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Status of demersal finfish stocks on the west coast of Australia

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Contents

1.0 Executive summary

Assessments of the key indicator species for the West Coast Demersal Scalefish Resource (WCDSR; West Australian dhufish *Glaucosoma hebraicum*, Snapper *Pagrus auratus* and Baldchin groper *Choerodon rubescens*) in 2007 and 2009 demonstrated that the stocks were experiencing overfishing. Thus, between late 2007 and early 2010, substantial changes were made to the management of the commercial and recreational fisheries that exploit the WCDSR. These were designed to reduce catches of the entire suite of demersal scalefish species (and of each indicator species) by both the commercial and recreational sectors in the West Coast Bioregion (WCB) by at least 50 % of the 2005/06 levels (the catch benchmark), to allow stocks to recover.

The current (third) stock assessment of indicator species for the demersal scalefish suite was based on age data collected between 2008/09-2010/11 for *G. hebraicum* and *P. auratus* and 2007/08-2010/11 for *C. rubescens* and on catch statistics for the commercial and recreational fishing sectors (including charter fishing) from 2008-2012. The assessment compared estimates of fishing mortality (*F*) for the most recent period with several previous time periods and against internationally accepted biological reference points to determine whether there was evidence of any stock recovery. The sampling period for this assessment included the period when major changes were being made to management in the WCB of commercial and recreational/charter fishing for demersal species. As each of the indicator species is relatively long-lived, it is expected that it will take at least 10 years from these management changes before their stocks show strong signs of recovery, and that it may take substantially longer before they fully recover (~15-20 years).

Catches of the demersal suite of species in the WCB by the commercial sector and of the top 15 species taken by the recreational sector have been reduced to less than the catch benchmark. Although catches of all indicator species have been reduced, those of two indicator species, *P. auratus* and *C. rubescens*, have not been reduced below the catch benchmark by all sectors.

Stock assessment results for Glaucosoma hebraicum

- The most recent estimates of catches of *G. hebraicum* by commercial and recreational fishers were both less than the catch benchmark.
- Estimates of the instantaneous rate of fishing mortality (*F*) and spawning potential ratio (*SPR*), based on data from the 2008/09-2010/11 period, indicated that the current management arrangements have sufficiently reduced the level of fishing on *G. hebraicum* by both the recreational and commercial sectors. This has allowed the overall stock (*i.e.* at the Bioregion level) and the assemblages of this species in each management area in which it was assessed, to begin recovering.
- Although there are indications that recovery has commenced, the *G. hebraicum* stock has not yet recovered to acceptable levels (*i.e. F* below the threshold reference point).

Stock assessment results for Pagrus auratus

- The most recent estimates of total recreational and commercial catch of *P. auratus* across the WCB were lower than in 2005/06. However, the total recreational catch and the commercial catch in the northern management areas of the WCB were both still greater than the catch benchmark.
- Estimates of *F* for the 2008/09-2010/11 period demonstrated that the current management arrangements have reduced the level of fishing of *P. auratus*, allowing recovery of the

overall stock to begin at the Bioregion level. An overall estimate of *SPR* for the WCB was not produced for *P. auratus* as its biology differs substantially among management areas.

- While there was evidence of recovery of *P. auratus* stocks at the bioregion level, the estimate of *F* in 2008/09-2010/11 was higher than that for *G. hebraicum* and much higher in the northern half of the WCB than the southern half.
- The *P. auratus* stock in the WCB has begun to recover. However, as for *G. hebraicum*, it has not yet recovered to acceptable levels.

Stock assessment results for Choerodon rubescens

- The most recent estimates of commercial catch of *C. rubescens* were approximately equivalent to the catch benchmark but recreational catches were slightly greater.
- The *F* and *SPR* for *C. rubescens* in the Abrolhos Islands Zone A area for the 2007/08-2010/11 period have not improved since the 2000/01-2001/02 period.
- While the lack of evidence of recovery could indicate that overfishing was still occurring, it is more likely that recovery was not yet evident due to the overlap of the sampling period for this assessment (2007/08-2010/11) and the introduction of changes to management (2007-2010).

Advice

- The levels of fishing mortality for *G. hebraicum* at the bioregion level and in each area and of *P. auratus* in the southern half of the WCB already provide evidence of initial recovery and, if current catch levels are maintained for at least five more years, this will allow recovery to continue.
- Catches of *P. auratus* in the northern half of the WCB by the commercial sector and of both *P. auratus* and *C. rubescens* in the whole WCB by the recreational sector have not been reduced to less than the catch benchmark. Significantly, these assemblages have exhibited little or no evidence of recovery. Reduction of catches of these to benchmark catch levels by the commercial and recreational sectors is still required to ensure an appropriate level of recovery of their stocks.

Future stock assessments and catch monitoring

- A five-yearly cycle of stock assessments is normally appropriate for the demersal indicator species, given their biological characteristics and if their stocks were at sustainable levels. The next scheduled assessment would thus follow the collection period of 2011/12-2015/16.
- However, with stocks of these species currently in a recovery phase, depending on priority and resourcing, it may be more appropriate to conduct assessments of indicators on a three-yearly cycle, *i.e.* after the 2011/12-2013/14 collection period.
- Ongoing monitoring of commercial and recreational catches is required to enable comparisons with the 50 % of 2005/06 catch benchmarks.

Key words: indicator species, inshore demersal, *Glaucosoma hebraicum*, *Pagrus auratus*, *Choerodon rubescens*, weight of evidence, fishing mortality

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2.0 Introduction

2.1 The West Coast Demersal Scalefish Resource

Using the Department of Fisheries' Ecosystem Based Fisheries Management framework (Fletcher *et al.*, 2012), the West Coast Demersal Scalefish Resource (WCDSR) comprises suites of demersal teleost species that occur predominantly in "inshore" waters (20-250 m deep) and "offshore" waters (> 250 m deep) of the West Coast Bioregion (WCB; Fig. 2.1). In this Bioregion, up to about 100 demersal species are caught by various fisheries each year. A number of demersal fish species in inshore waters are important to commercial and recreational fishers, including West Australian dhufish *Glaucosoma hebraicum* (Glaucosomatidae), Snapper *Pagrus auratus* (Sparidae), Redthroat emperor *Lethrinus miniatus* (Lethrinidae), Bight redfish *Centroberyx gerrardi* (Berycidae) and Baldchin groper *Choerodon rubescens* (Labridae). Important demersal species caught in offshore waters include Eightbar grouper *Hyporthodus octofasciatus* (Epinephelidae), Hapuku *Polyprion oxygeneios* and Bass groper *Polyprion americanus* (both Polyprionidae), Blue-eye trevalla *Hyperoglyphe antarctica* (Centrolophidae) and Ruby snapper *Etelis carbunculus* (Lutjanidae).

Biological characteristics of these species typically include substantial longevity (> 20 y, up to ca 80 y) and thus low natural mortality, relatively large maximum sizes (> 500 mm TL in many cases) that are approached relatively slowly (von Bertalanffy $k < {\sim}0.3$ year^{-1}) and reproductive strategies which may include spawning aggregation behaviour and sequential hermaphroditism. Such factors make these species inherently vulnerable to exploitation.

2.2 Assessments of stock status of the WCDSR

Available data sources for the WCDSR currently allow a weight of evidence approach (Wise *et al.*, 2007) that incorporates assessments of fishing mortality (*F*) rates (Level 3, as categorised by the Department of Fisheries, WA) for indicator species for the suite of inshore demersal species and catch-based (Level 1) assessments of the offshore demersal suite (Department of Fisheries, 2011; Fletcher and Santoro, 2012). Both of these include annual monitoring of catches in the WCB by commercial fisheries and by charter fishers and periodic estimation of boat-based recreational catches (see sections 2.3 and 2.4; Fairclough *et al.*, 2012). Effort data and relative abundance measures may also be considered in level 3 assessments (Fletcher and Santoro, 2012). The levels of assessment undertaken on fishery resources by the Department are determined through a risk-based approach (Fletcher *et al.*, 2010; 2012) that considers the social and economic value of the fishery and species, the inherent vulnerability of the resources, the most recent status and risk assessment, the management requirements, the amount and quality of available data and the level of sophistication of the analyses. As higher levels of assessment are likely to provide more robust indicators of stock abundance than lower levels of assessment, the Department aims to undertake the highest possible levels of assessment for each stock given the available data, priority and resources available.

Figure 2.1. Boundaries of the West Coast Demersal Scalefish (Interim) Managed Fishery and its management areas (Kalbarri, Midwest, Metropolitan, South-west and Offshore) and of Zone A of the Western Rock Lobster Managed Fishery. Note the boundary of the West Coast Bioregion lies at 27°S.

Level 3 assessments of *F* are conducted only on inshore demersal indicator species, as present catches of offshore demersal species are too small to be able to obtain sample sizes large enough to produce robust estimates of *F* (Craine *et al.*, 2009; Fairclough *et al.*, 2012). Based on their importance to the fishery, the indicator species chosen for the inshore suite were West Australian dhufish, Snapper and Baldchin groper and for the offshore suite were Hapuku, Blue-eye trevalla and Eightbar grouper (Department of Fisheries, 2011).

A Department of Fisheries weight of evidence level 3 assessment of the WCDSR was conducted for the first time by Wise *et al.* (2007) and included examinations, for the inshore demersal indicator species, of (1) historical catch and effort data from commercial and recreational fishing (including charter industry) in the WCB and (2) fishing mortality rates and per recruit analyses, based on biological parameters estimated during various biological studies and length and age composition data collected primarily between 2002/03 and 2005/06. These data were used in combination with other subjective criteria on the inherent vulnerability and susceptibility of the stocks to fishing pressure (Wise *et al.*, 2007; see also Department of Fisheries, 2011). The approach involves refining recommendations regarding acceptable exploitation levels, as indicated by decision rules relating to fishing mortality-based performance indicators (*i.e.* as produced by the quantitative assessment), through using the additional subjective information on stock vulnerability and susceptibility. The use of all available information is recommended as best practice for any fisheries stock assessment (Pauly *et al.*, 2013) and the approach used for the WCDSR has been shown to be robust by independent reviewers (Haddon in Wise *et al.*, 2007; O'Neill, 2009). Due to the limited time series of reliable catch and effort data from both the commercial and recreational sectors, it was not possible in this assessment to use an integrated model to produce estimates of biomass and derive predictions of future stock biomass. However, as high quality catch and effort data are now being collected from commercial fishers' daily logbooks and regular surveys of boat-based recreational fishing are being conducted (Ryan *et al.*, 2013), such an assessment should become possible within the next decade in at least some management areas for this fishery.

The Wise *et al.* (2007) assessment compared values of F estimated from age compositions for each inshore demersal indicator species for each management area and fishing sector in relation to internationally accepted biological reference points (see Table 3.1). These reference points corresponded to ratios between estimates of F and natural mortality (M). For these relatively long-lived and thus vulnerable demersal species, the reference points include: (1) a target of $F = 2/3M$, which is considered a desirable level of fishing; (2) a threshold of $F = M$, beyond which greater restriction on the fishery(ies) is required to return F towards the target value and (3) a limit of $F = 1.5M$, which represents a level at which there is a high and unacceptable risk of recruitment failure, thereby requiring strict management responses to reduce risks to sustainability and allow stock recovery. The "weight of evidence" approach employed by Wise *et al.* (2007), also took into account the inherent vulnerability of each indicator species, based on their biological characteristics, operational characteristics of the fishery and potential influences of environmental change.

The assessment by Wise *et al.* (2007) revealed that, in the four management areas of the WCB (Kalbarri, Mid-west, Metropolitan and South-west), overfishing was occurring of: (1) *G. hebraicum* in the latter three of those; (2) *P. auratus* in all four areas and (3) *C. rubescens* in the Houtman-Abrolhos Islands region which straddles the Mid-west and Kalbarri areas (Fig. 2.1). A second assessment of F, based on data collected in 2007/08, indicated the stock status of these three species had not changed (Fairclough *et al.*, 2009). Independent external reviews concluded that the analyses, assessment outcomes and recommendations were valid (Haddon, in Wise *et al.* 2007, O'Neill, 2009). Wise *et al.* (2007) recommended that effort and thus catches of demersal scalefish in the WCB needed to be reduced by at least 50 % of those in 2005/06 to allow stocks to recover. As catch data were available for both commercial and recreational fisheries in the WCB in that year, it was decided that the catch in that reference year should be used as the benchmark. The primary management objective of reducing catches to 50% of 2005/06 levels was formalised, which resulted in significant changes to the management of commercial and recreational fisheries (see below; Department of Fisheries, 2010).

2.3 Management of commercial exploitation of the WCDSR

The West Coast Demersal Scalefish (Interim) Managed Fishery (WCDSIMF), which employs hand-lines and drop-lines (collectively referred to as wet-lines), is the main commercial fishery that targets demersal fish species in the WCB. This fishery commenced operation at the beginning of 2008, following restructuring of the previous open access wet-line fishery, which comprised substantial latent effort in the > 1200 vessels that could access the fishery. The WCDSIMF operates between 26°30' south (north of Kalbarri) and 115°30' east (east of Augusta) (Fig. 2.1) and comprises four inshore management areas, *i.e.* Kalbarri, Mid-West, Metropolitan and South-West, that each extend from the coast outwards to the 250 m depth contour. An Offshore Area includes the waters from the northernmost to southernmost boundary of the fishery and from the 250 m depth contour to the boundary of the AFZ.

The WCDSIMF was developed as a limited entry fishery, with initially only 61 permits allowed access to the fishery. Each of the four inshore management areas is allocated a maximum number of annual hours of fishing time, with the Metropolitan Area currently allocated zero hours, *i.e.* fishing is not permitted. Units are allocated to permits and provide entitlement in "hours" of fishing time. The total number of annual hours for the Offshore Area is available to all permit holders and once consumed the area is closed to fishing for the remainder of that year. The use of a Vessel Monitoring System allows fishing effort to be monitored and entitlement use acquitted. The total capacity of the fishery, which can be adjusted by altering unit values as required, restricts fishing effort in order to meet catch objectives. Gear and other restrictions apply (in the form of maximum numbers of lines and hooks that may be used and arrangements regulating the carriage of lines and fish), including minimum legal lengths (MLL) for retention of species.

The management objectives for the WCDSIMF are to maintain catches of all scalefish and also of the suites of demersal species at or below 50 % of the catches recorded in the WCB during 2005/06. The catch of demersal scalefish in each management area should also not exceed 50 % of the 2005/06 catch in that area. The annual catch for each indicator species in the WCDSIMF and in each of the areas where they are an indicator should also remain below 50 % of the 2005/06 level. Draft catch management guidelines for this fishery, which allow for fluctuations around the benchmark, and a departmental harvest strategy policy, are in development.

Other state-managed commercial fisheries that are permitted to take demersal scalefish in the WCB include the West Coast Demersal Gillnet and Demersal Longline (Interim) Managed Fishery and Zone 1 of the Joint Authority Southern Demersal Gillnet and Demersal Longline Managed Fishery, referred to collectively as the Temperate Demersal Gillnet and Demersal Longline Fisheries (TDGDLF), which mainly target some species of sharks. The West Coast Rock Lobster Managed Fishery (WCRLF), the Cockburn Sound Line and Pot Managed Fishery (CSLPF) and the South-West Trawl Managed Fishery (SWTMF) are also permitted to retain demersal species in the WCB (see Fletcher and Santoro, 2012 for description of management arrangements). The catch of demersal fishes by these other fisheries is relatively small. The total catch of demersal species by each of these fisheries and the WCDSIMF is required to remain below 50 % of those recorded for those fisheries during 2005/06. The Commonwealth managed Western Deepwater Trawl Fishery and the Great Australian Bight Trawl Sector of the Southern and Eastern Scalefish and Shark Fishery, which operate in waters of the WCB > 200 m deep, also catch demersal fish species (see www.afma.gov.au).

Table 2.1. Abbreviations of fishery names used in this document

WCB	West Coast Bioregion
WCDSR	West Coast Demersal Scalefish Resource
WCDSIMF	West Coast Demersal Scalefish (Interim) Managed Fishery
WCDSF	Collective term used for WCDSIMF and recreational/charter sector of the WCB
WCDGDLF	West Coast Demersal Gillnet and Demersal Longline (Interim) Managed Fishery
JASDGDLF	Joint Authority Southern Demersal Gillnet and Demersal Longline Managed Fishery
TDGDLF	Temperate Demersal Gillnet and Demersal Longline Fisheries. Collective term for WCDGDLF & Zone 1 of the JASDGDLF, operating in the WCB
WCRLF	West Coast Rock Lobster Managed Fishery
CSLPF	Cockburn Sound Line and Pot Managed Fishery
SWTMF	South-West Trawl Managed Fishery

2.4 Management of recreational exploitation of the WCDSR

Demersal scalefish are targeted primarily by boat-based recreational fishers and the charter boat industry in the WCB (collectively referred to as the recreational sector). Line fishing is the main method used, although some spear fishing also occurs, mainly in waters < ca 20 m deep (Fairclough *et al.*, 2012). To achieve the management objective of reducing the recreational sector's catch by at least 50 % of that in 2005/06, a suite of new management arrangements was introduced during 2009/10. These arrangements included reductions to bag and boat limits for demersal scalefish species, an increase in the minimum legal length for retention of Snapper, the implementation of a temporal closure throughout the full fishery prohibiting fishing for "high risk" demersal species between 15 October and 15 December each year and a requirement to carry a release weight (to assist in minimising post-release mortality associated with the effects of barotrauma-related injuries to fish). Furthermore, since 2 March 2010, all persons fishing from a powered boat anywhere in the state have been required to hold a Recreational Fishing from Boat Licence or to fish in the company of a licence holder. There is a statewide cap on the number of charter boat licenses issued with operators required to adhere to recreational fishing regulations (Department of Fisheries, 2012; Fletcher and Santoro, 2012).

2.5 Assessment objectives

The objectives of this third assessment of the WCDSR were to:

1. Estimate the instantaneous rates of fishing mortality (F) and spawning potential ratio for each indicator species in each management area within the WCB and compare F against biological reference points to identify whether there is evidence that stocks are now starting to recover. Stock recovery will be evidenced by decreases in fishing mortality rates and/or increases in spawning potential ratios.
2. Determine whether the commercial fisheries and recreational sector in the WCB are meeting the overall management objective of maintaining catches of demersal scalefish at no more than 50 % of 2005/06 levels.
3. Document the continued improvements to the WCDSR assessments as recommended by O'Neill (2009).

3.0 Materials and methods

3.1 Biological data and stock assessment

3.1.1 Sampling

Fish frames of legal-size *G. hebraicum*, *P. auratus* and *C. rubescens* were obtained monthly, if possible, between July 2008 and June 2011 from wholesale and retail commercial processors, recreational fishing club competitions, donations by recreational fishers and limited research sampling in each management area/sector combination for which each species is used as an indicator (Table 3.1). The minimum legal lengths (MLL, total length) for capture and retention of *G. hebraicum* and *C. rubescens* remained constant during the sampling period at 500 mm and 400 mm, respectively. For *P. auratus*, the MLL was constant at 410 mm for the Kalbarri and Mid-west areas, but was increased from 410 mm to 450 mm on 1 Jan 2009 and then to 500 mm on 1 Jan 2010 in the Metropolitan and South-west areas. *Choerodon rubescens* is an indicator for demersal stocks only in the geographical area represented by Zone A of the West Coast Rock Lobster Managed Fishery (referred to as Zone A). This is located around the Houtman-Abrolhos Islands and straddles the Kalbarri and Mid-west areas and is where this species is most abundant (Fig. 2.1). Although this species is not an indicator for the broader Mid-West and Metropolitan areas, *C. rubescens* were obtained opportunistically from these areas to enable assessment and comparisons of stock status of this species between these parts of the WCB.

3.1.2 Laboratory processing and fish age determination

Methods for biological processing of fish samples in the laboratory and sectioning of otoliths follow those of Lenanton *et al.* (2009a) for *G. hebraicum* and *P. auratus* and of the similar approaches used by Fairclough (2005) for *C. rubescens*. All otoliths were sectioned. The number of opaque zones in each otolith section was counted by a single reader, and that reader then re-counted 25 % of the otolith sections to assess the level of bias and precision between the multiple opaque zone counts. The assessment involved using age-bias plots and indices of average per cent error, using standard operating protocols (*cf.* Campana, 2001; O'Sullivan, 2007; St John *et al.*, 2008; Jackson *et al.*, 2008). For each species, such counts resulted in an overall percentage error between reads of < 5.5 %. Differences between counts were usually no greater than one opaque zone (*i.e.* one year of age). When counts differed by > 1, otoliths were read a third time. In each case, the third count agreed with one of the previous counts and was thus adopted as the final count.

Ages at capture were calculated using counts of opaque zones, average birth dates (corresponding to the approximate midpoint of the spawning period), otolith margin categories and the time when newly-formed opaque zones typically become delineated from the otolith margin, as described in Lenanton *et al.* (2009a), Fairclough (2005) and Wakefield (2006). The birth dates of *G. hebraicum* and *C. rubescens* in the WCB are 1 February and 1 December, respectively, while that of Snapper in the Kalbarri and Mid-west areas was 1 August and in the Metropolitan and South-west areas was 1 November (Hesp *et al.*, 2002; Fairclough, 2005; Wakefield, 2006; Jackson *et al.*, 2008; St John *et al.*, 2008; Wakefield *et al.*, 2011).

Ages were able to be determined for the vast majority (≥ 90 %) of samples collected for each species/area/sector combination (Table 3.1). However, only 66 % of *P. auratus* samples collected from the commercial sector in the Kalbarri Area could be used due to a substantial number of otoliths being damaged by fishers using the *iki jimi* method to euthanase fish. A Kolmogorov-

Smirnov two-sample test demonstrated that there was no significant difference (p = 0.268) between the overall length distribution for the total sample versus the sample that could be aged. Thus, it was assumed that there would also have been no difference between their age distributions and that the inability to age all fish did not bias the assessment results. Note that 97 % of the otoliths of *P. auratus* that were able to be sectioned could be successfully read.

Table 3.1. Total numbers (N) of *Glaucosoma hebraicum*, *Pagrus auratus* and *Choerodon rubescens* samples collected; of fish from which otoliths were obtained; and of otoliths sectioned and ages able to be determined from otolith sections for each species/sector/management area combination between 2008/09 and 2010/11. Percentages of total sample that could be aged provided. Samples from 2007/08-2010/11 for *C. rubescens* were pooled for *F* assessments. A small number of fish collected during research programs were treated as recreational samples, as capture methods used were the same as those used by recreational line fishers. C, commercial; R, recreational.

Management Area		*Glaucosoma hebraicum*		*Pagrus auratus*		*Choerodon rubescens*	
		C	R	C	R	C	R
Kalbarri	N			2510			
	Otoliths			1872			
	Sectioned			1699			
	Ages			**1645**			
	%			**66**			
Mid-west	N	1312	1209	1602	1200	132	1355
	Otoliths	1309	1208	1601	1200	129	1354
	Sectioned	1287	1151	1548	1184	124	1339
	Ages	**1284**	**1150**	**1520**	**1165**	**122**	**1300**
	%	**98**	**95**	**95**	**97**	**92**	**96**
Abrolhos Zone A	N					902	352
	Otoliths					901	349
	Sectioned					884	339
	Ages					**849**	**337**
	%					**94**	**96**
Metropolitan	N		1045		391		376
	Otoliths		1045		386		367
	Sectioned		1035		374		351
	Ages		**1032**		**369**		**347**
	%		**99**		**94**		**92**
South-west	N	278	484	33	226		
	Otoliths	276	484	33	222		
	Sectioned	275	480	32	205		
	Ages	**275**	**480**	**31**	**204**		
	%	**99**	**99**	**94**	**90**		

The birth dates of *G. hebraicum* and *C. rubescens* in the WCB and of *P. auratus* in the Metropolitan and South-west Areas align approximately with the middle of the financial "sampling" year. If ages at capture were truncated to determine age classes, individual fish of the same cohort caught prior to the midpoint of the spawning season (*i.e.* the assigned mean birth date) will fall into different age classes to those caught after that time. Thus, the age class of each individual of each species collected in the months of the financial year prior to the birth date were increased by one, such that individuals of the same age cohort would fall in the same age class (O'Neill, 2009). Length (total length) and age composition data are presented for all years for which data were available, including from previous studies (Table 3.2; Hesp *et al.*, 2002; Fairclough, 2005; Nardi *et al.*, 2006; Wise *et al.* 2007).

3.1.3 Estimation of fishing mortality

Method of weighting samples to determine broad-scale estimates of F

Glaucosoma hebraicum and *P. auratus* are used as indicators across most or all of the WCB, within which they each represent a single genetic stock (Berry *et al.*, 2012; Gardner and Chaplin, 2011). Thus, using samples collected from both the commercial and recreational sector, fishing mortality rates (*F*) were estimated for each species at the Bioregion level to provide an overview of the change in fishing mortality over time for each genetic stock. The catch curve method used in these analyses was selected based on the fact that it had the fewest simplifying assumptions) of the four alternative methods used for estimating *F* in each management area (see later for description of *F* estimation methods).

For *P. auratus*, broad-scale estimates of *F* were produced separately for the northern and southern management areas (*i.e.* Kalbarri and Mid-west vs Metropolitan and South-west). This approach was undertaken due to the substantial differences found between the *F* estimates for this species in the northern and southern management areas and that combining these areas would mask important differences (see results).

In addition to the broad-scale estimates for each indicator species, *F* was also calculated for each species in each management area/sector combination for which it is used as an indicator species (Table 3.2). The results of these analyses were used to gain an understanding of spatial variations in stock status, given fully-recruited adults of each species and also juveniles of at least *G. hebraicum* and *C. rubescens* are typically resident within individual management areas (StJohn *et al.*, 2009; Fairclough *et al.*, 2011; 2013). These finer scale analyses involved the use of four methods of catch curve analysis to better understand the extent to which different modelling assumptions influenced assessment results

Estimation of *F* from age composition data combined across commercial and recreational sectors and management areas first required weighting of the age frequency data to take in to account differences in sampling intensities, catches and population sizes in each area/sector combination. Note that the "weighting factors" only represent approximations of the true values because the populations of these species would not have been at equilibrium at the time (2005/06 to 2007/08) when the biological information and catch data required to develop the analysis for weighting samples were obtained. An approximate value of F_r, the instantaneous rate of fishing mortality in area *r*, was calculated by averaging the values of *F* estimated using the age samples collected from the commercial and recreational fishing sectors (denoted *com* and *rec* , respectively) and the multi-year catch curve assuming variable recruitment (method 4; see later). F_r was calculated as;

$$F_r = \left(P_{com,r} . F_{com}\right) + \left[\left(1 - P_{com,r}\right) . F_{rec,r}\right],$$

where $P_{com,r}$ is the proportion of the total sample collected for area *r* from the commercial fishing sector. The value for the instantaneous rate of total mortality in area *r* was determined as $Z_r = F_r + M$, where *M* is the estimate for the instantaneous rate of natural mortality (Table 3.4). The annual harvest rate for area *r*, R_r, may thus be calculated as

$$R_r = \frac{F_r}{Z_r} . 1 - e^{-Z_r}$$

Table 3.2. Management areas and sectors for which *Glaucosoma hebraicum*, *Pagrus auratus* and *Choerodon rubescens* are used as indicator species. Also shown are the periods for which data were available for estimating fishing mortality. * denotes periods when data were pooled for both the commercial and recreational sector due to small sample sizes.

		WCB	Kalbarri		Mid-west		Abrolhos Zone A		Metropolitan		South-west	
Species	**Period**	**C&R**	**C**	**R**	**C**	**R**	**C**	**R**	**C**	**R**	**C**	**R**
Glaucosoma hebraicum	1995/96-1997/98	–			✓	–				✓		
	2002/03-2004/05	✓			✓	✓				✓	✓	✓
	2005/06-2007/08	✓			✓	✓				✓	✓	✓
	2008/09-2010/11	✓			✓	✓				✓	✓	✓
Pagrus auratus	2002/03-2004/05	✓	✓		✓	✓				✓	✓*	
	2005/06-2007/08	✓	✓		✓	✓				✓	✓*	
	2008/09-2010/11	✓	✓		✓	✓				✓	✓*	
Choerodon rubescens	1994/95-1995/96						✓					
	2000/01-2002/03						✓					
	2007/08-2010/11					✓	✓	✓		✓		

The catch, in numbers, C_r , for area, r , was calculated from the estimated weight (t) of the combined commercial (wet-line, gillnet and long-line) and recreational catch (charter logbook and point of entry boat-based recreational survey) in 2005/06 (Department of Fisheries, 2010), H_r, and the average weight (kg) of fish in the catch for that area, $\overline{W_r}$, in the catch, *i.e.* $C_r = H_r.\frac{1000}{\overline{W_r}}$. The total number of fully-selected fish in the population within each area, H_r, may be determined as $N_r = \frac{C_r}{R_r}$.

I_r, the sampling intensity in area r relative to the estimated population size for that area, was therefore determined as $I_r = \frac{N_r}{n_r}$, where n_r is the size of the sample collected for that area. The factor by which the frequency of each age class in each area should be scaled, S_r , was determined as $S_r=\frac{I_r}{I}$, where I is the overall sampling intensity for the WCB.

Methods of estimating F

Four catch curve methods were used to estimate total mortality (Z) from age composition data. Fishing mortality was calculated as $F = Z – M$, where M is the rate of natural mortality (Table 3.3). The empirical methods employed previously to estimate M are presented in Wise *et al.* (2007). Age composition data obtained prior to 2008/09-2010/11 by Hesp *et al.* (2002), Fairclough (2005), Nardi *et al.* (2006) and Wise *et al.* (2007) were re-analysed using each method to allow examination of trends in F over time and comparison among methods.

Two methods employed by Wise *et al.* (2007) were used in these analyses which for convenience throughout this report, we have labelled *Methods 1 and 2*. *Method 1* is the calculation of Z as the negative of the slope of a linear regression fitted to the natural logarithms of the frequencies of fish in each fully-selected age class (*i.e.* the method described in Ricker (1975), taking the age at full recruitment into the fishery as one year added to the age with the greatest number of fish). *Method 2* is a piecewise log-linear regression fitted to the relative frequencies of fish at age (see Wise *et al.*, 2007 for full details). Another method, that incorporates age-based selectivity as employed by Wise *et al.* (2007) was only successful in two instances in this assessment and thus not reported. The problems encountered in fitting this model were due to there being insufficient age classes in the data prior to the age at full recruitment to estimate selectivity. Two additional methods used are similar to those developed and described by Fisher (2012), but extended to allow the fitting of catch curves to multiple years of successive age composition data.

Table 3.3. Natural mortality rates (*M*) and internationally accepted biological reference points based on fishing mortality rates (*F*) as used in Wise *et al.* (2007).

Parameter	Reference point		*Glaucosoma hebraicum*	*Pagrus auratus*	*Choerodon rubescens*
M			0.11	0.12	0.21
	Target	*F* = 2/3*M*	0.07	0.08	0.14
F	*Threshold*	*F* = *M*	0.11	0.12	0.21
	Limit	*F* = 1.5*M*	0.165	0.18	0.32

Methods 3 and *4* are the same, except that the first assumes constant recruitment whereas the latter assumes that recruitment is variable and allows estimation of the recruitment deviations. As with all catch curve methods used in this assessment, *Methods 3 and 4* assume that recruited fish experience a constant instantaneous rate of M which is known, and a constant level of fishing (F) mortality. The selectivity S_a of fish of age a, *i.e.* the probability of capture of such fish relative to the probability of capture of fully-recruited fish, was assumed to be described by a logistic curve, where

$$S_a = \frac{1}{1+\exp\left[-\ln(19)\dfrac{a-A_{50}}{A_{95}-A_{50}}\right]} \tag{4}$$

and where A_{50} and A_{95} represent the ages by which the probability of capture is expected to be 50 and 95%, respectively, of that of fully-recruited fish. The fishing mortality of fish of age a may be calculated as $F_a = S_a F$. The total instantaneous rate of natural mortality that is experienced by fish of age a is $Z_a = M + F_a$.

It was assumed also that fish were randomly sampled from the annual catches taken between years t_1 and t_2 to form the age composition data to be analysed. Note that the convention adopted in this report is that time is measured in biological years, where a biological year is the twelve-month period following the assumed annual birth date for the fish species and the biological year is identified by the four digit calendar year in which (the peak of) spawning occurs. Each year class is identified in terms of the biological year of the spawning period in which the individuals of that year class were spawned. Thus, for example, if the birth date is 1 November, the biological year relating to 2012 extends from 1 November 2012 to 31 October 2013, and the year class associated with the spawning period around 1 November 2012 is the 2012 year class.

