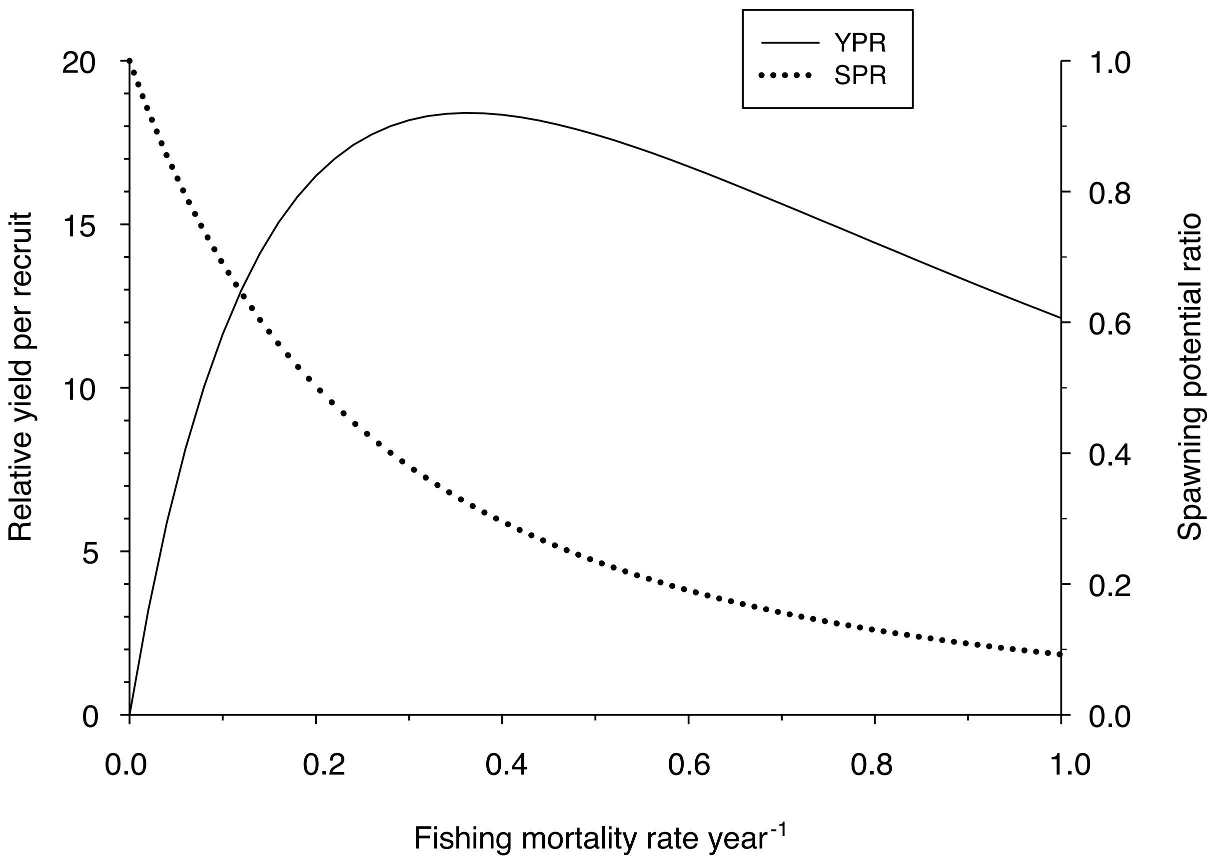


Figure 17. Curve of Yield Per Recruit (YPR) and Spawning Potential Ratio (SPR) for southern school whiting in the West Coast Bioregion of Western Australia.

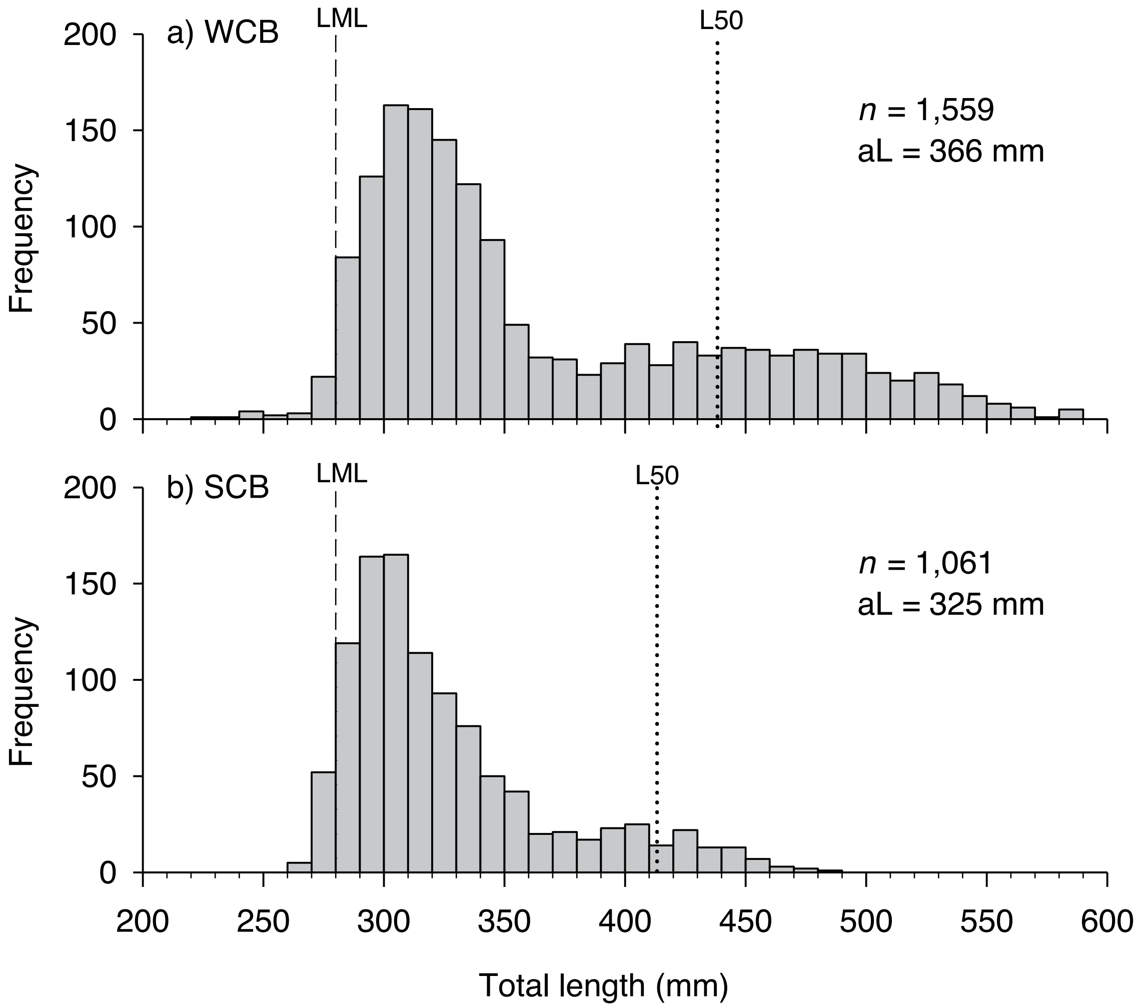


Figure 18. Length-frequency distribution of King George whiting caught in 2010–12 by shore- and boat-based recreational fishers in the **a)** West Coast Bioregion and **b)** South Coast Bioregion. *n*, number of fish measured; aL, average length of fish in sample. The estimated length at which 50% of fish attain maturity (L_{50}) (all sex) and the legal minimum length (LML) for each bioregion are also shown.

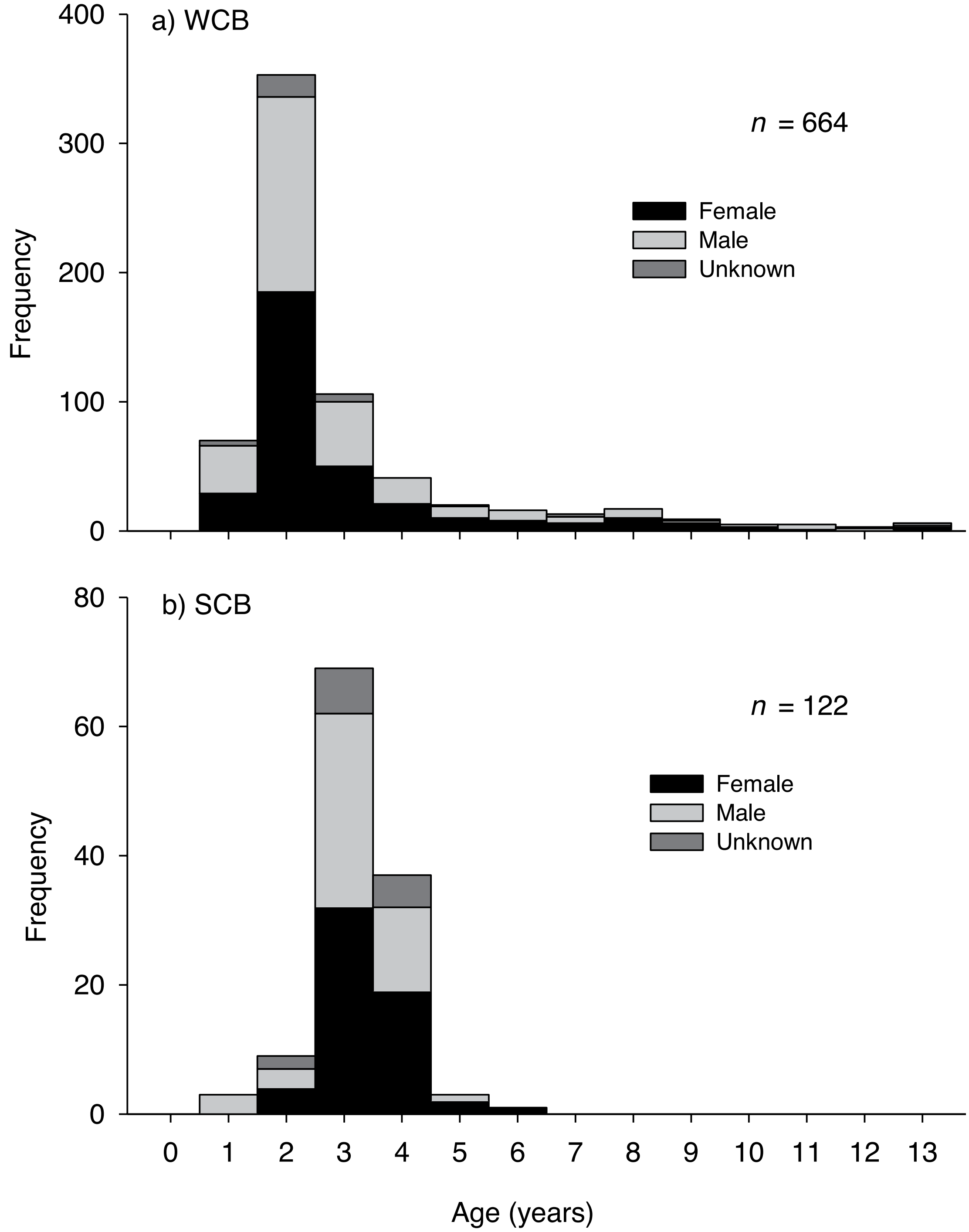


Figure 19. Age frequency distributions of female and male King George whiting caught in 2010–12 by recreational fishers in the **a)** West Coast Bioregion and **b)** South Coast Bioregion. *n*, number of fish aged.

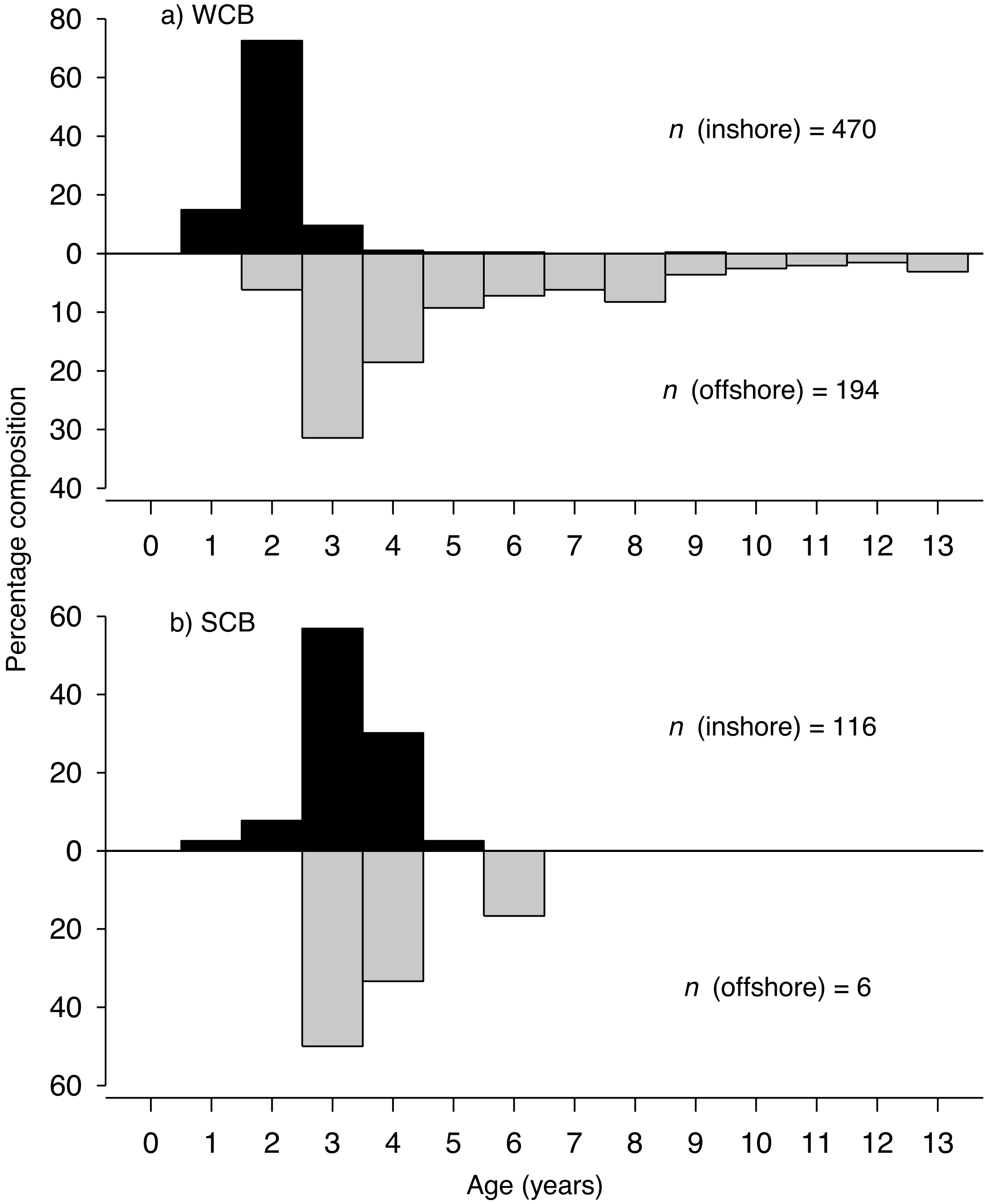


Figure 20. Age frequency distribution for King George whiting caught in 2010-12 by recreational fishers in 'inshore' estuarine and marine waters over sand/seagrass (white bars) and 'offshore' marine waters over reefs (grey bars) in the **a)** West Coast Bioregion (WCB) and **b)** South Coast Bioregion (SCB). n, number of fish aged.