Let R_y represent the number of 0-year-old fish that recruit to the population in year y. Assume that the number of recruits of age 0 years in year class y is

$$R_y = \begin{cases} \bar{R}\exp\left[\varepsilon_y - \dfrac{\sigma_R^2}{2}\right] & \text{for } t_1 - A + 1 \le y \le t_2 - 1 \\ \bar{R} & \text{for } y \le t_1 - A \text{ and } y = t_2 \end{cases} \tag{5}$$

where $\bar{R}$ is the average number of recruits, ε_y is the "recruitment deviation" for year class y , where $\varepsilon_y \sim N(0,\sigma_R^2)$, and σ_R^2 , is the variance of the natural logarithms of the recruitment deviations. For catch curve *Method 3*, ε_y are all set to zero, whereas for *Method 4*, ε_y are estimated for specified years. For this assessment, the year classes were selected on the basis that all year classes must be successive and be represented by at least ~ 30 fish. Although algorithms exist that allow statistically-based selection of year classes, *e.g.* forward-selection or backwards selection algorithms (Sokal and Rohlf, 1995), this was not explored in this assessment. Note that there is insufficient information in the age-composition sample to estimate ε_y for year classes $y \le t_1 - A$ and $y = t_2$. Although the analyses undertaken for this study assume that fishing mortality is constant, the equations below have been generalised to allow for time varying fishing mortality. The fishing mortality within year *t* of fully-recruited fish is denoted by F_t. The fishing mortality of fish of age *a* in year *t* may be calculated as $F_{a,t} = S_a F_t$. The total instantaneous rate of natural mortality that is experienced by fish of age *a* in year *t* is $Z_{a,t} = M + F_{a,t}$, where *M* is again assumed to be a known constant.

The expected number of fish $N_{a,t}$ of year class *y* = *t* - *a* that are of age *a* years at the beginning of (biological) year t_1 is

$$\hat{N}_{a,t_1} = \begin{cases} R_{t_1} & \text{if } a = 0 \\ R_{t_1-a} \exp\left[-\sum_{j=0}^{a-1} Z_{j,t_1-a+j}\right] & \text{if } 0 < a < A, \\ \bar{R} \exp\left[-\sum_{j=0}^{A-1} Z_{j,t_1-A+j}\right] \Big/ \left(1 - \exp\left[-Z_{A,t_1}\right]\right) & \text{if } a = A \end{cases} \tag{6}$$

where *A* is a plus group, *i.e.* all fish of age *A* years or older. For subsequent years,

$$\hat{N}_{a,t} = \begin{cases} R_t & \text{if } a = 0 \\ \hat{N}_{a-1,t-1} \exp\left[-Z_{a-1,t-1}\right] & \text{if } 0 < a < A, \\ \hat{N}_{A-1,t-1} \exp\left[-Z_{A-1,t-1}\right] + \hat{N}_{A,t-1} \exp\left[-Z_{A,t-1}\right] & \text{if } a = A \end{cases} \tag{7}$$

The expected catch of fish of age *a* in year *t* may be calculated as

$$\hat{C}_{a,t} = \frac{F_{a,t}}{Z_{a,t}} \left(1 - \exp\left[-Z_{a,t}\right]\right) \hat{N}_{a,t} . \tag{8}$$

The expected proportion of fish of age *a* (where $0 \le a \le A$) in the catch in year *t* is therefore

$$\hat{P}_{a,t} = \hat{C}_{a,t} \Big/ \sum_{j=0}^{A} \hat{C}_{j,t} . \tag{9}$$

If $n_{a,t}$ represents the number of fish of age *a* in the sample for year *t*, then the observed proportion at age *a* in the sample in year *t* may be calculated as

$$P_{a,t} = n_{a,t} \Big/ \sum_{j=0}^{A} n_{j,t} \; . \tag{10}$$

The log-likelihood of the age composition data was calculated as

$$\lambda_{\text{age}} = \sum_{t=t_1}^{t_2} \sum_{a=a_c}^{A} p_{a,t} \ln \hat{p}_{a,t}. \tag{11}$$

An additional likelihood component was introduced into the analysis to account for recruitment variability. Let the log-likelihood that is associated with the recruitment deviations be denoted by λ_R. This was calculated as

$$\lambda_R = \frac{1}{2\pi\sigma_R^2} \sum_k \varepsilon_k^2, \tag{12}$$

and the overall log-likelihood for both the age composition and recruitment deviations then become

$$\lambda = \lambda_{\text{age}} + \lambda_R. \tag{13}$$

When undertaking the catch curve analysis using this approach within this study, annual fishing mortality was assumed constant, *i.e.* $F_t = F$ for all *t*, and the model was fitted to the age-composition data to obtain estimates of F_t, σ_R^2 and ε_y (for $t_1 - A + 1 \leq y \leq t_2 - 1$) by maximising the overall log-likelihood. Alternatively, as there is often little information in the data to allow reliable assessment of σ_R^2, the model may be fitted by setting the value of this variance to a known value (see below). When fitting the recruitment deviations, a forward selection algorithm was employed to successively add recruitment deviations that contributed the greatest improvement to model fit while still improving that fit significantly. As described above, however, estimates of *Z* are confounded by trends in recruitment deviations. An additional assumption has therefore been introduced, *i.e.* that there is no trend in recruitment. Thus, if the recruitment deviations for two or more year classes deviate from zero, then their average must equal zero, and also, if the deviations for three or more year classes deviate from zero, then their slope must be equal to zero.

Let n_R represent the number of recruitment deviations ε_a to be fitted at a particular phase of the forward selection algorithm. For convenience, the recruitment deviations were renamed as ε_j, where $1 \leq j \leq n_R$. If $n_R = 1$, no constraint is applied to the model. If $n_R = 2$, only one recruitment deviation is fitted, as the second of the recruitment deviations is set equal to the negative of the first deviation such that the mean of the two deviations is constrained to zero. If $n_R > 2$, only the first $n_R - 2$ recruitment deviations are fitted, as the last two of the recruitment deviations are calculated from the other deviations such that the mean and slope of the deviations are constrained to zero. Let Y_j be the value of the recruitment deviation associated with recruitment anomaly *j*, where $Y_j = \varepsilon_k$. For the mean of the recruitment deviations to be equal to zero, it is required that

$$Y_1 + Y_2 + \sum_{j=3}^{n_R} Y_j = 0 \tag{14}$$

and, for the slope also to be equal to zero,

$$\sum_{j=1}^{n_R} jY_j = 0 \,. \tag{15}$$

That is,

$$Y_1 + 2Y_2 + \sum_{j=3}^{n_R} jY_j = 0 \,. \tag{16}$$

Thus

$$Y_1 = \sum_{j=3}^{n_R} jY_j - 2\sum_{j=3}^{n_R} Y_j \tag{17}$$

and

$$Y_2 = \sum_{j=3}^{n_R} Y_j - \sum_{j=3}^{n_R} jY_j \tag{18}$$

In stock assessment models, where similar recruitment deviations are estimated, it is typical to assume a prior probability distribution for the recruitment deviations. In a number of assessments (*e.g.* Smith and Punt, 1998; Maunder and Deriso, 2003), it has been assumed that the standard deviation of the natural logarithm of the recruitment deviation is 0.6, a value for teleosts based on meta-analyses reported by Beddington and Cooke (1983) and Mertz and Myers (1996). This estimate, *i.e.* SD(Z) = 0.6, was used in this study when attempting to estimate the recruitment deviations. As *Method 4* attempts to include the greatest amount of information, this method was used as the primary method for interpreting trends in F over time.

3.1.4 Estimation of spawning potential ratio

Spawning potential ratios (*SPR*) were estimated for each of the indicator species for each combination of sector and management area, including at the Bioregion level for *G. hebraicum*. *SPR* could not be calculated for *P. auratus* at the Bioregion level, as its biological parameters, minimum legal length and selectivity to fishing vary among areas. *SPR* was calculated for *P. auratus* for the northern areas combined (*i.e.* Kalbarri and Mid-west) and for the southern areas combined (Metropolitan and South-west). Also, *SPR* was only estimated for *C. rubescens* in the Abrolhos Islands Zone A.

The yield per recruit (*YPR*) and spawning stock biomass per recruit (*SSB/R*) for *G. hebraicum*, *P. auratus* and *C. rubescens*, and the egg per recruit (*EPR*) for *G. hebraicum* were calculated from age zero and assuming constant recruitment at age zero and constant mortality for fully-recruited fish. Biological parameters employed are provided in Tables 3.5-3.7. For fish of sex s, the yield per recruit, YPR_s, was calculated as:

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

where A is the assumed maximum age for each species (100 y, *i.e.* far larger than the maximum recorded ages of each species) 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, and ψ_{s_a} is the proportion of fish of sex s at age a. For *G. hebraicum* and *P. auratus*, yield per recruit (and spawning stock biomass per recruit) were estimated for females only. Thus, the value of ψ_{s_a} for the females of these species was always set to 1. The estimate of F employed for this analysis was that derived from *Method 4*.

For sex s, the spawning stock biomass per recruit, $SSBR_s$, was estimated as:

$$SSBR_s = \sum_{a=0}^{A} W_a \psi_{s_a} \psi_{mat_{a,s}} \exp[-(M + S_a F)]$$

where $\psi_{mat_{a,s}}$ is the proportion of fish of sex s that are mature at age a.

The number of eggs per female recruit was calculated as:

$$EPR = \sum_{a=0}^{A} Fec_a W_a \psi_{mat_{a,s}} \exp[-(M + S_a F)]$$

where Fec_a is the fecundity of females at age a. Denoting the catch curve estimate for F as $F_{current}$, the spawning potential ratio for female *P. auratus* and male *C. rubescens*, SPR_s, was estimated as $SPR_s = SSBR_{F=F_{current},s} / SSBR_{F=0,s}$

Similarly, SPR_s for female *G. hebraicum* was estimated as $SPR_s = EPR_{F=F_{current},s} / EPR_{F=0,s}$. Note that the per recruit analyses presented in this report differed from those employed by Wise *et al.* (2007) in several respects (see Tables 3.5-3.7).

3.2 Catch and effort data

Commercial and recreational catch and effort data prior to and including 2005/06 were analysed by Wise *et al.* (2007). In this assessment, the analyses of commercial catch and effort data focussed on data from compulsory logbooks of each fishery since 2008, when the WCDSIMF commenced. The WCDSIMF, TDGDLF and SWTMF each record catch and effort in daily/trip logbooks, while the CSLPF reports data in monthly catch summaries. The WCRLF report catch and effort per trip via electronic catch disposal records (see Fletcher and Santoro, 2012). The WCDSIMF, SWTMF and CSLPF operate on a calendar year fishing season and the TDGDLF and WCRLF operate on a financial year season. Catches of the TDGDLF reported in this assessment include those that were taken only in the WCB by the WCDGDLF and the JASDGDLF.

Charter catches were derived from compulsory logbooks, where each trip is reported separately. Catches of the recreational fishery presented here are from periodic surveys of boat-based recreational fishing in the WCB from 2005/06 onwards. Between 2005/06 and 2009/10, boat ramp ("creel") surveys of boat-based recreational fishing were used to estimate catch. These surveys were not designed to estimate total catch but instead provided consistent estimates that can be compared between surveys carried out in 1996/97, 2005/06, 2008/09 and 2009/10. A review of the 2005/06 creel survey (Steffe, 2009) confirmed that this type of survey would have provided underestimates of the total recreational catch and suggested improvements to the analysis. Re-analysis was undertaken and revised estimation methods and catch estimates were produced for 2005/06 (Department of Fisheries, 2013; Wise and Fletcher, in review).

Table 3.5. Biological parameters employed for the per recruit analyses for West Australian dhufish (*Glaucosoma hebraicum*)

Parameters	Value	Source of information	Additional information for per recruit analyses
von Bertalanffy growth parameters		Hesp *et al.* (2002)	As in Wise *et al.* (2007), $L_t = L_\infty(1 - \exp(-k\,(t - t_0)))$
L_∞ female (mm, total length)	929		
k (year^{-1})	0.111		
t_0 (years)	-0.141		
Weight from total length		S. A. Hesp, unpublished	$log_e W = a.log_e\, L + b$
a	2.857		Parameters based on wider length range than those reported in Wise *et al.* (2007).
b	-10.0764		
Proportion mature-at-length		S. A. Hesp, unpublished	$P = 1/(1 + \exp(-log_e(19)(L - L_{50)})/(L_{95} - L_{50})))$
L_{50} (mm, total length)	331		Updated from Hesp *et al.* (2002). Parameters based on wider length range than those reported in Wise *et al.* (2007).
L_{95} (mm, total length)	509		
Selectivity-at-age		This study	Derived using Method 4 catch curve model detailed above on data for 2008/09-2010/11. Note, Wise *et al.* (2007) assumed knife-edge selection. Selectivity parameters are those derived from the analysis of the weighted whole of Bioregion data, as growth patterns are not statistically different across the WCB.
A_{50} (years)	7.40		
A_{95} (years)	8.89		
Batch fecundity		St John *et al.* (2007)	
a	0.0841		As in Wise *et al.* (2007), $BF = (aL - b)^3$
b	10.432		
Natural mortality (M, year^{-1})	0.11	Hesp *et al.* (2002)	As in Wise *et al.* (2007)
Minimum legal length (mm)	500		

Table 3.6. Biological parameters employed for the per recruit analyses for Snapper (*Pagrus auratus*)

Parameters	Northern Areas combined	Southern Areas combined	Kalbarri/ Mid-west areas	Metro. Area	South-west Area	Source of information	Additional information for per recruit analyses
von Bertalanffy growth parameters						Wakefield (2006), Lenanton *et al.* (2009a), this study	Parameters differ from Wise *et al.* (2007). Parameters reported by Wakefield (2006) have values for t_0 that are closer to zero. $L_t = L_\infty(1 - \exp(-k\,(t - t_0)))$
L_∞ female (mm, total length)	674	1050	674	1050	985		
k (year^{-1})	0.23	0.12	0.23	0.12	0.16		
t_0 (years)	-0.28	-0.41	-0.28	-0.41	-0.16		
Weight from fork length						Wakefield (2006)	As in Wise *et al.* (2007), $W = a.L^b$
a	0.000056	same	same	same	same		
b	2.827						
Fork length from total length						Wakefield (2006)	As in Wise *et al.* (2007), $FL = a\,.TL - b$
a	0.897	same	same	same	same		
b	23.038						
Proportion mature-at-length						Wakefield (2006)	Parameters differ from Wise *et al.* (2007). Wakefield (2006) provides sound estimates for each region. $P = 1/(1 + \exp(-log_e(19)(L - L_{50)})/(L_{95} - L_{50})))$
L_{50} (mm, total length)	378	585	378	585	585		
L_{95} (mm, total length)	482	752	482	752	752		
Selectivity-at-age						This study	Derived using Method 4 catch curve model detailed above. Note, Wise *et al.* (2007) assumed knife-edge selection.
A_{50} (years)	3.8	4.7	4.0	4.2	5.7		
A_{95} (years)	4.9	6.1	5.1	5.3	7.7		
Natural mortality (M, year^{-1})	0.12	same	same	same	same		As in Wise *et al.* (2007).
Minimum legal length (mm)	410	500	410	500	500		

Table 3.7. Biological parameters employed for the per recruit analyses for Baldchin groper (*Choerodon rubescens*)

Parameters	Value	Source of information	Additional information for per recruit analyses
von Bertalanffy growth parameters		Fairclough (2005)	As in Wise *et al.* (2007), $L_t = L_\infty(1 - \exp(-k\,(t - t_0)))$
L_∞ female (mm, total length)	534.7		
k (year^{-1})	0.192		
t_0 (years)	-0.162		
Weight from total length		Fairclough (2005)	As in Wise *et al.* (2007), $log_e W = a.log_e L + b$
a	3.024		
b	-10.981		
Proportion mature-at-length		Fairclough (2005)	As in Wise *et al.* (2007), $P = 1/(1 + \exp(-log_e(19)(L - L_{50}))/(L_{95} - L_{50})))$
L_{50} (mm, total length)	279.0		
L_{95} (mm, total length)	352.3		
Proportion males-at-length		Fairclough (2005)	As in Wise *et al.* (2007), same equation as above for maturity.
L_{50} (mm, total length)	478.9		
L_{95} (mm, total length)	594.7		
Selectivity-at-age		This study	Derived using Method 4 catch curve model detailed above. Note, Wise *et al.* (2007) assumed knife-edge selection.
A_{50} (years)	9.07		
A_{95} (years)	11.48		
Natural mortality (M, year^{-1})	0.21	Wise *et al.* (2007)	Derived by inserting the maximum recorded age for *C. rubescens* (22 years) into Hoenig's (1983) regression equation for fish.
Minimum legal length (mm)	400		

Implementation of Integrated Fisheries Management for the WCDSR was based on catch allocations using the total catch from all sectors. The year 2005/06 was selected as the reference year for the allocation of the WCDSR. Given the available creel catch estimates in 2005/06 underestimate the total catch, the Integrated Fisheries Allocation Advisory Committee (IFAAC) adjusted the revised catch estimated for allocation purposes (Integrated Fisheries Allocation Advisory Committee, 2013). With the introduction of the Recreational Fishing from Boat Licence (RFBL), an integrated phone diary survey (*iSurvey*) using the RFBL and boat-ramp survey was carried out in 2011/12 (Ryan *et al.*, 2013). This and future *iSurveys* will provide the mechanism to monitor estimates of total recreational catch. To compare the 2011/12 *iSurvey* catch estimates with historical estimates and also provide a validation of the IFAAC adjustments the current estimates were weighted, by restricting the *iSurvey* data to similar characteristics of the 2005/06 creel survey, *i.e.* marine line fishing from 9am to 5pm from boats launched from public boat ramps in the WCB. Initial estimates suggest that the IFAAC adjustments generally provide reasonable adjustments to the 2005/06 creel survey total recreational catch. A post-graduate study will investigate this further.

Catches of species groupings (all scalefish, demersal suite) and indicator species in the WCB and in each management area are compared with management objectives of reducing catches by at least 50 % of 2005/06 catches (Table 3.8). For the commercial fisheries other than the WCDSIMF, and for the recreational sector, catch data are available only at the Bioregion level. Raw effort data are also presented for the WCDSIMF.

Table 3.8. Groupings of species and spatial arrangement used to report catch for the WCDSIMF and recreational/charter sector in the West Coast Bioregion. C, WCDSIMF; R, Recreational/Charter.

Group	Indicator species	Bioregion		Management area	
		C	R	C[2]	R
All scalefish		✓	–	✓	–
Demersal suite		✓	✓[1]	✓	–
Inshore indicator species	West Australian dhufish	✓	✓	✓	–
	Snapper	✓	✓	✓	–
	Baldchin groper	✓	✓	✓	–
Offshore indicator species	Hapuku	✓	✓	✓	–
	Blue-eye trevalla	✓	✓	✓	–
	Eightbar grouper	✓	✓	✓	–

[1] Catch of the demersal suite by the recreational/charter sector is based on that of selected species (top 15) that dominate the catch and for which catch weight can be estimated from obtained length data and the use of length-weight equations.

[2] Except Metropolitan Area, where the WCDSIMF is not permitted to fish.

3.3 Catch per unit effort in the WCDSIMF

A preliminary examination was conducted of catch per unit effort (CPUE) for each of the indicator species (*G. hebraicum*, *P. auratus* and *C. rubescens*) in the WCDSIMF from 2008 to 2011 when those species were being targeted. CPUE was calculated for each indicator in the management areas in which they are an indicator. Catch and effort data were not available for 2012 at the time of this analysis. These analyses were designed to produce a standardised CPUE for each species via the evaluation of the influence of different factors and covariates, such as hours searched, month, species targeted, block or latitude and longitude, skipper, boat or combination of skipper with boat. Generalised linear mixed models (GLMM) were used such that only statistically significant factors were identified and retained for CPUE standardisation.

In these analyses, skipper, boat and skipper-boat combinations were treated as random effects (*e.g.* Helser *et al.*, 2004). Including these factors in the model acknowledges the often important influence of fishing power among vessels and/or skippers on CPUE (*e.g.* Hilborn, 1985; Squires and Kirkley, 1999). Modelling them as random effects reflects that, when fitting the statistical model to CPUE, we were not interested in the specific differences between levels of skipper and/or vessel but rather the intention was to model properties of the entire population of levels for each of these factors (West *et al.*, 2007). Skipper and Vessel are often highly correlated terms, although over a long time series there are often many levels of skipper and vessel due to vessel upgrades, skippers changing among boats and skippers entering and leaving the fishery over time. Fitting them as random effects is advantageous in that it avoids the estimation of many more parameters than would be required if they had been modelled as fixed effects, and thus potentially over-fitting the model. Additionally, as these data were fishery-dependent and unbalanced, treating the terms as random effects ensured that standardised indices would not likely have been as heavily influenced by data for any level of vessel and/or skipper with higher replication than others because of the method used to calculate estimated marginal means.

3.3.1 Data screening and manipulation

Datasets for each species were screened for high values, missing values and zero values prior to analysis. As Licensed Fishing Boat numbers (LFB) can be exchanged among vessels and vessels can be replaced under the same LFB, vessel names and LFBs were cross-referenced with licensing records to ensure that vessel data related to a unique boat. As hand-lining was the dominant fishing method, this was used for these analyses.

A generalised linear mixed model (GLMM) was fitted to the dataset for each species to detect values with relatively high statistically standardised residuals, as follows:

$$\log_e Y_{jicmta} = \mu + \nu_j + \log_e \chi_{jicmta} + \tau_c + \zeta_m + \beta_t \times \alpha_a + \varepsilon_{jicmta} \qquad (1)$$

where: Y = catch (kg); ν = boat (random effect); χ = number of hooks used per hour; τ = was the species targeted (c = yes, no); ζ = month; β = year; α = spatial term (management area); $\nu_j \sim N(0,\sigma_j^2)$ and $\varepsilon_{jicmta} \sim N(0,\sigma^2)$. Extremely high residuals were checked against raw datasheets, which revealed the following issues.

i. *Recording and entering of fishing method*. Greater than one method was reported in some sessions. However, this occurred in only 4.7% of records for *G. hebraicum* catches, 4.1% of records for *P. auratus* catches and 2.9% of records for *C. rubescens* catches. Cross-tabulation of method vs number of hooks for each dataset identified some unlikely records (*e.g.* 30 hooks used for hand-held, non gunwhale-mounted reels). These are issues where different classes of method (i.e., dropline (passive) and handlining (active) methods are combined. As there was a low number of reports of multiple methods in a single session, the factor “method” was omitted from further analysis. When combined methods were reported, it was assumed the summed numbers of hooks and lines recorded and entered were correct for those records. Potential biases attributed to this assumption were likely to be negligible given the low percentage of data where combined methods were reported.

ii. *Recording and entering of zero for hours fished (where catch was recorded)*. This occurred mostly in 2008, when < 2% of the fishing session data for that year contained “zero hours”.

As this is a small percentage of the data and there is no way to recover this information, “zero hours” records were omitted for this analysis.

iii. The percentage of zero catch records were assessed for each dataset for analysis to determine whether two-stage or “hurdle” GLMMs would be appropriate. A natural logarithm transformation of catch (the response variable) and some other explanatory covariates (such as effort) was considered appropriate (Appendix A2.1).

3.3.2 Model fitting algorithm

A manual forward selection algorithm was used, starting at the “base-level” GLMM:

$$\log_e Y_{jict} = \mu + \log_e \chi_{jict} + \tau_c + \nu_j + \beta_t + \epsilon_{jict} \qquad (2)$$

where: Y = catch (kg); ν = boat (random effect); χ = number of hooks used per hour; τ = was the species targeted (c = yes, no); β = year; $\nu_j \sim N(0,\sigma_j^2)$ and $\epsilon_{jict} \sim N(0,\sigma^2)$.

At each step, model fitting diagnostics were checked including convergence, overall model significance, Wald tests for the significance of explanatory factors and covariates, plots of residual distributions, residuals against fitted values, q-q plots (distributional assumptions) and half-normal plots (for outliers not removed by initial data screening; see Appendix 2), standardised residuals, parameter correlations, aliasing, deviance (lower deviance indicates higher goodness of fit), AIC and BIC (model parsimony) (Appendix 2). Plots of predicted against observed values for explanatory covariates were also examined to assess appropriateness of sub-model formulation (*e.g.* polynomial terms fitted or log-normal transformations for latitude, longitude, hours searched covariates).

At each step, assuming model assumptions were satisfactory, the selection of the best model (to progress with for adding subsequent terms) was determined as the one with the lowest residual deviance, AIC and BIC (given the relatively high number of data to parameters for all datasets). Residual deviance was most informative for this purpose (Maunder & Punt, 2004). For each dataset, there were 6 steps in the manual forward selection algorithm (Appendix 2). At each step, alternative terms were evaluated, and the term was retained for subsequent step(s) only if: (i) it contributed significant explanatory power as determined from Wald tests; (ii) the GLMM continued to meet appropriate statistical assumptions (above), and (iii) its inclusion resulted in the lowest residual deviance, AIC and BIC of the candidate GLMMs considered.

3.3.3 Generated standardised CPUE indices

Standardised model predictions were generated in Genstat. For the two component analyses, the mean annual standardised CPUE data were calculated as the product of the bias-corrected back-transformed predicted means for levels of year from each of the Gaussian (non-zero logged catch data) and Binomial (zero and non-zero catch presence/absence binary-coded data) GLMMs. Predicted means, and their standard errors were the means calculated across levels of other fixed effects, and adjusted for the mean of model covariates, from the multi-way table of predicted values corrected for marginal weights, which accounted for the unbalanced nature of these data (Lane, 1988; Gilmour *et al.*, 2004; Welham *et al.*, 2004).

Non-zero CPUE are shown for context (see Fig. 4.17), but as the standardised CPUE was derived from all CPUE (including zero catches), comparisons are best made with this series.

4.0 Results

4.1 Biological data and assessment of *Glaucosoma hebraicum*

4.1.1 Length composition data

Glaucosoma hebraicum collected between 2008/09 and 2010/11 from the commercial and recreational sectors in the Mid-west Area ranged in total length from the MLL of 500 mm to maxima of 1020 and 1040 mm, respectively (Fig. 4.1). This was similar to previous sampling years. Between 80 and 90 % of individuals were < 800 mm in length in each year from those sectors. A greater percentage of *G. hebraicum* in the Metropolitan Area between 2008/09 and 2010/11 were > 800 mm in length (24-28 %), while the maximum length recorded (1099 mm) was similar to previous sampling periods.

The largest recorded *G. hebraicum* collected from both the commercial and recreational sectors in the South-west Area (1070 mm) was similar to the other areas (Fig. 4.1). The modal length classes from both sectors in the South-west Area were between 600 and 849 mm in each year, in contrast to modal classes that were almost always < 650 mm in the other areas. Although samples from the recreational sector in the South-west Area were not large, the modal length class(es) increased from 2008/09 to 2010/11, which did not obviously occur in samples from other areas. The length ranges in the South-west Area in previous years were similar to 2008/09-2010/11, but the shape of the distributions varied, reflecting relatively greater numbers of larger fish in the latter period (Fig. 4.1).

4.1.2 Age composition data

The age frequency distributions of *G. hebraicum* collected in 2008/09-2010/11 from the three inshore management areas in which it is an indicator species consisted of individuals ranging from minima of either 4 or 5 y to maxima of 27-31 y (Fig. 4.2). Between 2008/09 and 2010/11, 90 % of fish sampled in the Mid-west Area were < 15 y old and < 2.5 % were 20 y old or greater. Similarly, in the Metropolitan Area, 87-92 % of fish in those three years were < 15 y old, with < 2% being ≥ 20 y old. The percentage of *G. hebraicum* collected from both the commercial and recreational sectors in the South-west Area between 2008/09 and 2010/11 that were < 15 y was considerably lower (72-78 %), and the percentage of fish that were at least 20 y old was also considerably higher (3.5-10 %) (Fig. 4.2).

The average percentages of fish ≥ 15 y old derived from samples collected from the Mid-west commercial and Metropolitan recreational sectors in consecutive three year periods, *i.e.* 2002/03-2004/05, 2005/06-2007/08 and 2008/09-2010/11, were similar, ranging from 6-12 %. However, the above percentages were substantially lower than the 20-22 % of fish ≥ 15 y old between 1995/96 and 1997/98 from those two areas and sectors (Figs 4.2, 4.3; Hesp *et al.* 2002).

The degree to which the relative abundances of different year classes of *G. hebraicum* varied differed markedly among management areas. Relatively strong cohorts from 1999, 2002 and 2004 occurred in the age distributions for the Mid-west and Metropolitan regions between 2008/09 and 2010/11 (Fig. 4.2). The relative abundances of year classes of *G. hebraicum* in the South-west Area between 2008/09 and 2010/11 were more variable than other areas during this period (Fig. 4.2). The age distributions in the South-west area were dominated in each year by the 1999 cohort, and to a lesser extent, by the 2002 cohort in 2010/11 samples.

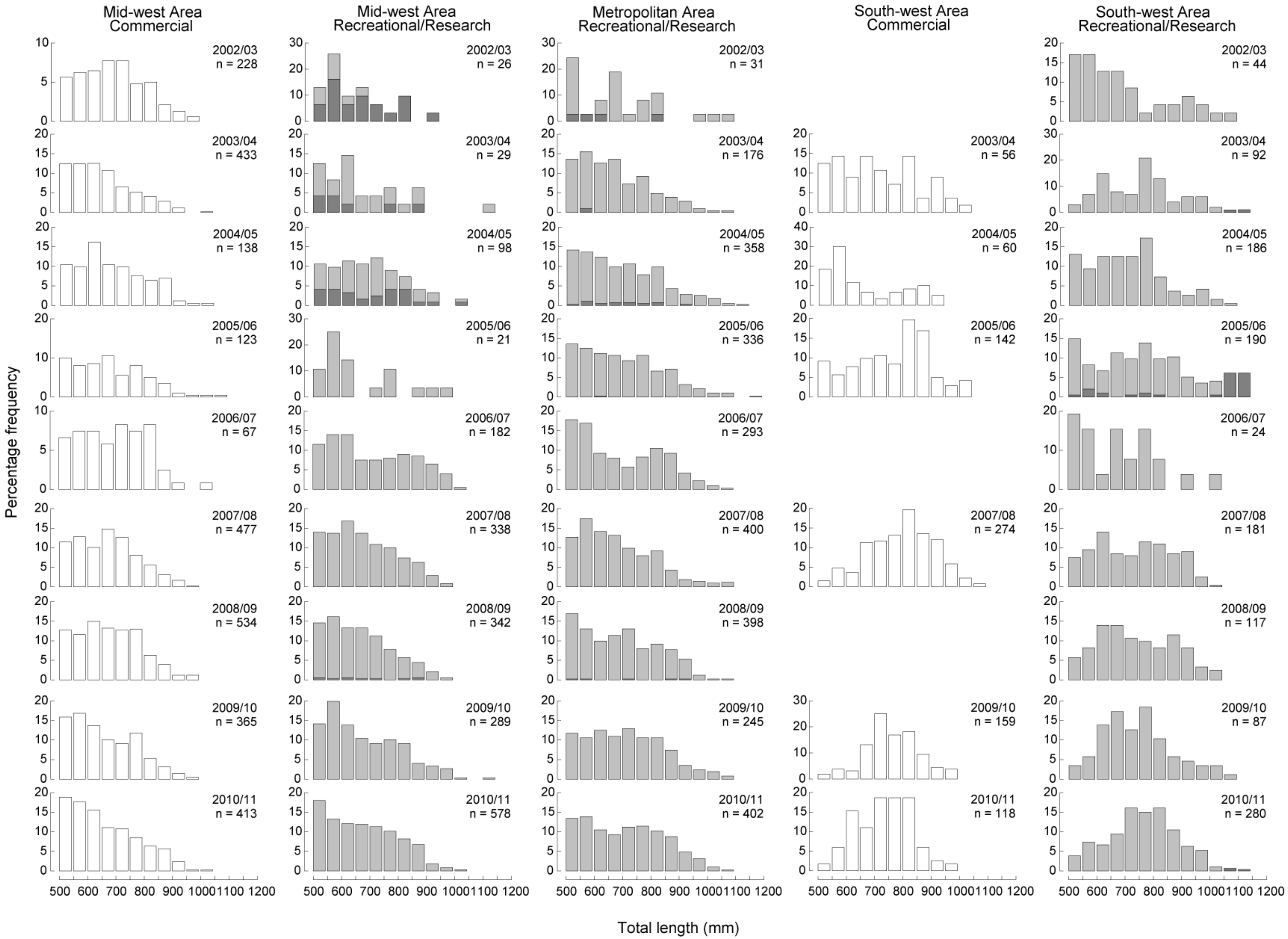

Figure 4.1. Total length frequency distributions for *Glaucosoma hebraicum* collected from fishery-dependent and -independent sampling in each management area of the West Coast Bioregion between 2002/03 and 2010/11. ☐ Commercial, ☐ Recreational, ■ Research.