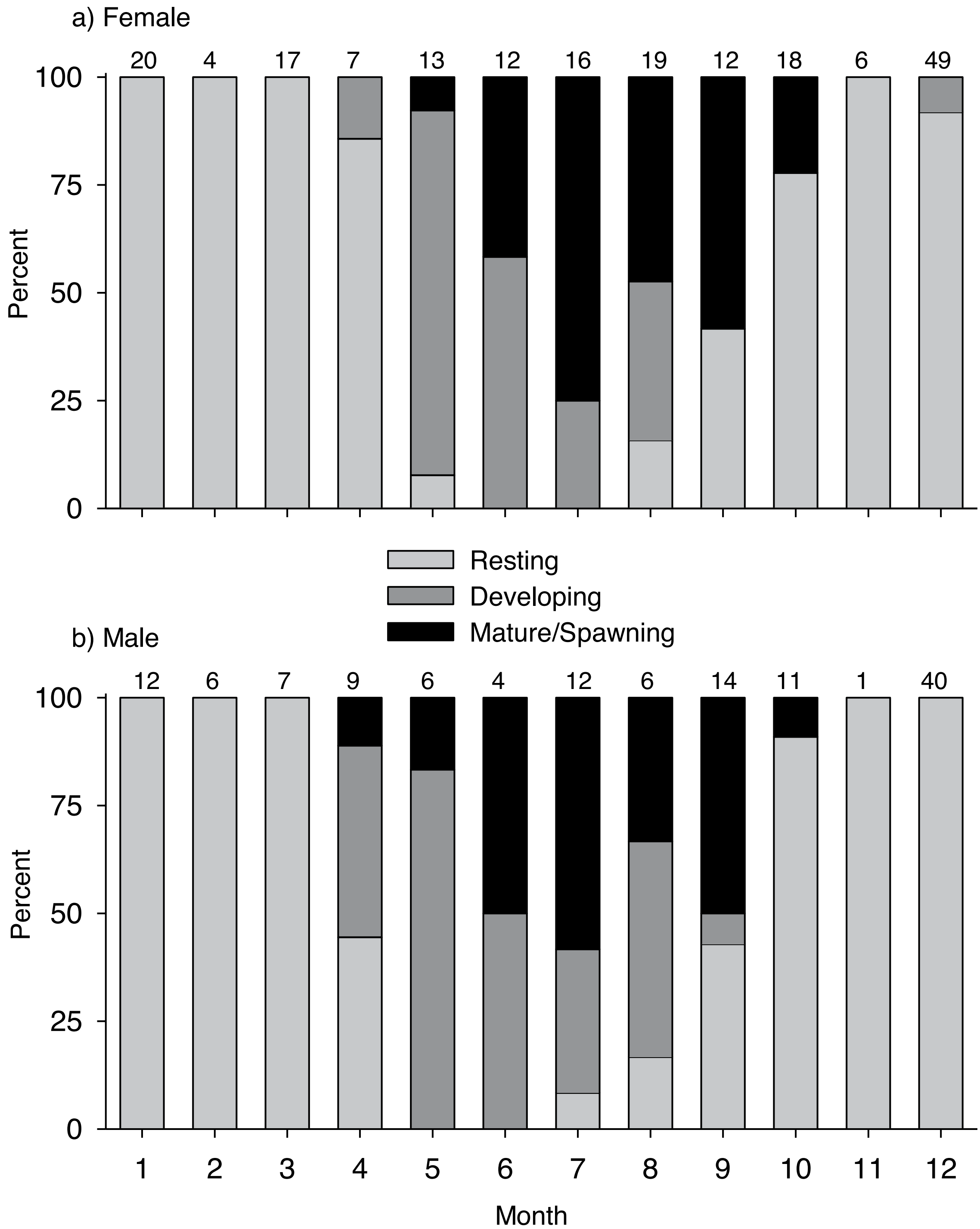


Figure 21. Percentages, in each calendar month for King George whiting $\geq L_{50}$ at maturity caught during 2010–2012 in the West Coast Bioregion, of **a)** female and **b)** male gonads that were categorised macroscopically as either 'resting', 'developing' or 'mature/spawning'. Sample sizes for each calendar month are shown above each bar. (Month 1 = January, 2 = February, etc.).

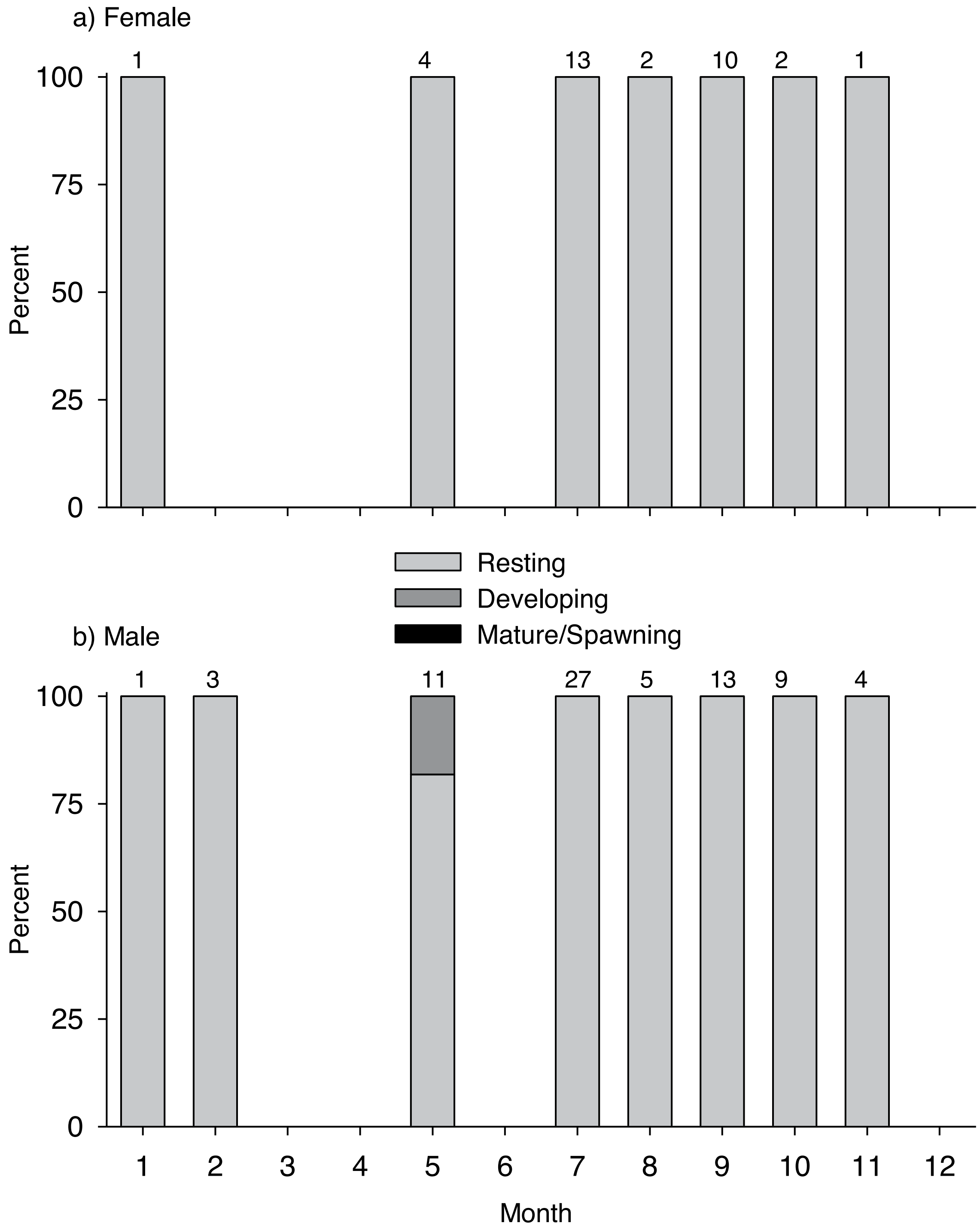


Figure 22. Percentages, in each calendar month for King George whiting $\geq L_{50}$ at maturity caught during 2010–2012 in the South Coast Bioregion, of **a)** female and **b)** male gonads that were categorised macroscopically as either 'resting', 'developing' or 'prespawning/spawning'. Sample sizes for each calendar month are shown above each bar. (Month 1 = January, 2 = February, etc.).

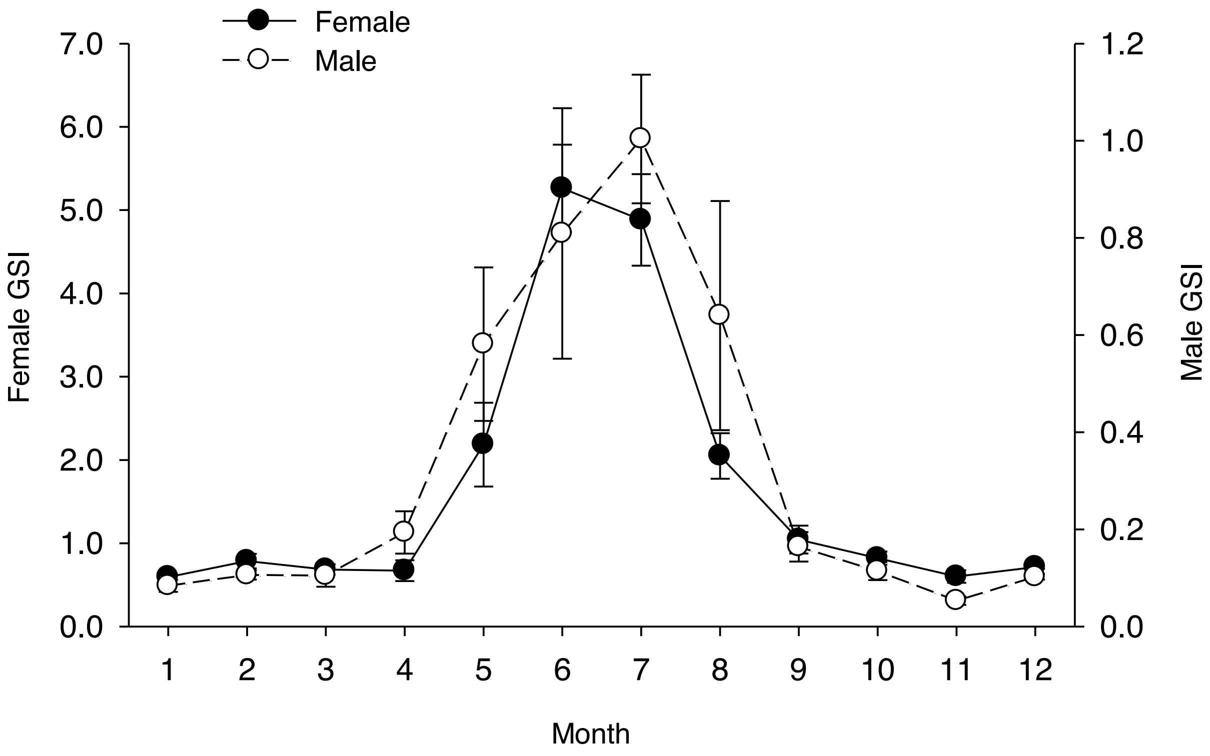


Figure 23. Mean monthly gonadosomatic indices (GSIs) (± 1s.e.) for female and male King George whiting in the West Coast Bioregion, 2010–2012. (Month 1 = January, 2 = February, etc.).