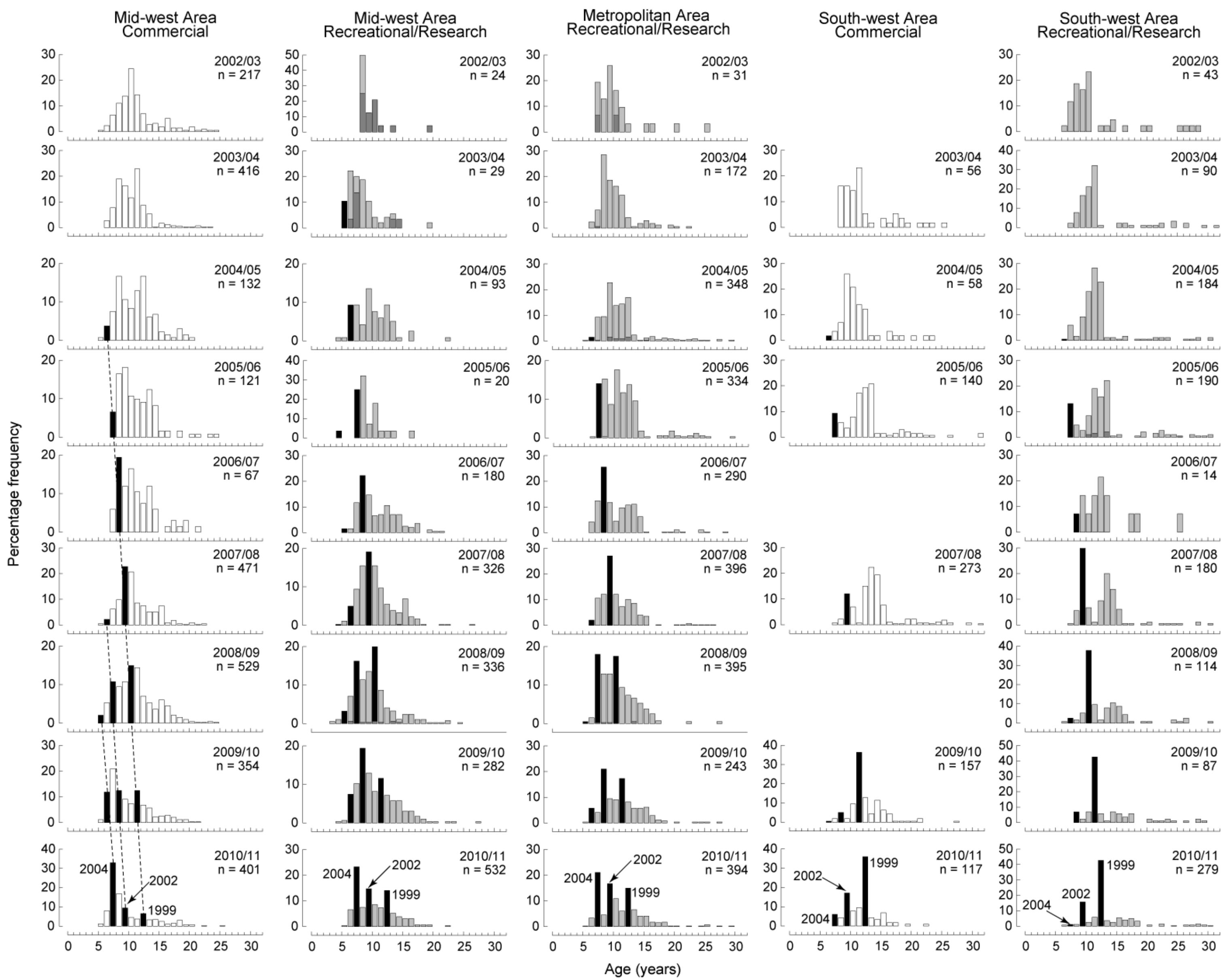

Figure 4.2. Age frequency distributions for *Glaucosoma hebraicum* collected from fishery-dependent and -independent sampling in each management area of the West Coast Bioregion between 2002/03 and 2010/11. Commercial, Recreational, Research.

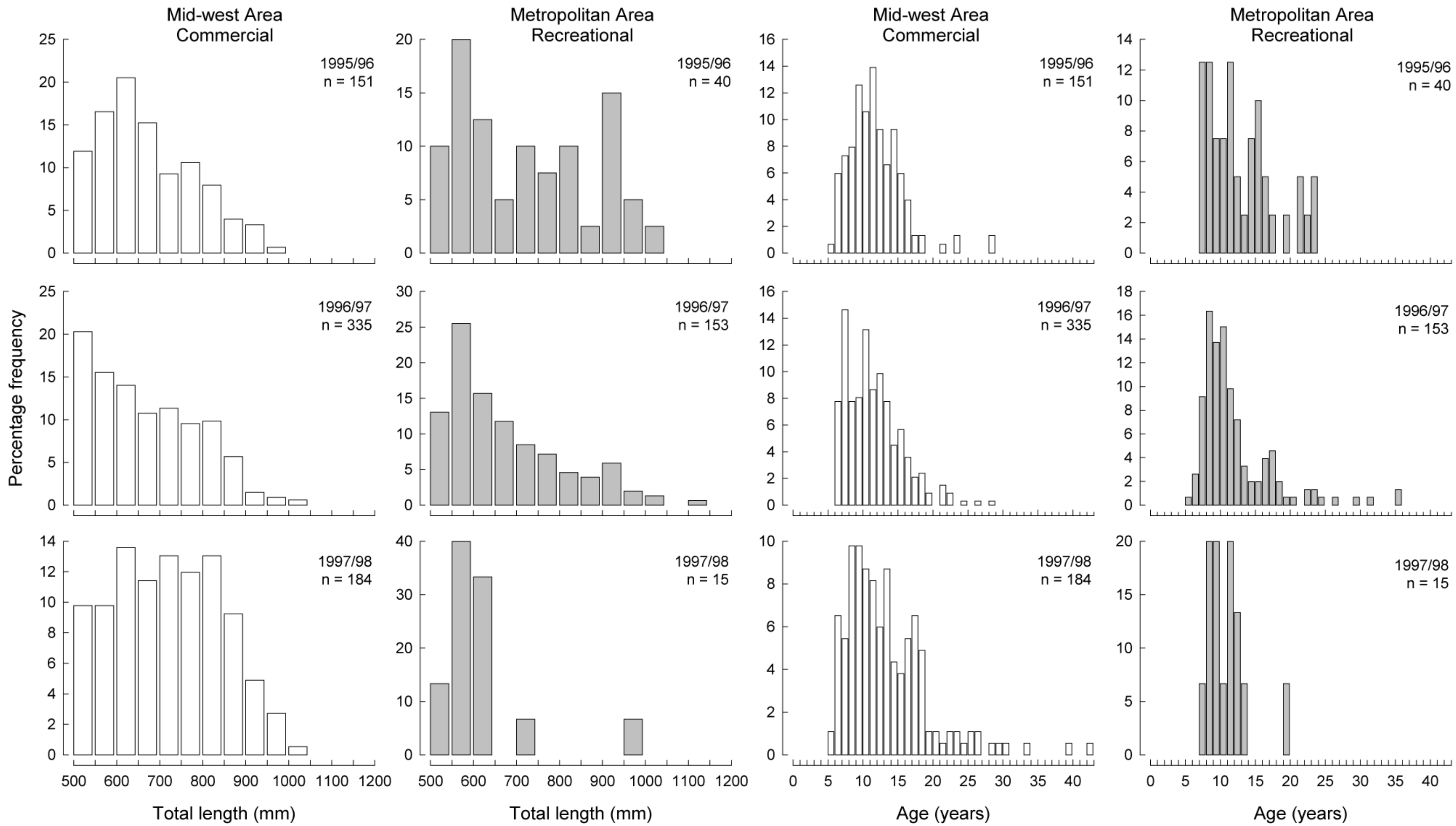

Figure 4.3. Total length and age frequency distributions for *Glaucosoma hebraicum* collected from fishery-dependent sampling in the Mid-west and Metropolitan areas of the West Coast Bioregion between 1995/96 and 1997/98 from Hesp *et al.* (2002).

The strength of the 1999 year class, relative to adjacent year classes, could be traced back to 2006/07 in the Metropolitan Area, when fish in that age class were eight years old and, at that stage, not yet fully-recruited to the fishery (Fig. 4.2). Similarly, the relative strength of the 2002 and 2004 classes were first evident at age 7 y, *i.e.* in 2008/09 and 2010/11, respectively, in the Mid-west and Metropolitan areas.

4.1.3 Assessment of *Glaucosoma hebraicum* in the WCB

The *F* estimate for the whole of WCB stock of *G. hebraicum* in 2008/09-2010/11 was lower than that for the 2005/06-2007/08 assessment period (Fig. 4.4a). *F* in 2008/09-2010/11 is approximately the same as the limit reference point of 1.5*M* or 0.165 year^{-1}. The point estimate of 0.26 for *SPR* in 2008/09-2010/11 increased from that in 2005/06-2007/08 and was the same as in 2002/03-2004/05 (Fig. 4.4b).

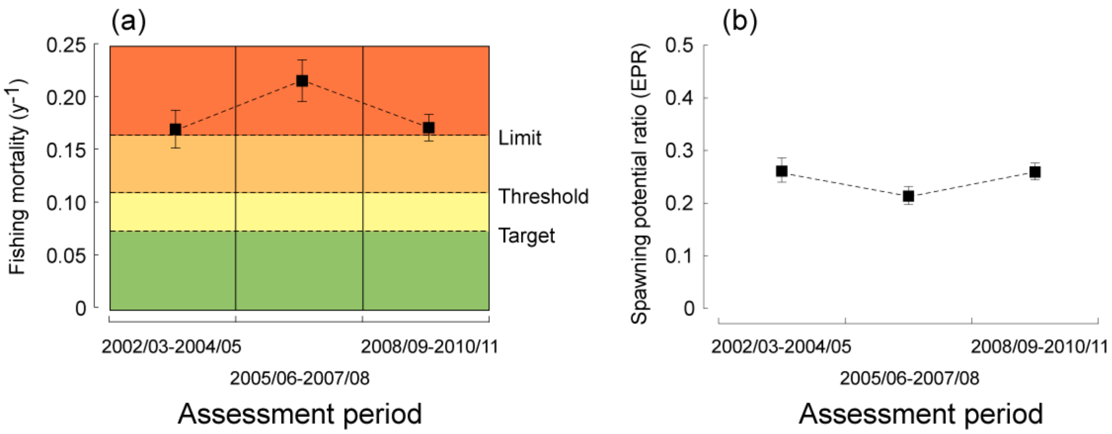

Figure 4.4. (a) Estimates of fishing mortality (±2 SE) derived using catch curve method 4 and (b) spawning potential ratio (in terms of EPR) (±2 SE) for *Glaucosoma hebraicum* in the West Coast Bioregion, for three consecutive three-year assessment periods between 2002/03 and 2010/11. *F* estimates are compared with Limit, Threshold and Target reference points (Table 3.3).

4.1.4 Assessment of *Glaucosoma hebraicum* by management area

Estimates of *F* for *G. hebraicum* derived using the four different methods of catch curve analysis broadly exhibited consistent trends among assessment periods in each management area. In the Mid-west and Metropolitan areas for the period 2008/09-2010/11, *F* estimates were, in most cases, greater than the limit reference point, but were lower than in the previous assessment period of 2005/06-2007/08 (Fig. 4.5; Appendix 1 Table A1.1). However, they have not yet decreased to the same level as in 1995/96-1997/98, when *F* derived using method 4 was just above the threshold of $F = M = 0.11$ (Fig. 4.5, Appendix Table 1), and was consistent with the estimate of Hesp *et al.* (2002). In the South-west Area, *F* estimates for 2008/09-2010/11 derived from recreational samples using methods 3 and 4 were between the threshold and limit (Appendix Table 1). The *F* value from method 4 decreased from the limit in 2005/06-2007/08 to the threshold in 2008/09-2010/11 and was lower than in 2002/03-2004/05. In contrast, *F* derived using method 3 did not apparently change over the three assessment periods (Fig 4.5; Appendix Table 1). *F* estimates derived from commercial samples in the South-west Area were substantially higher in 2008/09-2010/11 than in 2005/06-2007/08, although the approximate 95% confidence limits (*i.e.* ±2SE) were very broad. These estimates are not likely to be reliable, as they are not representative of the whole stock in that area because the samples were obtained from a relatively limited area and time of year.

Estimates of *SPR* for *G. hebraicum* in the Mid-west and Metropolitan areas at the levels of *F* estimated (based on the values of *F* estimated using catch curve method 4) increased between 2005/06-2007/08 and 2008/09-2010/11 (Fig. 4.5). In the South-west Area, *SPR* (calculated using *F* values estimated from recreational samples) also increased between 2005/06-2007/08 and 2008/09-2010/11, but was higher than that for the Mid-west and Metropolitan areas (Fig. 4.5). Note the *SPR* estimated at the level of *F* determined for commercial samples in the South-west Area in 2008/09-2010/11 may not be representative of the stock in that area due to sampling biases.

4.2 Biological data and assessment of *Pagrus auratus*

4.2.1 Length composition data

Maximum lengths of *P. auratus* (≥ 410mm MLL) collected from the commercial and recreational sectors (including charter and research samples) in the Kalbarri and Mid-west areas in 2008/09-2010/11 ranged from 787 to 937 mm. However, modal length classes were always between 400 and 549 mm, and > 86, 74 and 71 % of fish in the Kalbarri commercial, Mid-west commercial and Mid-west recreational/charter/research samples, respectively, were < 600 mm (Fig. 4.6).

Length distributions of *P. auratus* from recreational sector and research samples collected in the Metropolitan Area and from all sectors in the South-west Area in 2008/09-2010/11 comprised modal length classes which were usually > 500 mm. Furthermore, the length distributions from the Metropolitan and South-west areas comprised 34-48 % and 62-79 % of fish ≥ 600 mm, respectively, in comparison to 4-5 % in the Kalbarri Area and 8-17 % in the Mid-west Area (Fig. 4.6). The maximum length recorded in the Metropolitan Area in those three years ranged from 964 to 1018 mm, which was similar to the 995-1044 mm in the South-west Area.

4.2.2 Age composition data

The age compositions of *P. auratus* obtained from each sector in each management area between 2008/09 and 2010/11 were extremely truncated, as was the case in previous years (Fig. 4.7). Greater than 95 % of fish sampled from the commercial sector in the Kalbarri area and both sectors in the Mid-west area were < 10 y old in those three years and the modal age class was either 4+ or 5+ in any one year (Fig. 4.7). Maximum ages of 26 and 28 y were recorded in those two areas, respectively. The age distributions of *P. auratus* in the Metropolitan Area also had modal age classes of 4 or 5 y between 2008/09 and 2010/11 and a maximum age of only 23 y, but 12 % of fish were ≥ 10 years of age in those three years (Fig. 4.7). Although only small samples were obtained from all sectors in the South-west Area between 2008/09 and 2010/11, the age frequency was essentially bimodal, with one mode at between 5+ and 7+ years and another between 8+ and 11+ years in those three years (Fig. 4.7). The maximum age in samples from the South-west Area was 31 y, and 36 % if fish were ≥ 10 years of age.

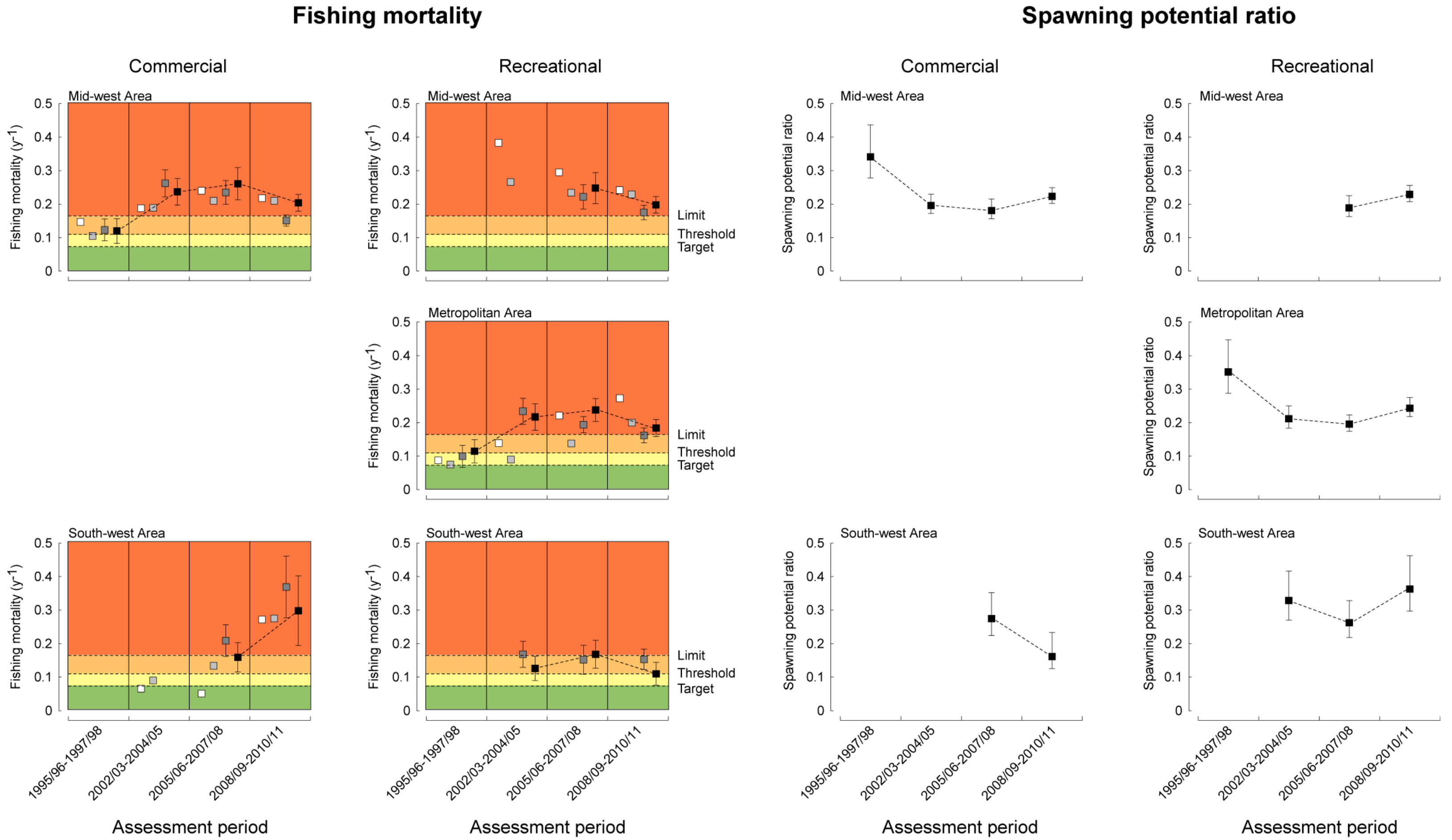

Figure 4.5. Estimates of fishing mortality (F ± 2 SE where available) and spawning potential ratio (SPR ± 2 SE in terms of EPR) for *Glaucosoma hebraicum* collected from the commercial and recreational sectors in the Mid-west, Metropolitan and South-west Management Areas in four time periods between 1995/96 and 2010/11. F derived using four different methods and SPR calculated using F estimation method 4. F estimates are compared with Limit, Threshold and Target reference points (Table 3.3). Symbols: F estimation method 1 = white, 2 = light grey, 3 = dark grey, 4 = black).

4.2.3 Assessment of *Pagrus auratus* in the WCB and in the combined northern and southern areas of the WCB

The *F* estimate (using catch curve method 4) for the whole of WCB stock of *P. auratus* in 2008/09-2010/11 declined from that in the 2005/06-2007/08 assessment period, but was ca 1.5 times the limit reference point of 0.18 $year^{-1}$ (Fig. 4.8). In 2008/09-2010/11, the *F* and *SPR* estimates derived from data for both sectors in the combined northern management areas (Kalbarri and Mid-west) of the WCB improved, *i.e.* decreased and increased, respectively (Fig. 4.9). However, *F* was still extremely high (*i.e.* ≈ 2.4×limit) and *SPR* was very low (Fig. 4.9).

Improvement in *F* and *SPR* also occurred in the combined southern management areas (Metropolitan and South-west) of the WCB in 2008/09-2010/11 from those in 2005/06-2007/08, but *F* was much lower (≈ limit of 0.18 $year^{-1}$) than for the combined northern areas and the *SPR* was greater (Fig. 4.9).

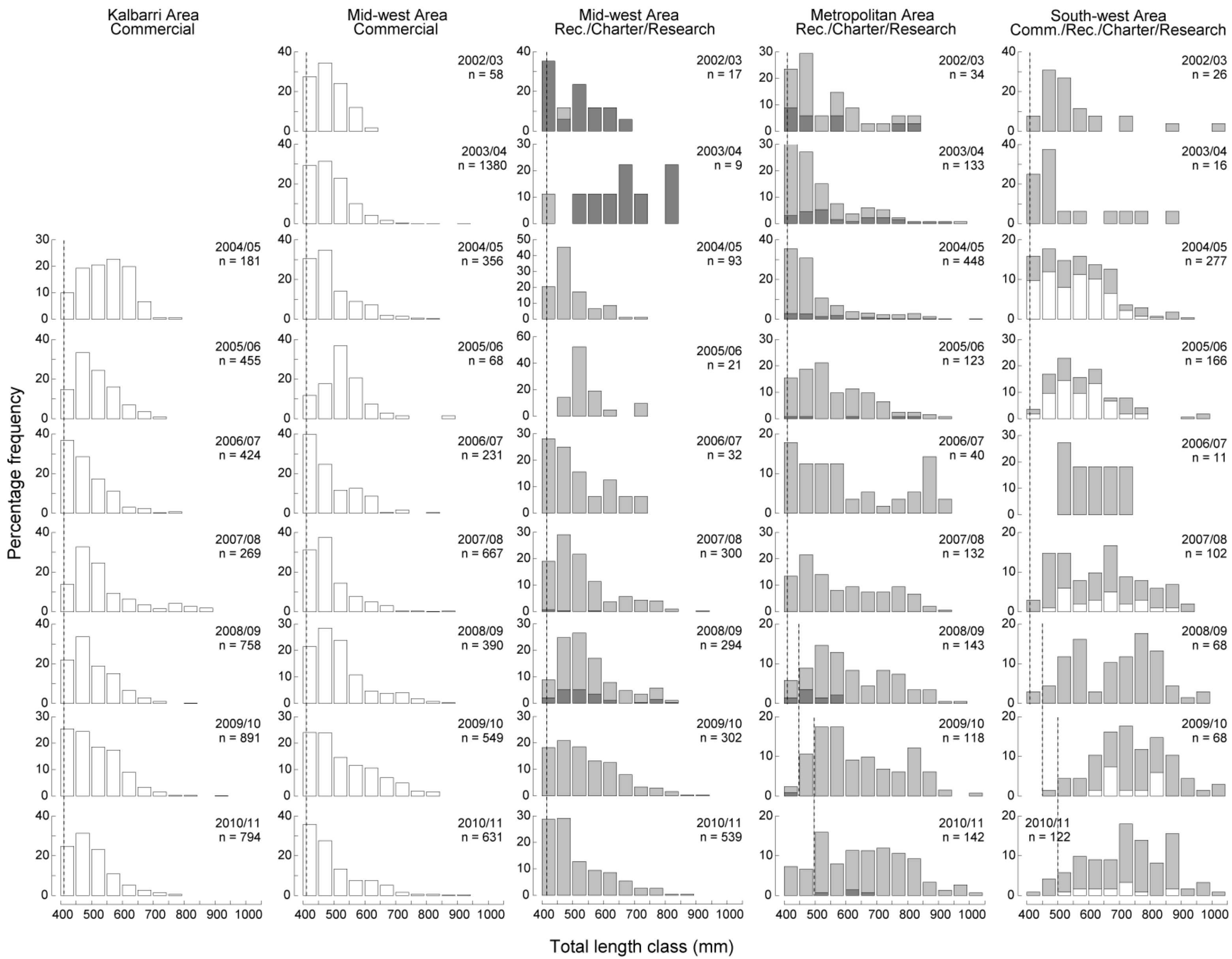

Figure 4.6. Length frequency distributions for *Pagrus auratus* collected from fishery-dependent and -independent sampling in each management area of the West Coast Bioregion between 2002/03 and 2010/11. Commercial, Recreational/charter, Research. ·······Minimum legal lengths.

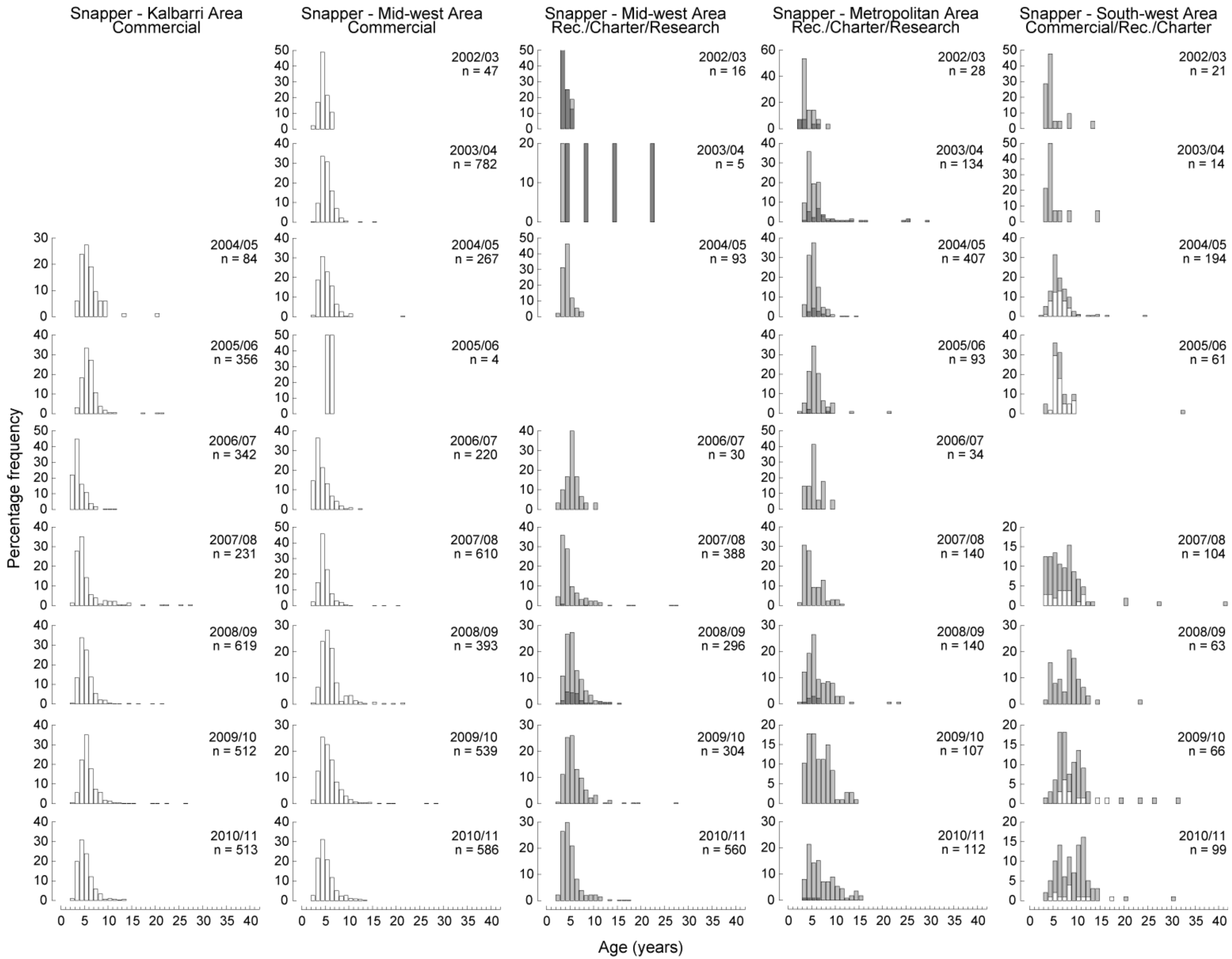

Figure 4.7. Age frequency distributions for *Pagrus auratus* collected from fishery-dependent and -independent sampling in each management area of the West Coast Bioregion between 2002/03 and 2010/11. ☐ Commercial, ☐ Recreational/charter, ■ Research.

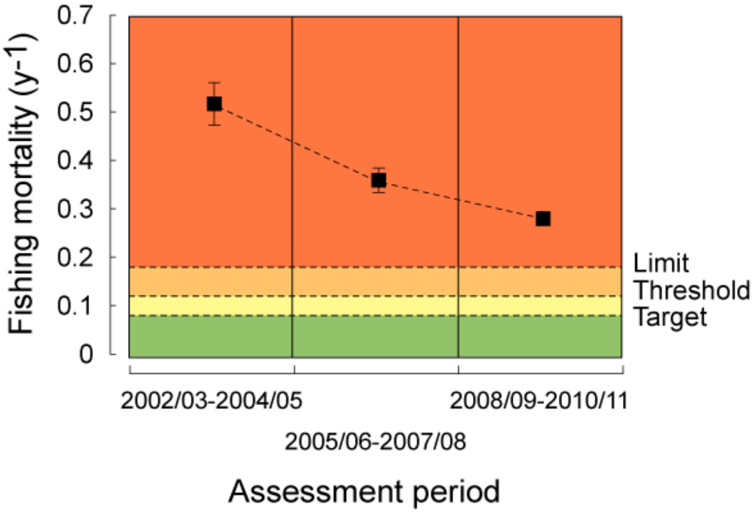

Figure 4.8. Estimates of fishing mortality (±2 SE) derived using catch curve method 4 for *Pagrus auratus* in the West Coast Bioregion for three consecutive three-year assessment periods between 2002/03 and 2010/11. *F* estimates are compared with Limit, Threshold and Target reference points (Table 3.3).

4.2.4 Assessment of *Pagrus auratus* by management area

Estimates of *F* for *P. auratus* derived from commercial samples collected in the Kalbarri Area in 2008/09-2010/11 using four different methods of catch curve analysis were *ca* 2-3 times the limit reference point of $F = 0.18$ year^{-1} (*i.e.* 1.5*M*) (Fig. 4.9; Appendix Table A2). The results for method 4 were unlikely to be significantly different between periods, given the overlap of the approximate 95% confidence limits (±2SE). In contrast, *F* estimates derived from commercial samples collected in 2008/09-2010/11 from the Mid-west area, indicated that there had been a substantial decrease in exploitation from the previous two periods (Fig. 4.9; Appendix Table A2). Although *F* estimates from recreational samples in that area increased in 2008/09-2010/11 from the previous period, data for that previous period came almost exclusively from one year of sampling and may thus be less representative than those from the commercial sector. However, estimates of *F* from samples from both of those sectors in the Mid-west Area in 2008/09-2010/11 were well above the limit reference point of 1.5*M*.

F estimates for *P. auratus* in both the Metropolitan and South-west areas in 2008/09-2010/11 were either lower or about the same as those for 2005/06-2007/08 (Fig. 4.9). Although those *F* values lay at or just above the limit reference point, they should be interpreted with some caution due to relatively small sample sizes in each year of sampling.

SPR estimates for *P. auratus* derived from Kalbarri commercial samples changed little from 2005/06-2007/08 to 2008/09-2010/11 (Fig. 4.9). The *SPR* derived from Mid-west commercial samples increased between those two periods, while it decreased when using Mid-west recreational samples. In both the Metropolitan and South-west areas, *SPR* at the levels of *F* estimated (using catch curve method 4) increased from the 2005/06-2007/08 to the 2008/09-2010/11 assessment period (Fig. 4.9).

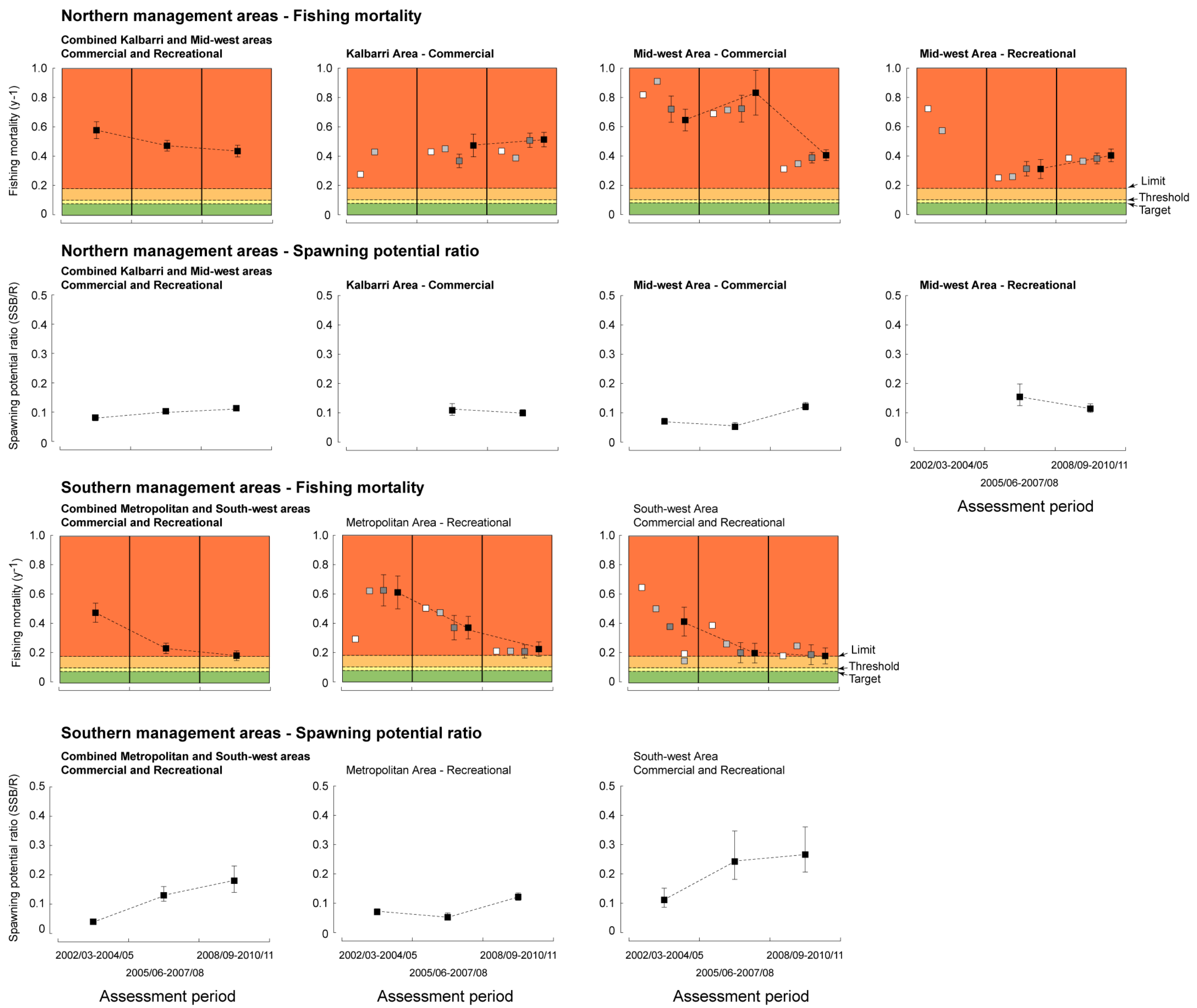

Figure 4.9. Estimates of fishing mortality (*F* ±2 SE where available) and spawning potential ratio (*SPR* ± 2 SE in terms of *SSB/R*) for *Pagrus auratus* collected from the commercial and recreational sectors in the combined northern management areas (Kalbarri and Mid-west) and combined southern management areas (Metropolitan and South-west) and separately for each of the Kalbarri, Mid-west, Metropolitan and South-west Management Areas in three time periods between 2002/03 and 2010/11. *F* derived using four different methods of catch curve analyses and *SPR* calculated using *F* estimation method 4. *F* estimates are compared with Limit, Threshold and Target reference points. Symbols: *F* estimation method 1 = white, 2 = light grey, 3 = dark grey, 4 = black.

4.3 Biological data and assessment of *Choerodon rubescens*

4.3.1 Length composition data

The length distributions of *C. rubescens* collected from commercial and recreational/research sources in the Abrolhos Islands Zone A, Mid-west Area (excluding Zone A) and Metropolitan Area had similar ranges, *i.e.* minima of 400 mm to maxima between 631 and 696 mm (Fig. 4.10). Length distributions from recreational sector samples in the Mid-west Area (not including Zone A) were dominated to a greater extent by fish < ca 500 mm in each year from 2007/08 to 2010/11 than from the commercial sector in Zone A. When a reasonable number of *C. rubescens* were obtained from recreational/research sources in Zone A, those samples comprised similar percentages of fish in each length class between 400 and 579 mm (Fig. 4.10). Only small samples were obtained from the commercial sector in the Mid-west Area between 2007/08 and 2010/11. Relatively small samples of *C. rubescens* were collected from the recreational sector in each year in the Metropolitan Area between 2007/08 and 2010/11. Their length distributions were centred around a mode of 500-519 mm (Fig. 4.10). The length distributions for *C. rubescens* collected from the commercial sector in Zone A in the mid-1990s and early 2000s were similar to those in 2007/08-2010/11, ranging from 400-639 mm (Fig 4.12).

4.3.2 Age composition data

The age frequency distributions of *C. rubescens* collected in the Abrolhos Islands Zone A and the Mid-west and Metropolitan areas between 2007/08 and 2010/11 comprised fish of 4-20, 4-25 and 7-23 years of age, respectively (Fig. 4.11). In Zone A samples for each year between 2007/08 and 2010/11, modal age classes ranged from 8-12 y in commercial samples and 8-13 y in recreational samples (Fig. 4.11). When a large Zone A commercial sample was obtained in 2009/10, the modal age class was 10+ y. In the Mid-west Area, modes lay between 10 and 12 y in the small commercial samples and 11 and 13 y in recreational samples. When a large Mid-west recreational sample was obtained in 2010/11, the modal age class was 13+ y. The modal ages of recreational samples of *C. rubescens* from the Metropolitan Area ranged from 11-14 y, although sample sizes in each year were relatively small (Fig. 4.11).

Between 1993/94 and 1994/95, age distributions of *C. rubescens* from the commercial sector in Zone A ranged from 3-20 y and had a modal age class of 11+ years (Fig. 4.12). In 2000/01-2001/02, an age range of 5-22 y and modal age classes of 12-13 y were recorded (Fig. 4.12).

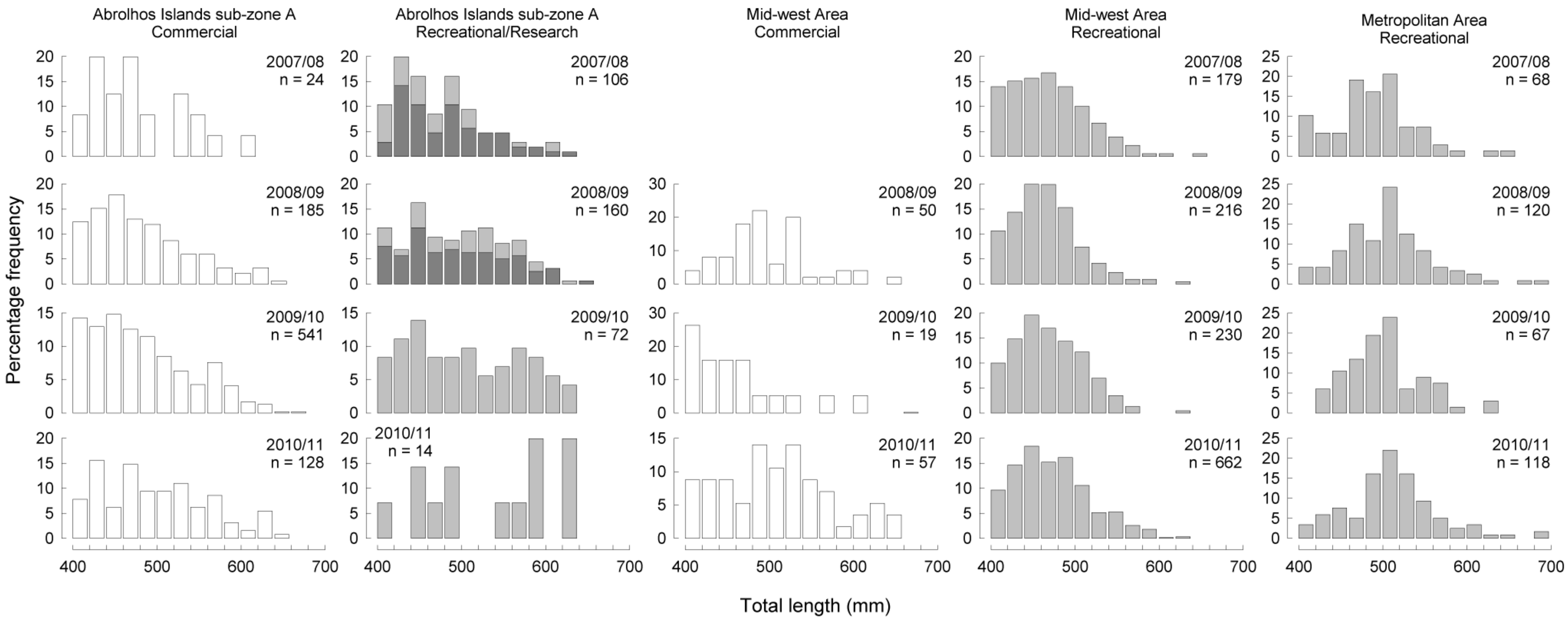

Figure 4.10. Total length frequency distributions for *Choerodon rubescens* collected from fishery-dependent and -independent sampling in the Abrolhos Islands sub-zone A area of the West Coast Rock Lobster Managed Fishery and the Mid-west and Metropolitan areas of the West Coast Demersal Scalefish (Interim) Managed Fishery between 2007/08 and 2010/11.
☐ Commercial, ▒ Recreational/charter, ■ Research.

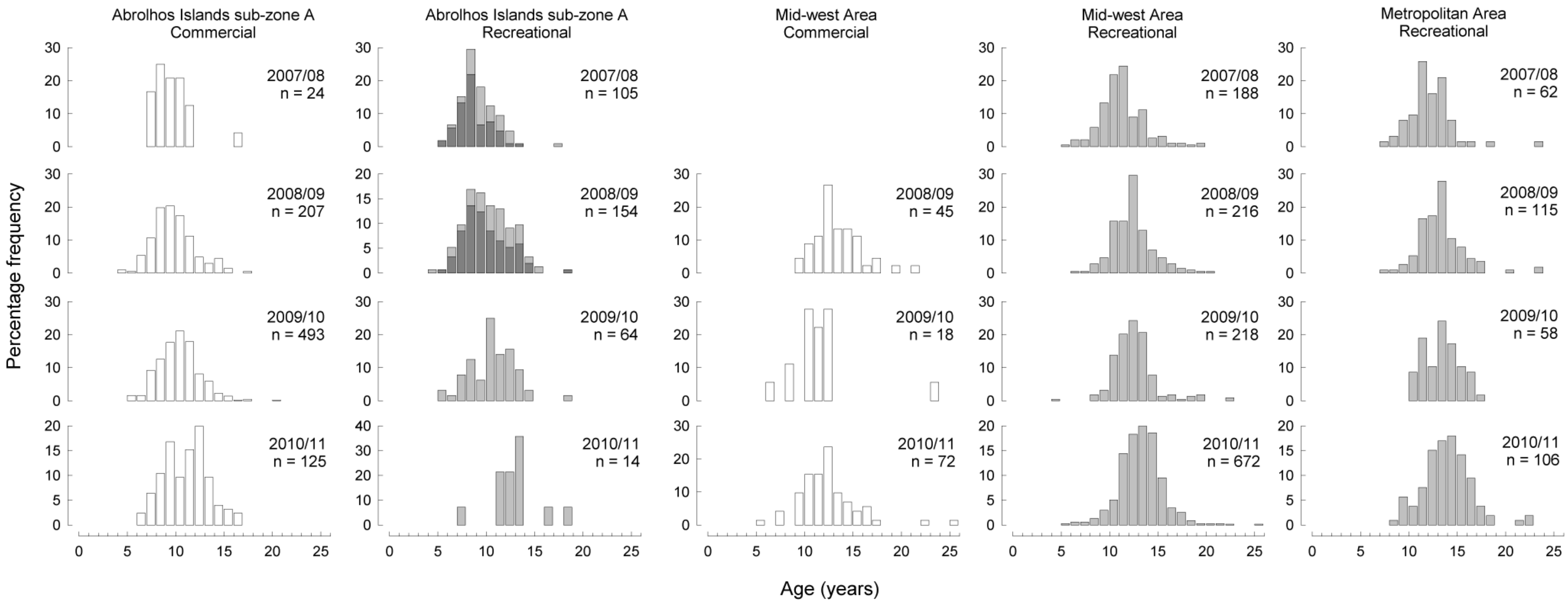

Figure 4.11. Age frequency distributions for *Choerodon rubescens* collected from fishery-dependent and -independent sampling in the Abrolhos Islands Zone A area of the West Coast Rock Lobster Managed Fishery and in the Mid-west and Metropolitan areas of the West Coast Demersal Scalefish (Interim) Managed Fishery between 2007/08 and 2010/11.
□ Commercial, ▒ Recreational/charter, ■ Research.

4.3.3 Assessment of *Choerodon rubescens*

Each of the estimates of *F* derived from the age structure for *C. rubescens* collected in 2007/08-2010/11 from the commercial sector in Zone A indicated an increase from those in 2000/01-2001/02 (Fig. 4.13; Table 4.2). However, there was some overlap of the standard errors for *F* derived using method 4 in those two periods, indicating they may not be significantly different. The current estimate derived using method 4 remains well above the limit reference point of 1.5*M*, while estimates obtained using other methods lay between the limit and threshold (Fig. 4.13; Table 4.2). A decrease in the *SPR* derived for the male portion of the stock from 2000/01-2001/02 to 2007/08-2010/11 reflected the increase in *F*.

Estimates of *F* calculated using all methods and the age compositions of *C. rubescens* obtained from the recreational sector in Zone A (except method 2) and the Mid-west and Metropolitan areas were all greater than the limit of 1.5*M*, *i.e.* 0.32 (Table 4.2). Notably, the estimates of *F* derived from methods 3 and 4 (which incorporated age-based selection curves) were substantially higher than those derived using methods 1 and 2. The *SPR* values derived for each of those sector/area combinations using the *F* obtained with method 4 ranged from 0.21-0.26 and had wide errors (Table 4.3).

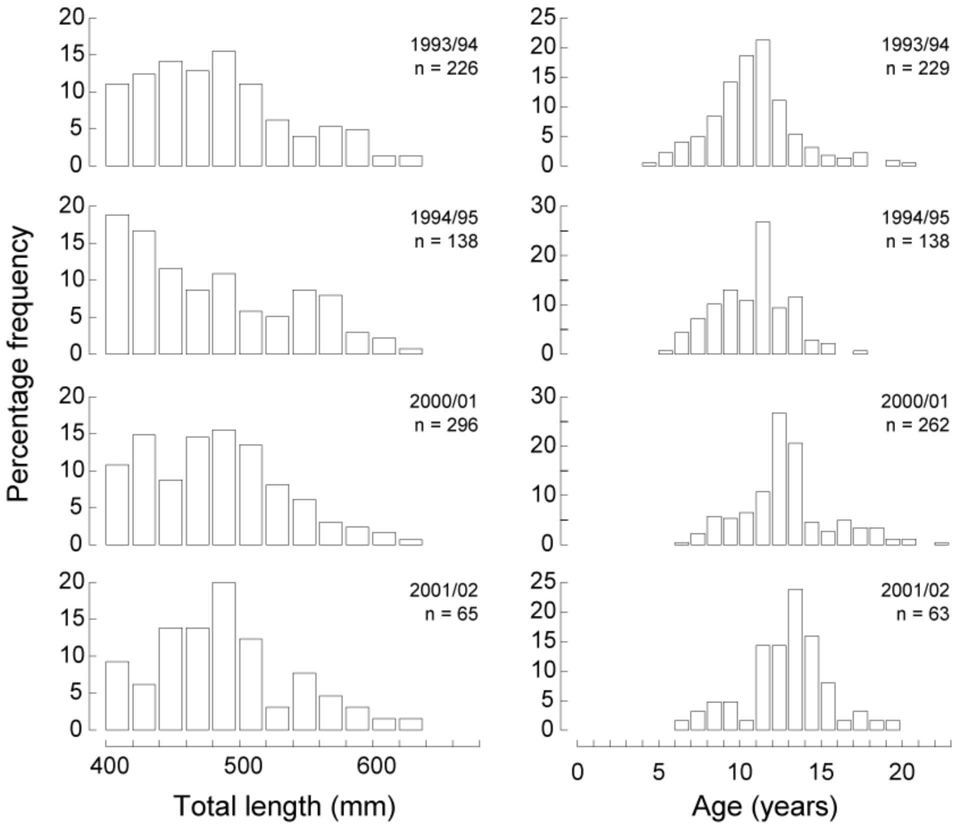

Figure 4.12. Length and age frequency distributions for *Choerodon rubescens* sampled from commercial catches in the Abrolhos Islands sub-zone A area of the West Coast Rock Lobster Managed Fishery between 1993/94 and 2001/02.

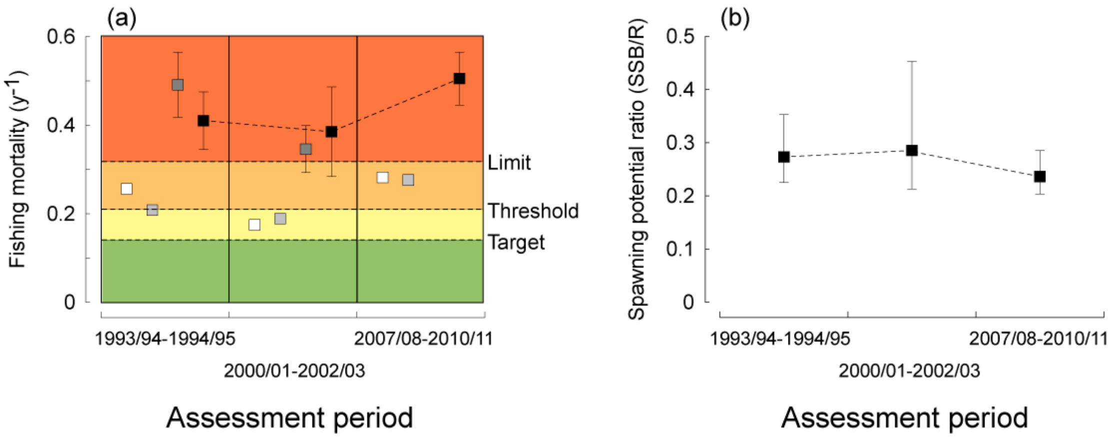

Figure 4.13. Estimates of (a) fishing mortality derived using 4 catch curve methods (*F* ±2 SE where available) and (b) spawning potential ratio (*SPR* ±2 SE in terms of SSB/R) for male *Choerodon rubescens* collected from the commercial sector in the Abrolhos Islands Zone A for three assessment periods between 1993/94 and 2010/11. *F* derived using four different methods and *SPR* calculated using *F* estimation method 4. *F* estimates are compared with Limit, Threshold and Target reference points (Table 3.3). Symbols: *F* method 1 = white, 2 = light grey, 3 = dark grey, 4 = black).

Table 4.2. Estimates of fishing mortality for *Choerodon rubescens* in each management area, sector and year combination derived using four different models, where *M* = 0.21. Current assessment period in bold.

		Commercial					Recreational				
		n	1	2	3	4	n	1	2	3	4
Abrolhos Zone A	1993/94-1994/95	367	0.256	0.208	0.491	0.410					
	2000/01-2002/03	335	0.175	0.189	0.346	0.385					
	2007/08-2010/11	849	0.282	0.276	–	0.505 (0.39-0.62)	167	0.267	0.197	0.589	0.553 (0.28-0.89)
Mid-west	2007/08-2010/11						1294	0.345	0.321	0.553	0.586 (0.48-0.70)
Metro-politan	2007/08-2010/11						341	0.377	0.331	0.439	0.446 (0.30-0.59)

Table 4.3. Estimates of spawning potential ratio (*SPR*±2 SE) for *Choerodon rubescens* derived from data collected between 2007/08 and 2010/11 from the commercial sector in the Abrolhos Islands Zone A and from the recreational sector in Zone A and the Mid-west and Metropolitan areas.

	Management area		
	Zone A	Mid-west	Metropolitan
Commercial	0.24 (0.20-0.28)		
Recreational	0.22 (0.16-0.41)	0.21 (0.19-0.25)	0.26 (0.21-0.33)

4.4 Catch and effort of the commercial sector

4.4.1 Overall composition of commercial catches

WCDSIMF catches between 2008 and 2012 comprised 71-90 species. Five species or species groups, *i.e. G. hebraicum*, *P. auratus*, lethrinid species (mainly *L. miniatus*), berycid species (mainly Bight redfish) and *C. rubescens*, consistently dominated catches of the inshore demersal suite and together comprised ca 85 % of the total catch of the fishery in any one year (Table 4.4). The remainder of the annual catch consisted of other inshore demersal species (4-6 %), offshore demersal species (*H. octofasciatus*, *P. oxygeneios*, *P. americanus*, *H. antarctica* and *E. carbunculus*; 2-4 %), pelagic species (*e.g. Seriola hippos*; 4-6 %) and nearshore/estuarine species (*e.g. Pseudocaranx* sp. 2-3 %; Table 4.4). Between 2008 and 2012, catches in the Kalbarri Area were dominated by *P. auratus* and *L. miniatus* (combined catch of 96-141 t, 78-83%), in the Mid-west Area by *P. auratus*, *G. hebraicum*, *L. miniatus* and *C. rubescens* (91-167 t, 77-83 %) and in the South-west Area by *Centroberyx* spp. (mainly *C. gerrardi*) and *G. hebraicum* (48-69 t, 79-89 %).

The majority of the catch of demersal species by other commercial fisheries in the WCB is taken by the TDGDLF. Between 2006/07 and 2011/12, catches of demersal species by the TDGDLF were dominated by Western blue groper *Achoerodus gouldii*, *G. hebraicum*, *P. auratus*, Blue morwong *Nemadactylus valenciennesi* and, in some years, Sweetlip species (Haemulidae) (Table 4.5). Those species represented 85-92 % of the total catch of demersal species in each year between 2006/07 and 2011/12. The WCRLF and CSLPF each currently take very small catches of demersal species (< 5 t), which include predominantly *C. rubescens* and Breaksea cod *Epinephelides armatus* by the WCRLF and *P. auratus* by the CSLPF. Almost no catches of demersal species are taken by the SWTMF.

4.4.2 Catches of demersal species and indicator species by the commercial sector vs 50 % of 2005/06 catches

The total catch of 407 t of demersal species in the WCB in 2012 (or 2011/12) by all commercial fisheries which are permitted to take demersal species fell from the 438 t landed in 2011 (or 2010/11). Since 2009 (2008/09), catches of all demersal scalefish have remained below 50 % of 2005/06 catches of 450 t. Similarly, catches of *G. hebraicum* in the WCB have remained below 50 % of 2005/06 catches (82 t) since 2009, with 73 t landed in 2012 (2011/12) (Fig. 4.14).

Commercial catches of *P. auratus* in the WCB have ranged from 171 to 190 t since 2010 (2009/10), with 180 t landed in 2012, which is ca 43 % greater than 50 % of 2005/06 catches of 126 t. Commercial catches of *C. rubescens* in the WCB between 2008 and 2012 ranged between 17 and 20 t and were thus below 50 % of 2005/06 catches of 22 t.

Table 4.4. Catches of the top five inshore demersal species/species groups and the remaining species suites (by weight and %) by the West Coast Demersal Scalefish (Interim) Managed Fishery between 2008 and 2012.

		Year									
		2008		2009		2010		2011		2012	
Common name	**Species name**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**
Snapper	*Pagrus auratus*	141	34	109	36	156	43	182	44	170	44
West Australian dhufish	*Glaucosoma hebraicum*	76	18	49	16	55	15	67	16	64	17
Emperors	*Lethrinus* spp	99	24	48	16	52	14	62	15	55	14
Redfish species	*Centroberyx* spp	29	7	42	14	39	11	29	7	24	6
Baldchin groper	*Choerodon rubescens*	12	3	11	4	12	3	16	4	16	4
Other inshore demersal species		22	5	16	5	14	4	19	5	23	6
Offshore demersal species		10	2	6	2	14	4	7	2	9	2
Pelagic		17	4	17	6	18	5	18	4	18	5
Nearshore/estuarine species		9	3	5	1	7	1	11	3	10	2
Total		**415**		**303**		**367**		**411**		**389**	

Table 4.5. Catches of demersal teleost species in the Temperate Demersal Gillnet and Demersal long-line fisheries (WCDGDLF, JASDGDLF) in the West Coast Bioregion between 2006/07 and 2011/12. Indicator species in bold.

		Year											
		2006/07		2007/08		2008/09		2009/10		2010/11		2011/12	
Common name	**Species name**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**	**Catch (t)**	**%**
Western blue groper	*Achoerodus gouldii*	18	19	14	17	15	24	19	25	17	32	14	31
Western Australian dhufish	*Glaucosoma hebraicum*	19	20	20	24	15	23	16	21	13	24	9	21
Snapper	*Pagrus auratus*	17	17	14	17	9	13	11	15	7	13	10	22
Blue morwong	*Nemadactylus valenciennesi*	15	16	10	12	9	14	11	15	9	18	7	16
Sweetlips	Haemulid spp.	15	15	17	20	9	14	7	9	2	5	1	2
Baldchin groper	*Choerodon rubescens*	4	4	2	2	3	5	2	3	1	3	1	3
Boarfish species	Pentacerotid spp.	1	1	1	1	1	1	1	2	2	3	1	3
Redfish species	*Centroberyx* spp.	1	1	1	1	1	1	1	1	<1	<1	<1	<1
Other demersal scalefish		7	7	5	5	3	5	7	9	1	2	1	2
Total demersal species		**96**		**84**		**64**		**75**		**53**		**45**	

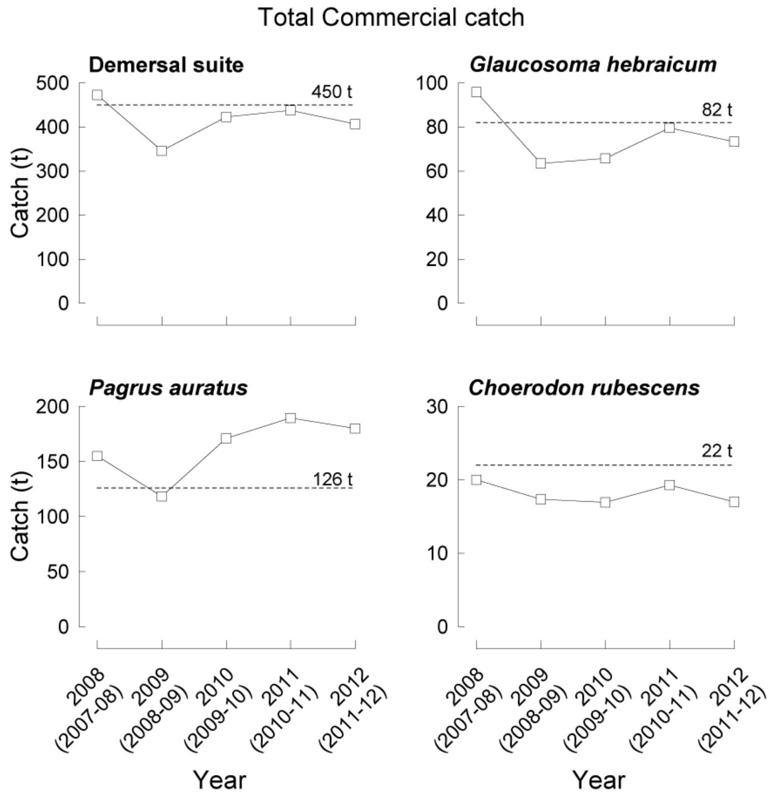

Figure 4.14. Catches in the West Coast Bioregion of all demersal species and of the inshore demersal indicator species by the commercial sector between 2008 (2007/08) and 2012 (2011/12).

4.4.3 Catches of all scalefish and the demersal suite by the WCDSIMF vs 50 % of 2005/06 catches

Catches of all scalefish and of the demersal suite (inshore and offshore species combined) by the WCDSIMF, in each year since the commencement of the fishery, (2008) have remained below the required level of 50 % of catches in 2005/06 (449-469 t and 410 t, respectively). Catches of all scalefish and the demersal suite in 2012 fell to 389 and 361 t, respectively, from 411 and 381 t in 2011 (Fig. 4.15). Catches of all scalefish and of the inshore demersal suite in the Kalbarri Area increased after 2009, remained steady during 2010 and 2011 at just above 50 % of 2005/06 catches, but then fell in 2012 to 141 t and 133 t, respectively, to be below 50 % of 2005/06 catches (Fig. 4.15). In the Mid-west Area, catches of all scalefish and the inshore demersal suites have increased since 2009 and remained steady in 2011 and 2012 at about 50 % of 2005/06 catches (Fig. 4.15). In the South-west Area, catches of all scalefish between 2008 and 2012 ranged between 44 and 63 t and have remained well below 50 % of 2005/06 catches of 82 t. Catches of the inshore demersal suite in the South-west Area make up the vast majority of the scalefish catch and were thus also below 50 % of 2005/06 catches (Fig. 4.15). Catches in the Offshore Area between 2008 and 2012 have ranged from 6 to 14 t, which is well below the nominal benchmark for that area of 20-40 t (Fig 4.15).

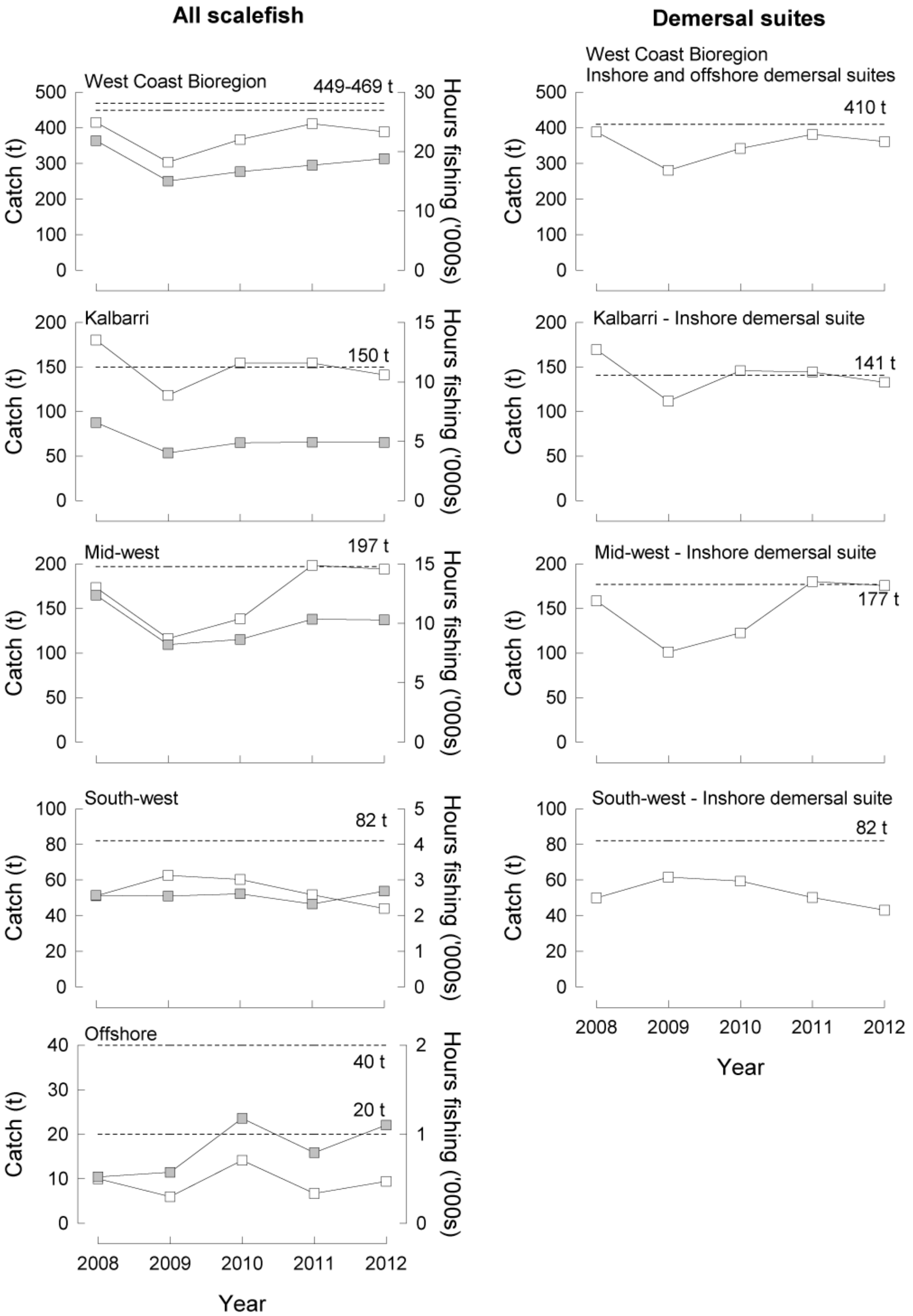

Figure 4.15. Catches of all scalefish and of the suites of inshore and offshore demersal species (white squares) and raw effort (grey squares) by the West Coast Demersal Scalefish (Interim) Managed Fishery in the West Coast Bioregion and each management area of the fishery between 2008 and 2012. Dotted lines represent 50% of 2005/06 catches for the Bioregion and each management area.

4.4.4 Total effort of the WCDSIMF and for each management area

Total effort has gradually increased from ca 15,000 fishing hours (hours searching + hours fished) in 2009, when effort entitlements were introduced, to almost 19,000 fishing hours in 2012 (Fig. 4.15). In the Kalbarri Area, effort increased from 2009 to 2010, but has been steady at around 5,000 h since. Effort in the Midwest Area also increased after 2009, but remained steady at ca 10,000 h in 2011 and 2012. In the South-west Area, reported annual fishing effort was around 2,500 h between 2008 and 2012. In the Offshore Area, fishing effort has been low in each year between 2008 and 2012 ranging from 500 to 1,200 hours.

4.4.5 Catches of *Glaucosoma hebraicum* by the WCDSIMF vs 50 % of 2005/06 catches

In 2008, prior to introduction of entitlements in the WCDSIMF, *G. hebraicum* catches in the WCB and in the Mid-west Area were > 50 % of 2005/06 catches (Fig. 4.16). Catches of *G. hebraicum* in the WCB and the Mid-west Area increased between 2009 and 2012. In 2012, the WCB catch of 64 t was just below 50 % of 2005/06 catches (72 t) and the catch of 44 t in the Mid-west Area was equivalent to 50 % of 2005/06 catches. In the South-west Area catches of *G. hebraicum* between 2008 and 2009 have ranged from 15 to 19 t and thus remained close to 50 % of 2005/06 catches of 19 t (Fig.4.16).