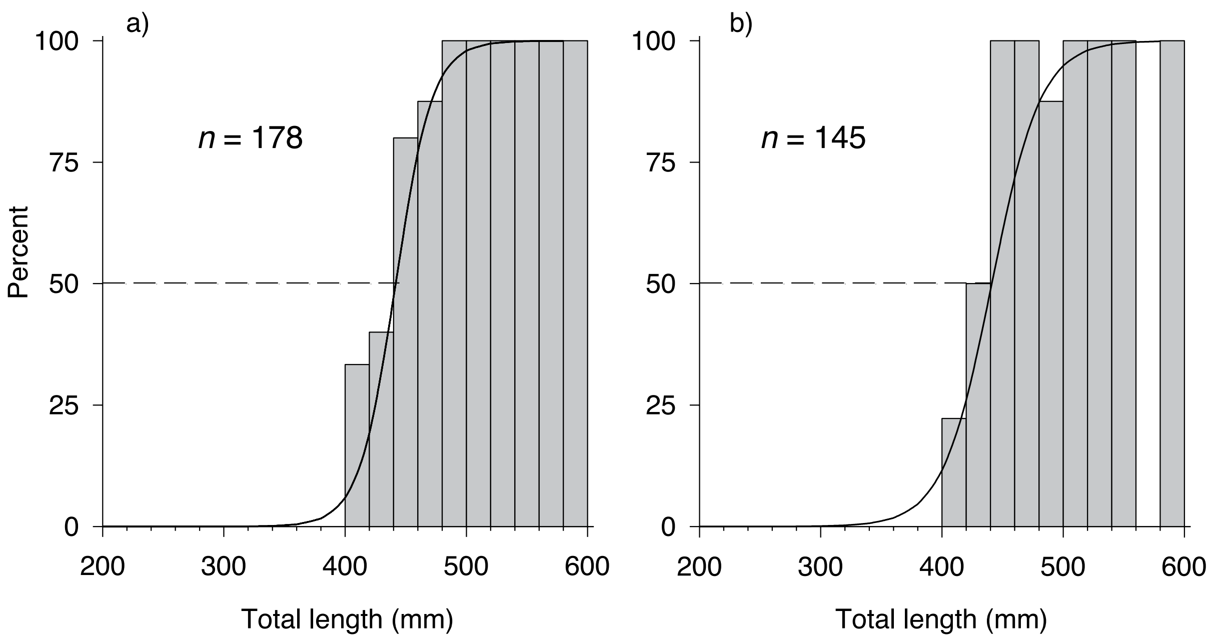


Figure 24. Percentages, in successive 20 mm length classes of **a)** female and **b)** male King George whiting in the West Coast Bioregion caught in 2010–2012 that were mature. Logistic curves describing the probability of individuals being mature at any length, and the lengths at which 50% of females and males attain maturity (L_{50}s), are also presented.

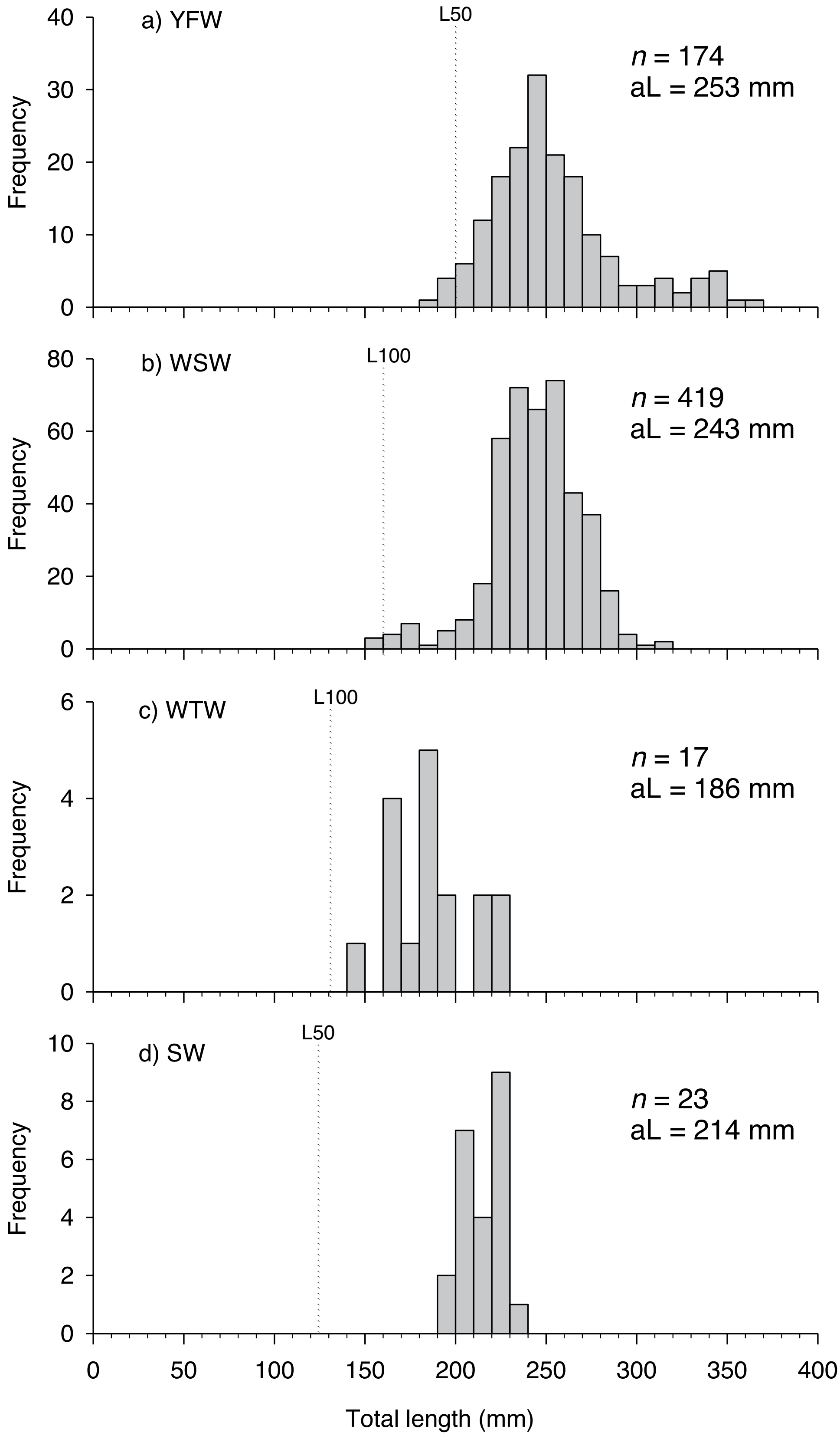


Figure 25. Length frequency distributions for **a)** yellowfin whiting (YFW), **b)** western school whiting (WSW), **c)** western trumpeter whiting (WTW) and **d)** stout whiting (SW) caught in 2010–12 by recreational fishers in the West Coast Bioregion. *n*, number of fish measured; aL, average length of fish in sample. For each species, the estimated lengths at which 50% or 100% of fish attain maturity (as determined by Hyndes 1996 and Gaughan *et al.* 2006) are shown.

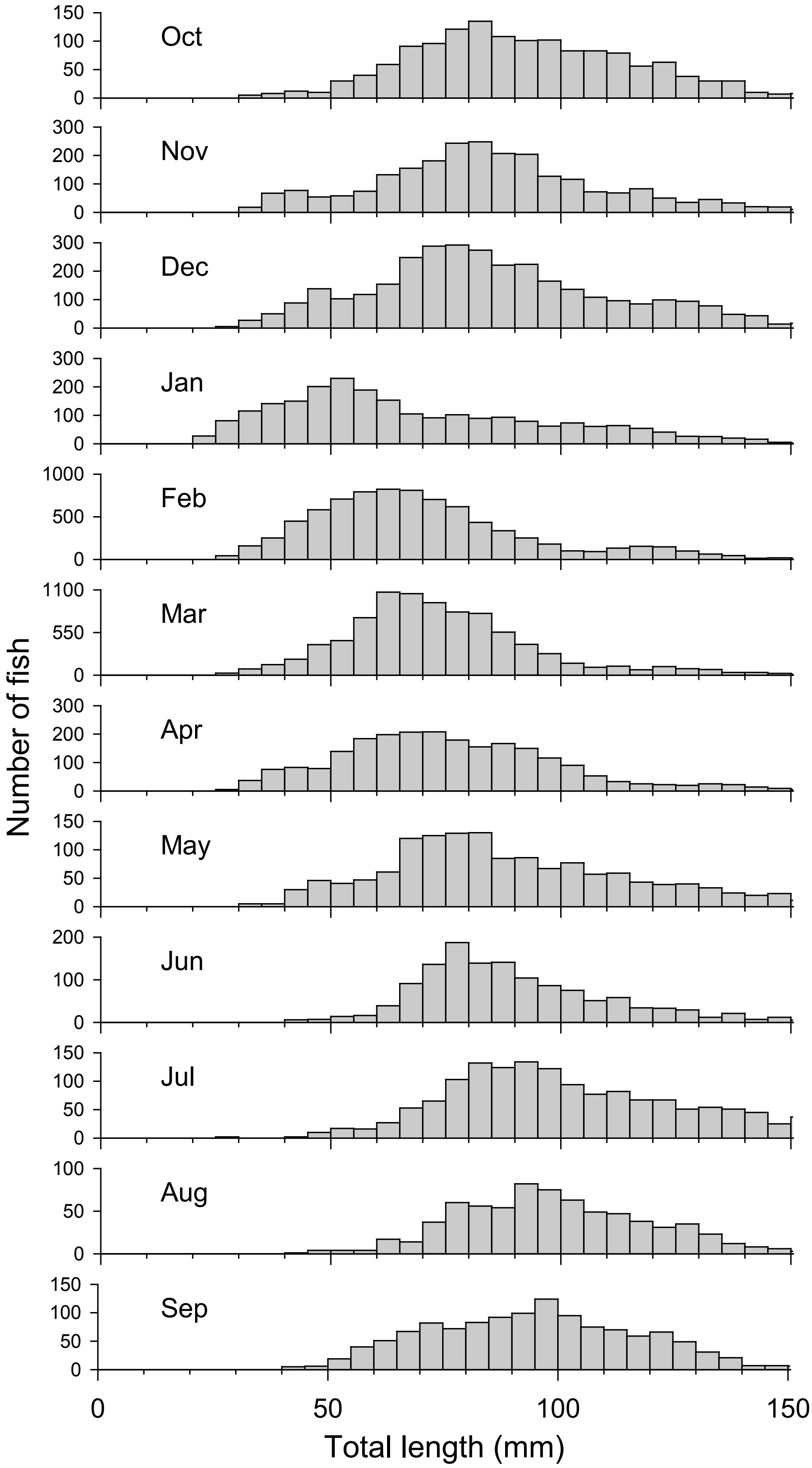


Figure 26. Length frequency distributions for southern school whiting in each calendar month caught by seine netting during recruitment surveys in the West Coast Bioregion (all sites pooled), in 1994 to 2012. Note that the data are restricted to fish ≤150 mm to examine the 0+ length cohort.

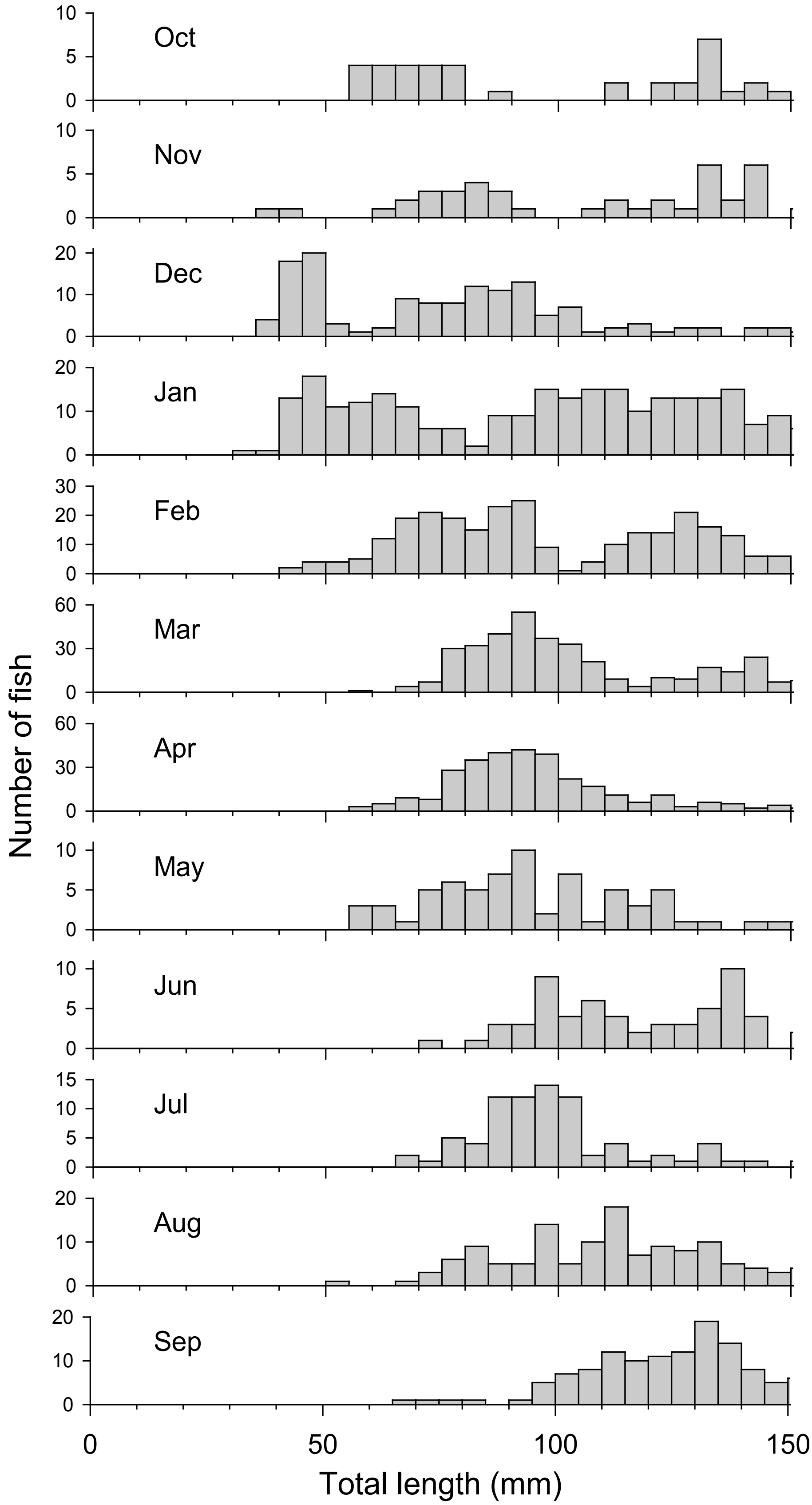


Figure 27. Length frequency distributions for southern school whiting in each calendar month caught by seine netting during recruitment surveys in the South Coast Bioregion (South zone) in 1994 to 2012. Note that the data are restricted to fish ≤150 mm to examine the 0+ length cohort.