4.4.6 Catches of *Pagrus auratus* by the WCDSIMF vs 50 % of 2005/06 catches

Catches of *P. auratus* by the WCDSIMF in 2008, prior to introduction of entitlements, were also > 50 % of 2005/06 catches at the Bioregion level and in the Kalbarri and Mid-west areas (Fig. 4.16). Other than in 2009, *P. auratus* catches at the Bioregion level and in the Kalbarri and Mid-west areas have been above 50 % of 2005/06 catches, *i.e.* 120 t, 65 t and 43 t, respectively. However, catches in 2012 fell from those of 2011, from 182 to 170 t in the WCB, 88 to 78 t in the Kalbarri Area and 91 to 87 t in the Mid-west Area (Fig. 4.16). In the South-west Area, *P. auratus* catches have remained low between 2008 and 2012 at 3-4 t and thus below 50 % of 2005/06 catches of 12 t.

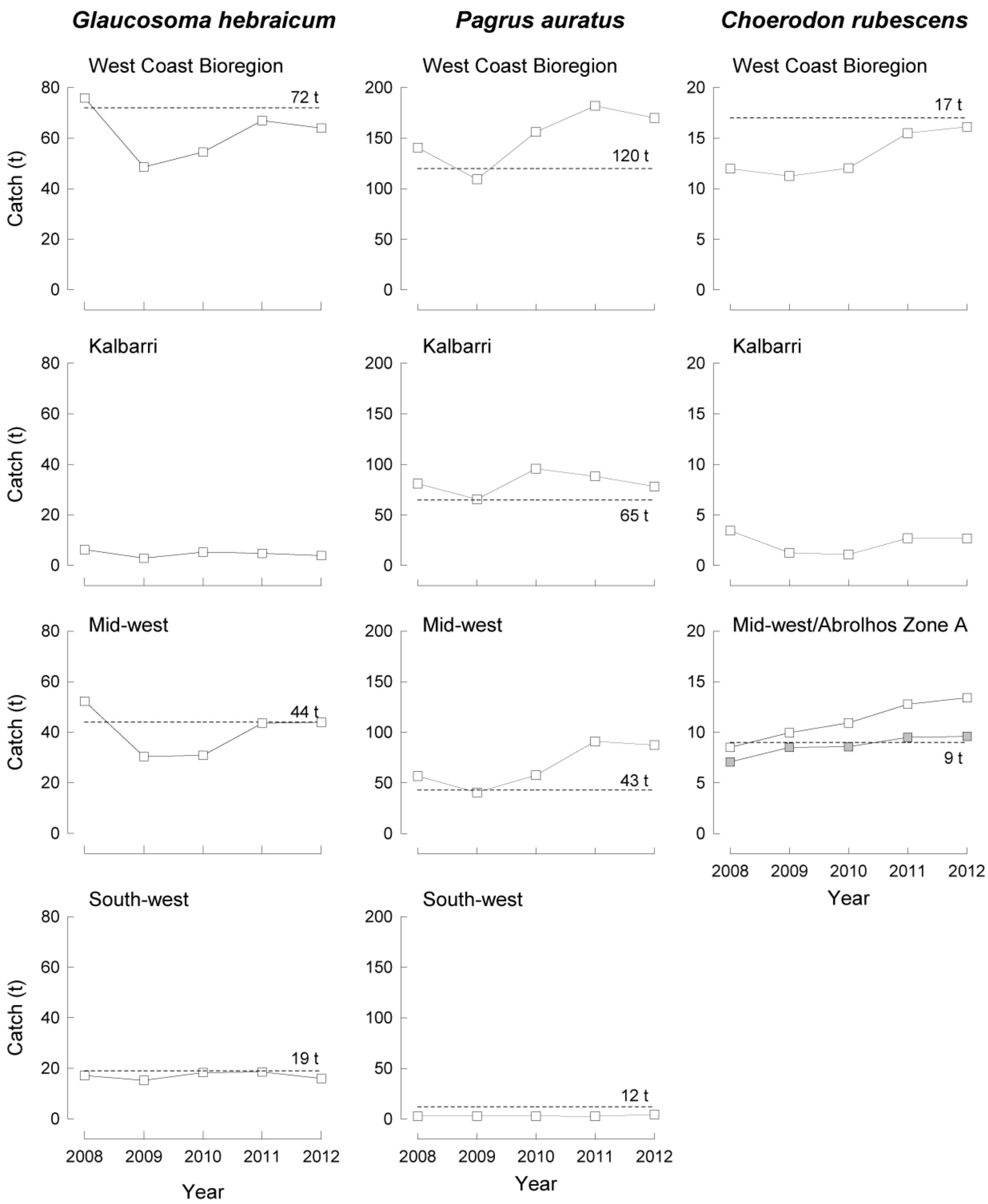

Figure 4.16. Reported catches of *Glaucosoma hebraicum*, *Pagrus auratus* and *Choerodon rubescens* by the West Coast Demersal Scalefish (Interim) Managed Fishery in the West Coast Bioregion and each management area of the fishery between 2008 and 2012. Dotted lines represent benchmark catches (50% of 2005/06 catch) for the Bioregion and each management area where each species is an indicator. For *C. rubescens*, this is the Abrolhos Zone A.

4.4.7 Catches of *Choerodon rubescens* by the WCDSIMF vs 50 % of 2005/06 catches

Catches of *C. rubescens* by the WCDSIMF between 2008 and 2012 have increased from 12 to 16 t in the WCB. These catches are taken in the Kalbarri and Mid-west areas, with the majority being caught in the Abrolhos Islands Zone A. In 2012, the catch of *C. rubescens* by the WCDSIMF in Zone A was similar to 50 % of 2005/06 catches of 9 t (Fig. 4.16).

4.5 Catches of demersal scalefish in the WCB by the recreational sector and comparison with 50 % of 2005/06 catches

The catches of the dominant (top 15) demersal species taken by boat-based recreational fishers and charter fishers during 2011/12 were estimated as 159 t and 41 t, respectively, totalling 200 t (Ryan *et al.*, 2013; Table 4.6). Catches of both recreational and charter fishers were dominated by *G. hebraicum*, *P. auratus* and *C. rubescens*. The total catch of 200 t in 2011/12 of the top 15 species by the combined recreational sector was less than 50% of 2005/06 catches of 252 t (IFAAC adjusted recreational boat-based catches of the top 15 species for 2005/06; Integrated Fisheries Allocation Advisory Committee, 2013). This was also the case for *G. hebraicum* (87 t vs 126 t). However, catches of both *P. auratus* and *C. rubescens* were both above 50 % of 2005/06 catches (Table 4.6).

Trends in catch and effort of the recreational sector cannot be compared among years at this stage, as estimates have been derived using different recreational catch survey methods. This issue is being investigated as part of post-graduate research projects. These studies are also investigating whether estimates of catch and effort can be derived for each management area of the WCB using the current *iSurvey* sampling frame.

Table 4.6 Estimated catches of the top 15 species by boat-based recreational fishers and charter fishers during 2011/12 and 50 % of 2005/06 catches of the top 15 species and of the indicator species *Glaucosoma hebraicum*, *Pagrus auratus* and *Choerodon rubescens* (adjusted upwards by IFAAC).

Species/species group		Recreational fishers	Charter fishers	Total	IFAAC adjusted 50% of 2005/06 catches
WA Dhufish	*Glaucosoma hebraicum*	74	13	87	126
Snapper	*Pagrus auratus*	33	10	43	37
Baldchin Groper	*Choerodon rubescens*	29	9	38	33
Breaksea Cod	*Epinephelides armatus*	10	4	14	
Emperors	*Lethrinus spp.*	4	1	5	
Blue Morwong	*Nemadactylus valenciennesi*	4	1	5	
Sergeant Baker	*Aulopus purpurrisatus*	2	1	3	
Redfish species	*Centroberyx spp.*	2	1	3	
Sea Sweep	*Scorpis aequipinnis*	1	1	2	
Eightbar Grouper	*Hyporthodus octofasciatus*	<1	1	1	
Bass Groper	*Polyprion americanus*	<1	0	<1	
Blue-Eye Trevalla	*Hyperoglyphe antarctica*	<1	<1	<1	
Foxfish	*Bodianus frenchii*	<1	<1	<1	
Hapuku	*Polyprion oxygenios*	0	<1	<1	
Ruby Snapper	*Etelis carbunculus*	0	<1	<1	
Total		**159**	**41**	**200**	**252**

4.6 Catch per unit effort in the WCDSIMF

4.6.1 Best fitting GLMMs and resulting standardised CPUE indices

The manual forward selection analysis of non-zero catch data resulted in different models selected and variable goodness of fit among species and management areas (Appendix A2). The range of adjusted coefficients of determination in each model indicated weak ($R_a^2 = 0.37$) to moderate ($R_a^2 = 0.67$) representations of trends in the observed data (Appendix A2). Log_e(hours fished), management area and species targeted were significant retained terms in final selected Gaussian GLMMs fitted to non-zero catch data for all datasets (Table 4.7). Seasonal terms were significant for all datasets except for *C. rubescens* data from the Mid-west. Log_e(hours searched) was found significant and retained in the final selected GLMM only for *P. auratus* from the Mid-west, *i.e.* the largest non-zero catch dataset (Table 4.7). However, this term was found to be non-significant and so excluded from the Binomial GLMM fitted to *P. auratus* data from this area (Table 4.7).

Seasonal terms found significant in the Gaussian GLMM analyses were found non-significant in (and so were omitted from) the Binomial GLMM analyses for *G. hebraicum* from the Mid-west and South-west and *C. rubescens* from Kalbarri (Table 4.7). Although "species targeted" was found significant for the Gaussian GLMM, it was found non-significant for the Binomial GLMM for *C. rubescens* from Kalbarri. Also, although $\log_e$(longitude) was found significant for the Gaussian GLMM it was found non-significant for the Binomial GLMM for the *G. hebraicum* from the Mid-west (Table 4.7).

4.6.2 Standardised CPUE indices

Mean standardised CPUE for *P. auratus* increased steadily from 2008 to 2011 in both the Kalbarri and Mid-West areas (Fig. 4.17). However, the 95% confidence intervals for the standardised CPUEs in all years overlapped, indicating that observed trends were not significant among years. Furthermore, the presented trends may differ when several additional years of data become available, and spatio-temporal imputations are incorporated into future CPUE standardisations.

Standardised CPUE for *G. hebraicum* increased slightly after 2009 in the Mid-west Area and to a greater extent in the South-west Area, each with substantial overlap of 95 % CIs (Fig. 4.17). Standardised CPUE for *C. rubescens* in the Abrolhos Islands Zone A remained relatively steady between 2008 and 2010 before increasing in 2011, while in the Mid-west Area standardised CPUE increased between 2008 and 2011. In both the Abrolhos Islands Zone A and Mid-west Area, 95% CIs overlapped among years, but to a lesser extent between 2008 and 2011, with a higher mean CPUE in the latter year in both cases.

Table 4.7. Summary of significant effects retained in final selected GLMMs. Detection of significance from Wald tests contingent upon forward selection algorithm used.✓ = Significant effect ($P < 0.05$); × = Not significant. 'N/A' = not assessed. Term found to be non-significant for Gaussian GLMM fitted to non-zero catch data and so was not tested for inclusion in the Binomial GLMM for that dataset. *= although this term was found to be significant, it was not retained in the final selected GLMM as its inclusion resulted in less than 0.5% reduction in residual deviance. **= Two-stage modelling not doing for this dataset as there was only 3.3% of data with zero catches (Table 2).

GLMM type	Species	Area	Spatial	Species targeted	$\log_e$(hours fished)	$\log_e$(hooks)	Seasonal	$\log_e$(hours searched)
Gaussian	*P. auratus*	MW	✓	✓	✓	✓	✓	✓
	P. auratus	Kal	✓	✓	✓	✓	✓	×
	G. hebraicum	MW	✓	✓	✓	×	✓	×
	G. hebraicum	SW	✓	✓	✓	✓*	✓	×
	C. rubescens	Kal	✓	✓	✓	✓	✓	×
	C. rubescens	Abrol	✓	✓	✓	✓	✓	×
	C. rubescens	MW	✓	✓	✓	✓	×	×
Binomial	*P. auratus*	MW	✓	✓	✓	✓	✓	×
	P. auratus	Kal**						
	G. hebraicum	MW	✓	✓	✓	N/A	×	N/A
	G. hebraicum	SW	✓	✓	✓	✓	×	N/A
	C. rubescens	Kal	✓	×	✓	✓	×	N/A
	C. rubescens	Abrol	×	✓	✓	✓	✓	N/A
	C. rubescens	MW	✓	✓	✓	×	N/A	N/A

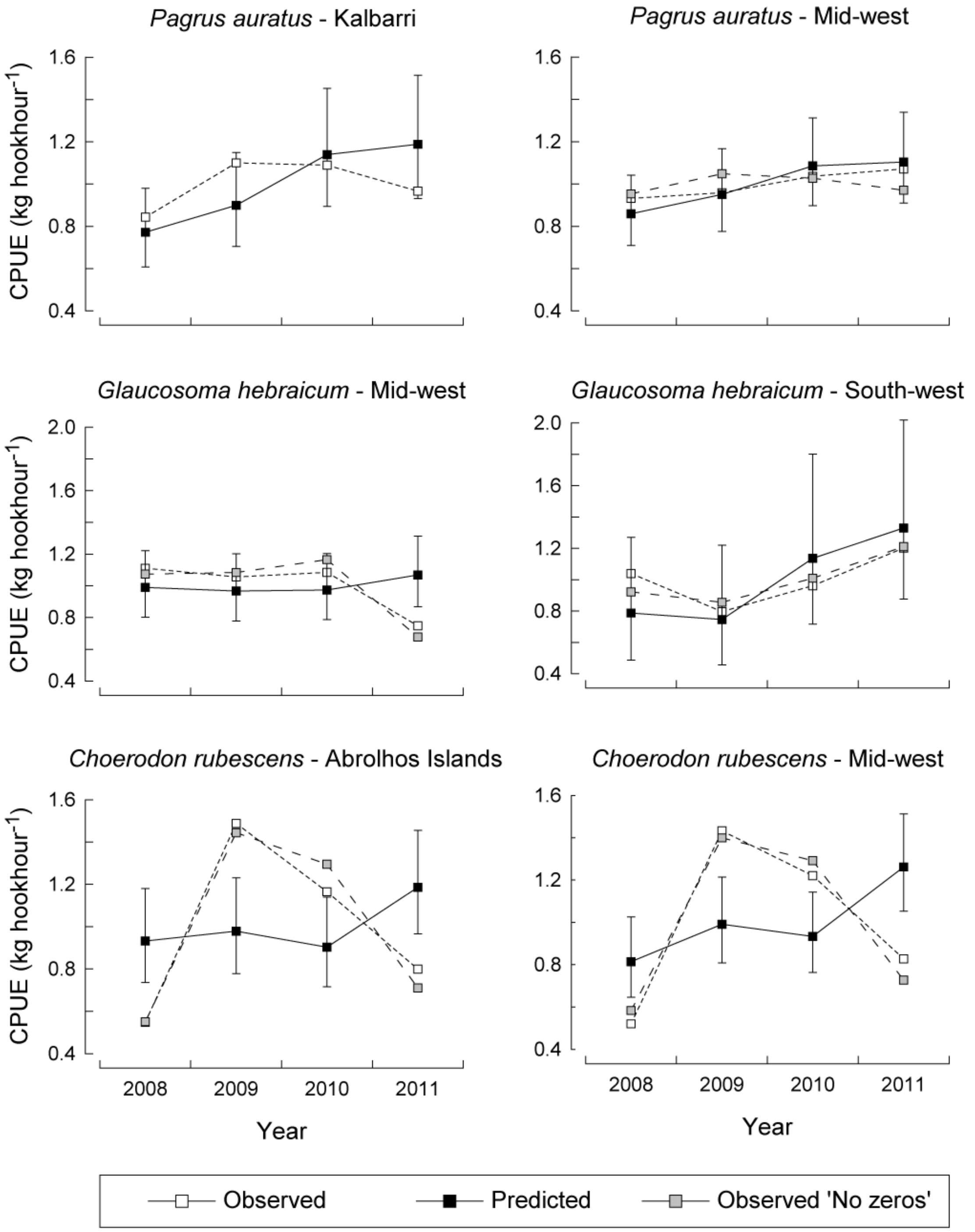

Figure 4.17. Standardised (predicted) CPUE indices ± 95 % CIs for the WCDSIMF generated from GLMMs, observed CPUE and observed CPUE fitted to non-zero catches only (for context). All values are normalised to a mean score of 1.

4.7 Main recommendations of O'Neill (2009) and actions.

Recommendation	Actions to date
Complete estimates of recreational catch and effort at least every two years	• Since 2009 - 2009/10 boat-based ramp survey of recreational catch • Integrated survey (*iSurvey* - phone diary and ramp) – 2011/12 (Ryan *et al.*, 2013), 2nd *iSurvey* underway in 2013/14
Maintain annual-time series of age composition data to estimate F	• Annual fisheries-dependent monitoring of indicator species (West Australian dhufish and Snapper) since 2002/03 and of Baldchin groper since 2007/08. • New indicator species adopted for future level 3 assessments to diversify representation of suite and respond to changes in proportional catches of species as a result of commercial management changes - Redthroat emperor for Kalbarri/Mid-west areas; Bight redfish for South-west Area.
Develop age-structured population models to explore stock status and degree of overfishing	• Requires longer time series of CPUE to determine applicability as an index of abundance. Only four years of data available at end of 2011 for WCDSIMF.
Explore use of longitudinal (cohort) methods to estimate improved measure of F	• Not yet explored. However, new catch curve methods developed for estimating *F*, which have fewer simplifying assumptions and consider variable recruitment using multiple years of data (see also Fisher, 2013).
Verify the appropriate shape of fishing selectivity schedules and allow modification due to changes in size limits	• New mortality estimation methods and *SPR* methods incorporate age-based, logistic selection curves, rather than adopting knife-edge selectivity. Data sets from periods of different size limits were analysed separately to account for these changes.
Further develop annual time series of fishery-independent abundance indices for dhufish, snapper, baldchin groper – both recruit and adult	• Not currently feasible to monitor both life cycle stages of each indicator in each management area of the WCB. • Independent monitoring of adult relative abundance - Not possible to monitor full WCB with existing data or methods, *e.g.* voluntary rec. fisher logbooks (RAP program), BRUV programs. BRUVs can provide comparable length data (Langlois *et al.*, 2012) and statistical power for relative abundance measures (Harvey *et al.*, 2012). • Annual collection of data for Daily Egg Production Method of estimating spawning stock biomass for Snapper in Cockburn Sound (CS) & monitoring of juvenile recruitment ongoing. Methods involving DNA probes being explored to verify visual identification of Snapper eggs in plankton samples. • W.A. Dhufish – WA State NRM & FRDC projects to investigate juvenile habitats and egg/larval occurrence complete (Lewis *et al.*, 2013; Strzelecki *et al.*, 2013). Data inform potential for developing juvenile/larval relative abundance indices. A substantial time period of monitoring each would be required to determine whether these would reflect cohort relative abundance. • Baldchin groper – UWA PhD project to identify juvenile habitats.
Develop formal quantitative management evaluation models	• Departmental harvest strategy policy being finalised. • Draft catch management guidelines awaiting completion of above. • No formalised harvest strategy for the WCDSR • Single area, single species, sex-, size- and age-structured MSE model developed by Fisher *et al.* (2011) allows examination of the effectiveness of alternative management options (*e.g.* changes to bag limits, size limits, reductions in exploitation etc.) for a single species stock with different biological characteristics. Model developed for *F*-based assessments, as employed by the Department for indicator species in this fishery.
Develop the potential for commercial and recreational catch rates as indices of abundance	• CPUE for WCDSIMF explored to evaluate significant influencing factors and standardisation. Insufficient years of data to use as index of abundance at this stage. CPUE with recreational data not yet explored as only one year of data available under iSurvey.

5.0 Discussion

Assessments of key indicator species, *G. hebraicum*, *P. auratus* and *C. rubescens*, for the WCDSR in 2007 and 2009 demonstrated that overfishing was occurring of these stocks. Declines in adjusted historical catch rates of each species over time also reflected a reduction in stock abundance (Wise *et al.*, 2007; Marriott *et al.*, 2011). Significant changes were made to the management of the fisheries that exploit the WCDSR between late 2007 and early 2010. These were designed to reduce effort in the fishery and therefore the catches of the entire demersal scalefish suite by at least 50 % of the 2005/06 levels to allow stock recovery to commence.

This third assessment of stock status was based on age data collected between 2008/09-2010/11 for *G. hebraicum* and *P. auratus* and 2007/08-2010/11 for *C. rubescens*. The assessment has compared estimated fishing mortality rates (*F*) for that time period with internationally accepted biological reference points to determine stock status. Estimates of *F* and spawning potential ratios (*SPR*) were also compared with those for previous time periods to determine whether there was any evidence of stock recovery. This assessment has taken into account the recommendations of O'Neill (2009) in relation to the types of data that should be collected and analyses conducted to produce a robust assessment. This assessment has adopted each of those recommendations where currently possible (see Section 4.7). However, some could not be adopted at this time, *e.g.* age structured population models, until longer time-series of data are available.

Sampling for this assessment occurred during the time when the changes were being made to management in the WCB of commercial and recreational fishing for demersal species. As a long recovery trajectory is expected for these species because of their biological characteristics, such as longevity, the current assessment was not expected to demonstrate evidence of substantial recovery in their stocks. Furthermore, recovery of stocks of each species to better than the threshold reference point (for *F*) would not be expected for at least 10 years. However, the beginnings of recovery (*i.e.* improvements in *F* and *SPR*) may have been identifiable if management measures were sufficient.

5.1 Stock assessment outcomes

The overall Bioregion level estimates of *F* in 2008/09-2010/11 for *G. hebraicum* and *P. auratus* (derived from the multi-year catch curve method assuming variable recruitment) decreased from the previous period (2005/06-2007/08). At that *F*, an increase in *SPR* was also detected for *G. hebraicum* at the Bioregion level from the previous assessment period. This indicates that some recovery has been initiated in the stocks of these indicator species within the WCB. However, at the Bioregion level, *F* estimates for both species have not yet reached their respective threshold levels (Wise *et al.*, 2007). There was no evidence of recovery observed for Baldchin groper in the Abrolhos Islands Zone A, as *F* remained above the limit reference point.

5.1.1 *Glaucosoma hebraicum*

The lower values of estimates of *F* and higher values of *SPR* for the overall stock of *G. hebraicum* indicated that it has begun to recover at the Bioregion level. A reduction in catches (*i.e.* fishing mortality) that have improved the survival rates of fully-selected age classes, including three strong cohorts of recruitment (1999, 2002 and 2004), is the main driver of recovery.

Declining *F* and increasing *SPR* for *G. hebraicum* in the Mid-west, Metropolitan and South-west management areas, where it is used as an indicator species, indicated that the *G. hebraicum* stock was recovering in all areas. However, the “better” levels of *F* and *SPR* in the South-west Area (based on recreational samples) in 2008/09-2010/11 reflected the historically lower levels of commercial and recreational fishing mortality experienced by this part of the stock, which is consistent with the relatively lower estimates of *F* for this area during previous periods.

During the period of collection for this assessment, individual commercial and recreational fishers have indicated that the ability to catch *G. hebraicum* has increased and therefore fishers often believe that stocks have already recovered. However, the assessment results clearly demonstrate that stocks have not yet recovered to appropriate levels, as the fishing mortality remains too high and *SPR* remains too low, reflecting the lack of older fish in the population and reduced reproductive capacity. The anecdotally reported increase in catchability of *G. hebraicum* is likely to be driven by an increased relative abundance of fish as a result of reduced catches (via bag and boat limits, closed seasons and other management measures) and the presence of strong recruitment pulses in the stocks. This may also be reflected in the increase in standardised commercial CPUE in both the Mid-west and South-west areas by 2011, noting the uncertainty in the CPUE trend.

The estimated values of *F* and *SPR* determined in this assessment for *G. hebraicum* in the Mid-west and Metropolitan areas indicate that the stock is currently in a “poorer” state than was the case in 1995/96-1997/98 (Hesp *et al.*, 2002). In that earlier period, the value of *F* was close to the threshold reference point, in contrast to being at about the limit in 2008/09-2010/11. This difference reflects the greater proportion of older fish (> 15 y) in stocks in 1995/96-1997/98 compared with 2008/09-2010/11. Thus, as the 2008/09-2010/11 estimates of *F* in the Mid-west and Metropolitan Areas have not yet reached the threshold, more time is required for older fish to become more abundant and for *F* and *SPR* levels to recover towards those in 1995/96-1997/98.

5.1.2 *Pagrus auratus*

For *P. auratus*, evidence of stock recovery in the 2008/09-2010/11 period at the Bioregion level was driven predominantly by the improvement in stock status for the combined southern management areas (Metropolitan and South-West) of the WCB. There was limited evidence of recovery in the combined northern management areas (Kalbarri and Mid-west). The “better” status in the southern half of the WCB may have been influenced by several years of closures to fishing of *P. auratus* spawning aggregations in the Metropolitan Area (*i.e.* Cockburn Sound, Warnbro Sound and Owen Anchorage), which would have reduced fishing mortality at this time and may have contributed to the improved age composition. This closure may also have enhanced spawning stock biomass and reproductive output of these aggregations. The “better” status in the southern half of the bioregion may also have been influenced by the lower historical fishing effort in the South-west Area, which is reflected in a greater proportion of older fish in samples from that Area.

The limited recovery in the northern half of the WCB, indicated by the high *F* and low *SPR*, is likely to be linked to the requirement for reductions in catch of *P. auratus* by at least 50 % of 2005/06 catches not having been met by either the commercial or recreational sectors. Thus, catches by the WCDSIMF, which are taken almost exclusively in the Kalbarri and Mid-west areas, were ~42 % above that benchmark in 2012 (20 % above in the Kalbarri Area and 98 % above in the Mid-west Area). Catches by the recreational sector were ~14 % above that benchmark across the WCB in 2011/12. Also, the status of *P. auratus* stocks (level of *F*) in the previous assessment periods (2002/03-2004/05 and 2005/06-2007/08) was much worse than for *G. hebraicum*. Additionally, a specific *G. hebraicum* boat limit for recreational fishers was applied (2 per boat) as one of the recent management changes, whereas there is no specific boat limit for *P. auratus*. Thus, additional management measures applied to *G. hebraicum* may be influencing its recovery.

5.1.3 *Choerodon rubescens*

Estimates of *F* for *C. rubescens* were above the limit reference point for the Abrolhos Islands Zone A, the broader Mid-west Area and also the Metropolitan Area, as derived from samples collected between 2008/09 and 2010/11 (Table 5.1). In the Abrolhos Zone A, where this species is an indicator, *F* increased and *SPR* decreased from the early 2000s, but *F* has not yet reached the threshold reference point. While the change in *F* and *SPR* may indicate that stock status has declined since the previous period, there was substantial uncertainty around each estimate and the errors overlapped among assessment periods, indicating that the level of measured change is unlikely to be statistically significant.

The lack of evidence for recovery of *C. rubescens* may be influenced by the overlap in timing of collection of fish for this assessment and the timing of changes to management, which would reduce the likelihood of observing recovery at this time if it were occurring. It may also be influenced by catches by the recreational sector not meeting the management objective of a reduction in catch of this species by at least 50 % of 2005/06 catches. Recovery of *C. rubescens* is likely to be complicated by the high frequency of barotrauma and potential post-release mortality and the unknown magnitude of catches of *C. rubescens* by WCRLF fishers temporarily living in camps at the Abrolhos Islands, which are not included in current surveys.

The time required for evidence of recovery of stocks of *C. rubescens* to be observed could be further complicated by it being a protogynous hermaphrodite, where females occur in the lower length and age classes and males in the upper length and age classes. As males are typically greater than the MLL of 400 mm, they are fully recruited to the fishery and thus able to be fully exploited. Thus, overfishing of the upper (male) part of the length/age distribution may affect reproductive success through modifying the population sex ratio and increasing the likelihood of sperm limitation and/or by affecting growth rates and the lengths and ages at which maturation and sex change occurs (Bannerot *et al.*, 1987; Coleman *et al.*, 2000; Armsworth, 2001; Heppell *et al.*, 2006; Hamilton *et al.*, 2007).

5.2 Catches of demersal species in the West Coast Bioregion

Since substantial changes were made to the management of the fisheries that exploit stocks of demersal species within the WCB, the trends in catches have demonstrated that the management regime has been largely successful. The total catch of demersal species by the commercial sector (in 2011/12 or 2012), which was dominated by that of the WCDSIMF, and of the top 15 demersal species by the recreational sector in 2011/12, were less than 50 % of 2005/06 catches. Furthermore, the catch of *G. hebraicum* by both the commercial and recreational sectors in those years were below 50 % of 2005/06 catches. However, the success has not been ubiquitous. Catches of *P. auratus* by the commercial sector (mainly WCDSIMF) were much greater than 50 % of 2005/06 catches in 2012 and they were also greater for the recreational sector in 2011/12. While the total commercial catch of *C. rubescens* in 2012 was just below 50% of 2005/06 catches, that in Zone A by the WCDSIMF was equivalent to 50% of the 2005/06 catch and the recreational catch of *C. rubescens* in 2011/12 was much greater than 50% of the 2005/06 catch.

5.3 Current assessment approach and limitations of the methods employed

i) Catch curve analyses

As discussed by Fisher (2012), catch curve analyses as employed in these assessments are used widely in stock assessments due to their relatively low data requirements (*i.e.* typically require only age composition data). This makes catch-curve analyses readily applicable to situations where a long times series of reliable catch per unit effort data is unavailable, as is the case for the WCDSR.

It is important to recognise, however, that catch curve analyses typically require several strong assumptions, some of which are difficult to satisfy. One of the most important assumptions is that the population is in a steady state, meaning that recruitment and mortality are considered to have remained constant over the lives of all fish in the current population (*e.g.* Chapman and Robson, 1960; Ricker, 1975; Jensen, 1984). Simulation studies have demonstrated that deviations from this assumption can lead to biased mortality estimates (*e.g.* Dunn *et al.*, 2002). Moreover, such studies have also demonstrated differences in the reliabilities of different catch curve approaches, with the commonly applied linear catch curve method (as described by Ricker, 1975), for example, often producing underestimates of mortality (*e.g.* Murphy, 1997; Dunn *et al.*, 2002).

Given these issues with catch curve analyses, four alternative catch curve approaches were used in this assessment of indicator species for the WCDSR. Wise *et al.* (2007) also took the approach of comparing several methods of catch curve analysis to explore uncertainties in *F* estimates associated with different modelling assumptions. In this assessment, two linear catch curve methods were used (as in the last assessment), and two new approaches were developed that limit, as far as possible, the assumptions that needed to be made. Both of the new methods (*Methods 3 and 4*) incorporate age-based selectivity, thereby overcoming the simplifying assumption of knife-edge selectivity (*i.e.* that all fish recruit into the population at the same time) and, when fitted to data, yield estimates of selectivity for use in per recruit analyses. In addition, one of the new approaches (*Method 4*) accounts for inter-annual variation in recruitment, which is assumed to be constant with most catch curve methods, but is rarely, if ever, true. Catch curve *Methods 3 and 4* are similar but extend those described by Fisher (2012) in that they can be fitted simultaneously to (separate) multiple years of age composition data, an approach which has been strongly recommended in the literature (Quinn and Deriso, 1999, see also Schnute and Haigh, 2007). The pooling of age composition data over successive three year periods when fitting the two linear regression based methods of catch curve analysis employed in this study (*Methods 1 and 2*) does partly overcome the issue of impacts of inter-annual variations in recruitment by smoothing out peaks in data (*e.g.* Ricker, 1975). However, this approach has issues with respect to the potential effects of relative weightings of data from different years.

There was a degree of consistency among the results provided by four methods of catch curve analysis (*i.e.* they generally provided a similar indication of stock status) in this assessment, which suggests that each method has some merit for providing information regarding the likely level of exploitation of fish stocks. However, given that *Method 4* had the fewest assumptions, it was considered appropriate that the overall assessment focus to the greatest extent on the results from this analysis method.

It must be recognised that the estimates of *F* derived from all of the approaches are likely to be biased in terms of how they reflect the current level of exploitation pressure. As exploitation has been reduced (as evidenced by reduced commercial and recreational catches in recent years), the stocks cannot be viewed to be currently in equilibrium with respect to fishing mortality (*i.e.* as exploitation has changed over the lives of the older fish in the population, particularly as a result of management changes). However, consideration of estimated values of *F* in such situations is still very useful for stock assessment and determining stock status, because the estimated values will reflect the overall extent to which the age composition (and thus the overall stock) has rebuilt from their previously depleted state.

ii) Per recruit analyses

In addition to using catch curve analyses, this assessment also involved the use of per recruit analyses to estimate *SPR* and thereby provide an indication of the current level of egg production relative to that expected for an unfished stock. The value of per recruit analyses in addition to estimates of *F* from catch curve analyses is that they incorporate a range of other biological information, including information on growth, size or age at maturity, fecundity (if available) and for hermaphroditic species, also size or age at sex change. Such analyses provide an insight into key factors which may affect the sustainability of a fish stock.