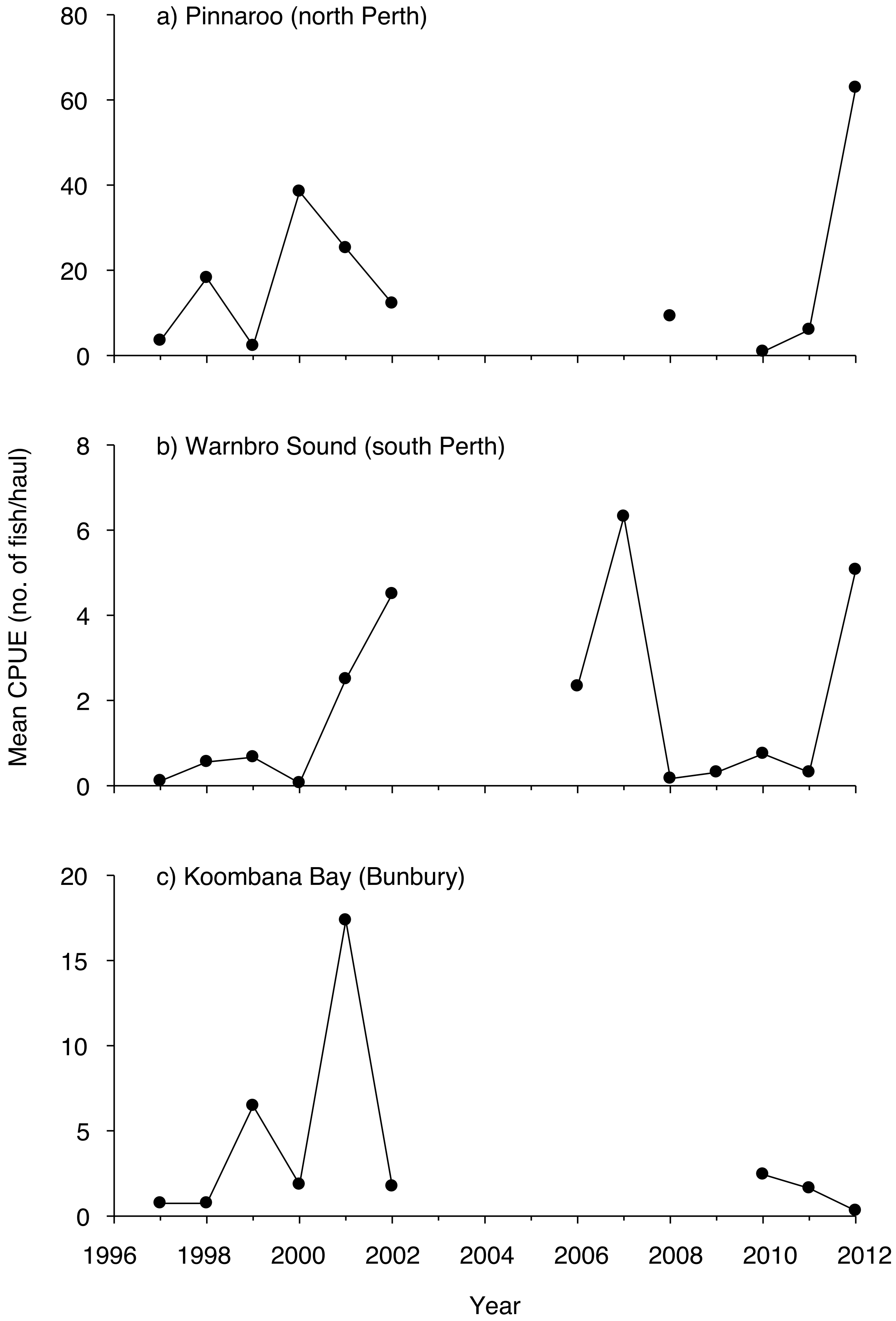


Figure 28. Annual recruitment indices (mean CPUE) for southern school whiting at **a)** Pinnaroo Point (north of Perth), **b)** Warnbro Sound (south of Perth) and **c)** Koombana Bay (Bunbury) from 1997 to 2012.

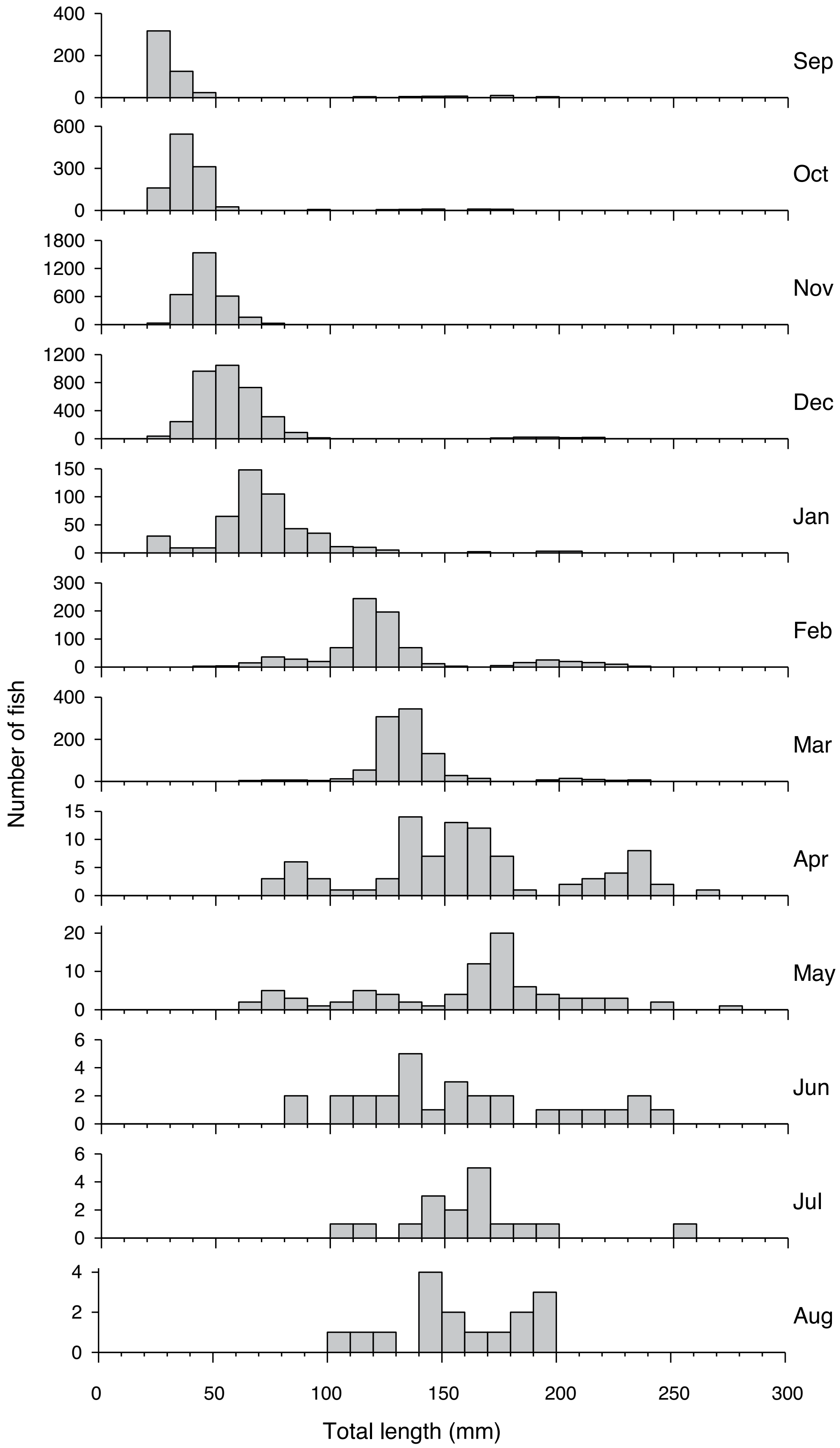


Figure 29. Length frequency distributions for King George whiting in each calendar month, caught by seine netting during recruitment surveys in the West Coast Bioregion (all sites pooled), in 1995 to 2012. Note that the data are restricted to fish ≤300 mm to examine the 0+ length cohort.

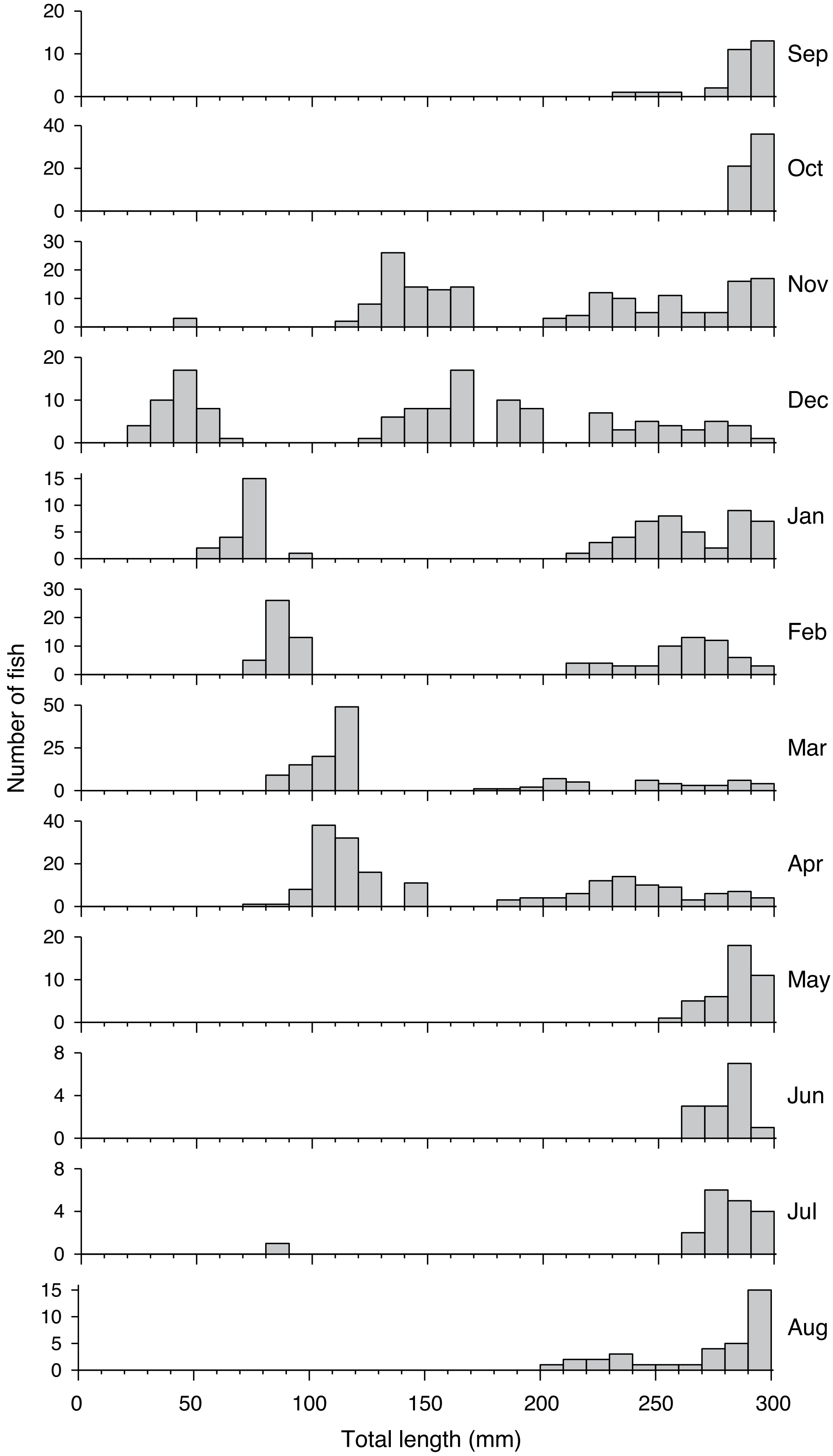


Figure 30. Length frequency distributions for King George whiting in each calendar month caught during recruitment surveys in the South Coast Bioregion (all sites pooled) in 1997 to 2012. Note that the data are restricted to fish ≤300 mm to examine the 0+ length cohort.

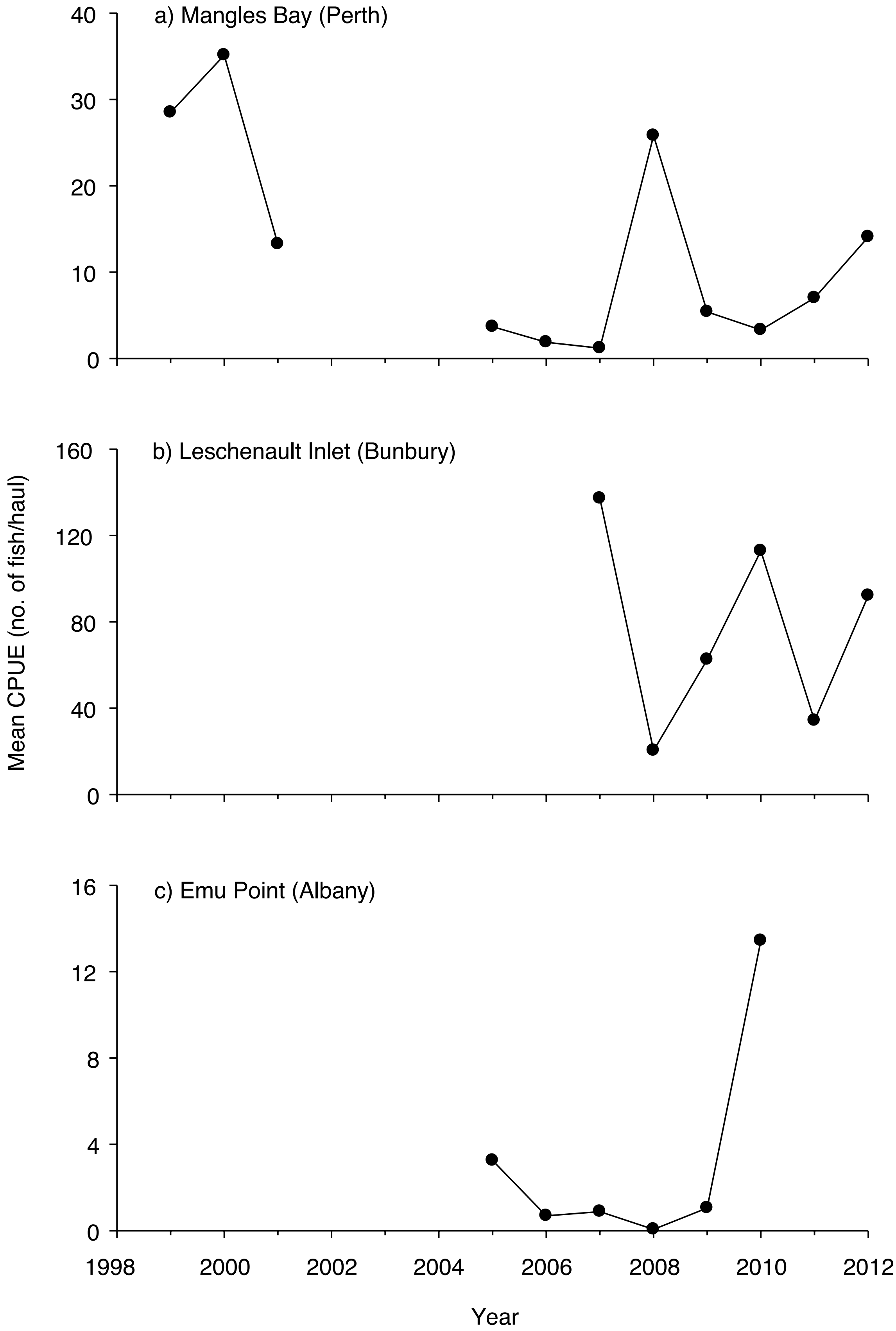


Figure 31. Annual recruitment indices (mean CPUE) for King George whiting at **a)** Mangles Bay (Perth), **b)** Leschenault Inlet (Bunbury) and **c)** Emu Point (Albany) from 1999 to 2012.