In the case of each species, the results of the per recruit analyses suggest that the reproductive potential (*i.e.* spawning biomass) of their populations has declined to relatively low levels with respect to that which would be expected in an unfished population. Depletion of spawning biomass to such levels represents an increased risk of recruitment failure. The fact that in the most recent assessment period, there was a small, but consistent increase in *SPR* from the last assessment period for *G. hebraicum* in all areas and *P. auratus* in the southern management areas provides evidence that spawning biomass is increasing and thus the overall condition of their stocks has improved. Thus, the results of the per-recruit analyses are consistent with those of the catch curve analyses. Likewise, as *SPR* for *P. auratus* and *C. rubescens* in the northern management areas did not increase from the last assessment period, this is consistent with the indications from the *F*-estimates that the stock status of these species in those areas has not improved.

The per recruit analyses undertaken for this assessment extend those used in previous assessments for this fishery through incorporation of new data (*e.g.* biological parameters in certain regions) and by accounting for age-based selectivity. For future assessments, it would be valuable to explore the importance of accounting for (i) effects of post-release mortality of undersize fish and (ii) size-based differences in duration and frequency of spawning, in per recruit analyses (Lowerre-Barbieri *et al.*, 2011; Fitzburgh *et al.*, 2012).

5.4 Summary and management implications

5.4.1 Stock assessment outcomes

Stock status results and catch data demonstrate that the significant management changes to both the recreational and commercial sectors have initiated some level of recovery of demersal stocks at the Bioregion level. However, the stocks have not yet recovered to acceptable management reference points and, consistent with their life-history characteristics, it is anticipated that this will take at least 10 years. There was evidence that, at current catch levels, *G. hebraicum* has begun to recover in all management areas, and that *P. auratus* in the southern management areas is also recovering. However, there was little evidence of recovery for *P. auratus* and *C. rubescens* in the northern half of the WCB. Although the timing of collection of data for the current assessment overlapped the timing of changes to management and thus substantial recovery was not expected at this early stage, the estimated catches of *P. auratus* by the commercial sector in the northern management areas and of both *P. auratus* and *C. rubescens* by the recreational sector in the WCB were still above 50 % of 2005/06 catches. Thus, further management may be required to ensure catches of those two species by both sectors are maintained at or below the objective of 50 % of 2005/06 catch levels.

5.4.2 Future stock assessments and monitoring

Ongoing monitoring and assessment in each management area (including of catch by sector and age structures) is required to determine if the recovery of *G. hebraicum* assemblages in the WCB and *P. auratus* in the southern management areas has continued and if improvements for *P. auratus* and *C. rubescens* in the northern part of the WCB have been initiated. If catches of both the commercial and recreational sectors are maintained below 50 % of 2005/06 catch levels, stocks are likely to take at least 10 years to recover to the threshold reference point for fishing mortality.

A five-yearly cycle of stock assessments is appropriate for the demersal indicator species, given their life-history characteristics. However, it may be more appropriate to conduct assessments on a three-yearly time scale during this stock recovery phase and until fishing mortality is below the threshold. The next assessment of fishing mortality would thus be based on age structure data from 2011/12-2013/14, but the adoption of a three-yearly cycle would be dependent on priority and availability of resources.

In addition to the fishery-dependent monitoring of age compositions and catch and effort, fisheries-independent monitoring programs could provide data that can be incorporated in future stock assessments in a weight of evidence approach. The Department has been conducting annual monitoring of *P. auratus* egg abundance in Cockburn Sound at the time of annual spawning aggregations. These data are being validated to confirm egg (species) identification via genetic (DNA) techniques (Dias, in prep). Following validation, the data may be used to produce an estimate of spawning stock biomass in Cockburn Sound using Daily Egg Production Methods.

A time series of baited remote underwater video surveys have also been conducted at the Houtman-Abrolhos Islands and in the Metropolitan Area by the University of Western Australia and Department of Fisheries (*e.g.* McLean *et al.*, 2010; Langlois *et al.* 2012a) and in south-western Australia by the Department of Fisheries (unpublished data). These data may provide estimates of relative abundance over time as well as information on size structure of indicator species (see Langlois *et al.*, 2012b). These data sources may also allow corroboration of standardised commercial CPUE trends. Moreover, comparisons between the length compositions estimated from commercial and recreational catches could help evaluate the appropriateness of certain modelling assumptions (*e.g.* logistic selection) employed in catch curve and per recruit analyses.

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7.0 Appendix 1

Glaucosoma hebraicum

Table A1.1. Estimates of fishing mortality derived using each method (±2SE for method 4) for *Glaucosoma hebraicum* for the combined West Coast Bioregion (both sectors and all areas; method 4) and for each management area, sector and year combination derived using different models.

		Combined sectors	Commercial					Recreational				
		(± 2 SE)	n	1	2	3	4	n	1	2	3	4
West Coast Bioregion	2002/03-2004/05	0.17 (0.15-0.19)										
	2005/06-2007/08	0.22 (0.20-0.23)										
	2008/09-2010/11	0.17 (***0.16-0.18***)										
	1995/96-1997/98		***670***	0.147	0.105	0.123	0.120	-	-	-	-	
Mid-West	2002/03-2004/05		***765***	0.188	0.189	0.262	0.237	***146***	0.383	0.266	-	-
	2005/06-2007/08		***659***	0.240	0.210	0.235	0.261	***526***	0.295	0.234	0.222	0.248
	2008/09-2010/11		***1284***	**0.218**	**0.210**	**0.151**	**0.204 (0.18-0.23)**	***1150***	**0.242**	**0.229**	**0.175**	**0.198 (0.17-0.22)**
	1995/96-1997/98							***208***	0.088	0.075	0.100	0.115
Metropolitan	2002/03-2004/05							551	0.139	0.090	0.234	0.217
	2005/06-2007/08							***1020***	0.221	0.138	0.194	0.238
	2008/09-2010/11							***1032***	**0.273**	**0.200**	**0.162**	**0.184 (0.16-0.21)**
South-west	2002/03-2004/05		***114***	0.066	0.090	-	-	***317***	0.032	0.029	0.168	0.126
	2005/06-2007/08		***413***	0.051	0.134	0.209	0.159	***384***	0.012	0.045	0.152	0.168
	2008/09-2010/11		***274***	**0.272**	**0.275**	**0.369**	**0.298**	***480***	**0.031**	**0.051**	**0.153**	**0.110 (0.08-0.14)**

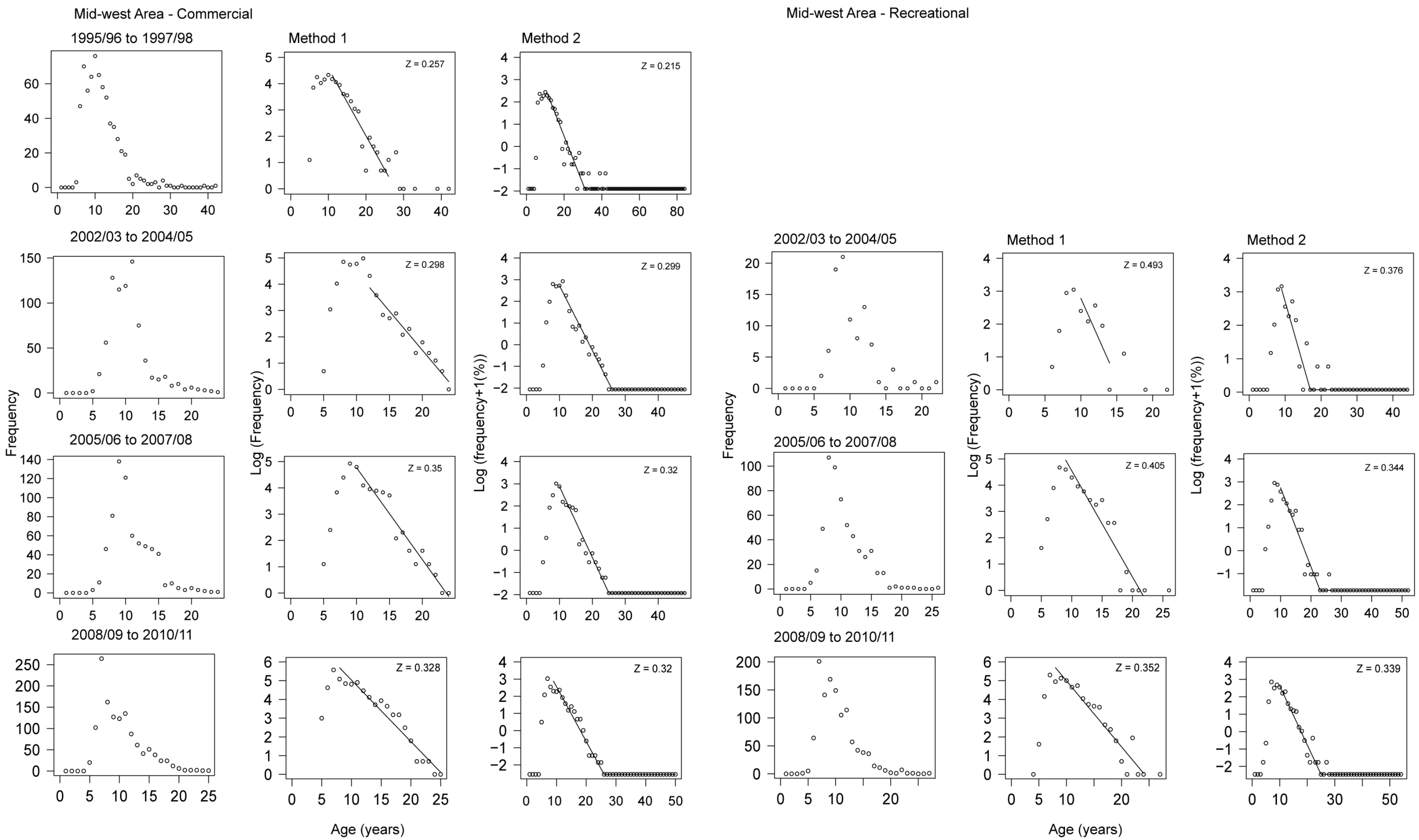

Figure A1. Age frequency compositions and regressions (methods 1 and 2) fitted to age structure data for *Glaucosoma hebraicum* collected from the commercial and recreational sectors in the Mid-west Area between 1995/96 and 2010/11.

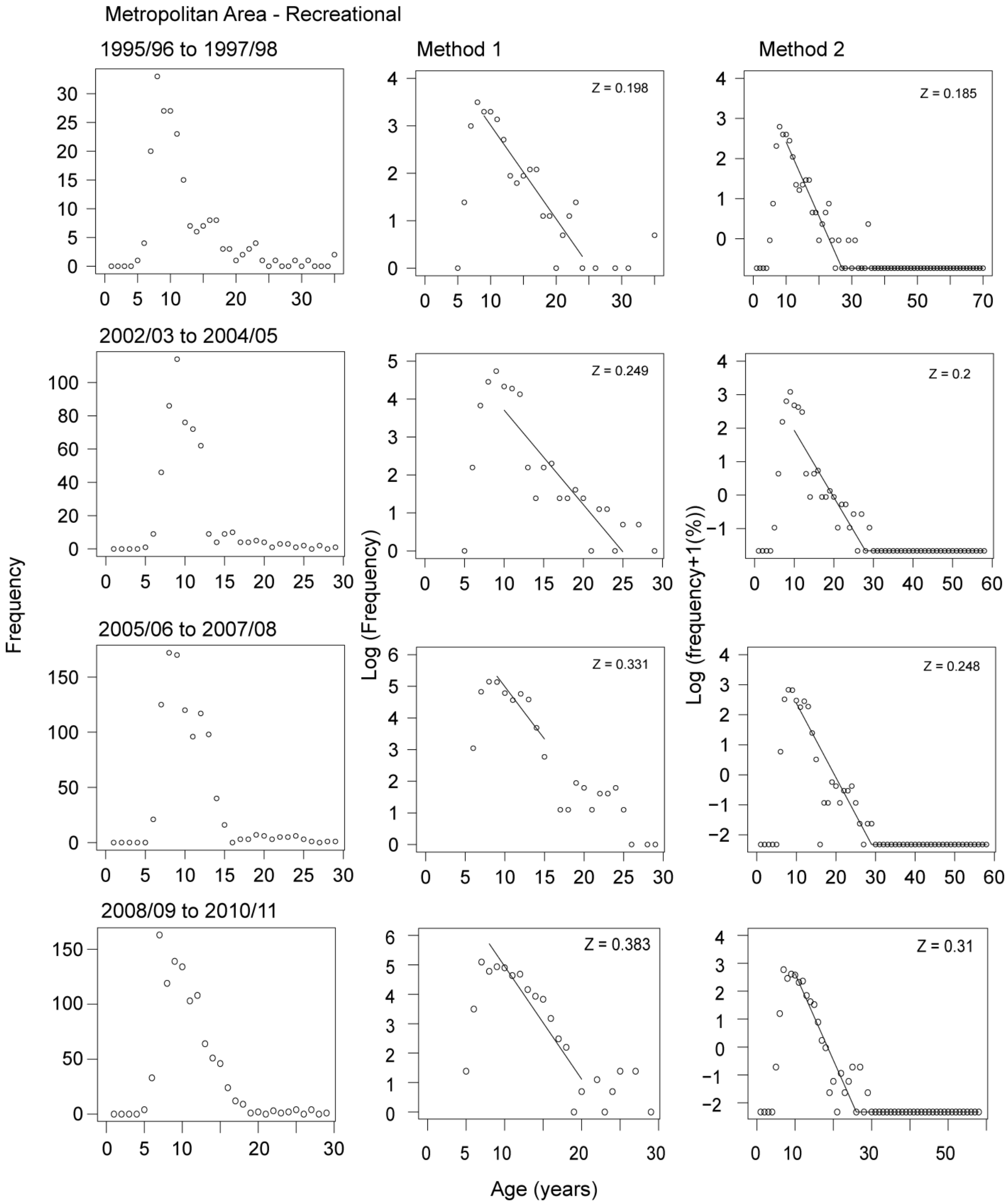

Figure A2. Age frequency compositions (left column) and regressions (methods 1 and 2) fitted to age structure data for *Glaucosoma hebraicum* collected from the recreational sector in the Metropolitan Area between 1995/96 and 2010/11

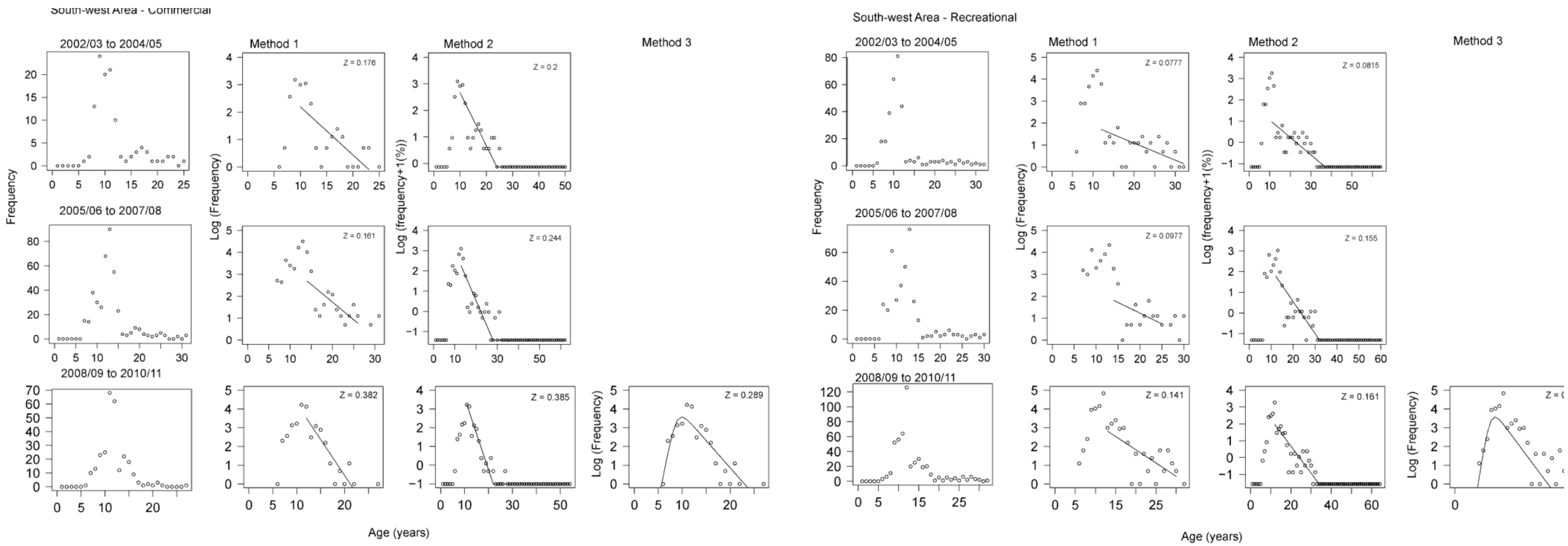

Figure A3. Age frequency compositions and regressions (methods 1, 2 and 3) fitted to age structure data for *Glaucosoma hebraicum* collected from the commercial and recreational sectors in the South-west Area between 2002/03 and 2010/11.

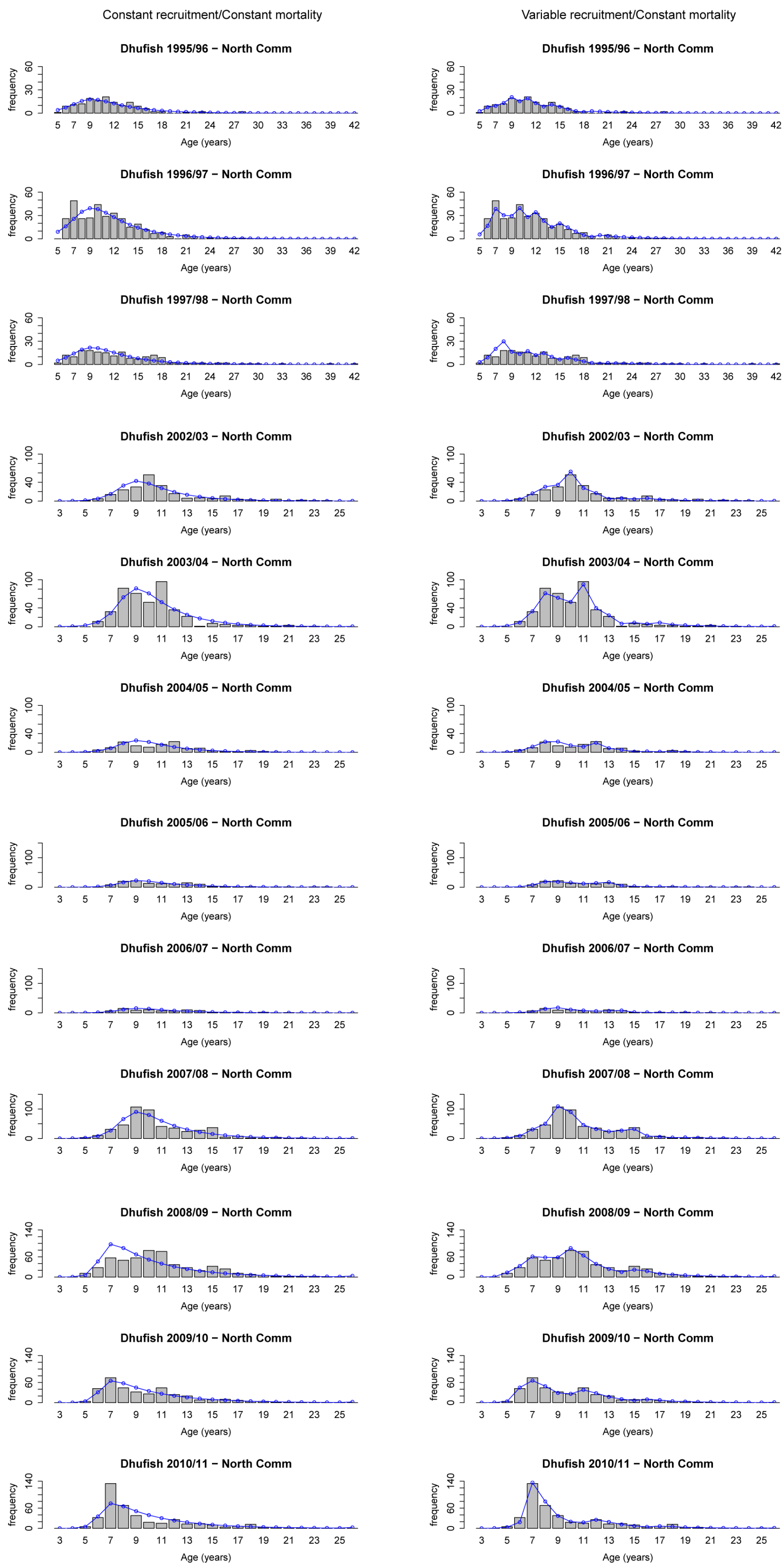

Figure A4. Constant recruitment, constant mortality (left column) and variable recruitment constant mortality models fitted to the age structures of *Glaucosoma hebraicum* in each year of four different periods of sampling (1995/96-1997/98, 2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) of the commercial sector in the Mid-west Area.

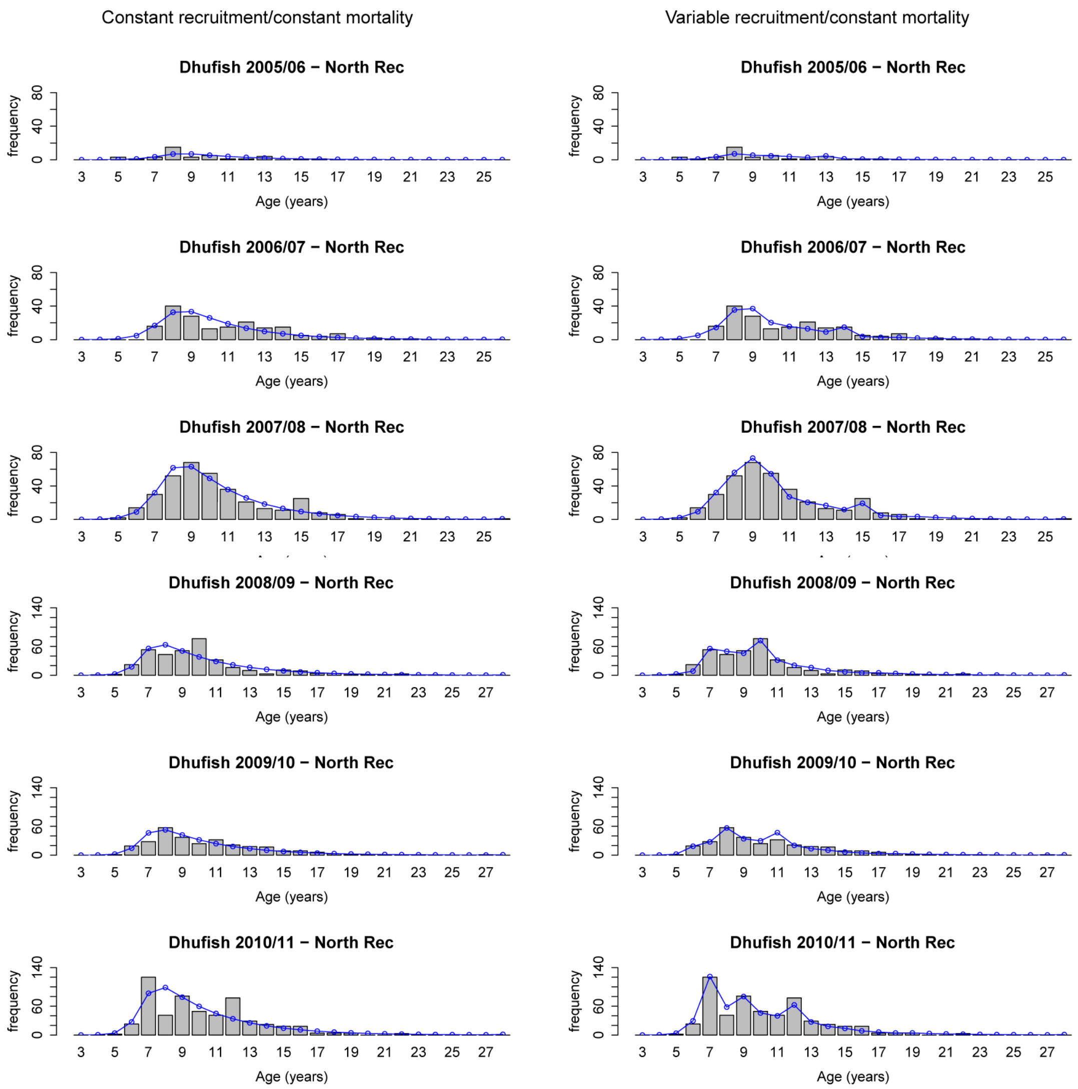

Figure A5. Constant recruitment, constant mortality (left column) and variable recruitment constant mortality models fitted to the age structures of *Glaucosoma hebraicum* in each year of two different periods of sampling (2005/06-2007/08, 2008/09-2010/11) of the recreational sector in the Mid-west Area.

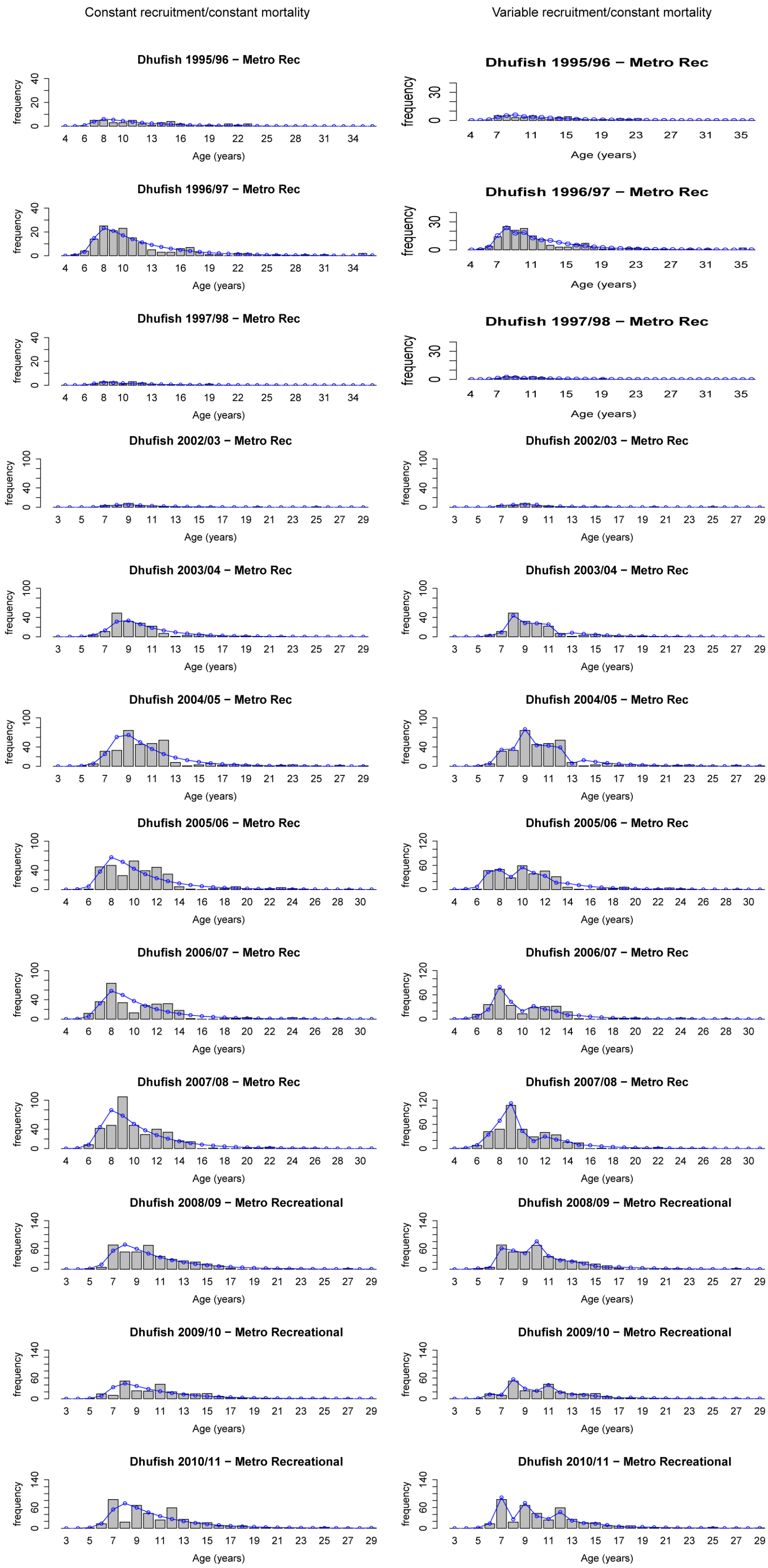

Figure A6. Constant recruitment, constant mortality (left column) and variable recruitment constant mortality models fitted to the age structures of *Glaucosoma hebraicum* in each year of four different periods of sampling (1995/96-1997/98, 2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) the recreational sector in the Metropolitan Area.

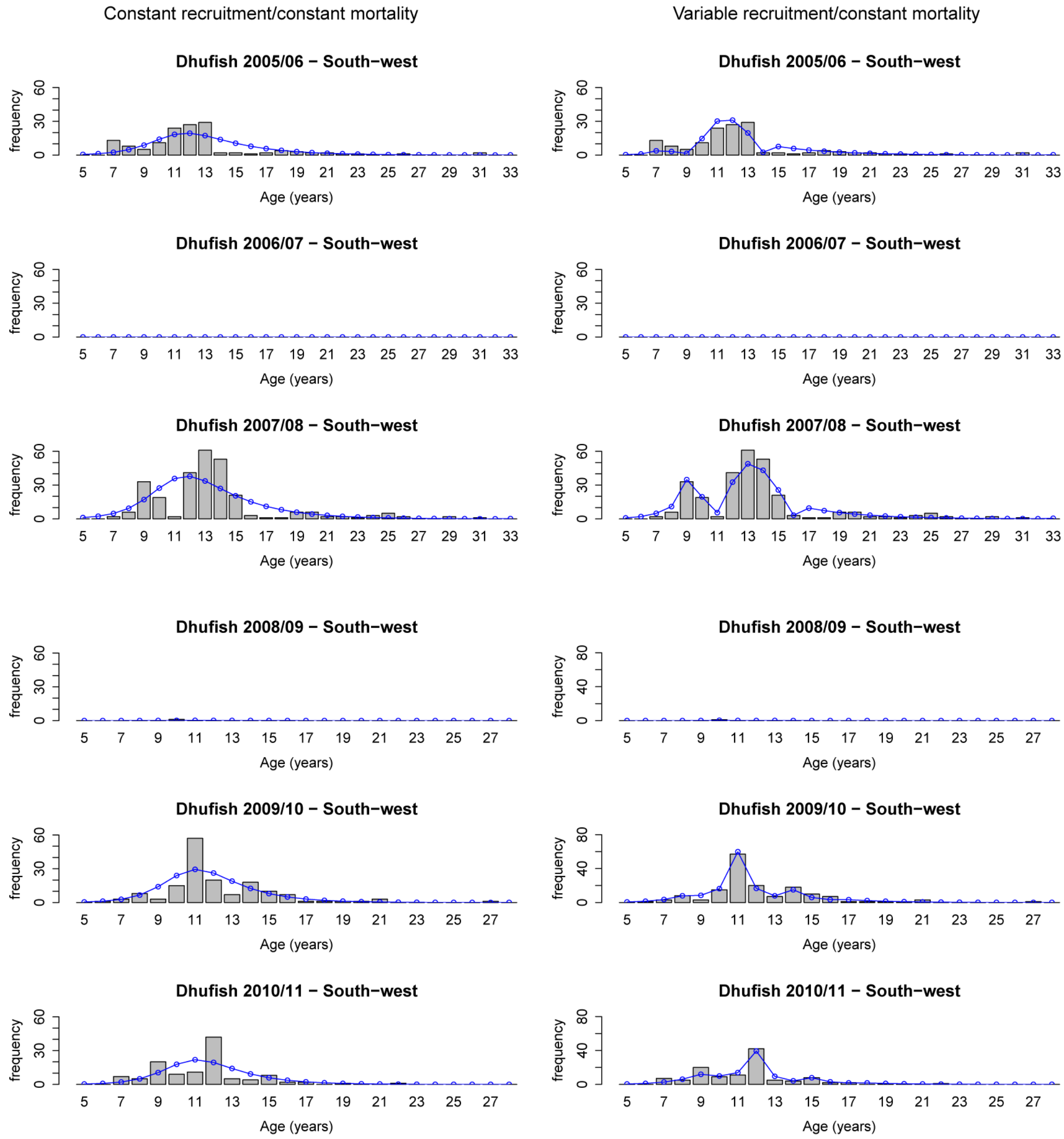

Figure A7. Constant recruitment, constant mortality (left column) and variable recruitment constant mortality models fitted to the age structures of *Glaucosoma hebraicum* in each year of two different periods of sampling (2005/06-2007/08, 2008/09-2010/11) the commercial sector in the South-west Area.