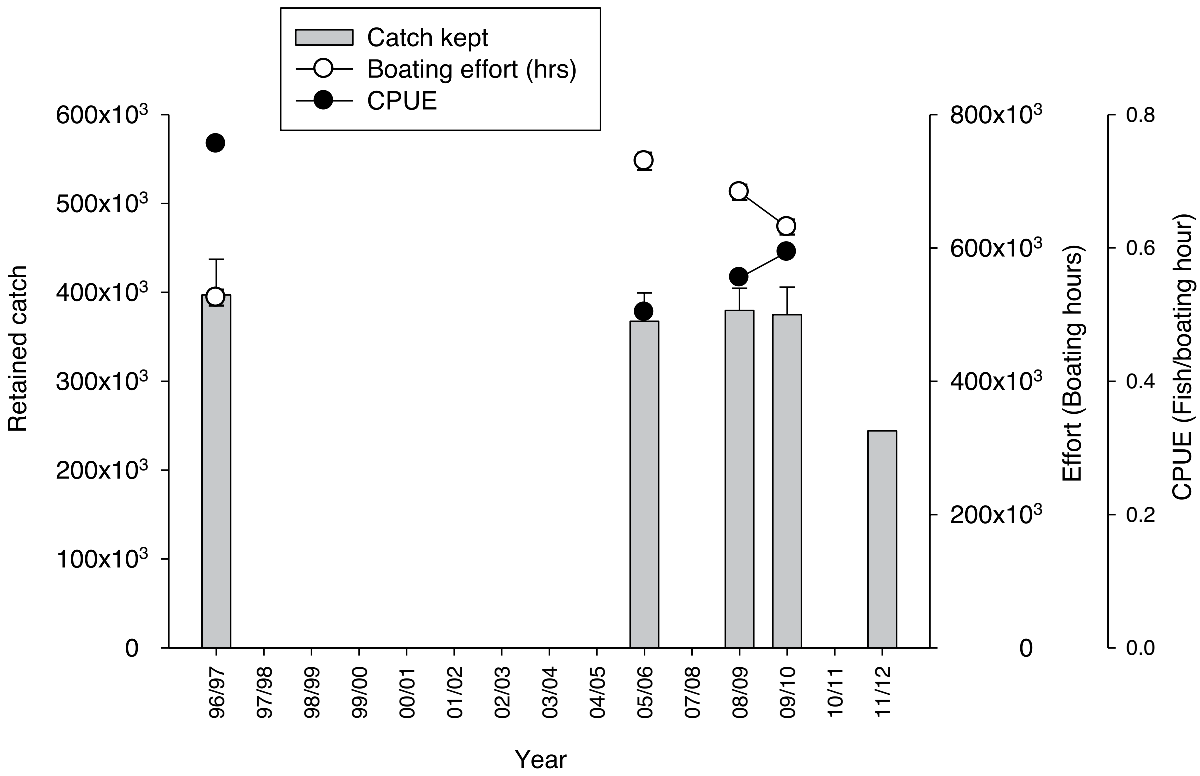


Figure 32. Estimated annual retained catches (number of individuals) (+95% confidence limits), boating hours and nominal mean catch rates of *Sillago* species caught by boat-based recreational fishers in the West Coast Bioregion in 1996/97, 2005/06, 2008/09, 2009/10 and 2011/12. Note that the retained catch estimates for 2011/12 has not been adjusted for differences in survey methods to allow a direct comparison with the four earlier surveys.

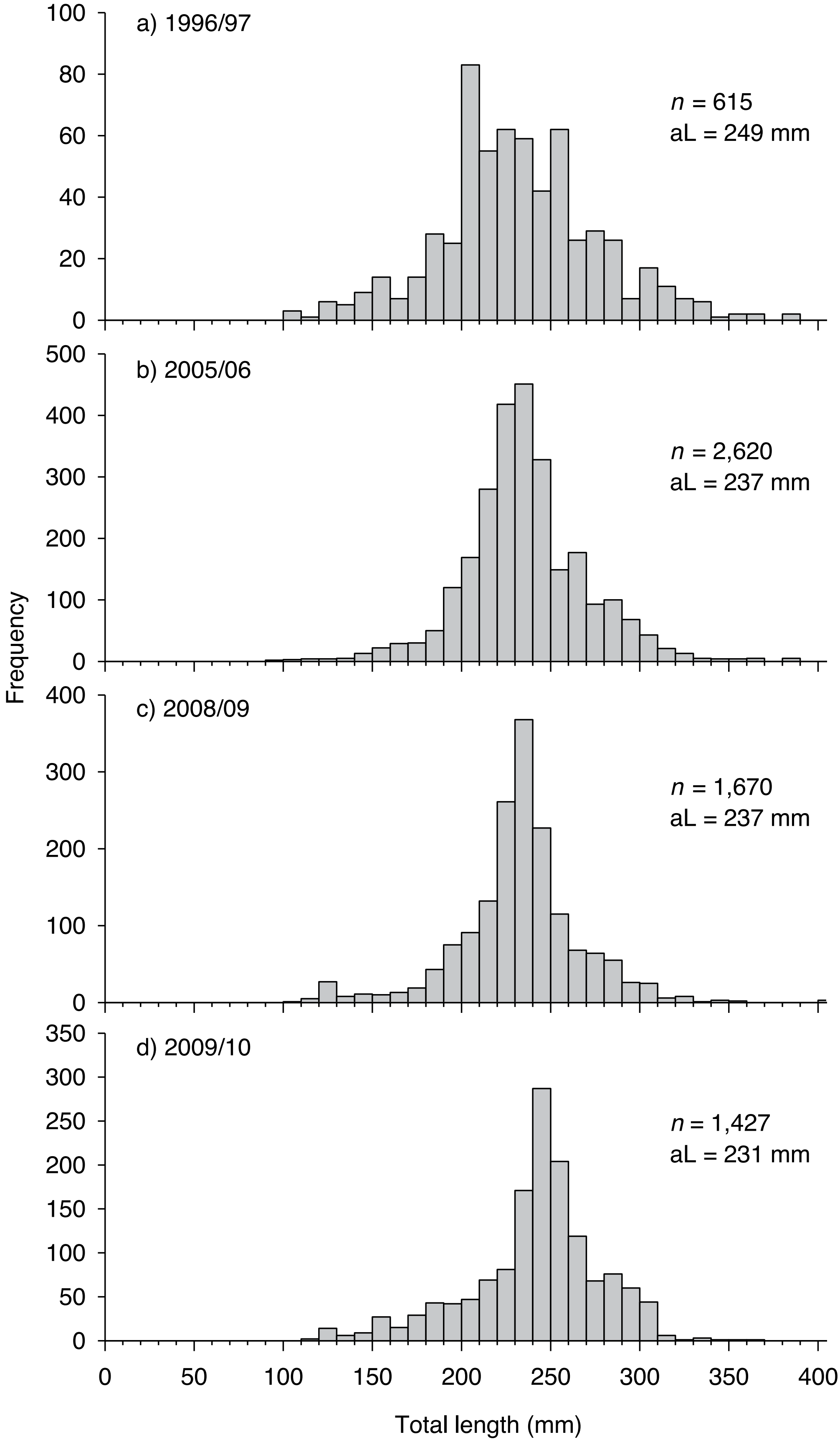


Figure 33. Length frequency distributions for *Sillago* species (assumed to be comprised mainly of southern school whiting) caught by recreational fishers, from fish measured during the West Coast Bioregion boat-based surveys in **a)** 1996/97, **b)** 2005/06, **c)** 2008/09 and **d)** 2009/10. aL, average length of fish in sample. *n* = number of fish.

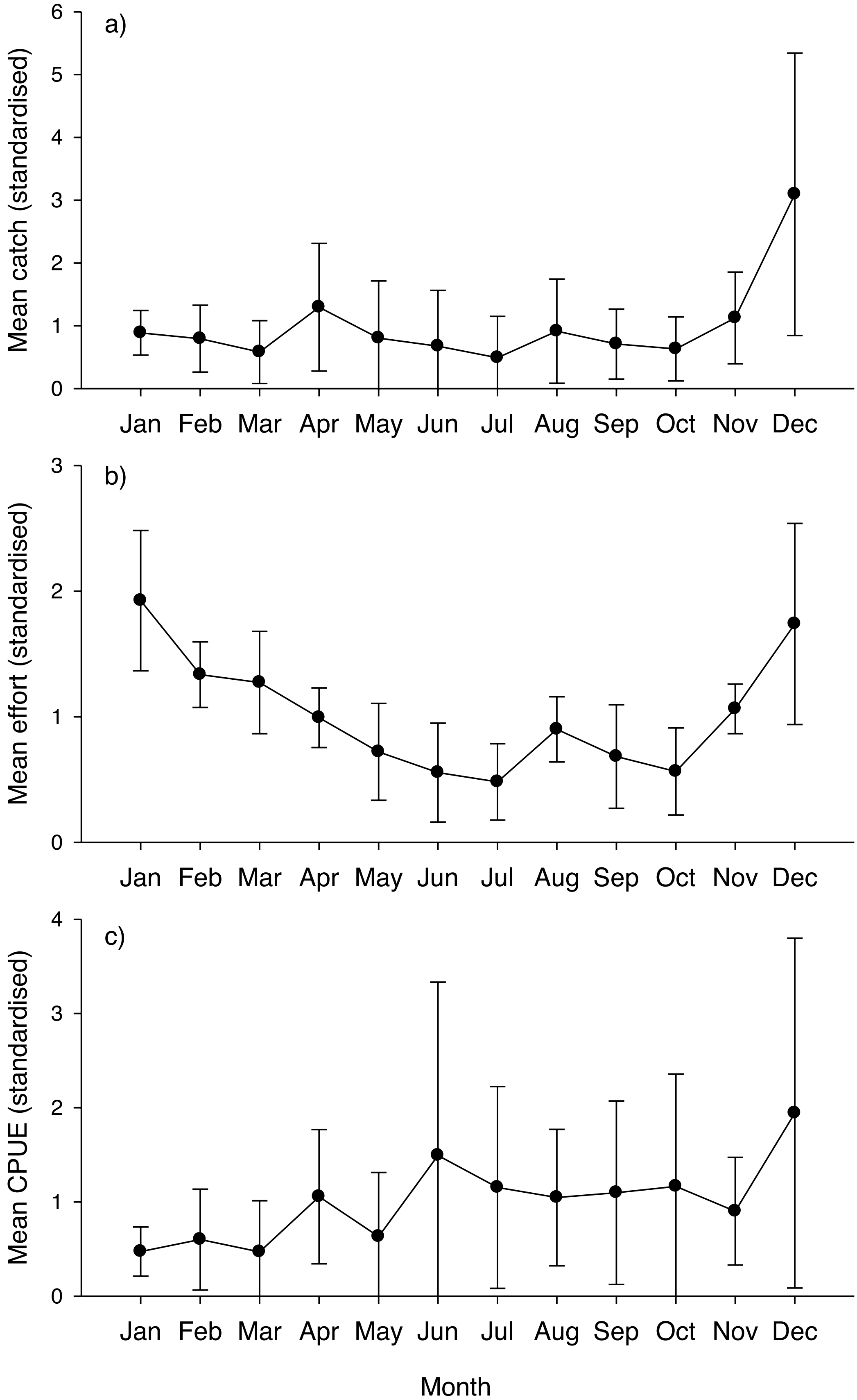


Figure 34. Standardised mean (**±** 1s.e.) monthly **a)** catches (retained and released), **b)** effort (hours fished) and **c)** catch rates of *Sillago* species (assumed to be comprised mainly of southern school whiting) as reported by voluntary logbook fishers each month during boat-based fishing in the Perth area from January 2006 to December 2011.