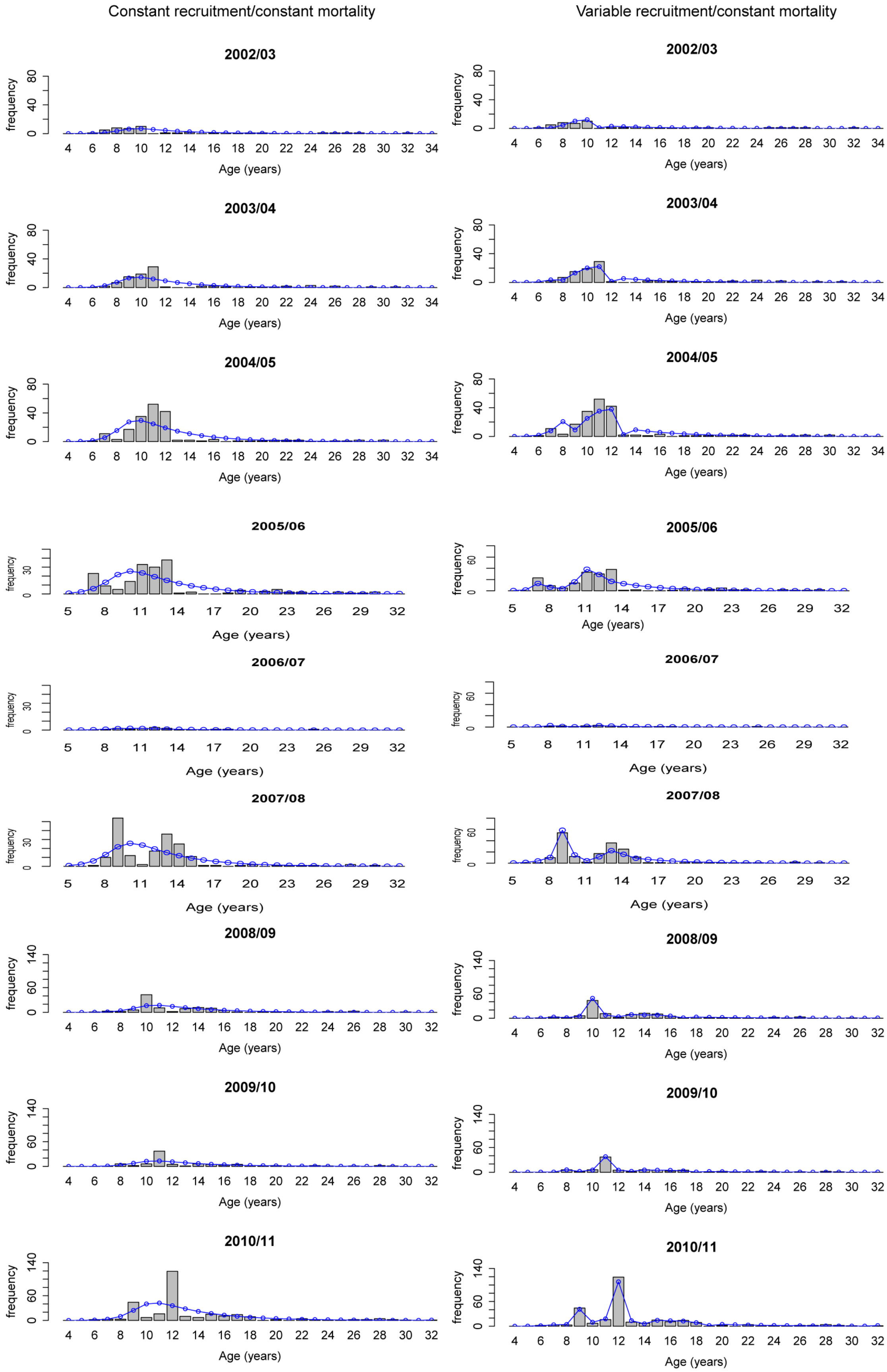

Figure A8. Constant recruitment, constant mortality (left column) and variable recruitment constant mortality models fitted to the age structures of *Glaucosoma hebraicum* in each year of four different periods of sampling (1995/96-1997/98, 2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) the recreational sector in the South-west Area.

Pagrus auratus

Table A1.2. Estimates of fishing mortality (F) for *Pagrus auratus* for the combined West Coast Bioregion (all sectors, method 4), for the combined northern management areas (Kalbarri and Mid-west) and for the combined southern management areas (all sectors) in each management area, sector and year combination derived using different models, where M = 0.12. [a]F estimates in parentheses for Metropolitan Area in 2008/09-2010/11 represent F prior to and after management change (extension of closure to fishing in Cockburn Sound in 2005). [b]F estimates for the South-west Area were derived from the combined data set from both the commercial and recreational sectors.

		Combined sectors	Commercial					Recreational				
		(± 2 SD)	n	1	2	3	4	n	1	2	3	4
West Coast Bioregion	2002/03-2004/05	0.52 (0.47-0.56)										
	2005/06-2007/08	0.36 (0.33-0.38)										
	2008/09-2010/11	0.28 (0.26-0.30)										
Northern Mgt areas combined	2002/03-2004/05	0.58 (0.52-0.63)										
	2005/06-2007/08	0.47 (0.43-0.51)										
	2008/09-2010/11	0.43 (0.41-0.46)										
Southern Mgt areas combined	2002/03-2004/05	0.47 (0.41-0.54)										
	2005/06-2007/08	0.23 (0.19-0.26)										
	2008/09-2010/11	0.18 (0.15-0.21)										

Table A1.2. (Continiued)

		Combined sectors	Commercial					Recreational				
		(± 2 SD)	n	1	2	3	4	n	1	2	3	4
Kalbarri	2002/03-2004/05		84	0.276	0.429	–	–					
	2005/06-2007/08		929	0.433	0.450	0.368	0.473					
	2008/09-2010/11		1644	0.435	0.388	0.508	0.513					
Mid-west	2002/03-2004/05		1096	0.818	0.910	0.720	0.646	114	0.723	0.573	–	–
	2005/06-2007/08		834	0.689	0.715	0.723	0.832	418	0.251	0.259	0.313	0.311
	2008/09-2010/11		1518	0.312	0.347	0.388	0.405	1160	0.386	0.364	0.383	0.404
Metropolitan [a]	2002/03-2004/05							569	0.292	0.621	0.625	0.611
	2005/06-2007/08							267	0.503	0.473	0.370	0.370
	2008/09-2010/11							359	0.210	0.210	0.208 (0.311, 0.067)	0.224 (0.328, 0.067)
South-west [b]	2002/03-2004/05		229	0.644	0.499	0.377	0.411					
	2005/06-2007/08		165	0.385	0.258	0.199	0.196					
	2008/09-2010/11		228	0.178	0.246	0.186	0.177					

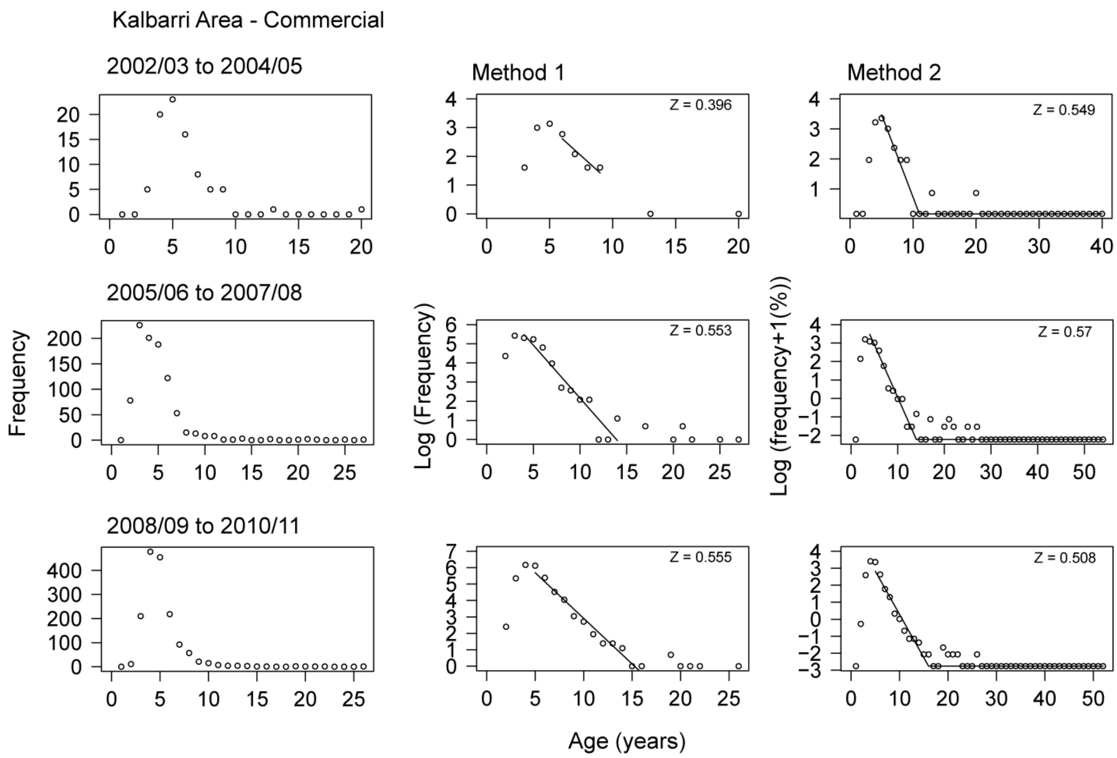

Figure A9. Age frequency compositions (left column) and regressions (methods 1 and 2) fitted to age structure data for *Pagrus auratus* collected from the commercial sector in the Kalbarri Area between 2002/03 and 2010/11.

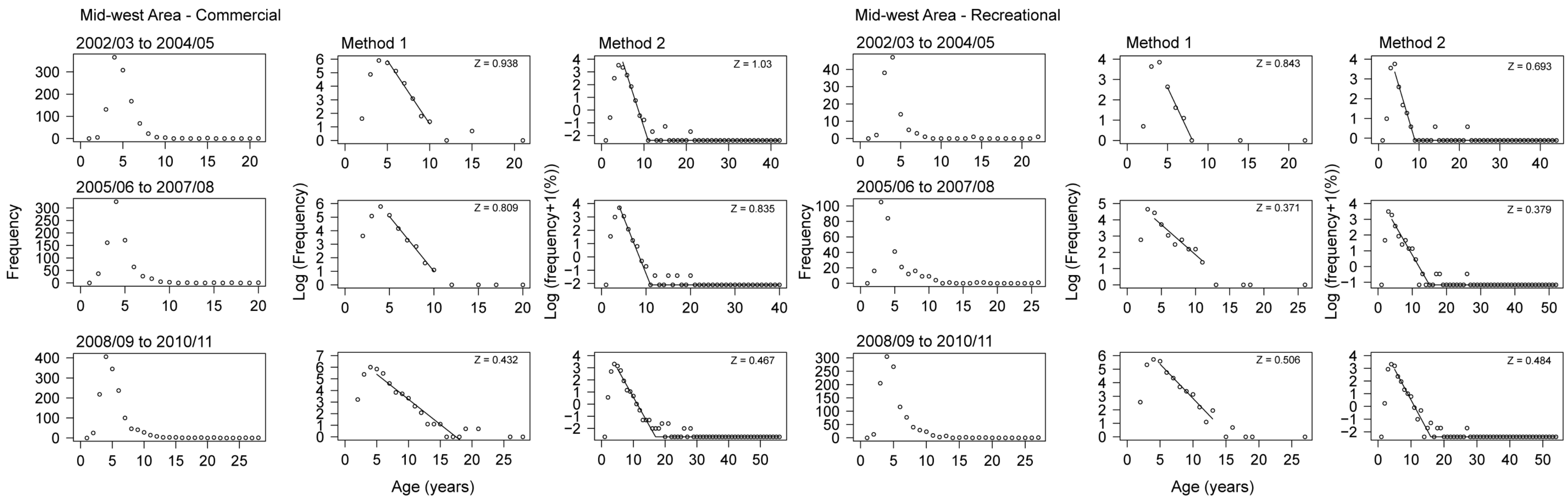

Figure A10. Age frequency compositions (left column) and regressions (methods 1 and 2) fitted to age structure data for *Pagrus auratus* collected from the commercial and recreational sectors in the Mid-west Area between 2002/03 and 2010/11.

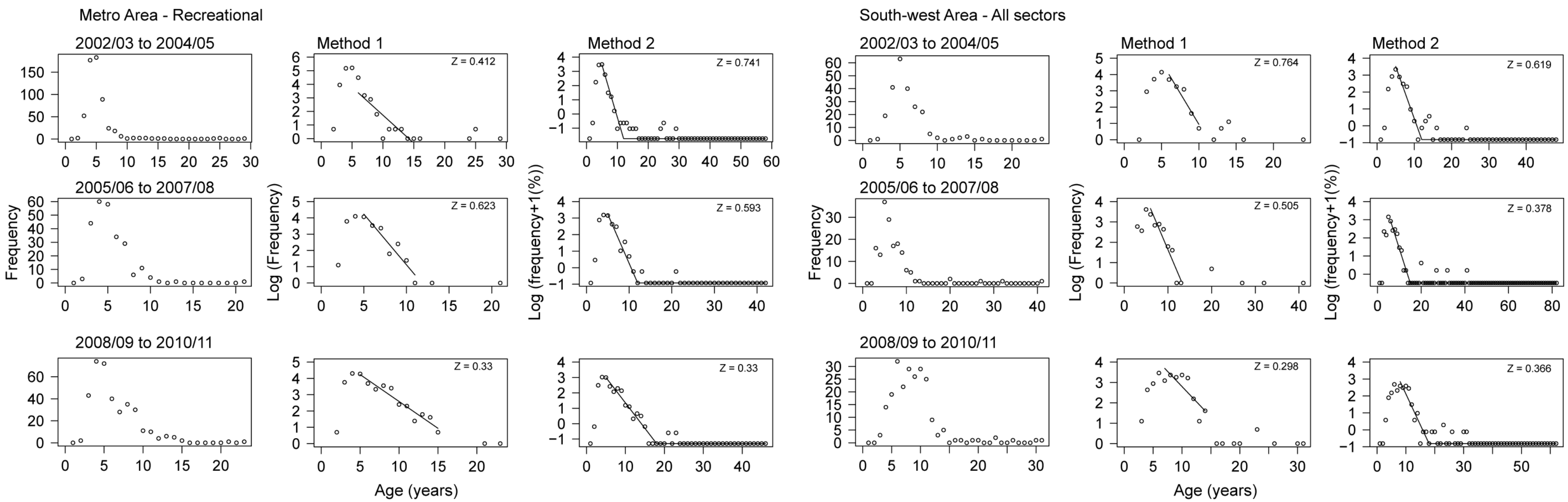

Figure A11. Age frequency compositions and regressions (methods 1 and 2) fitted to age structure data for *Pagrus auratus* collected from the recreational and all sectors in the Metropolitan and South-west Areas, respectively, between 2002/03 and 2010/11.

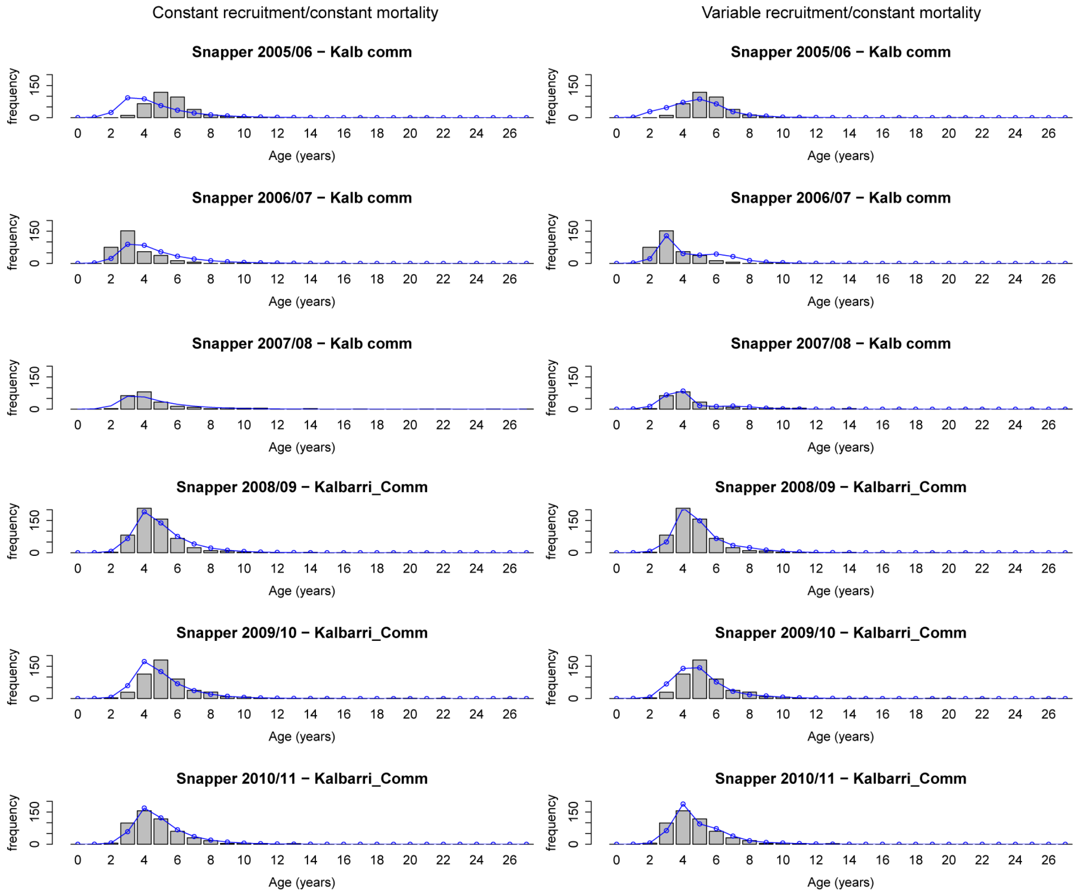

Figure A12. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Pagrus auratus* in each year of two different periods of sampling (2005/06-2007/08, 2008/09-2010/11) the commercial sector in the Kalbarri Area.

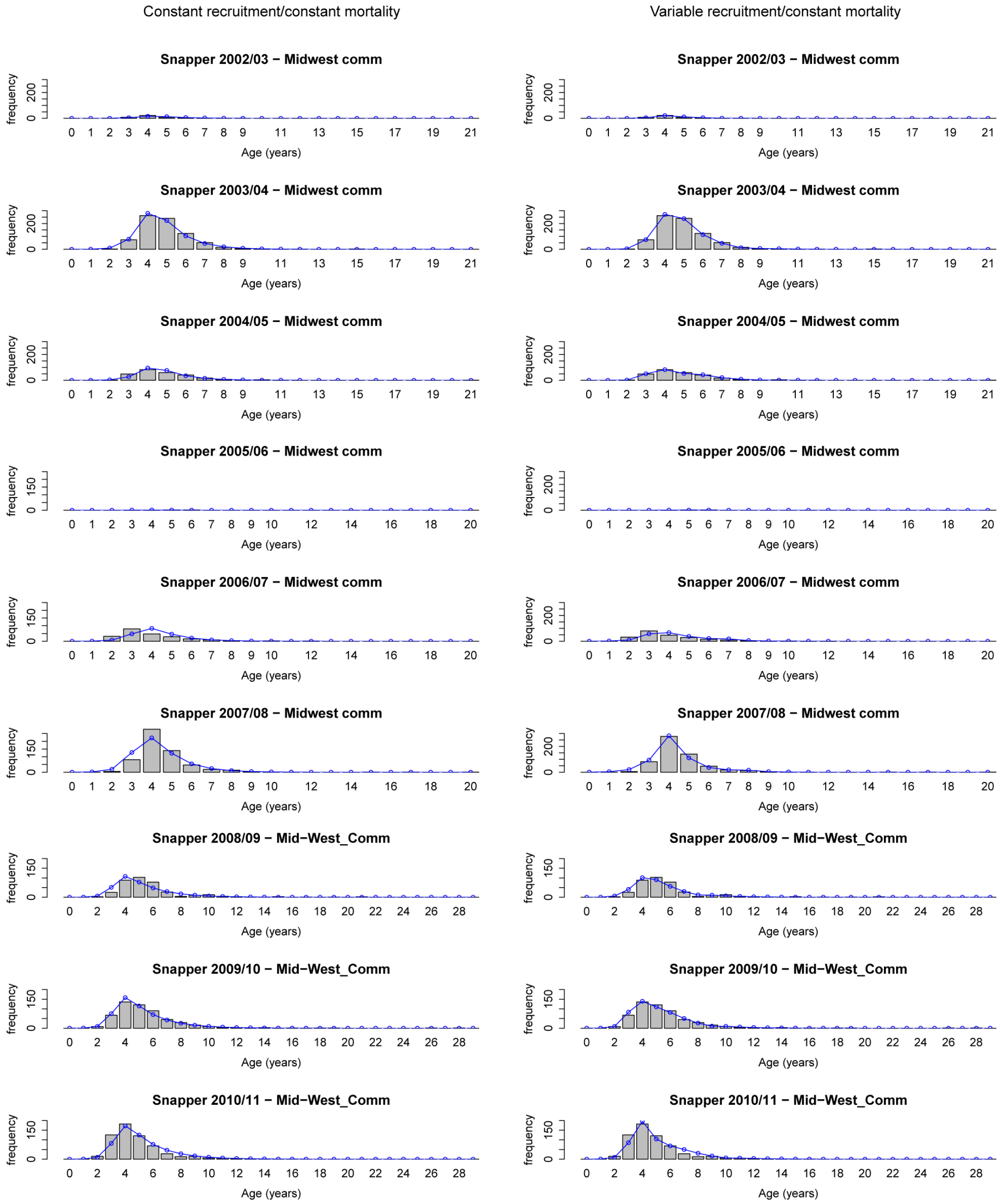

Figure A13. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Pagrus auratus* in each year of three different periods of sampling (2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) the commercial sector in the Mid-west Area.

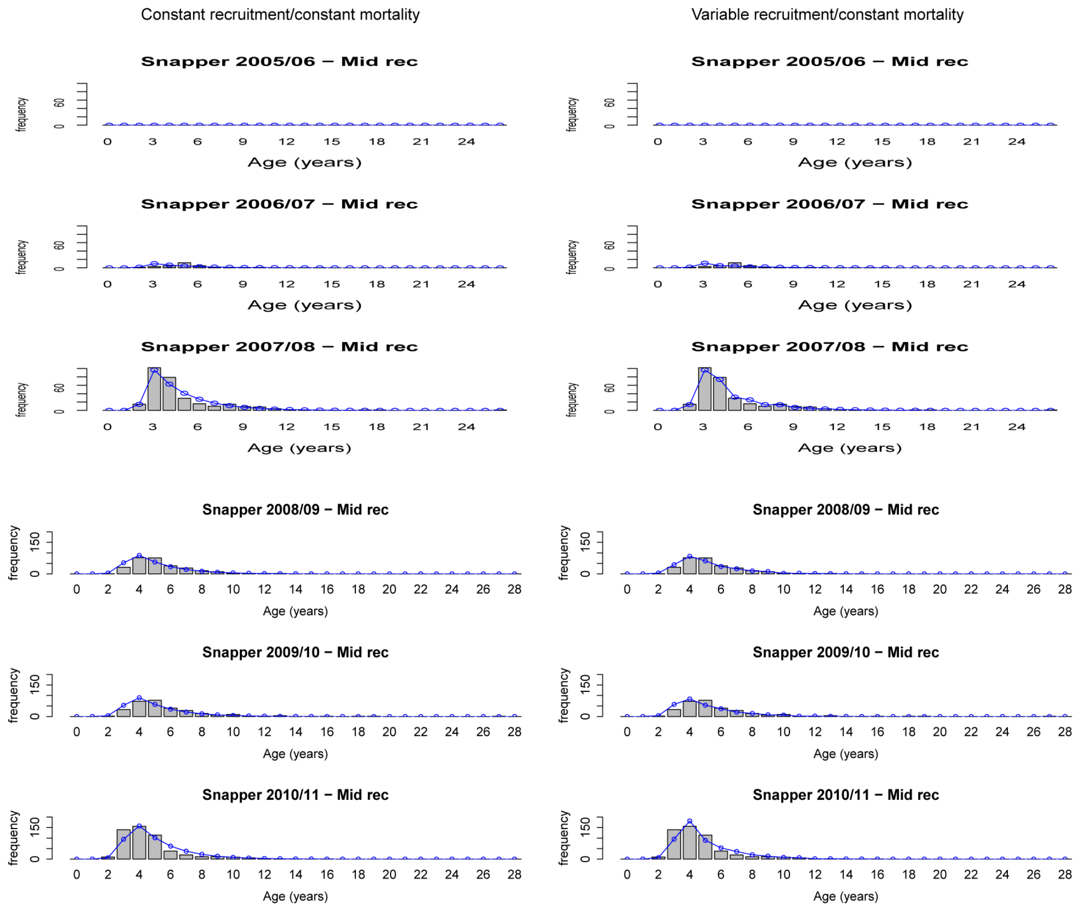

Figure A14. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Pagrus auratus* in each year of two different periods of sampling (2005/06-2007/08, 2008/09-2010/11) the recreational sector in the Mid-west Area.

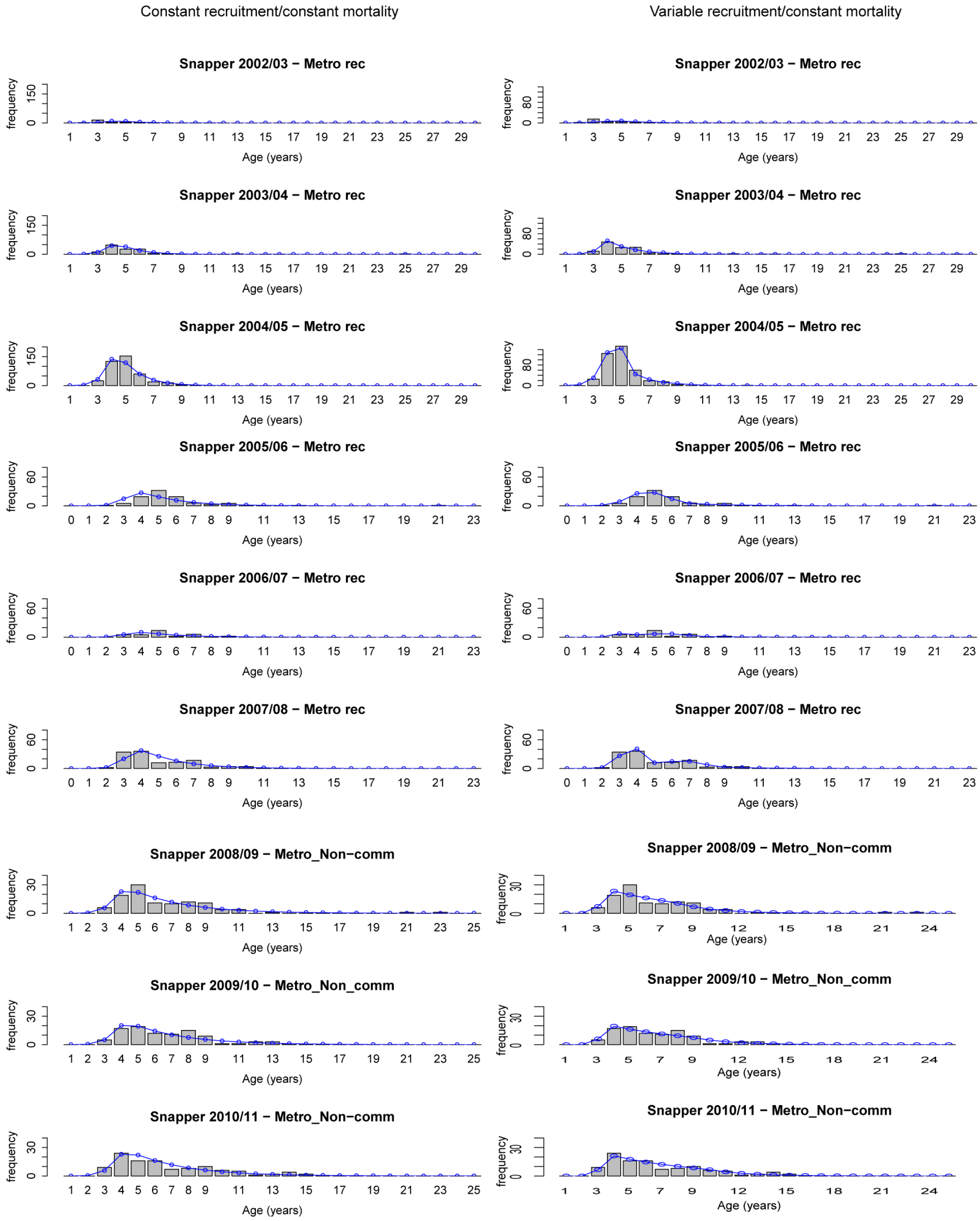

Figure A15. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Pagrus auratus* in each year of three different periods of sampling (2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) the recreational sector in the Metropolitan Area.

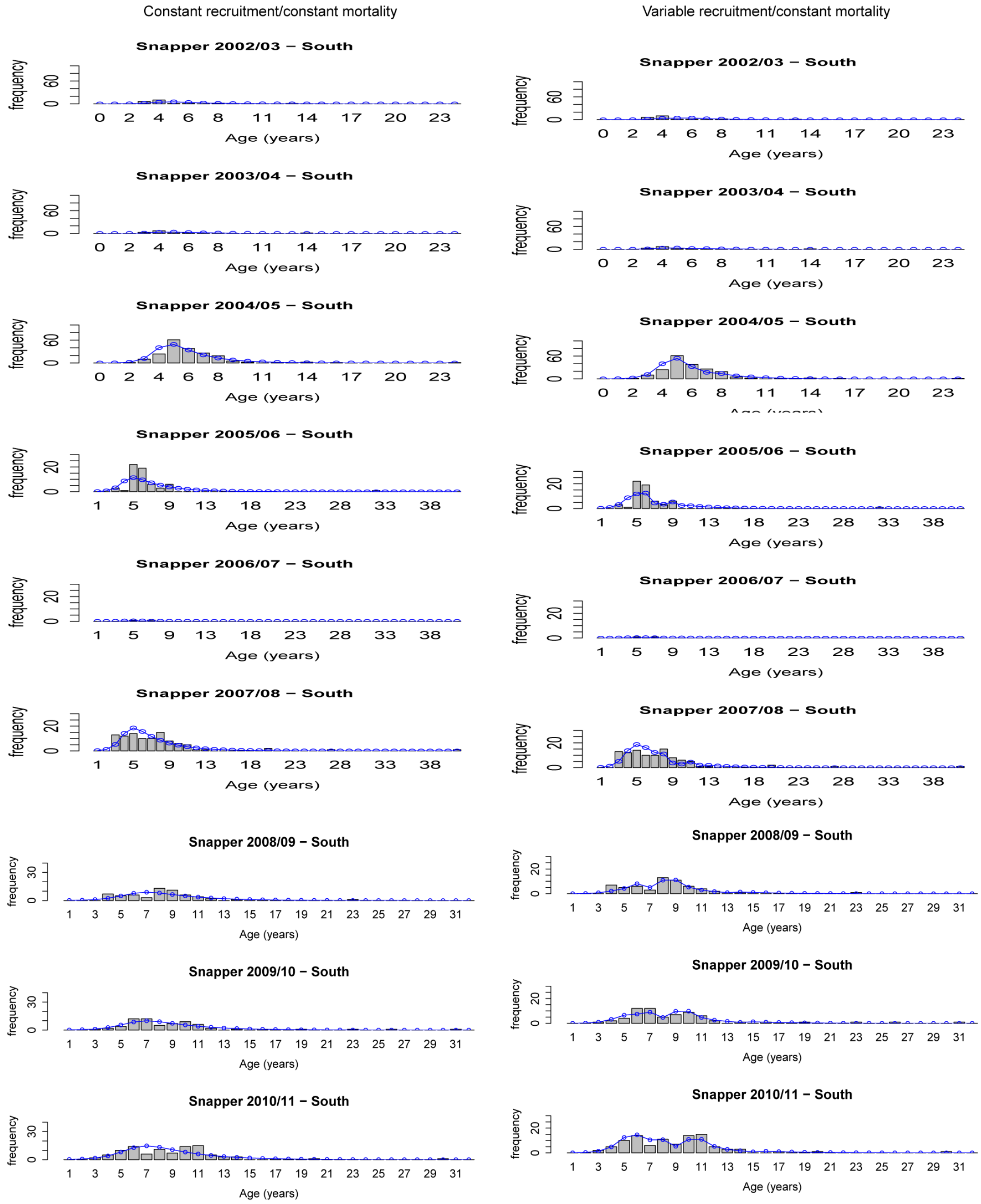

Figure A16. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Pagrus auratus* in each year of three different periods of sampling (2002/03-2004/05, 2005/06-2007/08, 2008/09-2010/11) the recreational and commercial sectors in the South-west Area.