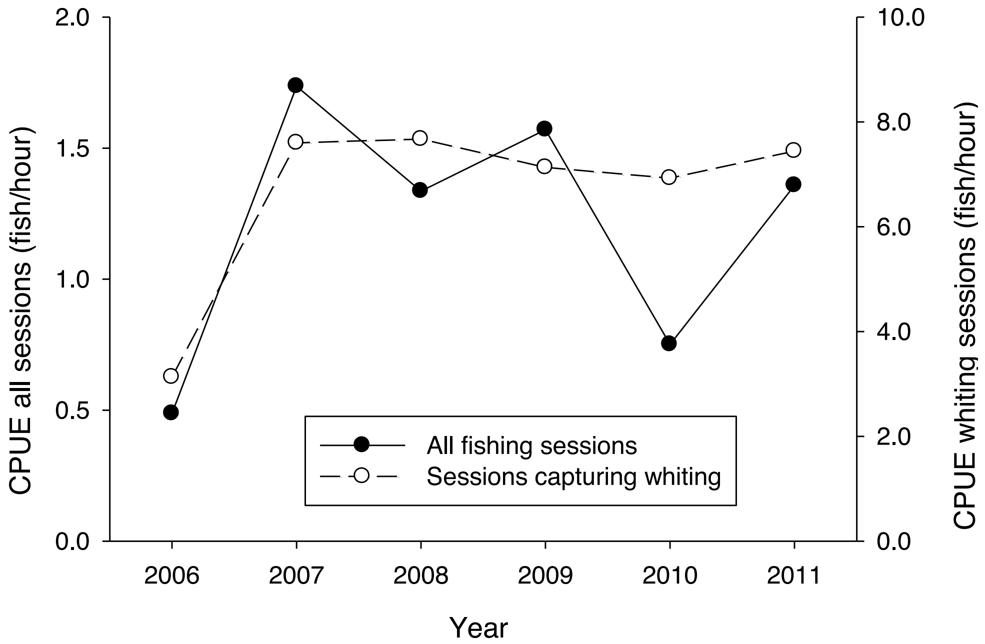


Figure 35. Annual catch-per-unit-effort (CPUE) for *Sillago* species (assumed to be comprised mainly of southern school whiting) as reported by boat-based voluntary logbook fishers in the Perth area from 2006 to 2011. CPUE has been calculated including retained and released fish. 'All fishing sessions' (solid line) includes fishing sessions resulting in the capture of all species (including whiting and non-whiting) and zero catch, 'Sessions capturing whiting' (dashed line) excludes fishing sessions resulting in captures of non-whiting species and zero catch.

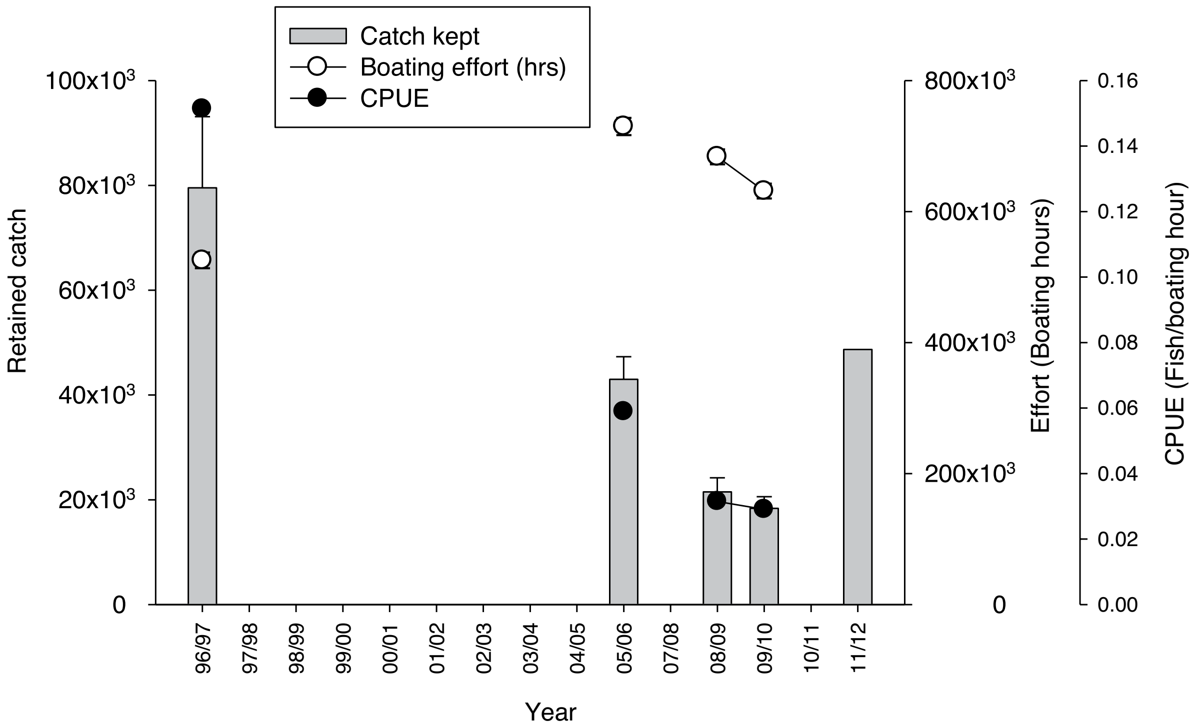


Figure 36. Estimated annual retained catches (numbers of individuals) (+95% confidence limits), boating hours and nominal mean catch rates of King George whiting caught by boat-based recreational fishers in the West Coast Bioregion in 1996/97, 2005/06, 2008/09, 2009/10 and 2011/12. Note that the retained catch estimates for 2011/12 has not been adjusted for differences in survey methods to allow a direct comparison with the four earlier surveys.

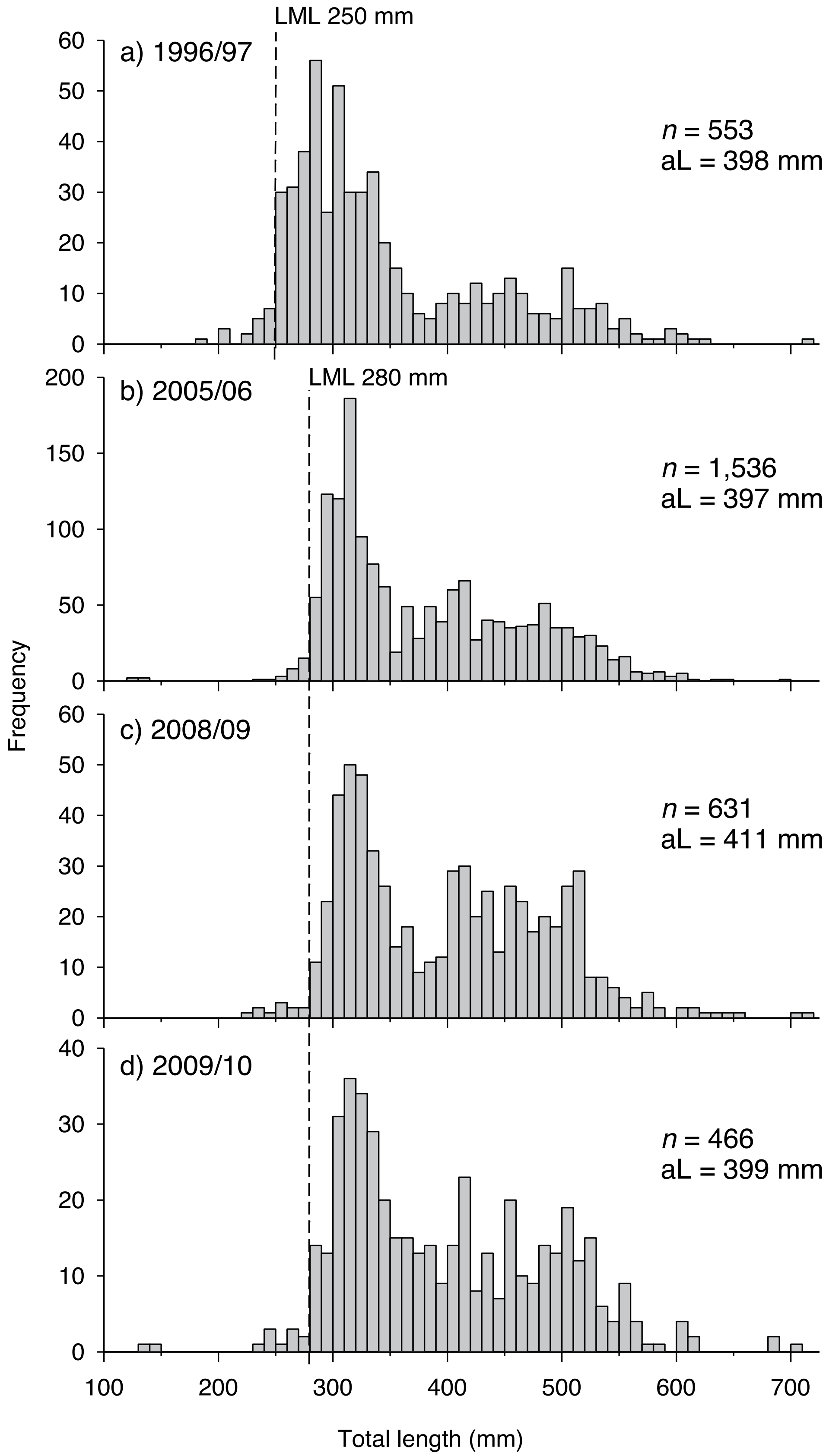


Figure 37. Length frequency distributions of King George whiting caught by recreational fishers, from measurements recorded during boat-based surveys in **a)** 1996/97, **b)** 2005/06, **c)** 2008/09 and **d)** 2009/10 in the West Coast Bioregion. aL, average length of fish in sample. *n* = number of fish. The legal minimum length (LML) at the time of all survey periods is shown (dashed line).

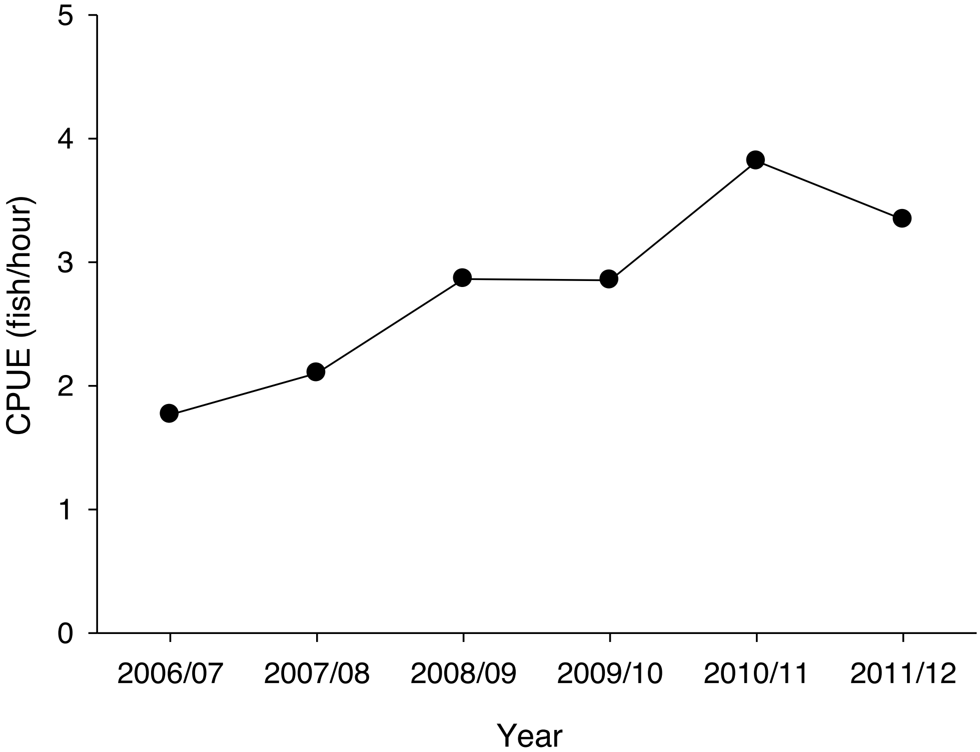


Figure 38. Annual catch-per-unit-effort (CPUE) of King George whiting reported by boat-based voluntary logbook fishers in Geographe Bay (WCB: South-west Zone) from 2006/07 to 2011/12 (September to February only). Effort excludes fishing sessions resulting in catches of fish species other than King George whiting and all zero catches. The catch rates were calculated including both retained and released King George whiting.

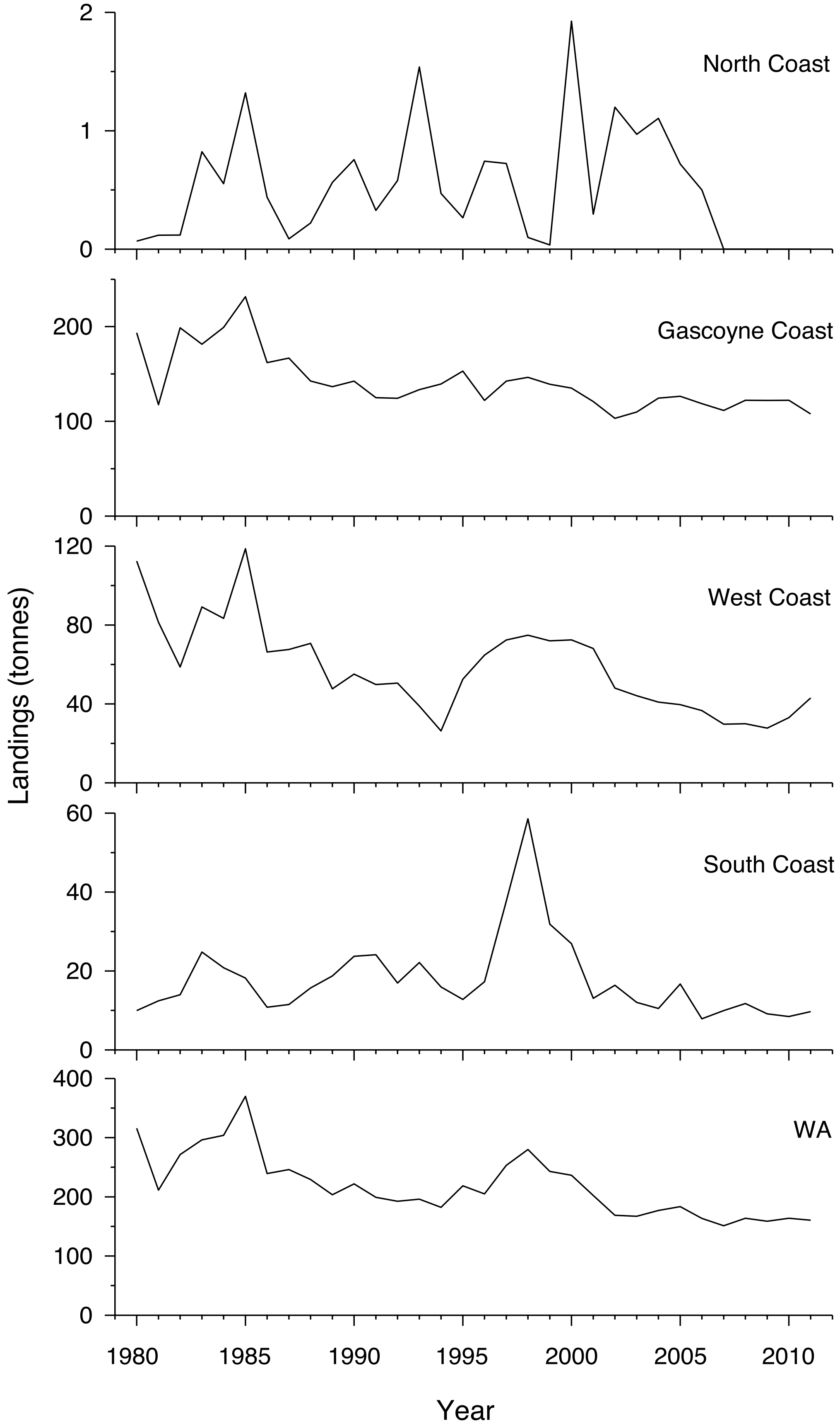


Figure 39. Total annual commercial landings (tonnes) of all whiting species in each of the four bioregions of Western Australia between 1980 and 2011.

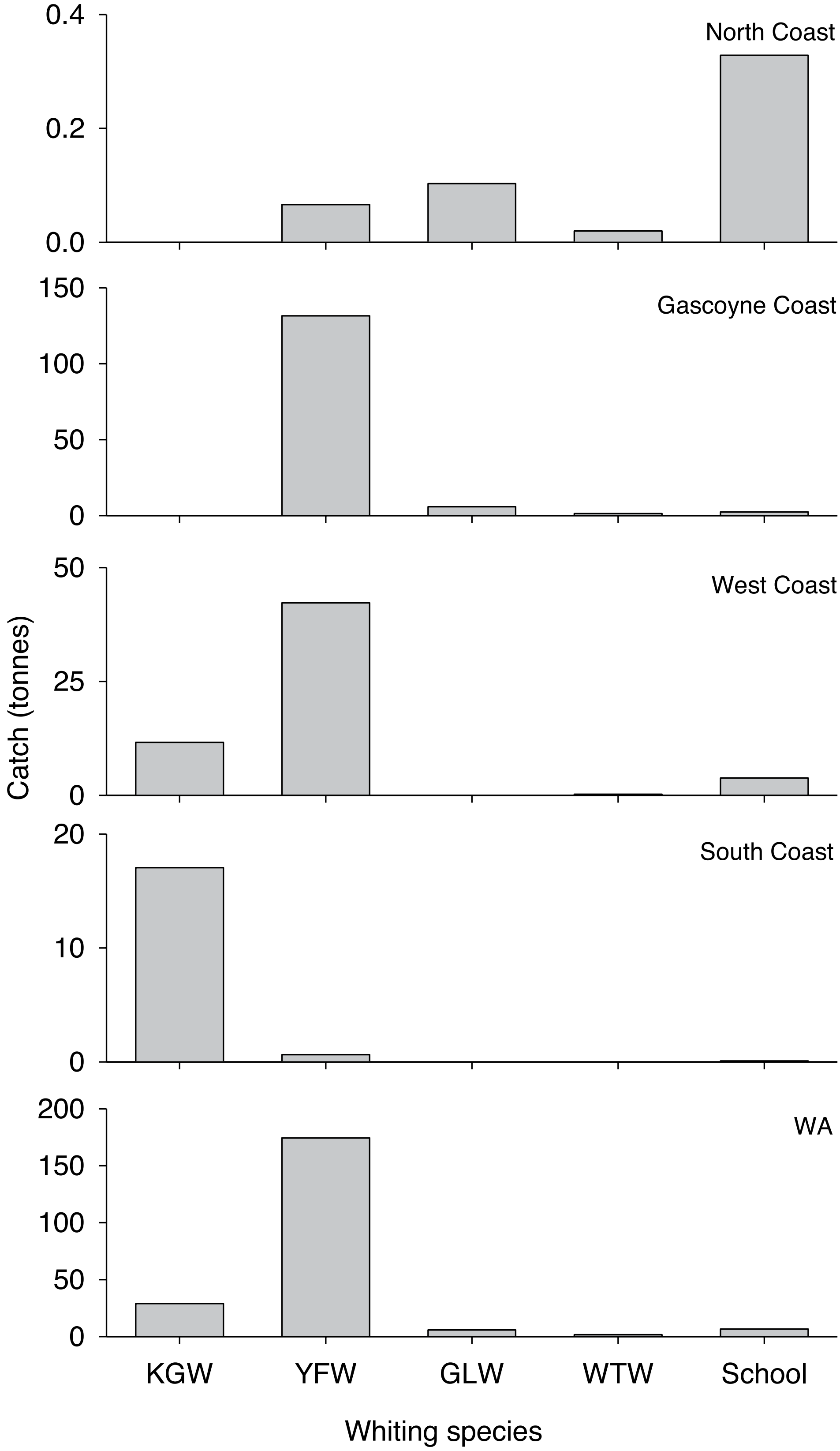
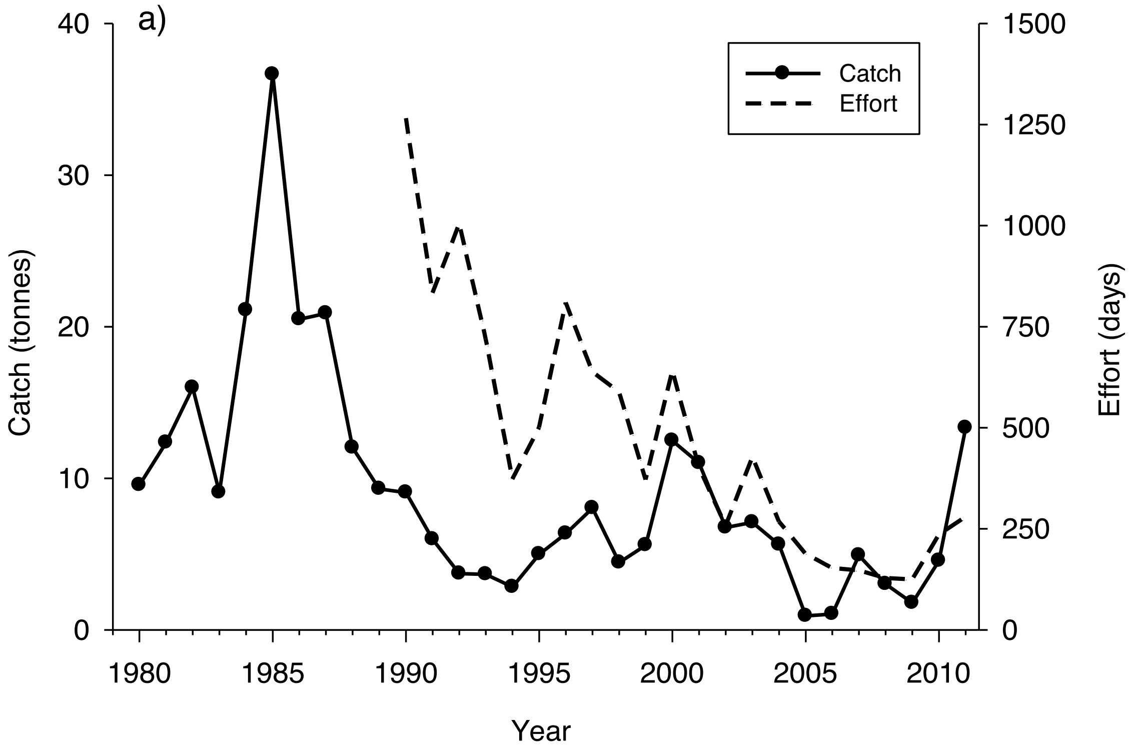


Figure 40. Average annual commercial whiting catches during 1980–2011, by species, for each of the four bioregions in Western Australia (WA). The whiting species listed are as recorded in the Department of Fisheries commercial Catch and Effort Statistics (CAES) database. KGW, King George whiting; YFW, yellowfin whiting; GLW, goldenline whiting; WTW, western trumpeter whiting; school whiting, all other whiting species in WA, including southern school whiting, western school whiting and stout whiting.



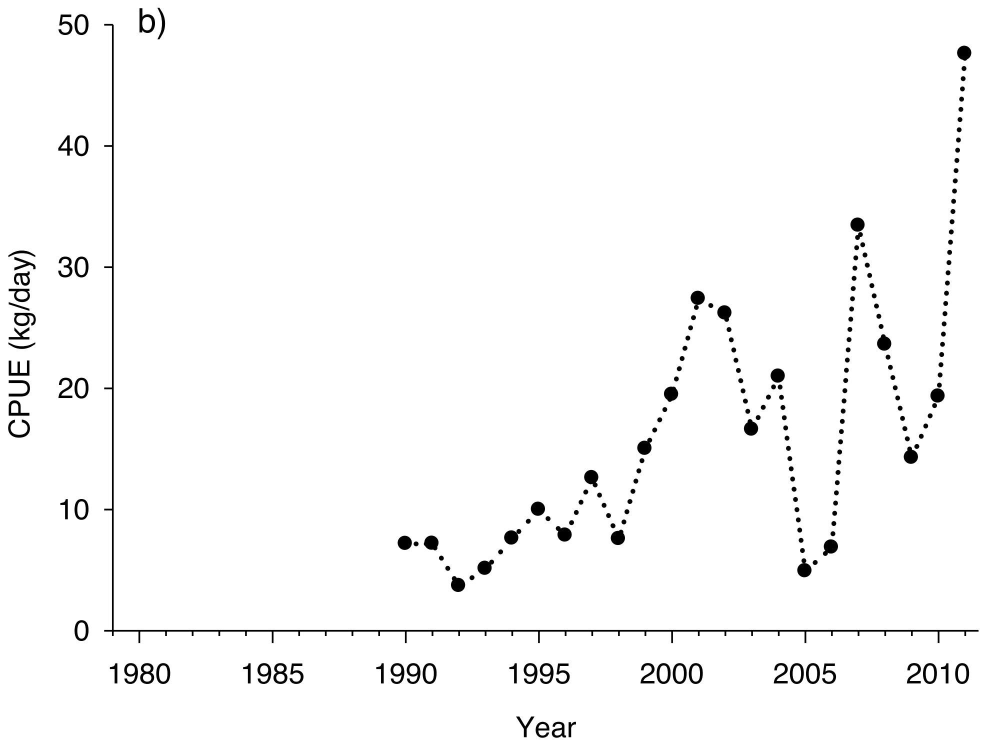


Figure 41. **a)** Annual commercial landings of *Sillago* species (assumed to be comprised mainly of southern school whiting) caught by commercial trawl netting and total annual trawling effort by the South-West Trawl Fishery in the West Coast Bioregion, 1980–2011 (effort is for all vessels). **b)** Average annual catch-per-unit-effort (CPUE) of *Sillago* species (assumed to comprise mainly of southern school whiting) taken by trawl netting by the South-West Trawl Fishery in the West Coast Bioregion in 1980–2011.

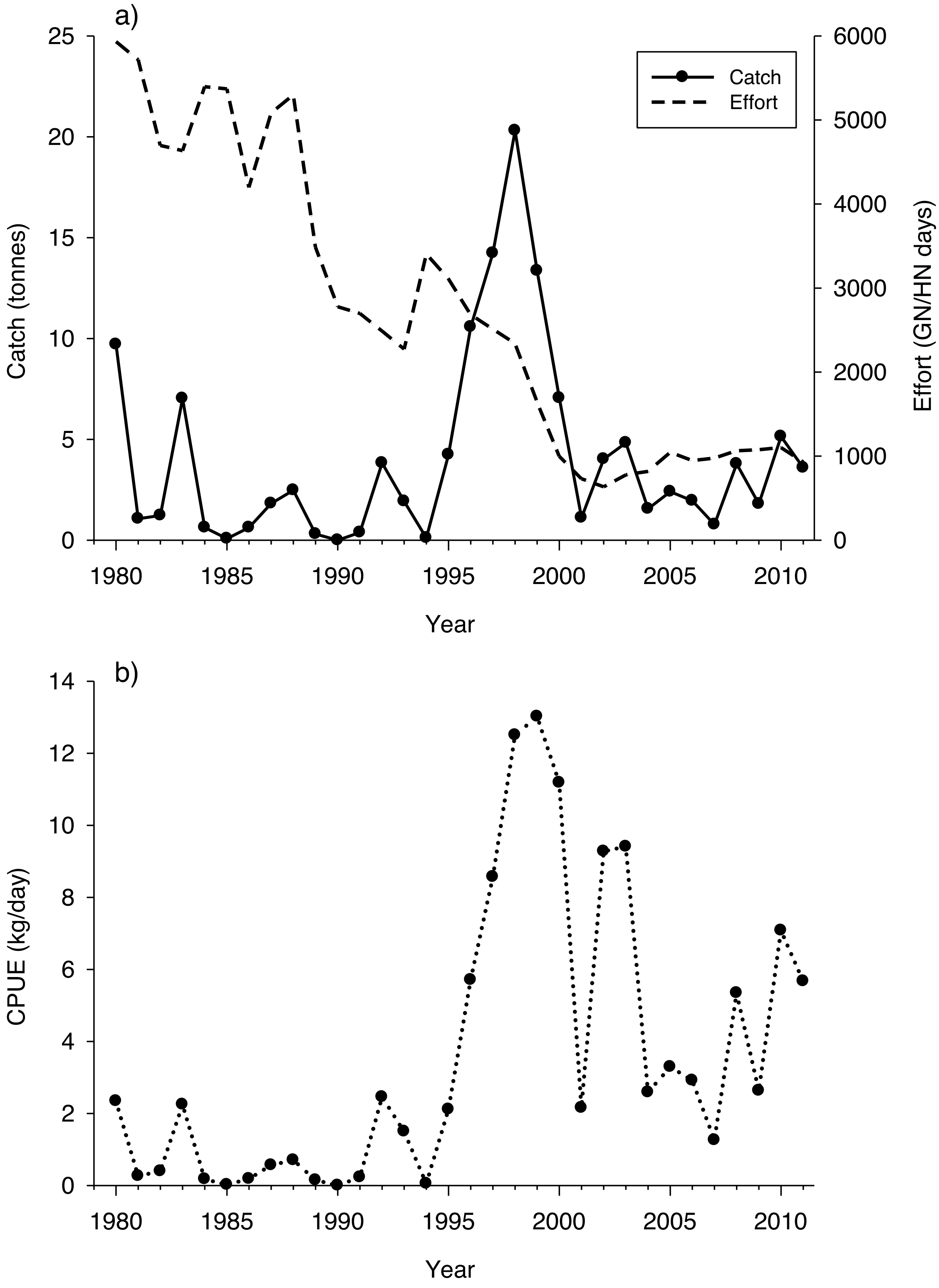


Figure 42. **a)** Annual commercial landings of King George whiting and annual gill and haul netting effort in Peel-Harvey Estuary in 1980–2011 (effort is for all vessels using gill and haul netting only). **b)** Average annual catch-per-unit-effort (CPUE) for King George whiting caught by gill and/or haul netting (March to October only) in the Peel-Harvey Estuary in 1980–2011.