Choerodon rubescens

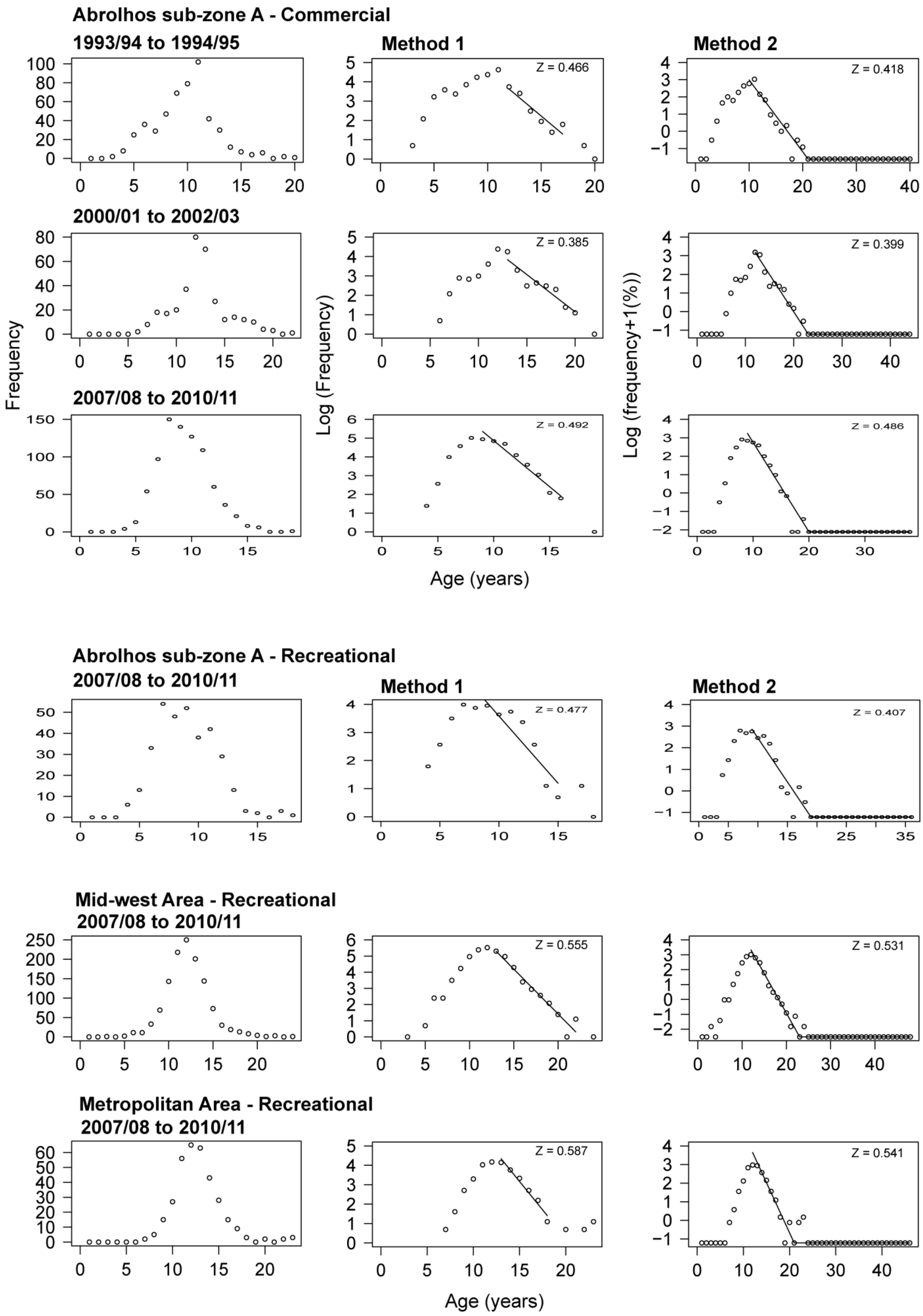

Figure A17. Age frequency compositions and regressions (methods 1 and 2) fitted to age structure data for *Choerodon rubescens* collected from the commercial and recreational sectors in the Abrolhos Islands sub-zone A and the Mid-west and Metropolitan areas between 1993/94 and 2010/11.

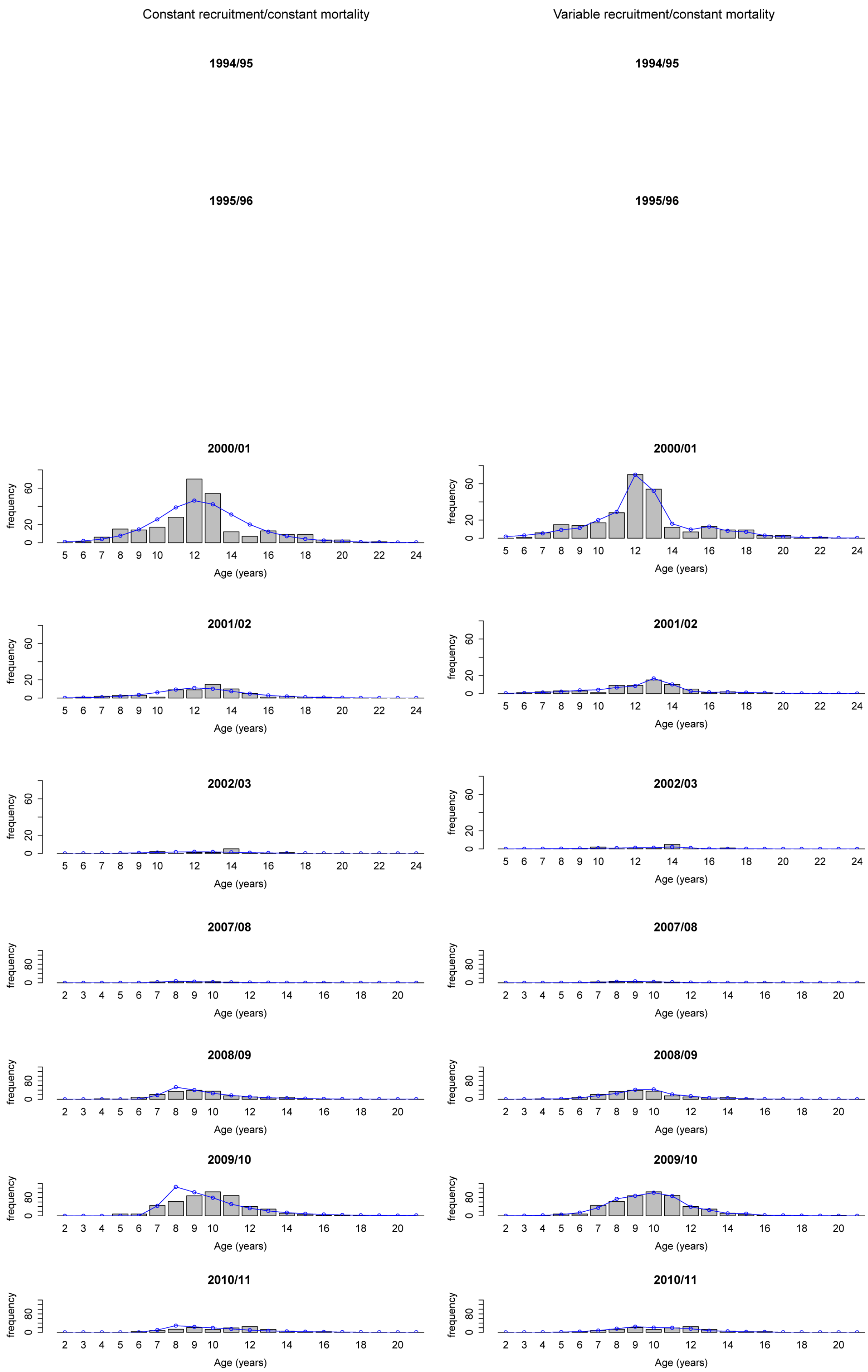

Figure A18. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Choerodon rubescens* in each year of three different periods of sampling (1994/95-1995/96, 2000/01-2002/03, 2007/08-2010/11) the commercial sector in the Abrolhos Island sub-zone A.

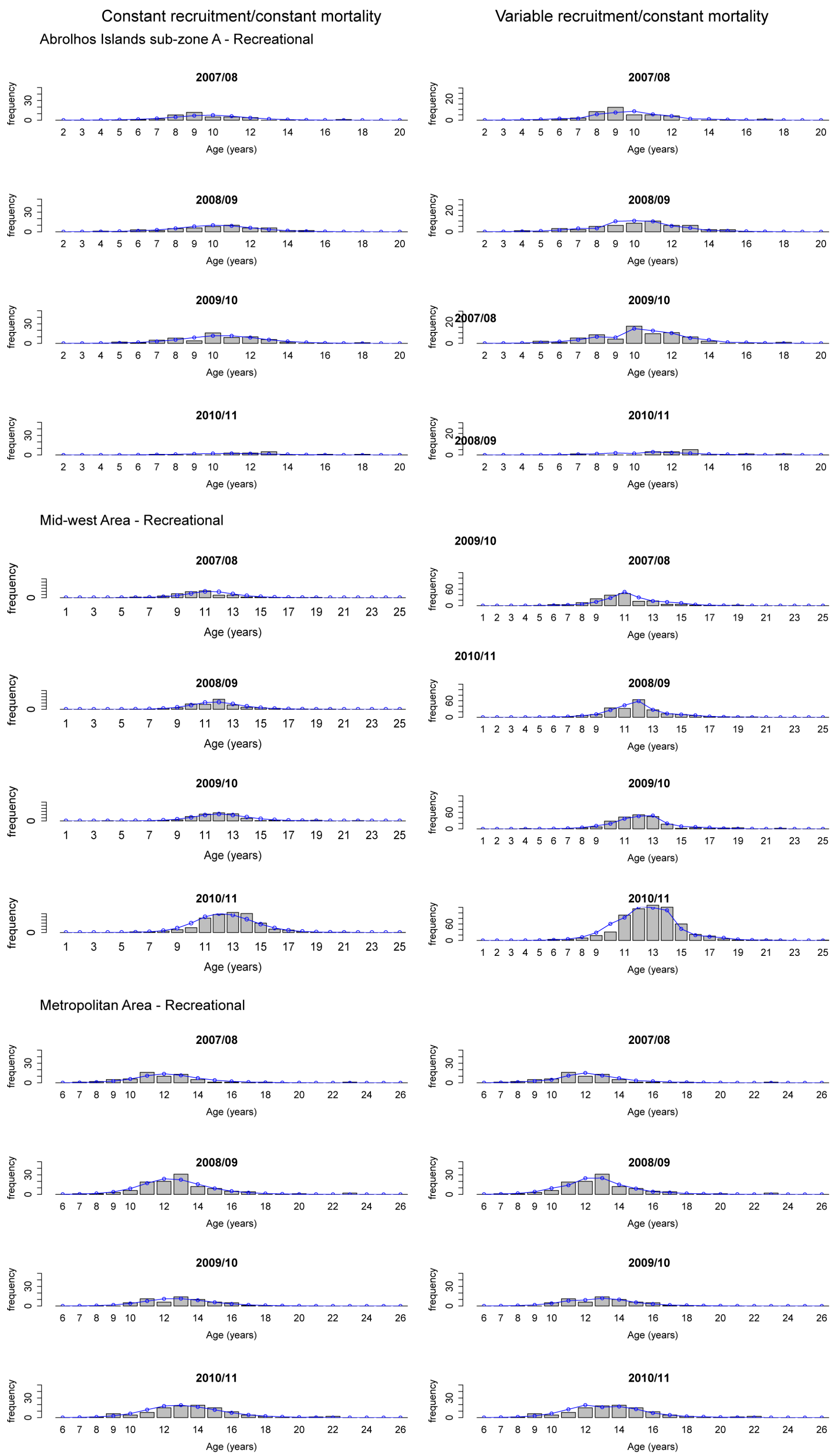

Figure A19. Constant recruitment, constant mortality and variable recruitment constant mortality models fitted to the age structures of *Choerodon rubescens* in each year of sampling between 2007/08-2010/11 of the recreational sector in the Abrolhos Island sub-zone A, Mid-west Area and Metropolitan Area.

8.0 Appendix 2.

A2.1 Additional methodology applied in CPUE analyses

Manipulations of catch and effort data were required to obtain the final dataset for analysis, including:

i. Skipper names had to be corrected to account for spelling mistakes / inconsistent data entry for same skipper.

ii. Records for sessions with Nil Catch had missing catch values and needed to be replaced with zero catches for analysis.

iii. Records for sessions with Nil Catch had missing values for data at the trip level, which needed to be filled with corresponding trip level data that were available for other records entered for the same trip.

iv. Creation of “Session” identifier for subsequent data checking and corrections.

v. Creation of additional explanatory factors and covariates for analysis: “Season” was calculated from “Month”, “DateNo” (chronological measure related to date starting at 0 for start of the time series, 1/1/2008), “latitude” and “longitude” covariates from calculated centroids of 10’ x 10’ blocks, “Skipper-Boat” from concatenating Skipper and Boat.

vi. Separating datasets by species and fishery management area for analysis.

vii. Tabulating data to determine appropriate reference level for each explanatory factor for each dataset.

Testing model assumptions: GLM types

Catch and effort data typically have a lognormal error structure, thus log-transformation is often desirable to obtain data with normal additive errors to satisfy the assumption of fitting a Gaussian family generalized linear model (GLM) with identity link to catch and effort data (Hilborn & Walters 1992). To assess whether the log-transformation removed initial suspected positive skew, consistent with a log-normally distributed dataset, frequency distributions of the untransformed and $\log_e$-transformed response variable were compared, as were the calculated skewness parameters. As the Gaussian GLM is generally robust to violations of normally distributed errors (Winer *et al.* 1992), as a “rule of thumb” important skew was detected if the difference between the mean and minimum was more than three times the standard deviation or less than a third of the difference between maximum and mean (M. O’Neill, pers. comm.). Further, the Box-Cox method of evaluating effects of the parametric family of power transformations was applied (Box & Cox 1964; Andrews 1971; Atkinson 1985). As the maximum likelihood for the initial GLMM fitted to each dataset by species (see Equation (1) above) for untransformed response variables was close to zero, a natural logarithm transformation of the response variable (and some other explanatory covariates such as effort) was considered appropriate.

Table A2.1. Skew of untransformed response (catch) versus *ln*-transformed response.

Species	Catch	SE	Loge(Catch)	SE
Snapper	2.70	(0.03)	-0.34	(0.04)
WA Dhufish	2.54	(0.03)	-0.06	(0.04)
Baldchin groper	6.82	(0.03)	-0.69	(0.05)

1. The percentage of zero catch records was assessed for each dataset for analysis to determine whether two-stage GLMMs would be appropriate.

Table A2.2. Sample sizes, percent zero catches and statistical outliers excluded. 'Kal' = Kalbarri; 'MW' = Mid-west; 'SW' = South-west; 'Abrol' = Abrolhos management zones of the WCDSIMF. * This is the total sample size, including zero catches. 'Reduction in Deviance' is the percentage reduction in residual deviance attributable to the removal of that (those) outlier(s).

Species	Dataset	N*	Zero Catches (%)	Outliers excluded	Reduction in Deviance (%)
Snapper	MW	3,394	14.9	0	–
	Kal	2,006	3.3	2	0.99
WA Dhufish	MW	3,389	24.8	0	–
	SW	1,733	46.7	0	–
Baldchin groper	Kal	2,007	60.5	1	16.7
	Abrol	3,025	40.5	1	8.18
	MW	3,394	43.0	0	–

A2.2 Examples of residual checking diagnostics

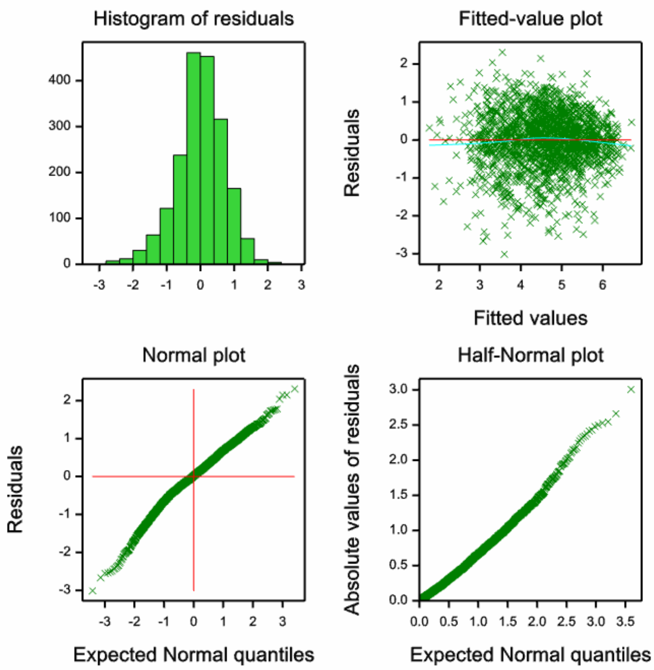

Figure A7. Residual diagnostic plots: Pink Snapper, Kalbarri.

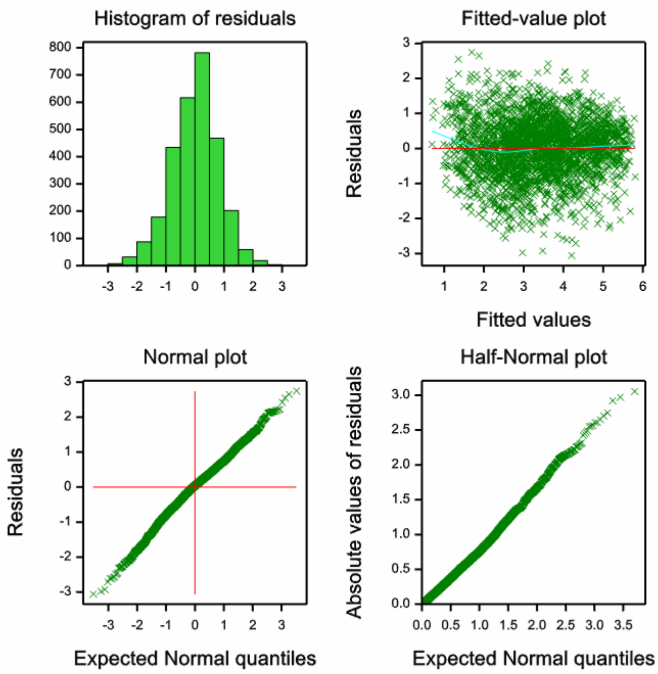

Figure A8. Residual diagnostic plots: Pink Snapper, Mid-west.

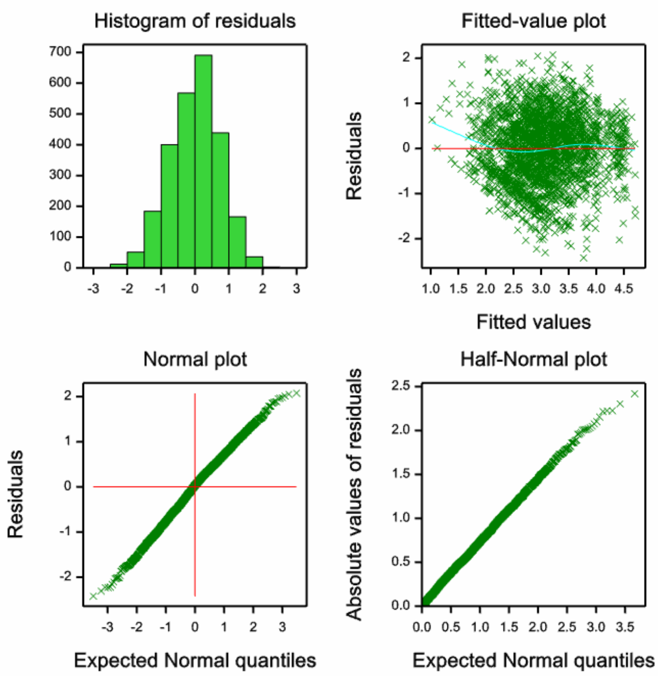

Figure A9. Residual diagnostic plots: WA Dhufish, Mid-west.

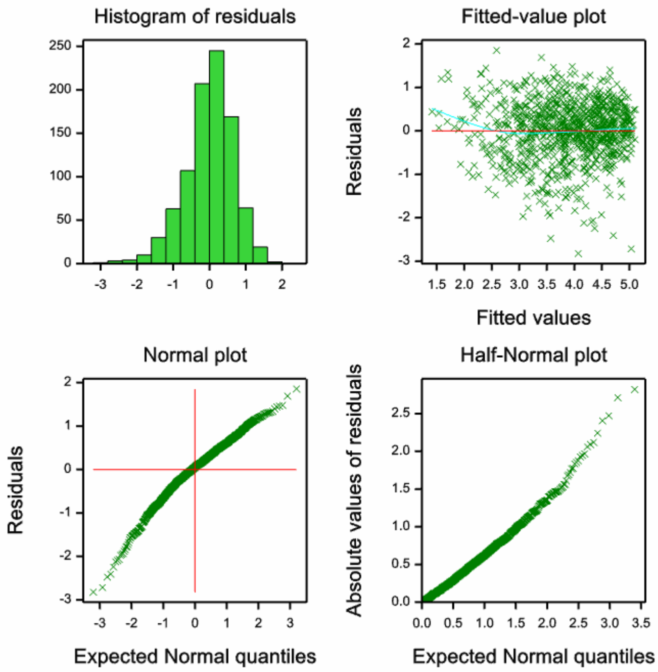

Figure A10. Residual diagnostic plots: WA Dhufish South-west.

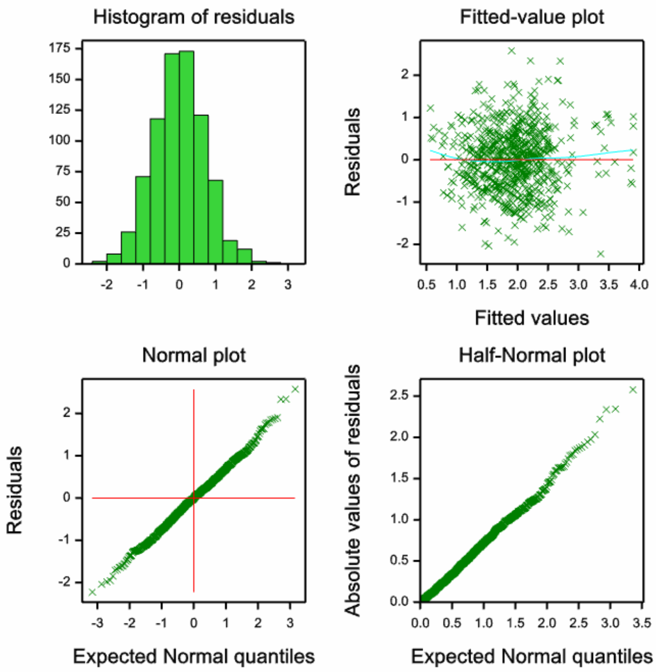

Figure A11. Residual diagnostic plots: Baldchin Groper, Kalbarri.

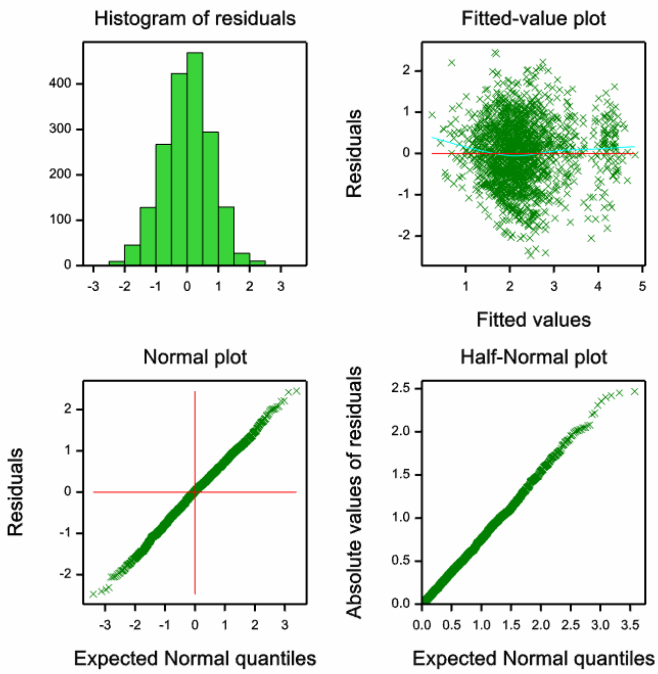

Figure A12. Residual diagnostic plots: Baldchin Groper, Abrolhos.

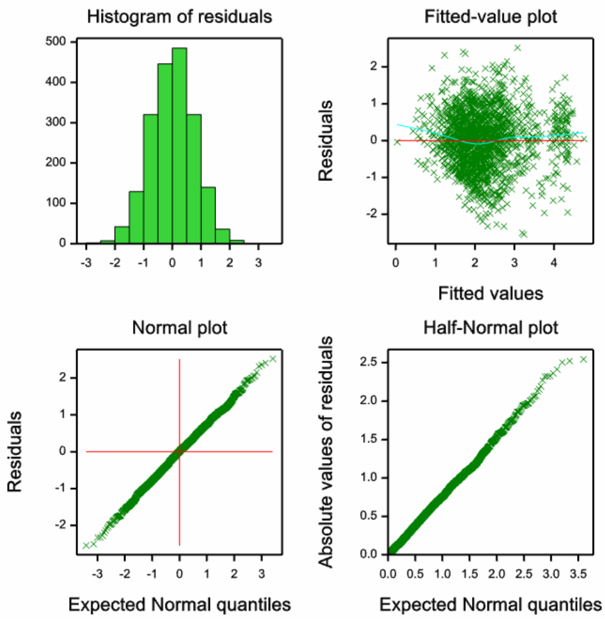

Figure A13. Residual diagnostic plots: Baldchin Groper, Mid-west.

Model fitting algorithm

The six steps in the manual forward selection algorithm were as follows.

1. Add seasonal effects? The set of alternative seasonal effects for evaluation included {month, season, cos(2π d_m /365.25), sin(2π d_m/365.25), cos(4π d_m /365.25), sin(4π d_m/365.25)}. The candidate seasonal terms 3 to 6 of this set were trigonometric functions modelling an annual cycle using sine, an annual cycle using cosine (i.e., offset by 6 months from the model using sine), a six-monthly cycle using cosine and a six-monthly cycle using sine respectively, where d_m is the calculated day of year corresponding to the middle of the capture month, m. Only those significant terms of the four trigonometric terms were retained in the candidate GLMMs, although it is also valid to retain all four if were significant (M. O'Neill, pers. comm.).
2. Add spatial effects? The set of alternative spatial effects for evaluation included {xshelf, latitude, longitude, blockx}. "blockx" is a spatial factor with each level being a CAES block. "xshelf" is a spatial factor with each level being a cross-shelf management zone based on the location of 10' x 10' blocks ('Inshore', 'Straddling Inshore/Offshore', 'Offshore'). Latitude and longitude are covariates, calculated as centroids of the 10' x 10' blocks.
3. Add hours searched?
4. Evaluate alternative random effects. The alternative random effects for evaluation included {boat, skipper, skipper-boat}.
5. Add year × blockx interaction term? This was considered where blockx was previously demonstrated to contribute significant explanatory power to the GLMM but may or may not have been the spatial term contributing the most explanatory power (i.e., resulting in the lowest deviance). However, this term was either not significant or aliased for all model fits, so results were not explored further for this term.
6. Fit corresponding binomial GLMM to data, as consistent with the "delta approach" for datasets with a high proportion of zero catches. For consistency, the binomial GLMM was formulated with the same explanatory terms as the best approximating Guassian GLMM fitted to the non-zero catch data (from steps 1-5) except where one of those terms was non-significant. In those cases, non-significant terms were dropped from binomial GLMMs. Binomial GLMMs were fitted to all datasets in Table 2 except for Pink Snapper data from Kalbarri, where there was a low percentage of zero catches (Table 2).

Calculation of confidence intervals on standardised CPUE indices

Ninety-five per-cent confidence intervals about the mean annual standardised CPUE values were calculated as follows:

$$(3) \qquad E(Y \mid y \geq 0) = \exp\Big(log(\pi) + \log(E(Y \mid y > 0)) + (\sigma^2_{log(E(Y \mid y>0))} / 2) \pm \sqrt{(se(\pi)/\pi)^2 + se(\log(E(Y \mid y > 0)))^2} \times 1.96 \Big)$$

where Y is the mean expected cpue on harvests y {0,…,y}, π is the observed proportion of catches of that species made (as modelled by the Binomial GLMMs) and σ^2 was the residual variance from the Gaussian GLMMs fitted to non-zero catch data (O'Neill *et al.,* 2011).

Best fitting GLMMs and resulting standardised CPUE indices

The manual forward selection analysis of non-zero catch data resulted in different models selected and variable goodness of fit among species and management areas (Table 3). The range of adjusted coefficients of determination in each model indicated poor ($R_a^{\,2} = 0.37$) to moderately good ($R_a^{\,2} = 0.67$) representations of trends in the observed data. The type of spatial and seasonal effects retained within final selected GLMMs also varied among the different datasets (Table 3). Log_e(hours fished) was consistently retained in best approximating GLMMs fitted to non-zero catch data, with Log_e(total hooks) consistently retained for GLMMs fitted to non-zero catch data for *P. auratus* and *C. rubescens*, but not for *G. hebaricum* (Table 3).

The random effects of skipper and skipper-boat were retained in final best approximating GLMMs, indicating that skipper was consistently important for explaining observed CPUE (Table 3). The retaining of skipper-boat for some datasets demonstrates that the combination of boat information with skipper resulted in a better representation of trends in observed CPUE for those datasets. Intra-class correlation coefficients calculated for *P. auratus* datasets were highest, indicating that the variance between data partitioned by different skippers or combinations of skipper-boat compared to the variance of data within those groups was relatively high, and therefore the influence of those random effects greatest, for GLMMs fitted to the *P. auratus* datasets. Conversely, the relative strengths of random effects of skipper or skipper-boat within Gaussian GLMMs fitted to *C. rubescens* data were the weakest of the models fitted, as these had the lowest ICC values (Table 3).

Table 3. Best-approximating models and goodness-of-fit statistics. Gaussian GLMMs fitted to non-zero logged catch data. *Y* = catch (kg); ν = boat, skipper or skipper-boat denoted by *j, p* or *q* respectively (random effect); χ = number of hooks used per hour; $\chi 1$ = total hooks; $\chi 2$ = hours fished; τ = was the species targeted (*c* = yes, no); ζ = month; $f_1(m)$ = cosine annual cycle $f_2(m)$ = sine annual cycle; $f_3(m)$ = cosine six-monthly cycle of $f_4(m)$ = sine six-monthly cycle; α = blockx; Γ = latitude; Ψ = longitude; β = year; *pol*(*X; n)* is the nth order polynomial sub-model for explanatory variable $X.\nu_j \sim N(0,\sigma_j^2)$ and $\epsilon \sim N(0,\sigma^2)$. $R_a^{\ 2}$ is the adjusted coefficient of determination calculated using residual deviance estimates from Genstat, which omits constants which depend on fixed model fitted. ICC is the intraclass correlation coefficient, which quantifies the relative strength of retained random effects (Faraway, 2006).

Species	Area	N	Model	$R_a^{\ 2}$	ICC
Pagrus auratus	Kalbarri	1,939	$\log_e Y_{pict} = \mu + \log_e \chi 1_{pict} + \log_e \chi 2_{pict} + \tau_c + f_2(m) + f_4(m) + \nu_p + \log(\Gamma_{pict}) + \beta_t + \epsilon_{pict}$	0.62	0.33
Pagrus auratus	Mid-west	2,888	$\log_e Y_{qict} = \mu + \log_e \chi 1_{qict} + \log_e \chi 2_{qict} + \tau_c + \zeta_m + \nu_q + pol(\Gamma_{qict};3) + \log_e(\Psi_{qict}) + \log_e(\Phi_{qict}) + \beta_t + \epsilon_{qict}$	0.61	0.37
Glaucosoma hebraicum	Mid-west	2,550	$\log_e Y_{qicat} = \mu + \log_e \chi 2_{qicat} + \tau_c + f_4(m) + \nu_q + \alpha_a + \beta_t + \epsilon_{qicat}$	0.49	0.26
Glaucosoma hebraicum	SW	924	$\log_e Y_{picat} = \mu + \log_e \chi 2_{picat} + \tau_c + \zeta_m + \nu_p + \alpha_a + \beta_t + \epsilon_{picat}$	0.67	0.24
Choerodon rubescens	Kalbarri	792	$\log_e Y_{qict} = \mu + \log_e \chi 1_{qict} + \log_e \chi 2_{qict} + \tau_c + f_4(m) + \nu_q + pol(\Gamma_{qict};2) + pol(\Psi_{qict};2) + \beta_t + \epsilon_{qict}$	0.37	0.16
Choerodon rubescens	Abrolhos Zone A	1,801	$\log_e Y_{pict} = \mu + \log_e \chi 1_{pict} + \log_e \chi 2_{pict} + \tau_c + \nu_p + f_1(m) + pol(\Gamma_{pict};2) + \log_e(\Psi_{pict}) + \beta_t$	0.50	0.20
Choerodon rubescens	Mid-west	1,936	$\log_e Y_{qict} = \mu + \log_e \chi 1_{qict} + \log_e \chi 2_{qict} + \tau_c + \nu_q + \log_e(\Psi_{qict}) + \beta_t + \epsilon_{qict}$	0.50	0.23