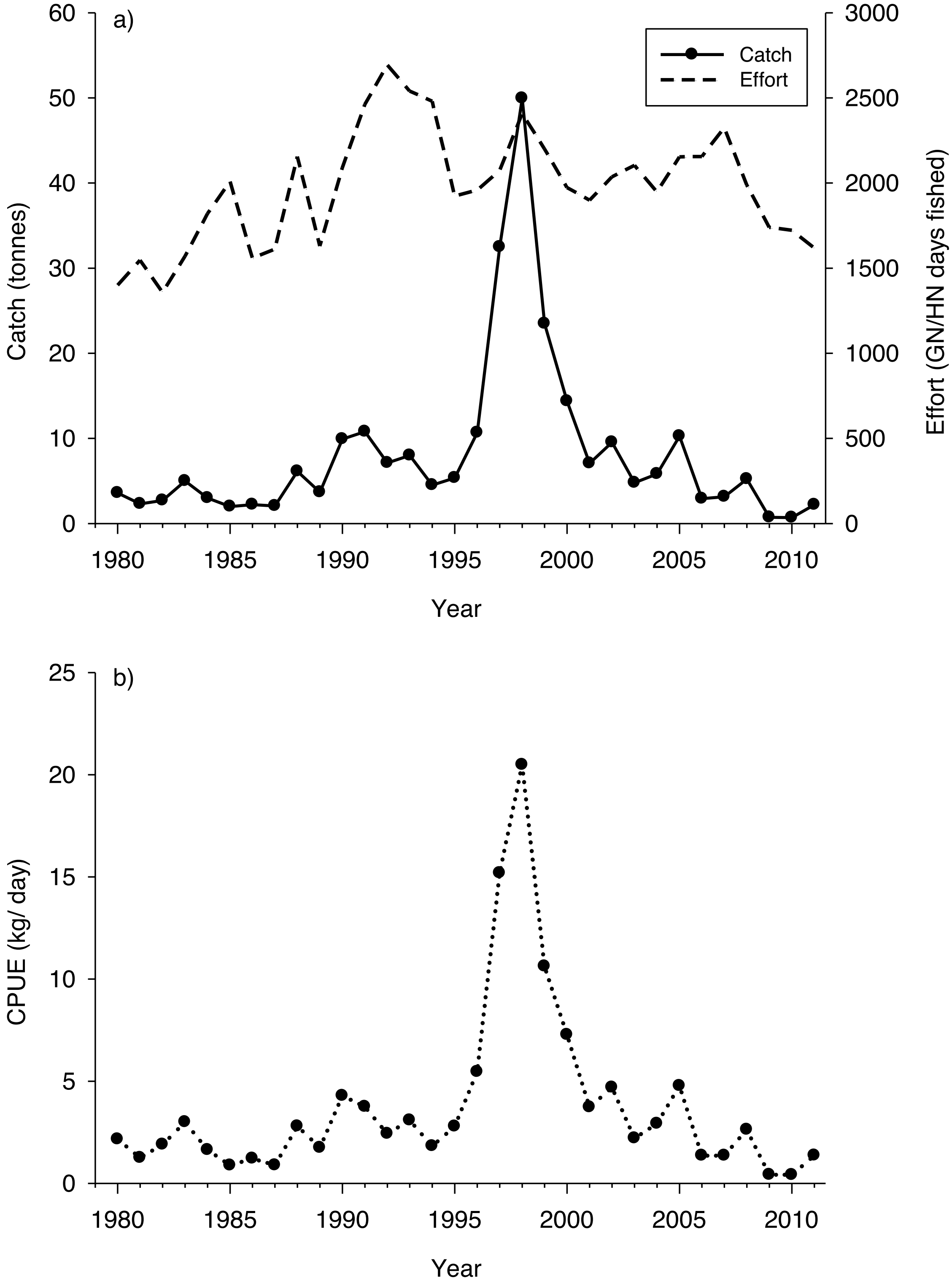


Figure 43. **a)** Annual commercial landings of King George whiting and annual gill and haul netting effort in Wilson Inlet in 1980–2011 (effort is for all vessels using gill and haul netting only). **b)** Average annual catch-per-unit-effort (CPUE) for King George whiting taken by gill and/or haul netting in Wilson Inlet in 1980–2011.

8.0 Appendices

Appendix 1. Whiting identification article published in the Research Angler Program newsletter (April 2011) to assist with improved reporting of individual whiting species of the West Coast Bioregion.

Whiting identification

Whiting (Family: Sillaginidae)

The whiting family is common throughout the Indian Ocean and the western Pacific Ocean (McKay 1992). There are 31 different species of whiting currently known, with at least 10 of these found in WA waters. These species, while similar in appearance, are often quite different in either the habitat they occupy (estuarine, nearshore and offshore waters to a depth of about 180 metres), the size they grow to, how long they live and the length/age at which they first reach maturity. Understanding these characteristics is important to sustainably manage this family.

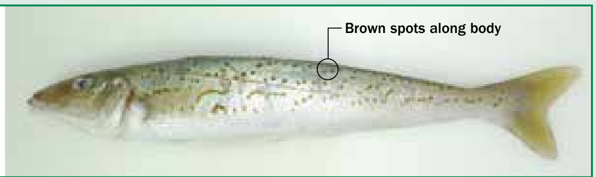
In WA, whiting are one of the most common fish caught by recreational anglers. If fishing in the West Coast Bioregion (Kalbarri to Augusta) there are six different whiting species that you could potentially catch. There is the much-loved King George whiting, the largest of the whiting family reaching a length of over 70 cm and obtaining a maximum age of around 15 years in WA. Of the other whiting species, these are often grouped together and referred to as sand or school whiting, but from careful examination, it is easy to distinguish these species from one another. Understanding which species of whiting are the most commonly captured by fishers will allow the Department to better focus its monitoring programme.

Josh Brown

Whiting species in the West Coast Bioregion

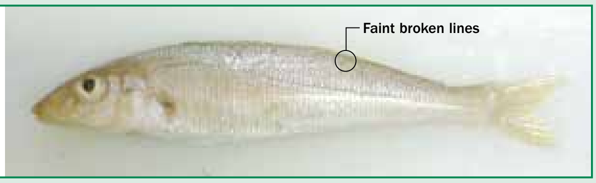
King george whiting
Sillaginodes punctata

Identification: Numerous small brown spots on side. Largest of all whiting.
WA Distribution: South of Jurien
Maximum Size: 72 cm



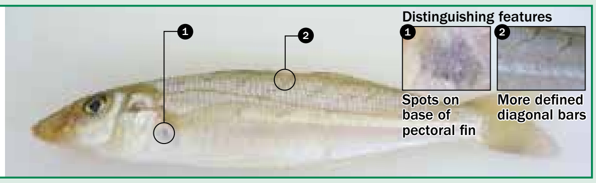
Southern school whiting
Sillago bassensis

Identification: Diagonal faint, broken brown bars along upper side. No spots on pectoral fin base.
WA Distribution: South of Geraldton
Maximum Size: 36 cm



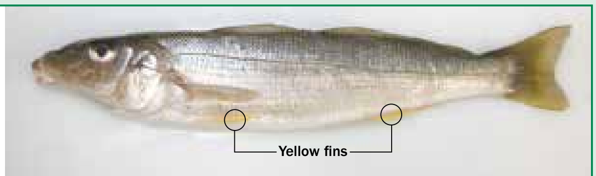
Western school whiting
Sillago vittata

Identification: Well defined brown bars along upper side. Dark spots on pectoral fin base distinguish this species from southern school (see insert).
WA Distribution: Geographe Bay to Exmouth
Maximum Size: 35 cm



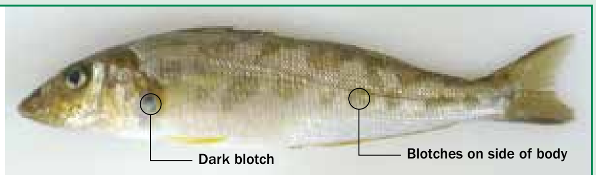
Yellowfin whiting
Sillago schomburgkii

Identification: Yellow ventral and anal fins. Weakly forked tail.
WA Distribution: South of Shark Bay
Maximum Size: 42 cm



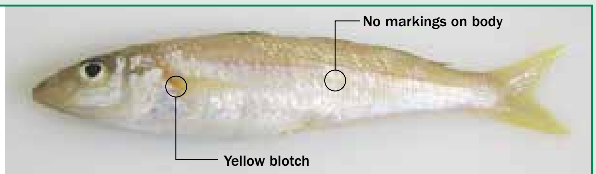
Western trumpeter whiting
Sillago burrus

Identification: Dark blotches on side of body. Dark blotch on pectoral fin base.
WA Distribution: North of Geographe Bay
Maximum Size: 31 cm (usually < 25 cm)



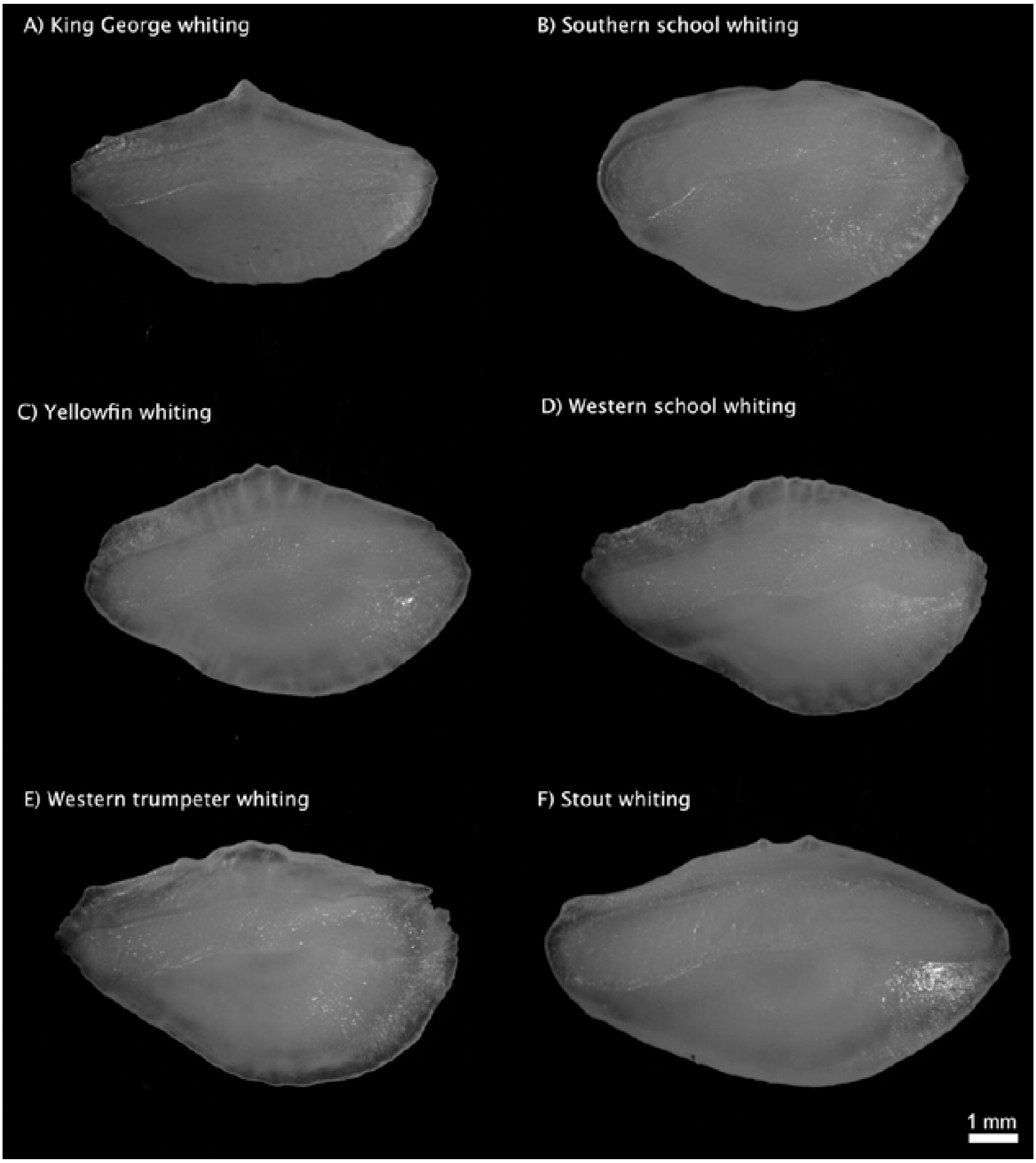
Stout whiting
Sillago robusta

Identification: May be a yellow blotch behind the pectoral fin. No other distinguishing markings. Strongly forked tail.
WA Distribution: Fremantle to Shark Bay
Maximum Size: 30 cm (usually < 25 cm)



Appendix 2. Sagittae otoliths of whiting species of south-western Western Australia.

Note: all fish had the same total length of 195 mm.



Appendix 3. Photographs of stout whiting from a) Western Australia and b) New South Wales.

a) *Sillago cf robusta* (Western Australia)

b) *Sillago robusta* (New South Wales)